Report of the

Oklahoma Produced Water Working Group

April 2017

WATER FOR 2060

EFFICIENCY · CONSERVATION · RECYCLING · REUSE

Oklahoma Water for 2060
Produced Water Reuse and Recycling

Prepared for

April 26, 2017

401 S. Boston Avenue, Suite 330
Tulsa, OK 74103-4425

This study made possible in part with a grant from the Oklahoma Dept. of Commerce & U.S. Department of Energy

Executive Summary

In support of the Oklahoma Governor's initiative, launched in December, to re-use or recycle water produced in oil and gas operations, this Produced Water Re-use and Recycling report assesses the potential alternatives to current practices of injecting produced water from oil and gas wells into disposal wells (The State of Oklahoma, 2015). This report is designed to evaluate the data, issues and opportunities with produced water, but also recognizes that there may not be easy answers. The efforts of the committee and this report are part of a long-term journey to improve water management in the state.

Produced Water Working Group Goals
Studying and Recommending *alternatives to produced water disposal from oil and gas operations in Oklahoma.* ***Discussing*** *opportunities and challenges associated with treating produced water for beneficial uses, such as industrial use or crop irrigation.*

To achieve this goal, a 17-member Produced Water Working Group (PWWG), led by the Oklahoma Water Resources Board, was tasked with studying and recommending alternatives to produced water disposal from oil and gas operations in Oklahoma. Produced water is a term used in the oil and gas industry to describe water that is produced as a byproduct along with the oil and gas. This includes naturally occurring formation water associated with the oil and gas in the reservoir as well as water used in well drilling and completions activities that returns to the surface with the product over time. The PWWG met five times from early 2016 to early 2017 to discuss and develop its recommendations.

In support of the PWWG efforts, the technical study team investigated the following key information:

- Produced water production in 66 counties and water quality in 29 counties
- The top 40 major water users in the state based on water permits
- Typical water treatment costs for various volumes and treatment levels from eight selected companies.

The data and information gathered through these efforts served as the basis to evaluate the cost-effectiveness of alternatives to current produced water disposal methods.

Ten representative cases were developed and further assessed by coupling a potential produced water user or alternative disposal method to an existing adjoining produced water source and evaluating the economics of each case in order for the PWWG to prioritize and make recommendations. The costs for the 10 cases range from $0.57 per barrel[1] of water to more than $7 per barrel of water.

Key Findings (in order of viability and timeframe)

1. Produced water re-use by the oil and gas industry is the most viable cost-effective alternative due to minimal water treatment needs and thus low treatment costs. Increased inter-organizational planning and sharing of resources to improve re-use viability are required. The oil and gas industry has built limited water pipeline networks to date; however, planned cooperative expansion of the water distribution systems over time would reduce conveyance costs and further facilitate produced water use for hydraulic fracturing.
2. A special case of water re-use was evaluated using surplus produced water from the Mississippi Lime play area around Alfalfa County. This surplus could be gathered and conveyed to sites in Blaine County for oil and gas re-use. Although the project could be technically and commercially complex,

[1] Barrel = 42 U.S. gallons

the screening analysis shows it has potential to be financially competitive with current disposal methods. A more detailed evaluation is needed.

3. Evaporation techniques for produced water should be further investigated and developed. Due to low water treatment costs and potentially limited water conveyance requirements, evaporation technology could be a viable alternative to disposal.
4. Water treatment and desalination techniques of produced water should be further investigated and developed if the PWWG intends to reduce the majority of water produced in the state. Although current technologies are technically implementable, they appear impractical at this time. The cases presented in this report were found to be the most expensive strategies by more than four times current disposal costs. Water treatment at or near fresh water levels could produce water for power, industry, and other beneficial uses including the potential to be discharged and augment local stream flow; thereby making PW an added benefit rather than a liability.

Recommendations

1. Reduce the challenges to water reuse through targeted regulations and legislation by
   a. Removing legal ambiguity about ownership of produced water when sold or in the event of an environmental impact
   b. Establishing bonding requirements for water impoundments that are appropriate without being an impediment; Evaluate technical standards or other data-driven risk strategies and financial assurance approaches to equitably manage risk and remove financial impediments to reuse project development.
   c. Clarifying rules and ownership when water is transferred from one company to another
   d. Requesting delegation from the U.S. Environmental Protection Agency (EPA) to Oklahoma for permitting the discharge of treated produced water consistent with water quality protections for the receiving stream; including the ability to permit mobile operations
   e. Considering methods that make obtaining right-of-way for pipelines that allow cost-effective transfer of recycled/re-used water easier as an alternative to impacts of trucking.
2. Further investigate methods to facilitate the re-use of produced water in oil and gas operations.
3. Study further the feasibility of the transferring Miss. Lime produced water to the STACK play (Case 3). The more detailed evaluation could include:
   - Evaluate the commercial challenges and how the many companies can be brought together most effectively.
   - Evaluate the potential water compatibility issues and technical solutions through lab work and collaboration with treatment companies.
   - Provide a more detailed cost estimate of the pipe infrastructure.
   - Evaluate the feasibility of tying into one or more of the existing Mississippi Lime produced water systems as an alternative to building a new one.
   - Assess the potential environmental risks and methods to reduce impacts.
4. Conduct a more detailed evaluation of evaporation as an alternative to injection (Cases 4 and 5). The additional studies could include:
   - Evaluate the technologies available or being developed, their potential economic viability, and their operations.

- Assess the potential environmental risks and ways to lower possible impacts.

5. Identify research needs and potential funding partnerships to further accomplish the group's goals, such as:
   - Improve the economic feasibility of Cases 6-10;
   - Research new technologies to lower the cost of effective water treatment;
   - Identify toxicological risks and protective water quality targets to ensure that the environment and public health are adequately protected under various reuse scenarios;
   - Research potential agricultural uses for produced water;
   - Research potential for marginal aquifer recharge with produced water, and
   - Identify other potential beneficial uses of treated water.
6. Continue the PWWG or subgroups to identify opportunities to continue cooperative planning and development of new techniques, infrastructure, water users, legislation and regulatory structure. A regular dialogue between producing companies, potential water users, regulators, technology providers, researchers, and stakeholders is warranted.
7. Support and build upon the Water for 2060 Advisory Council 2015 energy and industry water use sector water conservation findings and recommendations to the Governor and the Legislature (see details in Water for 2060 Report, 2015):
   - Facilitate increased sharing of information and supplies between industrial users
   - Promote industrial use of marginal quality waters

Contents

Executive Summary ..... **iii**

Acronyms and Abbreviations ..... **ix**

1 Introduction **1-1**
- 1.1 Background 1-2
- 1.2 Produced Water Working Group Process 1-3

2 Produced Water in Oil and Gas Operations **2-1**
- 2.1 Introduction 2-1
- 2.2 Produced Water Management 2-5
- 2.3 Produced Water Estimate 2-8
- 2.4 Potential Users of Produced Water 2-8
- 2.5 Alternatives Screening Matrix 2-9
- 2.6 Alternatives Not Evaluated 2-11

3 Produced Water Re-use Scenarios **3-1**
- 3.1 Typical Source and Disposal 3-1
- 3.2 Oil and Gas Re-use 3-2
- 3.3 Inter-county Clean Brine Transfer and Treatment 3-2
- 3.4 Forced Evaporation – Low TDS (SCOOP & STACK) 3-5
- 3.5 Forced Evaporation – High Total Dissolved Solids (Mississippi Lime) 3-6
- 3.6 Desalination for Surface Discharge in Beckham County 3-7
- 3.7 Desalination for Power Use in Seminole County 3-9
- 3.8 Desalination for Power Use in Pawnee County 3-11
- 3.9 Desalination for Industrial Use in Grant County 3-13
- 3.10 Desalination for Surface Discharge in Grant County 3-15

4 Estimating Costs **4-1**
- 4.1 Methodology (including key financial assumptions) 4-1
- 4.2 Estimated Cost - Benefit Range(s) (High, Likely, Low) 4-1

5 Challenges, Opportunities, and Risks **5-1**
- 5.1 Cost to Transport and Treat Water for Re-use and Recycling 5-1
- 5.2 Water Treatment Facility Bonding Requirements 5-1
- 5.3 Ownership and Value of Produced Water 5-1
- 5.4 Legal Custody of Water as it Relates to Potential Spills 5-2
- 5.5 Right-of-Way and landowner negotiations 5-2
- 5.6 Discharge Permit Challenges Including Timing 5-3

6 Implementation **6-1**
- 6.1 Implementation Considerations 6-1
- 6.2 Environmental and Stakeholder Considerations 6-1
- 6.3 Macroeconomic Considerations 6-3

7 Conclusions and Recommendations **7-1**

8 Literature Cited **8-1**

Appendixes

A Meetings Agenda, Summaries and Presentations
B Produced Water Data and Estimate Detail
C Water Demand Data and Estimate Detail
D Alternatives Screening Matrix
E Cost Estimate Assumptions

Tables

1-1 Produced Water Workgroup Members 1-3

2-1 Produced Water Volumes Injected and Total Dissolved Solids (TDS) by County in Oklahoma 2-2

3-1 Cost Estimates for Ten Produced Water Use Scenarios 3-1
3-2 Summary of Pipeline Gathering System for Case 3 3-4
3-3 Summary of Pipeline gathering System for Case 6 3-7
3-4 Summary of Pipeline Gathering System for Case 7 3-9
3-5 Summary of Pipeline Gathering System for Case 8 3-11
3-6 Summary of Pipeline Gathering System for Case 9 3-13
3-7 Summary of Pipeline Gathering System for Case 10 3-15

4-1 Treatment Cost Estimates for Different Cases 4-2

6-1 Produced Water Use Implementation Opportunities, Challenges, and Impacts. 6-2

Figures

1-1 Estimated Oklahoma Water Production Since 2009 1-1

2-1 Main Oil and Gas Areas 2-1
2-2 Total Dissolved Solids by County 2-4
2-3 Typical Simplified Oil, Gas and Water Process 2-5
2-4 Typical Simplified Oil, Gas and Water Process with Water Re-use 2-7
2-5 Frac Tanks at a Mississippi Lime Area Well Site 2-8
2-6 Preliminary Matches of Produced Water with Potential Users 2-10

3-1 Case 3 Layout and Infrastructure 3-3
3-2 Poseidon Saltwater Solutions vaporizer to evaporate water 3-6
3-3 Logic-ES evaporator. 3-6
3-4 Case 6 - Surface Water Discharge 3-8
3-5 Case 7 Layout and Infrastructure 3-10
3-6 Case 8 Layout and Infrastructure 3-12
3-7 Case 9 Layout and Infrastructure 3-14
3-8 Case 10 Layout and Infrastructure 3-16

Acronyms and Abbreviations

ASR	aquifer storage and recovery
bbl	barrel
bpd	barrels per day
BWPD	barrels of water per day
EPA	U.S. Environmental Protection Agency
fps	foot per second
HB	House Bill
mg/L	milligram per liter
MQW	marginal quality water
NORM	naturally occurring radioactive material
NPDES	National Pollutant Discharge Elimination System
OCC	Oklahoma Corporation Commission
OCWP	Oklahoma Comprehensive Water Plan
ODEQ	Oklahoma Department of Environmental Quality
OWRB	Oklahoma Water Resources Board
POTW	publicly owned treatment works
PWWG	Produced Water Working Group
ROW	right-of-way
TDS	total dissolved solids
USACE	U.S. Army Corps of Engineers

SECTION 1

Introduction

Oklahoma Governor Mary Fallin announced the formation of a fact-finding workgroup to look at ways that water produced in oil and natural gas operations may be recycled or re-used as a way to reduce injection into underground disposal wells[2]. The Water for 2060 Produced Water Working Group (PWWG) was charged with discussing opportunities and challenges associated with treating produced water for beneficial uses, such as industrial use or crop irrigation. Attention was focused primarily on how water produced from oil and gas activities in Oklahoma can be re-used. “Opening appropriate and environmentally responsible avenues for beneficial use of reclaimed produced water will require coordination across industry sectors and regulatory agencies,” said Governor Fallin.

Re-use and recycling is practiced by oil and gas companies in areas in the U.S. where disposal wells are limited (e.g., Pennsylvania, Ohio, and West Virginia) and where freshwater is more expensive and harder to find (e.g., in parts of west Texas and New Mexico). In Oklahoma, fresh water is available and relatively inexpensive, and disposal wells have been used to dispose of the produced water. In 2014, nearly 1.5 billion barrels of produced water were disposed underground in Oklahoma. In 2016, the underground injection of produced water was reduced due to Oklahoma Corporation Commission (OCC) regulations in critical areas to limit the volume of injections that correlated with recent earthquakes in Oklahoma. Figure 1-1 shows the estimated amount of produced water in Oklahoma since 2009.

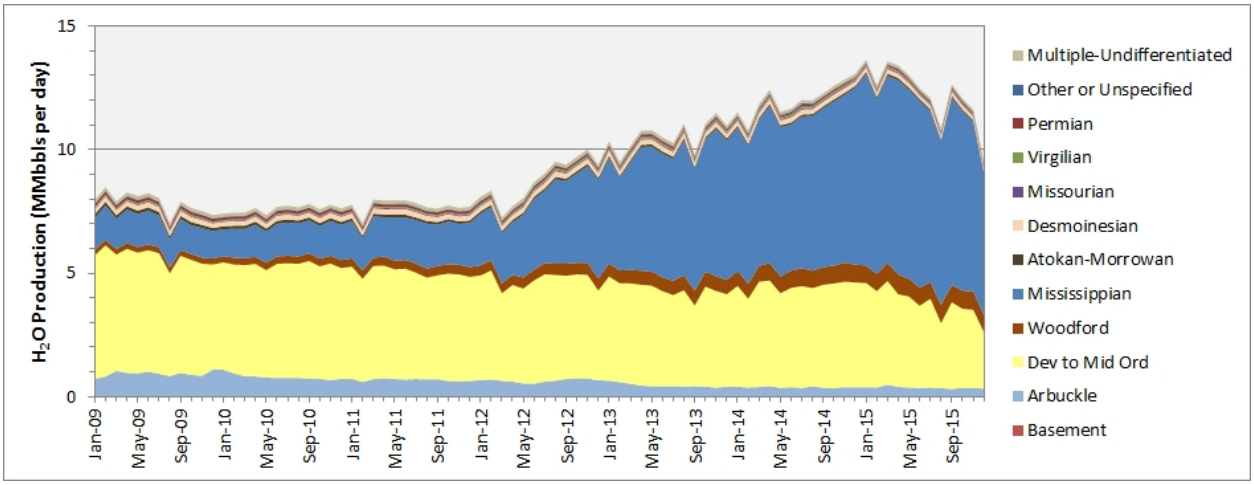


Figure 1-1. Estimated Oklahoma Water Production Since 2009

Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

As part of Oklahoma’s ongoing water planning, the Water for 2060 Advisory Council’s recommendations for the energy and industry sector includes promoting the industrial use of marginal quality water (MQW), such as produced water, and to work on increasing the sharing of information and supplies between energy and industry water users. To this end, Oklahoma’s energy industry is taking action. Several energy producers have developed facilities across Oklahoma for recycling produced water and using it to hydraulically fracture new wells. Companies are also taking steps to limit their use of fresh water.

[2] 36th Annual Oklahoma Governor’s Water Conference and Research Symposium in Norman, Oklahoma Tuesday, December 1, 2015.

The objectives of this report are two-fold: reduce the use of fresh water in oil and gas production and reduce produced water injection, potentially creating new water sources. This report summarizes discussions and development of alternative recommendations by the PWWG.

1.1 Background

To address water shortages forecast in the 2012 Update of the Oklahoma Comprehensive Water Plan (OCWP), as well as to avoid the costly development of new supplies and infrastructure, one of the primary recommendations of the OCWP was to maintain current levels of freshwater use statewide for all public, agricultural and industrial sectors through 2060. Subsequently, with passage of the Water for 2060 Act (HB 3055) in 2012, Oklahoma became the first state in the nation to establish a statewide goal of consuming no more fresh water in 2060 than was consumed in 2010.[3]

The 2012 OCWP Update (OWRB, 2012) prioritizes recommendations based on potential impact in solving Oklahoma's most pressing near- and long-term water issues, the necessity for ensuring a reliable future water supply, prioritizing funding requests, findings of technical analyses, and input from the Oklahoma Water Resources Board (OWRB) staff with long-standing experience in water management.

Increasing water efficiencies to help meet future demands was widely supported throughout the public input process. One of the eight priority recommendations was Water Conservation, Efficiency, Recycling & Re-use. It was recommended that to address water shortages forecasted in the 2012 Update of the OCWP, as well as avoid the costly development of new supplies and infrastructure, the OWRB and other relevant agencies should collaborate with various representatives of the state's water use sectors, with particular emphasis on crop irrigation, municipal/industrial, and thermoelectric power to "incentivize voluntary initiatives that would collectively achieve an aggressive goal of maintaining statewide water use at current levels through 2060". (OWRB, 2012).

OCWP Priority Recommendation (OCWP, 2012)
Water Conservation, Efficiency, Recycling and Reuse *to further support the recommendation of the Marginal Quality Water Workgroup findings and recommendations of further assessment and technical analysis of five categories of marginal quality water including oil and gas flowback and produced water.*

The Water Recycling & Re-use priority recommendation leveraged the 2008 Oklahoma Senate Bill 1627 requiring the OWRB to establish a technical workgroup to analyze the potential for expanded use of MQW from various sources throughout Oklahoma. The group included representatives from state and federal agencies, industry, and other stakeholders. The OCWP MQW Workgroup studied the potential utilization of several categories of water sources—such as brackish groundwater, treated wastewater effluent, production water from oil and gas operations, and stormwater runoff—demonstrating marginal quality. It was concluded that certain sources could augment supply in some areas of Oklahoma.

With passage of the Water for 2060 Act (HB 3055) in 2012, Governor appointed a 12-member Water for 2060 Advisory Council tasked with studying and recommending appropriate water conservation practices, incentives, and educational programs to moderate statewide water usage while supporting Oklahoma's population growth and economic development goals. In 2015, the Advisory Council submitted their findings and 12 water conservation recommendations to the Governor and the Legislature for encouraging efficient water use across all of Oklahoma's major water use sectors,

[3] http://www.owrb.ok.gov/2060/

including public water supply, crop irrigation, and energy and industrial uses (OWRB, 2015). Three of the recommendations were specific to energy and industry sectors. Those include:

- Facilitate Increased Sharing of Information and Supplies Between Industrial Users
- Promote Industrial Use of Marginal Quality Waters

Building on the OCWP Marginal Quality Water Workgroup findings and recommendations, on the public input received through the 2012 OCWP public participation process, and on the Water for 2060 findings and recommendations, the 17-member Water for 2060 Produced Water Working Group (PWWG) was appointed in 2015 and tasked with studying and recommending appropriate re-use and recycling options while supporting Oklahoma's population growth and economic development goals. The panel is a non-regulatory, fact-finding workgroup focused on identifying regulatory, technical, and economic barriers to produced water re-use.

1.2 Produced Water Working Group Process

The PWWG met four times in 2016 and once in early 2017 to guide analyses and develop the group's recommendations. The group was selected and chaired by J.D. Strong, OWRB Executive Director until November 2016, followed by Julie Cunningham, Interim Executive Director. The members represented agriculture, power generation, public water supply, oil and gas, industrial and commercial water, and environmental non-governmental organizations, along with the Oklahoma Corporation Commission (OCC), Oklahoma Department of Environmental Quality (ODEQ), and the Department of Agriculture. The membership list is shown in Table 1-1.

The PWWG effort builds upon the previous MQW Workgroup findings and recommendations, as well as the public input received through the 2012 OCWP public participation process, to further support one of the eight priority recommendations of the OCWP of exploring the water conservation opportunities through produced water re-use and recycling.

Consistent with these recommendations, the PWWG was charged to explore produced water re-use and recycling opportunities in Oklahoma and develop recommendations.

Table 1-1. Produced Water Workgroup Members
Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

Name	Representing	Notes
J.D. Strong (Chair)	OWRB	Chair - Director of OWRB until November 2016
Julie Cunningham, Chairman (Chair)	OWRB	Chair - Executive Director of OWRB
Michael Dunkel	CH2M	Facilitator
Fred Fischer	Oklahoma Panhandle Agriculture & Irrigation Association	
Bud Ground	Environmental Federation of Oklahoma	Non-Governmental Agency
Brent Kisling	Enid Regional Development Alliance	
Dr. David Lampert	Oklahoma State University	Academia
Mark Matheson	Oklahoma Rural Water Association	
Mike Mathis	Oklahoma Independent Petroleum Association	
Mike Ming	GE Global Research	

Table 1-1. Produced Water Workgroup Members
Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

Name	Representing	Notes
Mike Paque	Groundwater Protection Council	
Jim Reese	Department of Agriculture, Food & Forestry	Secretary of Agriculture
Tim Rhodes	Oklahoma Corporation Commission	
Alan Riffel	Oklahoma Municipal League	
Jesse Sandlin	Oklahoma Oil & Gas Association	
Terry Stowers	Coalition of Oklahoma Surface & Mineral Owners	
Scott Thompson	Oklahoma Department of Environmental Quality	Regulatory Agency
Usha Turner	Oklahoma Gas & Electric	Power Industry Representative

Five meetings were conducted at Oklahoma Water Resources Board in Oklahoma City with the PWWG:

- March 3, 2016
- June 7, 2016
- August 29, 2016
- November 2, 2016
- March 10, 2017

The meeting agendas, summaries, and presentations are included in Appendix A. The key findings of each meeting are included below. The PWWG meeting materials are also available on OWRB's Water for 2060 website. Separate subgroups were established to conduct focused discussion on produced water re-use in agriculture, oil and gas industry, as well as to address regulatory and legal challenges to re-use, and water users.

Meetings and teleconferences with subgroups were held throughout 2016.

The subgroup meeting output are summarized in the Meeting 4 (held November 2, 2016) summary.

Meeting 1 – March 3, 2016

(PWWG members introduced themselves and gave brief descriptions of their interest/representation in the water community. Mr. Michael Dunkel, CH2M, presented to the Group "Options to Produced Water Disposal" defining the problem of too much produced water, cutbacks to injections, and the need to explore economically viable alternatives. Mr. Mike Ming, GE Global Research, presented to the Group "Innovated Challenge to Cost and Scale," which concerned finding ways to use the water, a comparison of water needs and produced water generation, noting not all use is needed in the same quality. Following the presentations, the members discussed options in technology, current processes and uses, the value of aquifer storage recovery, and what information would be useful in developing a strategy forward. Mr. Strong, in summary, said the OWRB will provide a webpage for the PWWG under its current "Water for 2060" page and include the presentations from today's meeting, as well as other pertinent presentations from the Groundwater Protection Council's recent UIC conference in Denver, and the Energy Water Initiative by CH2M.

Meeting 2 – June 7, 2016

J.D. Strong opened the meeting. Kyle Murray, Oklahoma Geological Survey, presented on his recent studies related to quantity and quality of produced water. Some highlights included seismicity, produced water tracking, and other water issues. Mr. Lloyd Hetrick, Newfield Exploration, presented on the

challenges of recycling produced water in Oklahoma. Mr. Hetrick highlighted Newfield's plans for recycling in Kingfisher County, plans to cooperatively share water facilities, transportation, and storage with other operators and share water volumes for re-use. Mr. Michael Dunkel, CH2M, presented his proposal to evaluate multiple scenarios for re-use solutions as part of a U.S. Department of Energy DOE grant. The group also discussed aquifer storage, water flooding as a possible produced water use, setting up subcommittees, and potentially getting research funds from OSU's National Energy Solutions Institute.

Meeting 3 – August 29, 2016

Mr. J.D. Strong opened the meeting. Mr. Michael Dunkel noted that the primary goals for the meeting were to gain insights and ideas from PWWG regarding available data on produced water quality, volumes, production areas and potential end-users for the produced water. Four subcommittees were established: Agriculture; Oil and Gas; Water Users - Demand & Discharge; and Regulatory, Legal and Challenges to Re-use/Recycling. Mr. Dunkel summarized the key data categories and some criteria for the types of data that would be beneficial to the study. Saba Tahmassebi, ODEQ, gave a PowerPoint presentation on ODEQ's Produced Water Management Survey of 26 States. Tim Baker, Oklahoma Corporation Commission, provided a presentation about commercial recycling facilities classification and requirements.

Meeting 4 – November 2, 2016

Based on the feedback received from the previous meetings and coordination with PWWG subcommittees, a common theme emerged suggesting that some rules and regulations might be changed to simplify and incentivize potential produced water uses. Some of the difficulties identified were a need for clarification including water ownership, definition and liability of spills, classification of treated PW, regulatory authorities, infrastructure right-of-ways etc. Mr. Bud Ground of EFO offered to communicate with other interested members to develop shell bills to advance produced water use. In addition, ODEQ is considering requesting delegation of EPA National Pollutant Discharge Elimination System (NPDES) discharge permitting to Oklahoma Pollutant Discharge Elimination System delegation. Michael Dunkel provided a review of the data gathered to date and reviewed some of the economic cases to be evaluated.

Meeting 5 – March 10, 2017

The primary goal for the meeting was to present the findings and recommendation included in the draft Oklahoma Water for 2060 Produced Water Reuse and Recycling Report that was provided to the PWWG ahead of the meeting and to solicit input from the PWWG on the findings and make recommendations to include in the final report. The PWWG reviewed the different re-use alternatives and the costs associated with them. The PWWG concurred that the study points the direction what needs and can be done in the future with produced water in Oklahoma. The PWWG concurred that some re-use alternatives might be cost-prohibitive at this time, but may become viable later due to e.g. improved infrastructure and logistics. Thus, the produced water re-use alternatives could be ranked into short-, mid-, and long-term alternatives based on their implementability. The PWWG provided revision suggestions and recommendations that are incorporated into this report. In addition, Mr. Bud Ground provided a legislative overview and summarized the contents and status of the various bills that have applicability to produced water re-use and recycling.

SECTION 2

Produced Water in Oil and Gas Operations

2.1 Introduction

Water is produced with oil and gas production in wells across Oklahoma. Regional development areas, or plays, are often named after the geologic formations that produce the oil and/or natural gas resource. The primary producing plays in Oklahoma are shown in Figure 2-1 below. The plays have differing characteristics regarding the typical amount of water produced with the product (the "water cut"), represented as a percentage, and water quality (salinity). A few generalizations can be made about the Oklahoma plays.

- The Mississippi Lime produces high volumes of water relative to the oil production. It also has the highest salinity of the producing areas in the state.
- The Granite Wash and Tonkawa areas produce less water and the water has a lower salinity.
- The STACK and SCOOP areas are relatively new developments that have the most current exploration and production activity and have the highest potential for future development. This area will have the highest need for water in completion operations based on current and projected drilling and completion activity.
- Table 2-1 summarizes the produced water volumes injected and total dissolved solids (TDS) by County.
- In some special cases, produced water is injected back into the same formation in water flooding or enhanced oil recovery (EOR) operations. These reservoirs have rock properties that allow this improved recovery methods. The new shale plays that require hydraulic fracturing are not conducive to water flooding or EOR due to their unique rock characteristics.

Figure 2-1. Main Oil and Gas Areas

Oklahoma Water for 2060 Produced Water Re-use and Recycling Report
Courtesy: Oil and Gas Investor. Modified.

Table 2-1. Produced Water Volumes Injected and Total Dissolved Solids (TDS) by County in Oklahoma
Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

County	Produced Water Injected Barrels Per Day (December 2015)[1]	Minimum TDS (mg/L)[2]	Average TDS (mg/L)	Maximum TDS (mg/L)
ALFALFA	600,559.53	207,133	212,935	217,543
BEAVER	39,458.61	ND	ND	ND
BECKHAM	22,322.81	ND	ND	ND
BLAINE	25,676.97	3,427	16,870	35,202
BRYAN	-	ND	ND	ND
CADDO	36,095.58	2,403	20,369	147,501
CANADIAN	66,147.00	1,373	14,953	158,098
CARTER[3]	1,041,173.35	95,550	116,756	133,900
CIMARRON	4,375.68	ND	ND	ND
CLEVELAND[3]	5,597.03	106,738	129,059	148,639
COAL	22,115.13	ND	ND	ND
COMANCHE	973.42	ND	ND	ND
COTTON	17,468.26	ND	ND	ND
CRAIG	378.19	ND	ND	ND
CREEK	475,327.76	ND	ND	ND
CUSTER	12,675.71	20,261	21,591	23,308
DEWEY	122,761.81	70,867	70,867	70,867
ELLIS	29,566.71	ND	ND	ND
GARFIELD	146,793.31	208,250	222,025	232,183
GARVIN[3]	166,967.78	46,131	111,826	164,780
GRADY	54,725.17	122	16,815	33,174
GRANT	109,502.35	217,171	227,231	233,806
GREER	16.94	ND	ND	ND
HARMON	35.00	ND	ND	ND
HARPER	13,022.42	ND	ND	ND
HASKELL	14.48	ND	ND	ND
HUGHES	71,959.32	ND	ND	ND
JACKSON	4,701.48	ND	ND	ND
JEFFERSON	15,104.94	ND	ND	ND
KAY	173,718.90	ND	ND	ND
KINGFISHER	64,781.52	3,252	24,992	77,336
KIOWA	416.94	563	8,983	17,402
LATIMER	2,055.35	ND	ND	ND
LEFLORE	667.03	ND	ND	ND
LINCOLN[3]	149,864.10	119,556	132,128	158,100
LOGAN[3]	65,793.55	93,829	145,408	220,852
LOVE[3]	11,038.81	63,420	71,419	83,332

Table 2-1. Produced Water Volumes Injected and Total Dissolved Solids (TDS) by County in Oklahoma
Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

County	Produced Water Injected Barrels Per Day (December 2015)[1]	Minimum TDS (mg/L)[2]	Average TDS (mg/L)	Maximum TDS (mg/L)
MAJOR	19,653.92	ND	ND	ND
MARSHALL[3]	924.23	58,173	58,173	58,173
MAYES	332.16	ND	ND	ND
MCCLAIN[3]	13,619.51	39,554	122,090	174,840
MCINTOSH	9,344.48	ND	ND	ND
MURRAY	51,809.42	ND	ND	ND
MUSKOGEE	4,107.52	ND	ND	ND
NOBLE[3]	163,466.44	186,490	186,490	186,490
NOWATA	80,409.23	ND	ND	ND
OKFUSKEE	41,261.03	ND	ND	ND
OKLAHOMA[3]	191,322.58	62,433	131,973	184,710
OKMULGEE	28,388.50	ND	ND	ND
PAWNEE	93,786.77	163,070	179,727	188,993
PAYNE[3]	176,271.45	28,690	117,189	145,600
PITTSBURG	15,079.94	ND	ND	ND
PONTOTOC	429,430.65	ND	ND	ND
POTTAWATOMIE[3]	144,255.63	8,180	122,717	150,830
ROGER MILLS	23,385.61	374	8,855	23,388
ROGERS	2,977.32	ND	ND	ND
SEMINOLE	329,065.19	ND	ND	ND
STEPHENS	456,081.81	4,439	31,266	137,220
TEXAS	149,402.86	ND	ND	ND
TILLMAN	5,822.97	ND	ND	ND
TULSA	39,125.59	ND	ND	ND
WAGONER	8,515.81	ND	ND	ND
WASHINGTON	36,519.29	ND	ND	ND
WASHITA	7,389.13	3,585	15,312	26,933
WOODS	341,255.55	151,909	177,827	192,768
WOODWARD	30,769.13	ND	ND	ND

[1]Source:

[2]Source:

[3]TDS calculated

ND – No Data

The graphic below shows the produced water quality in total dissolved solids (TDS) by county.

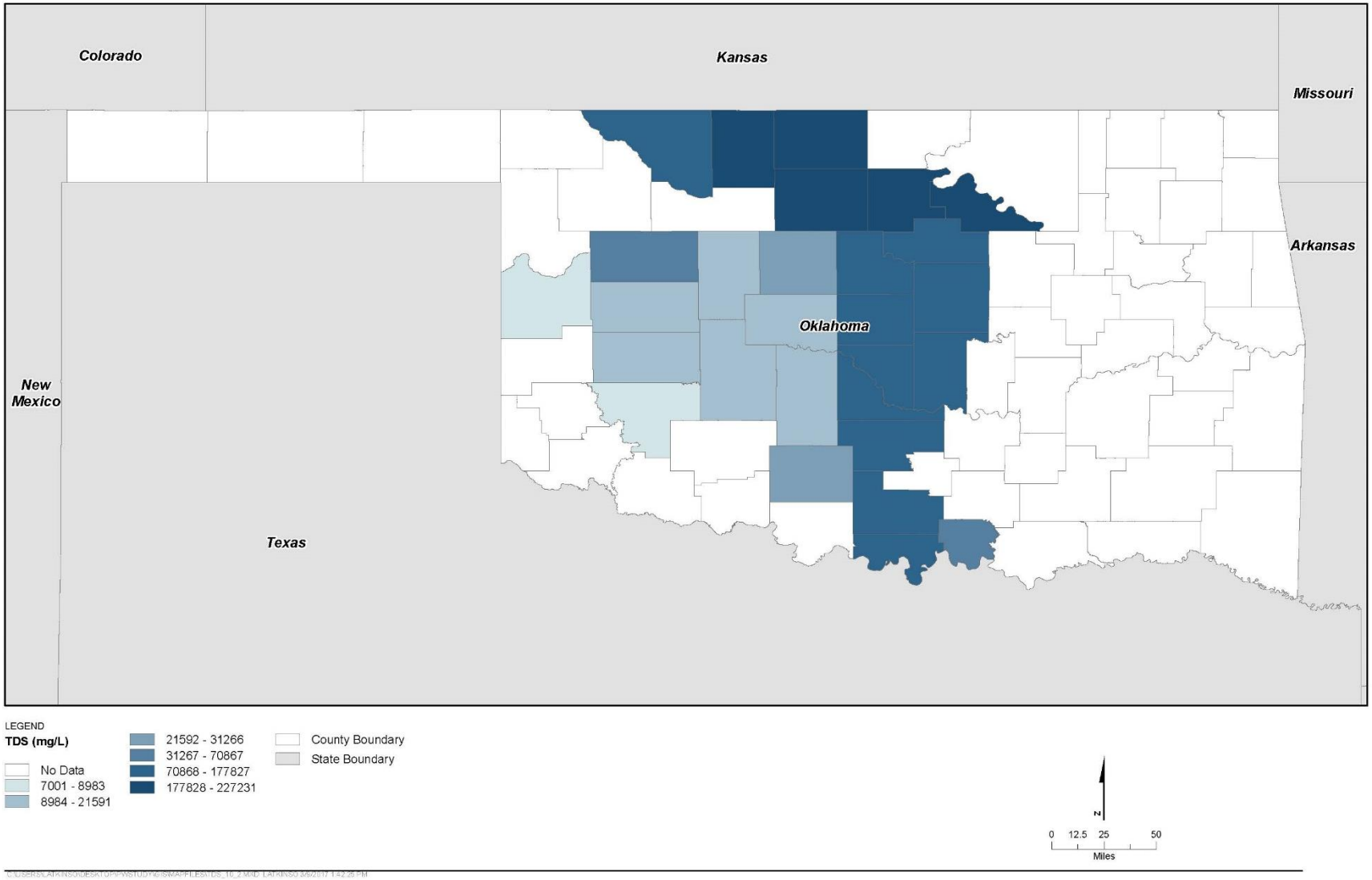


Figure 2-2. Total Dissolved Solids by County

Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

2.2 Produced Water Management

Figure 2-3 shows how multiple wells production is gathered at a separator and the oil, gas and water are directed to different locations. Early in the development of new oil and gas unconventional plays, water is usually locally sourced. When source water and disposal wells are readily available at low cost, the cost-benefit to develop water re-use infrastructure is not economic. Early in a new development, the emphasis is on proving the technical and economic viability of the area. Deep well water injection for disposal has been viewed as an environmentally protective and cost effective method of handling produced water. These factors were generally in place as unconventional oil and gas development accelerated in Oklahoma from 2005 to 2014. In 2014, oil prices dropped sharply. The lower oil prices reduced drilling and reduced capital budgets, making infrastructure and water re-use even more challenging in the short term.

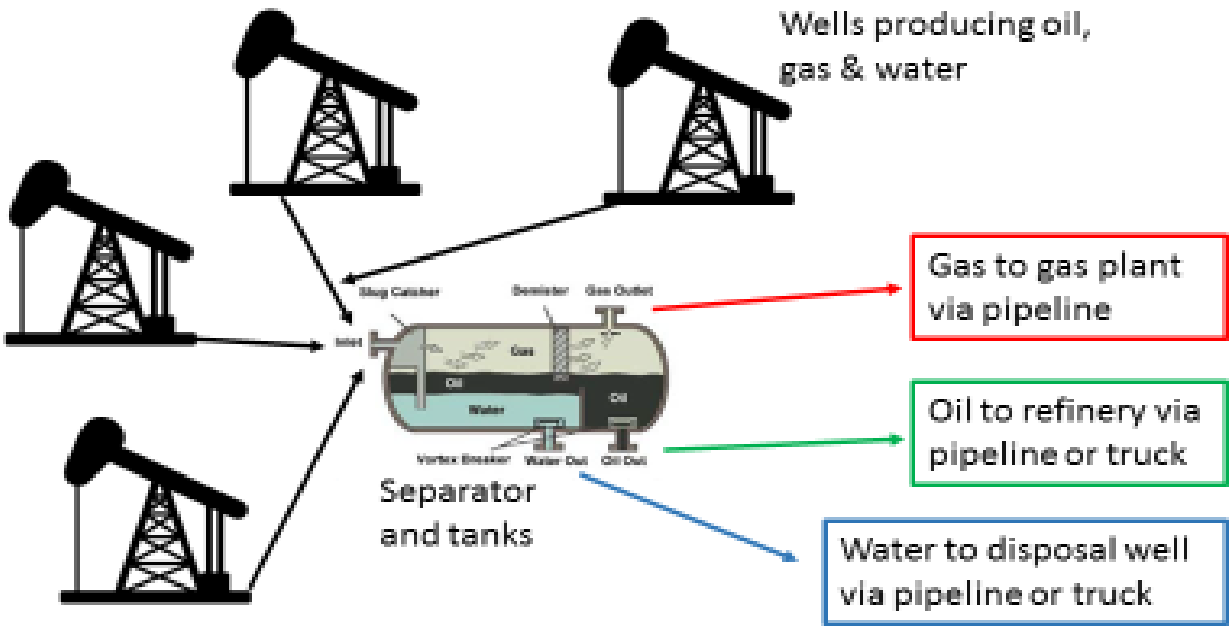


Figure 2-3. Typical Simplified Oil, Gas and Water Process
Oklahoma Water for 2060 Produced Water Re-use and Recycling Report
Source: CH2M

According to FracFocus, an average well in Oklahoma in mid-2016 used approximately 210,000 barrels, or about 8.8 million gallons of water. Hydraulic fracturing operations may last 1 to 2 weeks, according to industry sources. During the hydraulic fracturing operations, sand is blended with water and other chemicals to viscosify (make it thicker) the mix and carry the sand downhole. The blended fluid is pumped down the steel casing under high pressure to create a fracture network in the rock and allow the sand to prop open the gaps. For oil and gas produced water to be re-used, a number of operations are required. Produced water must be gathered at the well site or tank battery and transported to the new well site where it will be used in hydraulic fracturing operations. Normally, some level of water treatment is required to allow the water to be used as a carrier fluid for the proppant (normally sands). Typically, the water treatment may remove trace oil and suspended solids, and will disinfect the water to create what is referred to as “clean brine.” It is brine because the produced water will normally have total dissolved solids (TDS) ranging from 10,000 to 230,000 milligrams per liter (mg/L) in Oklahoma, whereas sea water is about 35,000 mg/L TDS. Until as recently as 2-3 years ago, many operators believed they needed largely “fresh” water in order to control the chemical reactions critical for hydraulic fracturing and indeed, some hydraulic fracturing methods, the requirements for which are

driven by formation geology, do require better water quality. However, due to significant industry advances produced water does not need to be desalinated (desalination removes the majority of the TDS) in order to be used for hydraulic fracturing source water. Therefore, the technological and economic barriers to desalinate water generally above 50,000 mg/L TDS, which comprises much of the produced water generated in Oklahoma, may not pose as much of a problem to oil and gas industry re-use. The required treatment often may vary by location and may be technically challenging. The produced water is often stored in impoundments or tanks ahead of the hydraulic fracturing operations that use large volumes of water in a short time. A treated water supply/demand mismatch may require volumes be collected and held over a period time to provide adequate volumes during the frac.

The cost to transport the water from where it was produced to the new well site for re-use may be higher than existing operations where the water is sourced and disposed of locally. Similarly, the cost to treat the water for re-use may be higher than existing operations where the water is sourced and disposed of locally. Thus, low-cost conveyance and low-cost treatment are keys to long-term re-use. Where companies have concentrated operations (drilling) and plans for long-term drilling, it may be more practical to install water pipelines to collect the produced water in some cases, instead of trucking the water. It is typically preferable to use aboveground temporary lines to supply water to fracturing sites rather than haul large volumes of water when considering community impacts and supply costs, but this decision is dependent upon local supply situations and distance to the frac site. Figure 2-4 shows a typical simplified oil, gas and water process with water re-use.

Some examples of Oklahoma water infrastructure documented on producing companies' websites and investor information include:

- Continental Resources operates water recycling facilities in both its SCOOP and STACK play operations. They estimate that these recycling facilities will reduce the amount of fresh water use by approximately 50% within their service areas.
- Newfield Exploration has installed over 160 miles of buried water pipeline infrastructure in the SCOOP and STACK operating areas. The company anticipates that the investment in water pipelines has the potential to reduce truck traffic by as many as 100,000 round trips per year. Newfield has also constructed OCC-regulated produced water storage pits accumulating a total storage capacity of 8.4 million barrels of which 4.4 million are permitted for produced water.
- Devon Energy initiated a water re-use system in the Cana-Woodford Shale. Through coordination with the Oklahoma Corporation Commission, Devon developed a 500,000-barrel storage and re-use facility for water produced from Devon's natural gas wells in Western Oklahoma. The system also included a network of pipelines designed to carry water from production sites to the re-use facility, then back to well completions sites. These types of systems and facilities lessen the number of trucks carrying water on local roadways and dramatically reduce Devon's need for fresh water.
- White Star Petroleum operates over 400 miles of produced water pipelines. This gathering network currently eliminates 1160 truck trips per day and is designed to efficiently capitalize on recycling technology by way of its robust water transfer capacity. White Star has evaluated over 100 recycling companies, and continues to dedicate R&D resources toward resolution of this challenging and promising opportunity.
- Chesapeake Energy has installed take-points on their extensive produced water infrastructure, allowing for the movement of produced water to a hydraulic fracturing site via temporary lines in the Mississippi Lime play in northwestern Oklahoma. For every Mississippi Lime well completed with produced water, this system eliminates 400-500 truckloads of produced water from being trucked to the wellsite.

- Cimarex Energy has used large portable storage tanks to re-use frac flowback fluids for hydraulic fracturing of new wells in the Cana field in Oklahoma.

For this study, the PWWG chose not to include specific development scenarios related to oil-and-gas re-use. The primary reason was that evaluating oil-and-gas re-use requires detailed company drilling plans that are often confidential and frequently revised. This level of planning is being performed internally by many producing companies. The majority of the scenarios evaluated for this report involve more permanent water users that have long-term water needs in one location.

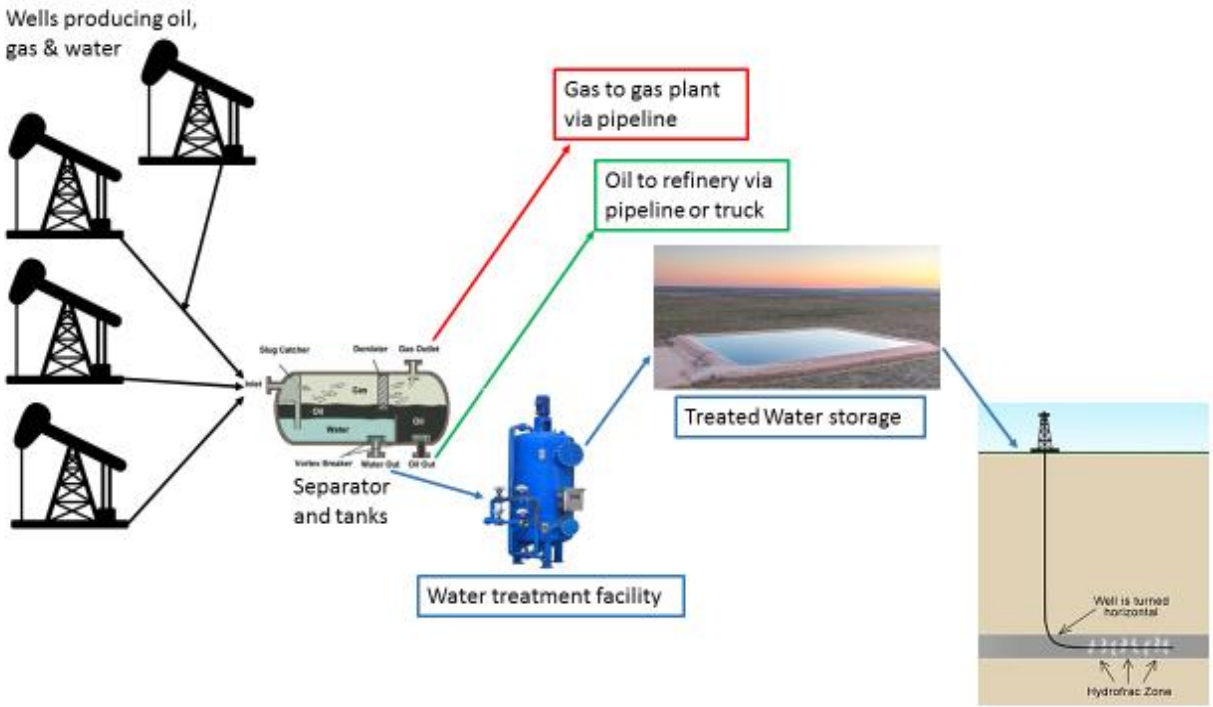


Figure 2-4 Typical Simplified Oil, Gas and Water Process with Water Re-use
Oklahoma Water for 2060 Produced Water Re-use and Recycling Report
Source: CH2M

The unique completion characteristic of the Mississippi Lime formation has allowed Chesapeake Energy to use produced water as the base completion fluid on hundreds of Miss Lime wells. In Figure 2-5, note the curved, white riser in the background bringing produced water to the working tanks.

Figure 2-5. Frac Tanks at a Mississippi Lime Area Well Site
Oklahoma Water for 2060 Produced Water Re-use and Recycling Report
Source: Chesapeake Energy

2.3 Produced Water Estimate

Disposal data were obtained from the OCC website for all injection wells permitted in the state of Oklahoma in 2015 and 2016. Based on discussions with OCC, the 2015 data provided the most complete and best available source for disposal data in the state. At the time of this evaluation, the 2016 data had not been updated with non-Arbuckle disposal data. Using the 2015 data set, the total barrels of water injected per well for 10,949 disposal wells was totaled up by County for the month of December 2015. The total barrels (bbls) per month was converted to barrels per day (bpd) per county and ranges from 0 bpd in Bryan County and 1,041,173 bpd in Carter County as shown on Figure 2-6.

Volume Conversions

1 Barrel = 42 gallons
1,000,000 barrels per day (bpd) is approximately:

- *29,167 gallons per minute (gpm)*
- *42 million gallons per day (MGD)*
- *47,046 acre-ft per year*

2.4 Potential Users of Produced Water

Two main data sources were used to identify entities with large volume water needs which could be potential users of treated produced water.

Data for all groundwater and surface water permits for non-potable use issued by OWRB as of September 6, 2016 were reviewed. The data identified 10,854 entities with non-potable water permits ranging from 8 bpd up to 2,094,503 bpd of permitted capacity for uses including agriculture, commercial, industrial, irrigation, mining, power, recreation-fish-wildlife, and other non-specified uses. Due to the number of non-potable permits, the data used for this evaluation were screened to include the top 40 entities based on total permitted volume.

In addition to the non-potable groundwater and surface water permits, National Pollutant Discharge Elimination System (NPDES) permits issued by ODEQ discharging an annual average flow rate of greater than 11,904 bpd (0.5 million gallons per day) were also reviewed. Data provided by ODEQ included 149 NPDES permits with annual average discharge rates ranging from 12,166 bpd to 15,788,505 bpd.

Several additional data sources were reviewed but not used in this evaluation, including:

- Facilities with Discharge Permits (non-pretreatment cities): Industrial users which discharge to publicly owned treatment works (POTWs) in non-pretreatment cities provided by ODEQ but not used due to low average annual flows of less than 11,904 bpd (0.5 million gallons per day).
- Facilities with Discharge Permits (pretreatment permits): Discharge indirectly to POTWs no data available.

2.5 Alternatives Screening Matrix

The top 40 non-potable water permits and the NPDES discharge permits were superimposed on top of the produced water disposal rates per county to identify areas with high produced water volumes which correlate to entities that could be potential users of treated produced water based on their high water needs. The preliminary matches of produced water and potential water users are identified in Figure 2-6. The high produced water volumes are identified by dark blue and the large water users are identified by the large maroon squares and orange circles.

A total of 13 scenarios were identified based on a correlation between high produced water volumes and entities requiring significant volumes of non-potable water for irrigation, power, mining, oil and gas use, and industrial uses. Four additional scenarios, including aquifer storage and recovery (ASR), surface water discharge (two different scenarios) and one additional industrial user, were added as a result of the PWWG meetings for a total of 17 scenarios as summarized on Figure 2-6. A semi-quantitative, multiple decision criteria screening matrix for all 17 scenarios was developed to identify the primary advantages and disadvantages of each produced water re-use alternative. This screening matrix is included as Appendix D. Based on this screening evaluation, the following shortlist of alternatives was developed for further economic evaluation along with assumed treatment requirements:

- Desalinate for Power Use by Oklahoma Gas and Electric Company in Pawnee County
- Desalinate for Power Use by Oklahoma Gas and Electric Company in Seminole County
- Desalinate for Industrial Use by Medford OK Natural Gas Liquids
- Clean Brine for Oil and Gas Use, Transferred from Alfalfa to Blaine County
- Desalinate for Surface Water Discharge in Beckham County with an Irrigation User Downstream
- Desalinate for Surface Water Discharge in Grant County Downstream of Great Salt Plains Lake

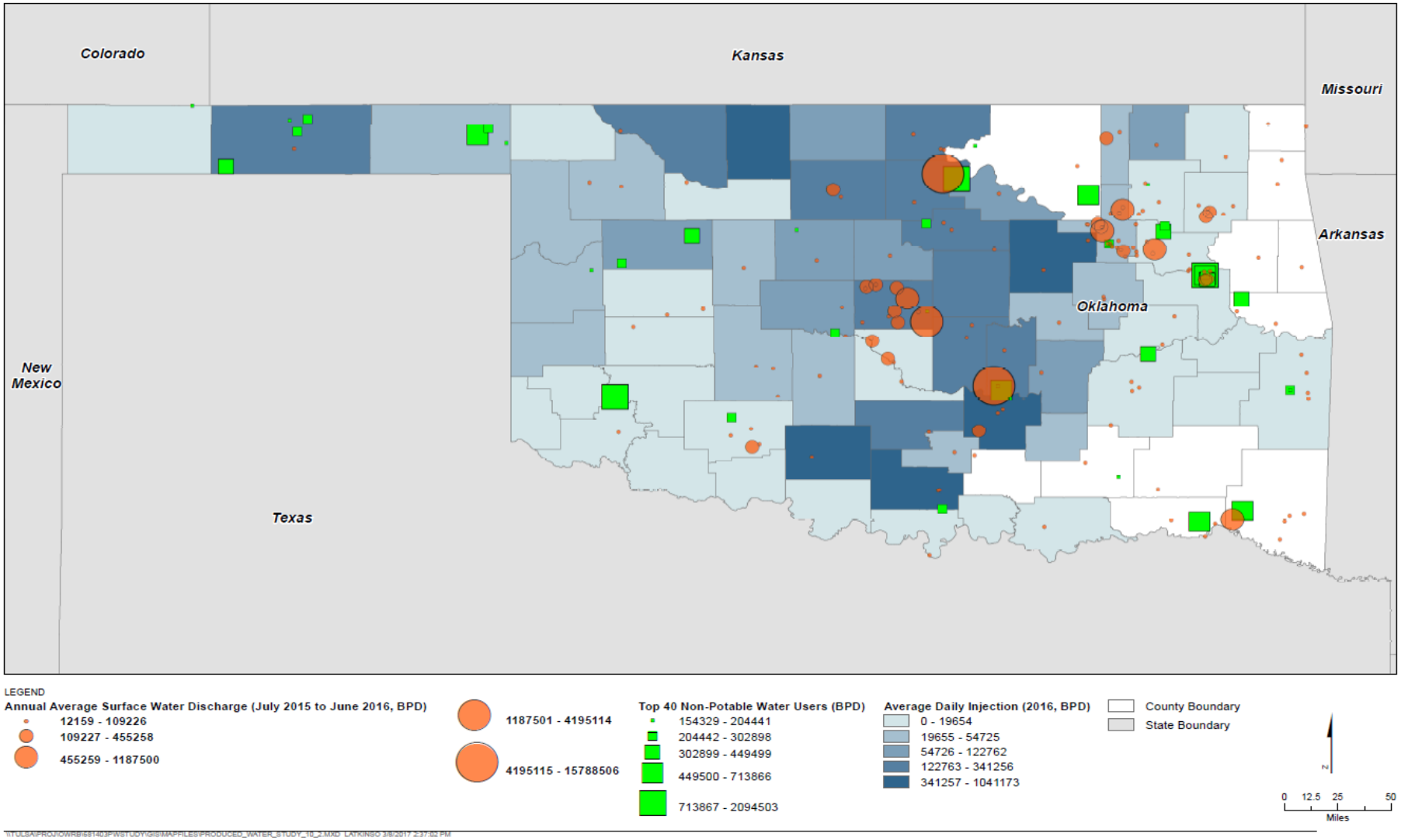


Figure 2-6. Preliminary Matches of Produced Water with Potential Users

Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

2.6 Alternatives Not Evaluated

The following potential uses for treated produced water were determined unfeasible for the following reasons:

- Agriculture/Irrigation: An agriculture subcommittee was established under the PWWG to assess the potential of using treated produced water with agriculture. The state's irrigation farming centers with water conveyance infrastructure are generally not located near the oil and gas production. Additionally, agriculture irrigation typically only occurs four or five months out of the year. This seasonality creates challenges for a plant that is producing water every day. Agriculture in Oklahoma is able to pump groundwater for as little as pennies per barrel. Thus, the typical farmer could not afford to pay more than pennies per barrel for water delivered to their infrastructure. No economic case was identified or evaluated. However, cases 6 and 10 involve desalination and discharge of the treated water to river. These two cases could benefit agriculture downstream of the discharge.

  More research may be warranted however, as one of multiple future solutions. While it is not likely to ever be a stand-alone solution, if some future technology were to make desalinization far less expensive, irrigation might play a role as one alternative in the toolbox for local production wells to discharge produced water nearby; perhaps even discharging to marginal aquifers as storage for use by irrigators during a different season or for times of drought.

- Aquifer Storage and Recovery (ASR): One scenario would be to take desalinated produced water and inject it into relatively shallow groundwater aquifers that contain fresh water or brackish water. This scenario was not evaluated economically because there are currently no state regulations allowing ASR from treated produced water. Also, groundwater aquifers are often used directly from ranchers' wells without the benefit of a municipal water treatment plant. From a cost perspective, ASR could be similar to the desalination and surface water discharge cases.

  More research may be warranted however, as one of multiple future solutions. If desalination technology were less expensive and toxicological questions resolved, aquifer recharge could be a solution for groundwater depletion or defense against drought.

- Mining: One potential user with a non-potable water permit to use groundwater for mining purposes was identified. This scenario was assumed to be comparable to the desalination for industrial and power uses.

SECTION 3

Produced Water Re-use Scenarios

Conceptual designs were developed for the six scenarios shortlisted for further economic evaluation (Section 2.5) including gathering systems to collect the produced water, intermediate pump stations, centralized storage and treatment facilities, and discharge structures.

Class V capital cost estimates (+50%/-30% estimated accuracy) were prepared for each scenario using CH2M's Parametric Cost Estimating System. The capital costs and operating costs were then normalized to today's dollars by discounting future costs and barrels treated using a 10% discount rate. This allows comparison of all scenarios using a single number.

Table 3-1 summarizes the results of the feasibility evaluation. Details on each of the ten scenarios are summarized in the following subsections. Assumptions used to develop the cost estimates are included as Appendix E.

Table 3-1. Cost Estimates for Ten Produced Water Use Scenarios
Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

New Case	Case Description	Total Capital ($Millions)	Capacity BWPD	County	Assumed Wtr TDS (mg/L)	Normalized $/BW
1	Typical Source and Dispose - STACK & SCOOP	NA	NA	Central OK	NA	1.09
2	Oil and gas re-use (treatment cost only)	NA	NA	State-wide	NA	0.57
3	Clean Brine Transfer & treatment	208	200,000	Alfalfa	213,000	1.03
4	Evaporation - low TDS (SCOOP & STACK)	NA	20,000+	Blaine	17,000	1.66
5	Evaporation - high TDS (Miss. Lime)	NA	20,000+	Alfalfa	213,000	1.79
6	Desalination for Surface Discharge	22	15,000	Beckham	9,000	3.58
7	Desalination for Power Use	88	130,000	Pawnee	125,000	4.37
8	Desalination for Power Use	95	230,000	Seminole	180,000	4.43
9	Desalination for Industrial Use	35	30,000	Grant	227,000	7.41
10	Desalination for Surface Discharge	38	30,000	Grant	227,000	7.49

3.1 Typical Source and Disposal

The majority of water used in oil and gas operations is sourced as close as possible to the well site because transportation of water is costly. Water is sourced from shallow groundwater from land owners or surface water supplies (i.e., lakes, rivers and streams) through existing water allocation frameworks. Operators report trucking costs average $1.00 to $3.00 per barrel of water. Similarly, most produced water is disposed of relatively close to the producing well to reduce transportation costs. In some cases, producing companies may own their disposal wells and in other cases they may use third-party wells for disposal. The produced water is transported to the disposal well by pipeline or truck.

CH2M polled the operators involved in the OWRB oil and gas PWWG subcommittee for their estimated average cost of sourcing water and disposing of produced water in central Oklahoma, without including trucking costs. The average cost of sourcing and disposing is $1.09 per barrel of water for the five responses.

3.2 Oil and Gas Re-use

Section 4 describes typical oil and gas re-use. The cost to re-use produced water includes the cost to store, treat and transport the produced water to the new location.

Based on this study's poll of selected water treatment vendors (see Section 4.2 for details), a representative cost to minimally treat produced water for hydraulic fracturing averages $0.57 per barrel of water.

If water pipelines exist and allow the transfer to occur near the fracturing operation, the additional cost is effectively the water treatment cost. Producing companies have installed a limited amount of water infrastructure, but more is expected. If pipe infrastructure does not exist, the cost to truck the water could be an additional $1 to $3 per barrel, depending on the distance traveled. Thus, it is difficult to easily characterize the cost of oil and gas re-use, but it can be as low as $0.57 per barrel in some situations.

3.3 Inter-county Clean Brine Transfer and Treatment

Case 3, Inter-county Clean Brine Transfer and Treatment, is an assessment of the cost to deliver 200,000 barrels of water per day (BWPD) from the Mississippi Lime area in Alfalfa County, to Blaine County in the emerging STACK play as shown on Figure 3-1.

The Mississippi Lime formation in north central Oklahoma produces high volumes of water per well. Woods and Alfalfa Counties are two of the top counties for produced water injection. Operations in the Mississippi Lime formation do not require significant volumes of water for re-use.

On the other hand, the STACK area in and around Blaine County has a high need for water for operations. Additionally, the STACK wells are not projected to provide sufficient produced water for ongoing operations. Therefore, the Blaine County area is likely to need water for 10 or more years of drilling.

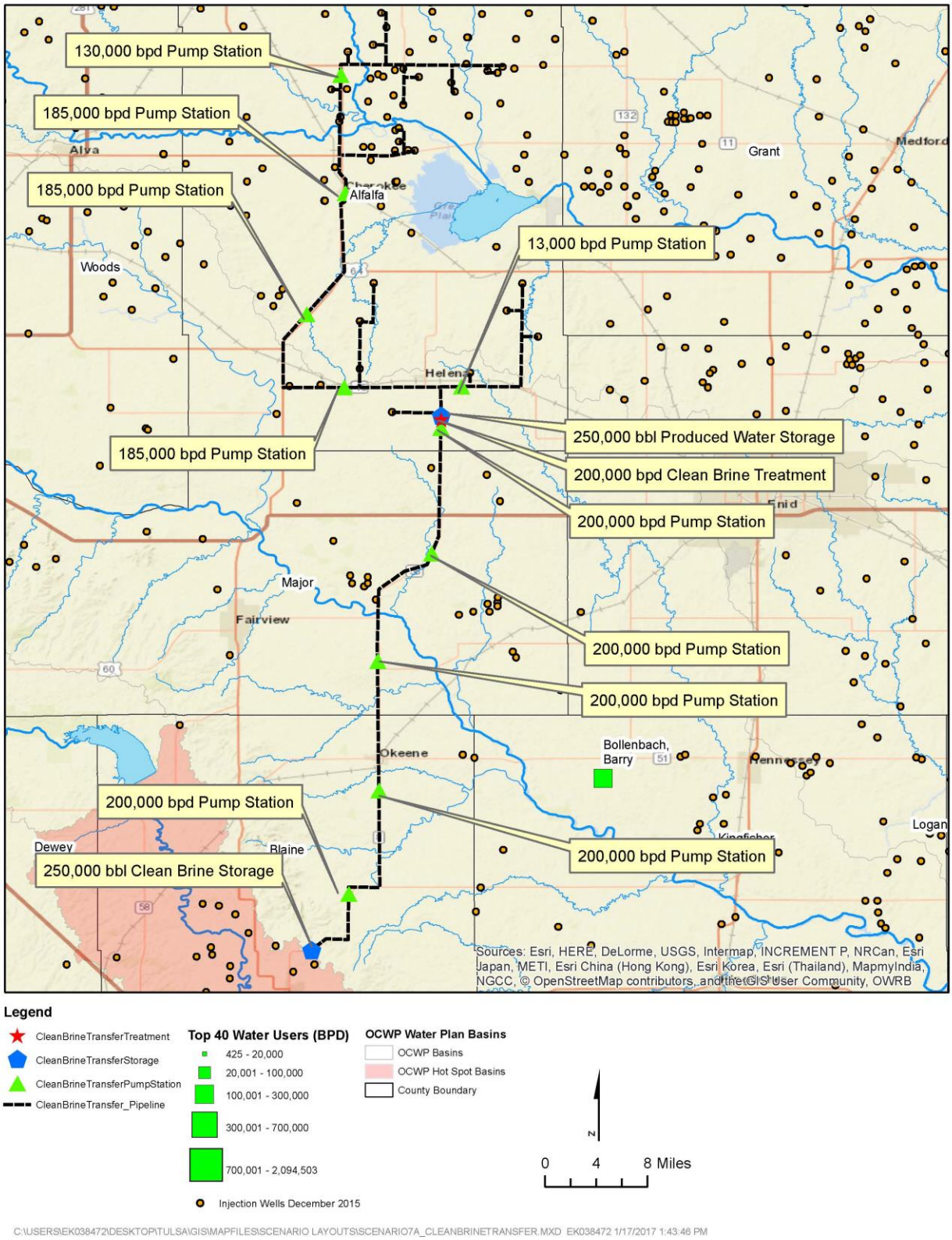


Figure 3-1. Case 3 Layout and Infrastructure

Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

The cost evaluation includes the following major components:

- Gathering system with five pump stations to collect produced water from 34 wells
- 250,000 bbl produced water storage impoundment
- 200,000 bpd clean brine treatment plant
- 250,000 bbl treated produced water impoundment
- Conveyance system with five additional pump stations to transfer the clean brine
- 250,000 bbl clean brine impoundment with truck filling stations

Pipeline lengths and diameters which make up the gathering and conveyance system are summarized in Table 3-2.

Table 3-2. Summary of Pipeline Gathering System for Case 3
Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

Pipe Size (inches)[1]	Length of Pipe (feet)
1	35,600
2	32,000
3	21,600
4	20,800
5	96,000
6	34,800
7	43,200
8	8,000
10	11,200
12	5,100
14	6,000
16	12,500
18	168,900
20	262,300

[1]Based on a velocity of 7 feet per second (fps)

It is assumed that oil and gas operators would be responsible for conveying the clean brine from the clean brine impoundment to the new well sites for hydraulic fracturing. The capital cost to gather and transport the water is $208 million. Additionally, the cost to minimally treat the produced water without removing salinity (TDS) and operate the pipeline is $0.57 per barrel, or $40 million per year. The infrastructure is assumed to have a 10-year life, consistent with most of the other cases in this report. The future costs and barrels of water are discounted at a 10 percent rate to provide an overall cost per barrel in today's dollars of $1.01 per barrel.

The positive economic aspects of this case are driven by a large volume of produced water that is within 30 or 35 miles of the need for water.

Mississippi Lime producers and STACK play users would have to make long-term commitments to supply/ use the produced water and pay for any required treatment, storage and transport infrastructure. The distribution network in Blaine County would also have to be constructed. Oil and gas companies could fund, construct and operate the system directly or through a cooperative arrangement and recover costs through per barrel recovery charge to the other user (i.e., Mississippi Lime operator

pays per-barrel disposal cost in lieu of injection well disposal cost or STACK operator pays per-barrel supply charge in lieu of fresh water source cost). Alternatively, a third party interest could finance and develop the system either at risk or backed by long term use agreements with the prospective users.

There is not an existing project within the United States that moves large volumes of produced water across distances like this project entails. The closest analogy is in the Permian Basin where Pioneer Natural Resources is using approximately 100,000 BWPD of municipal wastewater from Odessa, TX and plans to use approximately 200,000 BWPD of municipal wastewater from Midland, TX. In these cases, the water is not produced water and has TDS of about 1,000 mg/L (fresh water from a TDS standpoint). In contrast, the Mississippi Lime water is produced water with a TDS of about 218,000 mg/L.

Water compatibility could be a significant challenge and will require additional study. The cost estimate does include a low level of water treatment, but it is an estimate without having done detailed water compatibility studies.

Additionally, the commercial complexity of having a group of producers, a pipeline owner/operator, and a group of water users, each with different interests, will potentially make such as agreement challenging.

3.4 Forced Evaporation – Low TDS (SCOOP & STACK)

Case 4, Forced Evaporation of Produced Water, deploys an established method that may be cost-competitive with water disposal today. There are technologies to evaporate the produced water that vaporize the water and create a sellable industrial salt.

One such new evaporation project exists near Wakita, OK. Poseidon Saltwater Solutions, Inc.[4] is constructing a commercial water treatment system that will accept produced water from the surrounding Mississippi Lime play. Water will primarily be trucked to the facility, at least initially. Their treatment process will use a distributed air flotation process, glass bead filtration, and clay filtration. The evaporation is accomplished through a vaporizer that creates tiny water droplets. No heat is used in the process, thus energy costs are low. The area has a tall barrier around it to reduce wind and prevent solids from dropping out offsite. The plant's initial capacity will be about 5,000 to 7,000 BWPD. There are plans for an ultimate capacity of 10,000 to 12,000 BWPD. The process will create solids that will be primarily salts that will be sold to industrial users. Potential naturally occurring radioactive material (NORM) will be handled by removing any potential NORM-causing material before the water passes through the evaporator.

The plant, the first of its kind in Oklahoma, obtained a permit from the OCC as a commercial water treatment plant. Water disposal costs in the area are thought to be approximately $1 per barrel to $1.50 per barrel. The plant expects to be competitive with disposal costs. The plant was expected to be operating in early 2017.

[4] http://poseidonsaltwatersystems.com/

Figure 3-2. Poseidon Saltwater Solutions vaporizer to evaporate water
Used with Owner's permission.

Another method of evaporating produced water is in a contained vessel as shown below. This particular unit is for smaller volumes of produced water.

Figure 3-3. Logic-ES evaporator.
Used with Owner's permission.

Case 4 is based on the cost estimates from a number of companies focused on bringing evaporation technology to Oklahoma. The cost per barrel is $1.66 for comparison to other cases. This case is estimated based on a minimum of 20,000 BWPD per site. The plan would be to put the evaporator system next to a high-volume disposal well so no transportation would be needed. The cost estimate from the treatment companies included all costs, including power, fuel and waste removal. This case is based on low TDS in Blaine County (STACK play). For most technologies, low TDS is less expensive than high TDS. This case and Case 5 are assumed to have a 2-year life that is extendable. The treatment cost was based on a 2-year project. Since no significant capital is involved for pipelines or the treatment vendor, the project life is not as significant as the high capital projects.

3.5 Forced Evaporation – High Total Dissolved Solids (Mississippi Lime)

Case 5, Evaporation Case, is similar to Case 4, except the water quality is much higher salinity. Case 5 TDS is 213,000 mg/L TDS whereas Case 4 TDS is 17,000 mg/L. For reference, seawater is approximately

35,000 mg/L, much closer to the low TDS Case 4. The reference for this alternative is a high TDS evaporation project based on Alfalfa County, but would be similar for other counties in the Mississippi Lime area. The other assumptions are the same as Case 4: 2-year extendable life, no significant transport or other capital requirements, cost is based on the water treatment company paying for power, fuel and waste removal.

3.6 Desalination for Surface Discharge in Beckham County

Cases 6 through 10 are all desalination cases, where the produced water is treated to a high quality that is generally equivalent to potable water. The specifications for discharging water or using water for industrial uses requires this high quality of water. Case 6, Desalination for Surface Discharge in Beckham County, was selected because Beckham County has unusually low TDS in the produced water. This produced water is from a different formation than the STACK and Mississippi Lime areas. In fact, at 9,000 TDS, this water quality is substantially less saline than most unconventional plays across the United States, where the range of TDS averages 50,000 to over 200,000. The normalized cost per barrel for this case is $3.58, the lowest of the desalination cases. The lower cost is primarily related to lower treatment costs due to the lower TDS.

Case 6 gathers approximately 15,000 BWPD due to the low volumes of water produced by wells in Beckham County. The gathering system shown on Figure 3-4 would cost an estimated $22 million. The assumption is for a 10-year project, consistent with the other desalination cases.

Because of the low TDS, the water treatment technology was assumed to be reverse osmosis, which is less expensive than evaporative technologies used for produced water with greater than 50,000 TDS.

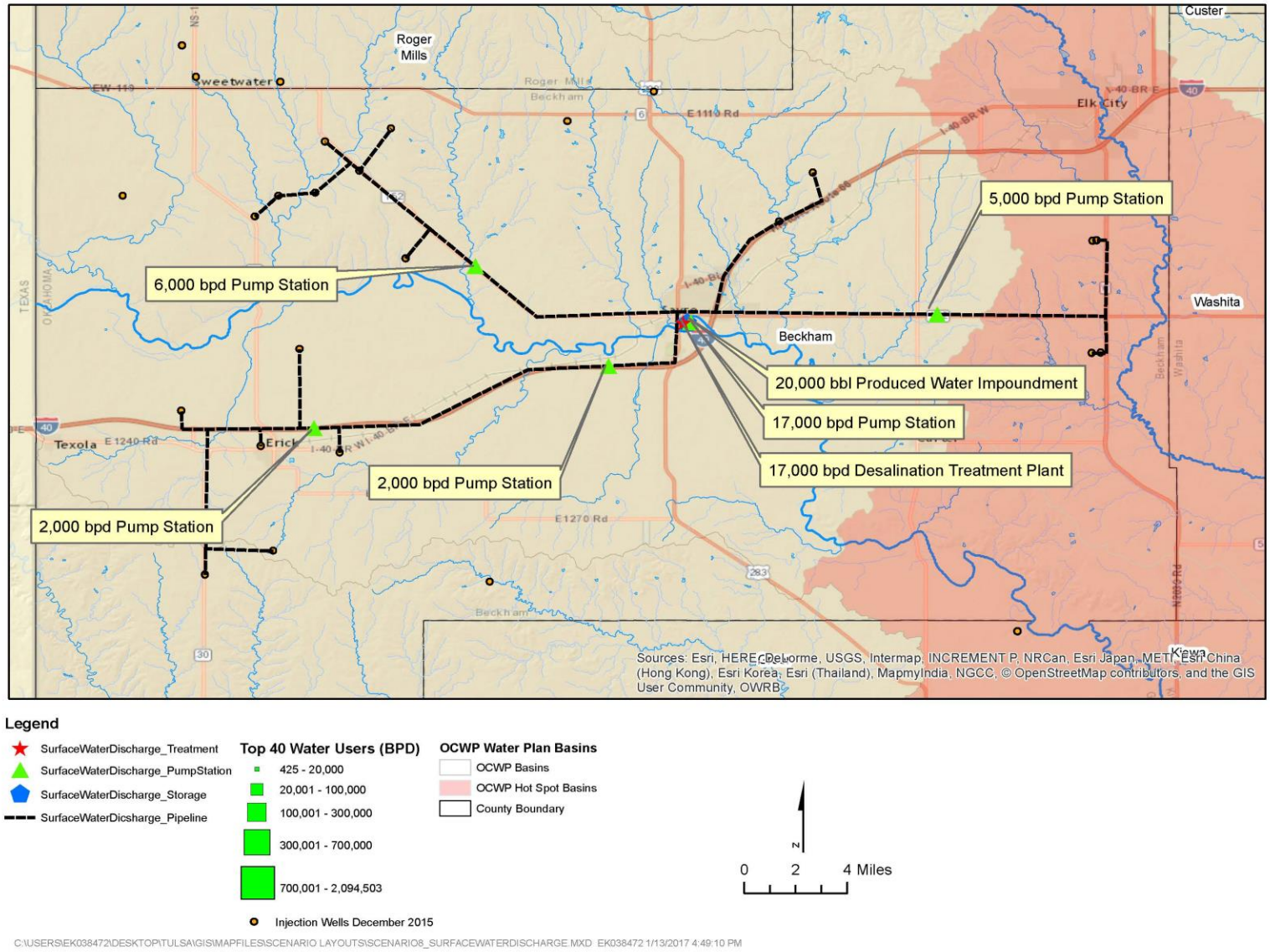
The cost evaluation includes the following major components:

- Gathering system with four pump stations to collect produced water from 17 wells
- 20,000 bbl produced water aboveground storage tank
- 15,000 bpd desalination treatment plant
- 20,000 bbl treated produced water aboveground storage tank
- 20,000 bpd surface water discharge structure
- Pipeline lengths and diameters which makeup the gathering and conveyance system are summarized in Table 3-3.

Table 3-3. Summary of Pipeline gathering System for Case 6
Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

Pipe Size (inches)[1]	Length of Pipe (feet)
1	75,900
2	142,800
3	100,800
4	55,800
5	4,300
Total	379,600

[1]Based on a velocity of 7 fps.



Legend

- SurfaceWaterDischarge_Treatment
- SurfaceWaterDischarge_PumpStation
- SurfaceWaterDischarge_Storage
- SurfaceWaterDicsharge_Pipeline

Top 40 Water Users (BPD)

- 425 - 20,000
- 20,001 - 100,000
- 100,001 - 300,000
- 300,001 - 700,000
- 700,001 - 2,094,503
- Injection Wells December 2015

OCWP Water Plan Basins

- OCWP Basins
- OCWP Hot Spot Basins
- County Boundary

N

0 2 4 Miles

C:\USERS\EK038472\DESKTOP\TULSA\GIS\MAPFILES\SCENARIO LAYOUTS\SCENARIO8_SURFACEWATERDISCHARGE.MXD EK038472 1/13/2017 4:49:10 PM

Figure 3-4. Case 6 - Surface Water Discharge

Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

Any time treated produced water is discharged to a river or lake, an EPA discharge permit is required, unless jurisdiction is within the state agency. This case would require a permit to discharge water to the North Fork of the Red River. The discharge of treated produced water is allowed via permit from the EPA. Section 6.3.6 discusses more about discharge permits. This case is the first of the beneficial re-use cases where new high-quality water would be generated. Cases 7 to 10 are also beneficial re-use cases that generate high-quality water for discharge or other industrial users.

3.7 Desalination for Power Use in Seminole County

Case 7, Desalination for Power Use in Seminole County, was selected because the power industry requires a significant amount to high quality water for cooling. The capital cost, $88 million, includes a gathering system for 130,000 BWPD of 125,000 mg/L TDS water. A desalination plant would be required and is included as an operating cost per barrel (Figure 3-5). The normalized cost per barrel for this case is $4.37 per barrel provided to the power plant. Although this case assumes a 10-year life, it would certainly be possible for a longer term project.

The major components included in the cost evaluation include:

- Gathering system with eight pump stations to collect produced water from 110 wells,
- 150,000 bbl produced water storage impoundment,
- 130,000 bpd desalination treatment plant,
- 150,000 bbl treated produced water impoundment

Pipeline lengths and diameters which makeup the gathering and conveyance system are summarized in Table 3-4.

Table 3-4. Summary of Pipeline Gathering System for Case 7
Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

Pipe Size (inches)[1]	Length of Pipe (feet)
2	289,600
3	58,400
4	107,000
5	30,300
6	81,900
7	9,500
8	39,200
10	175,700
12	101,900
16	20,600
Total	914,300

[1]Based on a velocity of 7 fps.

Discussions within the PWWG indicate that the power company would not need a new permit to use the highly treated produced water, but that the company's existing permit would continue to apply.

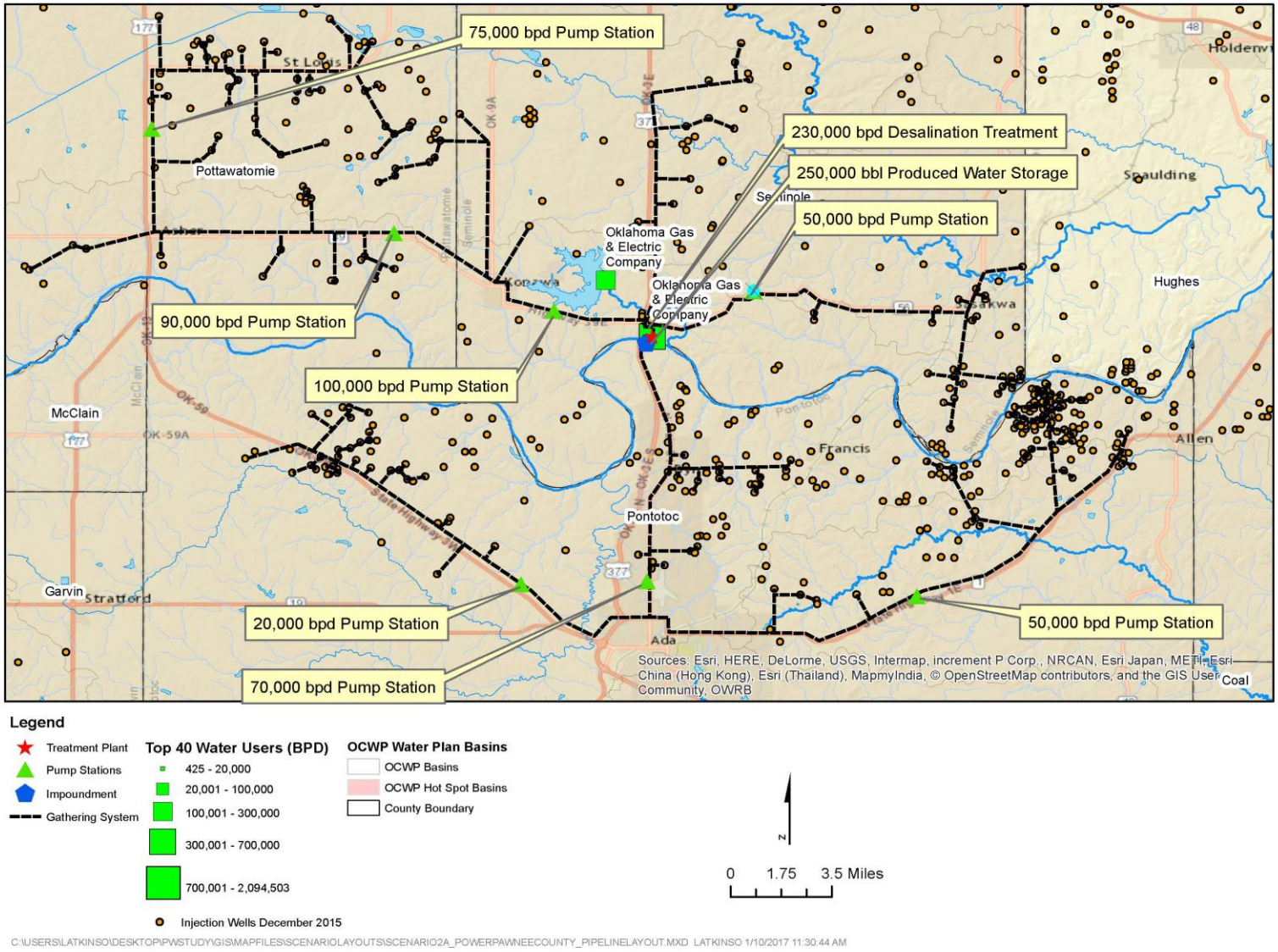


Figure 3-5. Case 7 Layout and Infrastructure

Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

3.8 Desalination for Power Use in Pawnee County

Case 8, Desalination for Power Plant in Pawnee County, is similar to Case 7. Case 8 was selected because the power industry requires a significant amount to high quality water for cooling and steam generation. The capital cost, $95 million, includes a gathering system for 230,000 BWPD of 180,000 mg/L TDS water. A desalination plant would be required and is included as an operating cost per barrel (Figure 3-6). The normalized cost per barrel for this case is $4.43 per barrel provided to the power plant. Although this case assumes a 10-year life, it would be possible for a longer term project.

Cases 7 and 8 have similar projected costs per barrel based on Case 8 having larger economics of scale, but offset by the poorer quality produced water (higher TDS).

The major components included in the cost evaluation include the following:

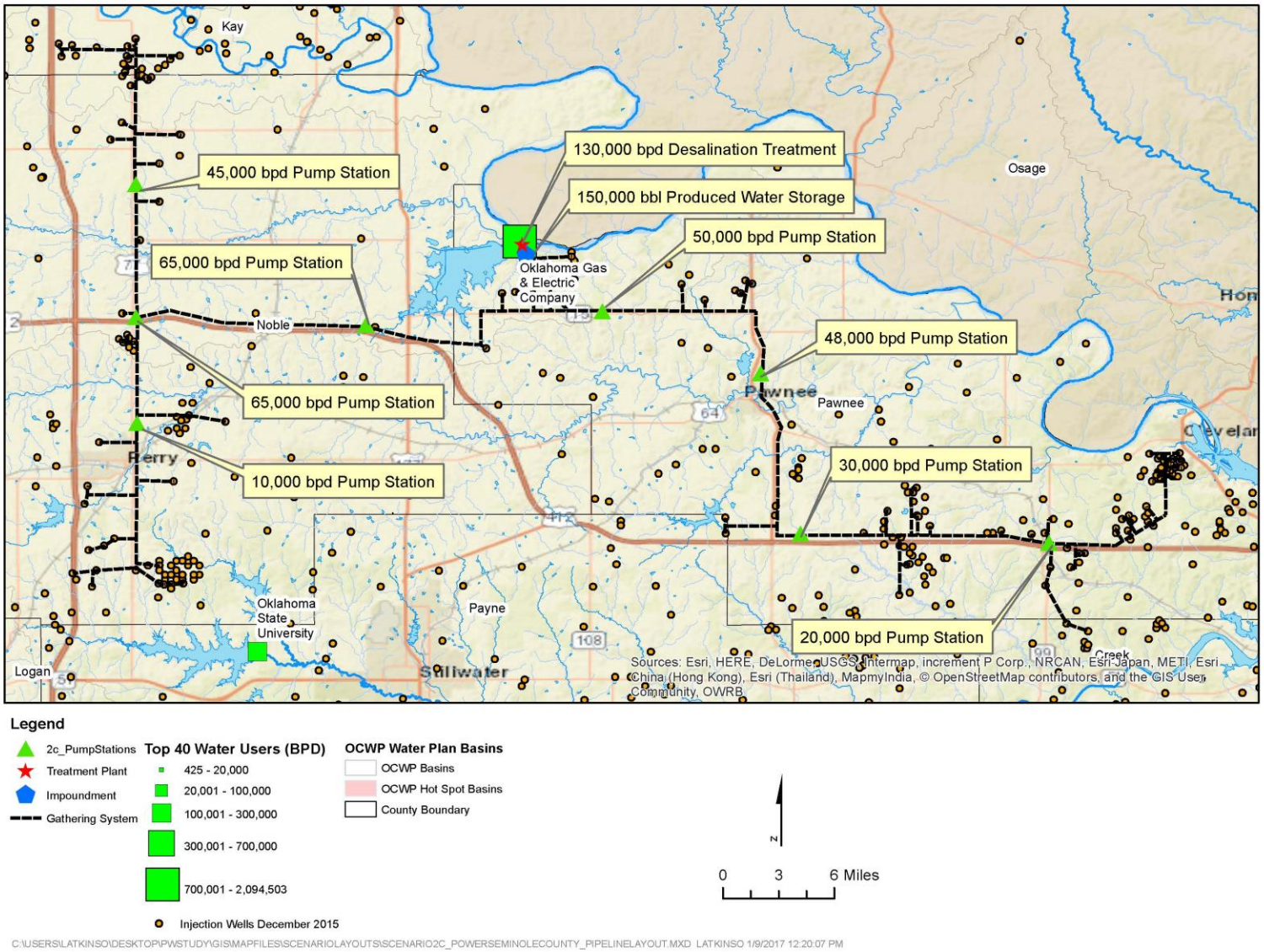
- Gathering system with seven pump stations to collect produced water from 220 wells
- 250,000 bbl produced water storage impoundment
- 230,000 bpd desalination treatment plant
- 250,000 bbl treated produced water impoundment

Pipeline lengths and diameters which makeup the gathering and conveyance system are summarized in Table 3-5.

Table 3-5. Summary of Pipeline Gathering System for Case 8
Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

Pipe Size (inches)[1]	Length of Pipe (feet)
2	424,100
3	105,900
4	104,200
5	45,600
6	81,800
7	23,800
8	5,300
10	168,000
12	112,000
14	56,500
18	1,800
Total	1,129,000

[1]Based on a velocity of 7 fps.



Legend

- 2c_PumpStations
- Treatment Plant
- Impoundment
- Gathering System

Top 40 Water Users (BPD)

- 425 - 20,000
- 20,001 - 100,000
- 100,001 - 300,000
- 300,001 - 700,000
- 700,001 - 2,094,503

OCWP Water Plan Basins

- OCWP Basins
- OCWP Hot Spot Basins
- County Boundary

- Injection Wells December 2015

N

0 3 6 Miles

C:\USERS\LATKINSO\DESKTOP\PWSTUDY\GIS\MAPFILES\SCENARIOLAYOUTS\SCENARIO2C_POWERSEMINOLECOUNTY_PIPELINELAYOUT.MXD LATKINSO 1/9/2017 12:20:07 PM

Figure 3-6. Case 8 Layout and Infrastructure

Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

3.9 Desalination for Industrial Use in Grant County

Case 9, Desalination for Industrial Use in Grant County, was selected based on a known water user. The capital cost, $35 million, includes a gathering system for 30,000 BWPD of 227,000 mg/L TDS water. A desalination plant would be required and is included as an operating cost per barrel (Figure 3-7). The normalized cost per barrel for this case is $7.41 per barrel provided to the power plant. Although this case assumes a 10-year life, it would certainly be possible for a longer term project.

This case is significantly higher cost per barrel that the prior desalination cases due to a smaller scale and poorer quality produced water (higher TDS).

The major components included in the cost evaluation include:

- Gathering system with four pump stations to collect produced water from 45 wells,
- 35,000 bbl produced water aboveground storage tank,
- 30,000 bpd desalination treatment plant,
- 35,000 bbl treated produced water aboveground storage tank.

Pipeline lengths and diameters which makeup the gathering and conveyance system are summarized in Table 3-6.

Table 3-6. Summary of Pipeline Gathering System for Case 9
Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

Pipe Size (inches)[1]	Length of Pipe (feet)
1	81,200
2	66,300
3	32,600
4	59,000
5	119,800
6	70,200
8	7,000
Total	436,100

[1]Based on a velocity of 7 fps.

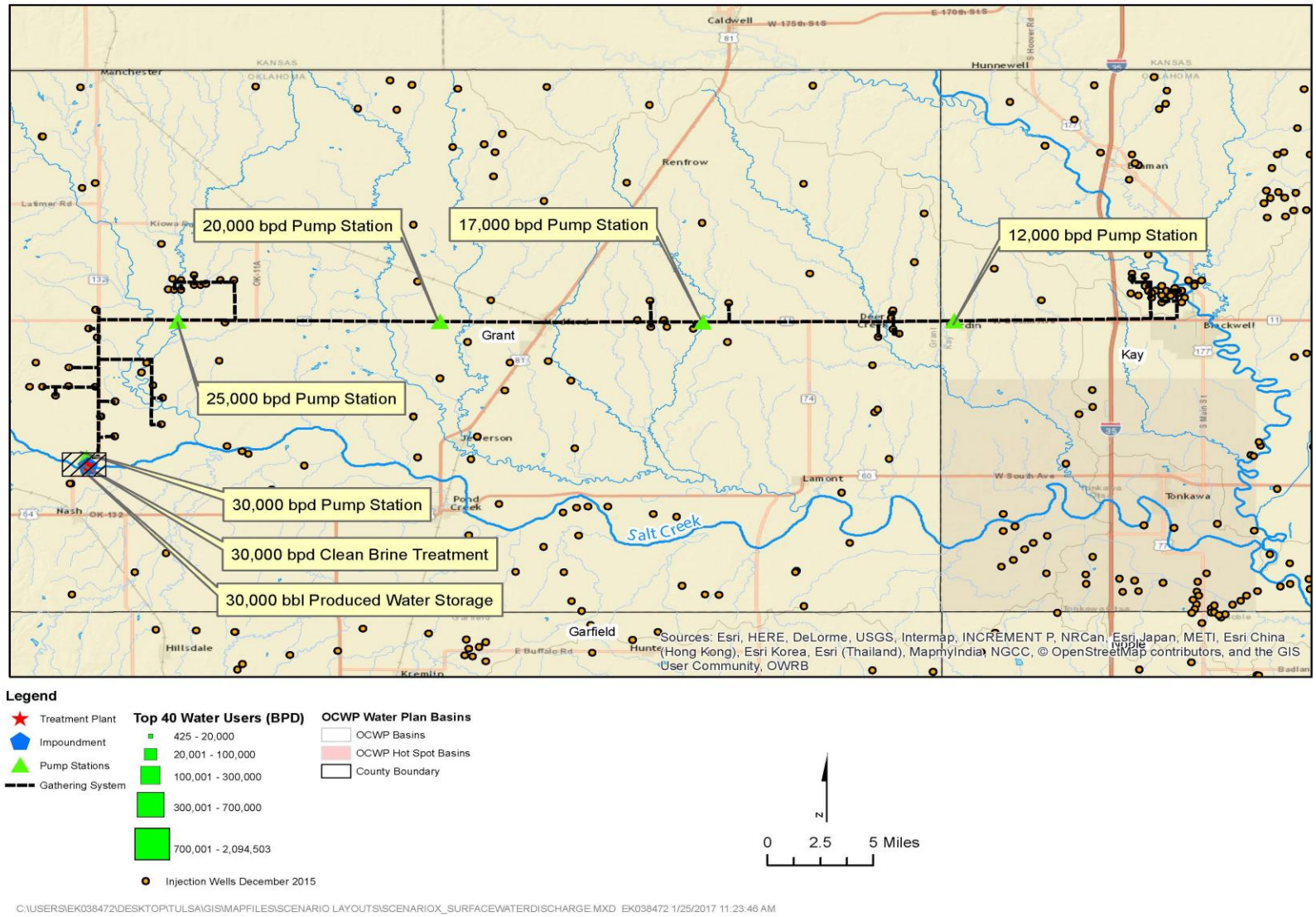


Figure 3-7. Case 9 Layout and Infrastructure

Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

3.10 Desalination for Surface Discharge in Grant County

Case 10, Desalination for Surface Discharge in Grant County, was selected as it is similar to case 9 in location and volumes. The capital cost, $38 million, includes a gathering system for 30,000 BWPD of 227,000 mg/L TDS water. A desalination plant would be required and is included as an operating cost per barrel (Figure 3-8). The normalized cost per barrel for this case is $7.49 per barrel discharged. The pipe infrastructure in this case is slightly different to account to the discharge to the Salt Fork Arkansas River. The discharge of treated produced water is allowed via permit from the EPA. Section 6.3.6 of this report discusses more about discharge permits. Although this case assumes a 10-year life, it would certainly be possible for a longer term project.

This case is significantly higher cost per barrel that the prior desalination cases due to a smaller scale and poorer quality produced water (higher TDS).

The major components included in the cost evaluation include:

- Gathering system with five pump stations to collect produced water from 45 wells
- 30,000 bbl produced water aboveground storage tank
- 30,000 bpd desalination treatment plant
- 30,000 bbl treated produced water aboveground storage tank
- 30,000 bpd surface water discharge structure

Pipeline lengths and diameters which make up the gathering and conveyance system are summarized in Table 3-7.

Table 3-7. Summary of Pipeline Gathering System for Case 10
Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

Pipe Size (inches)[1]	Length of Pipe (feet)
1	75,600
2	58,500
3	25,100
4	16,600
5	58,200
6	131,700
7	42,400
8	31,200
Total	439,500

[1]Based on a velocity of 7 fps.

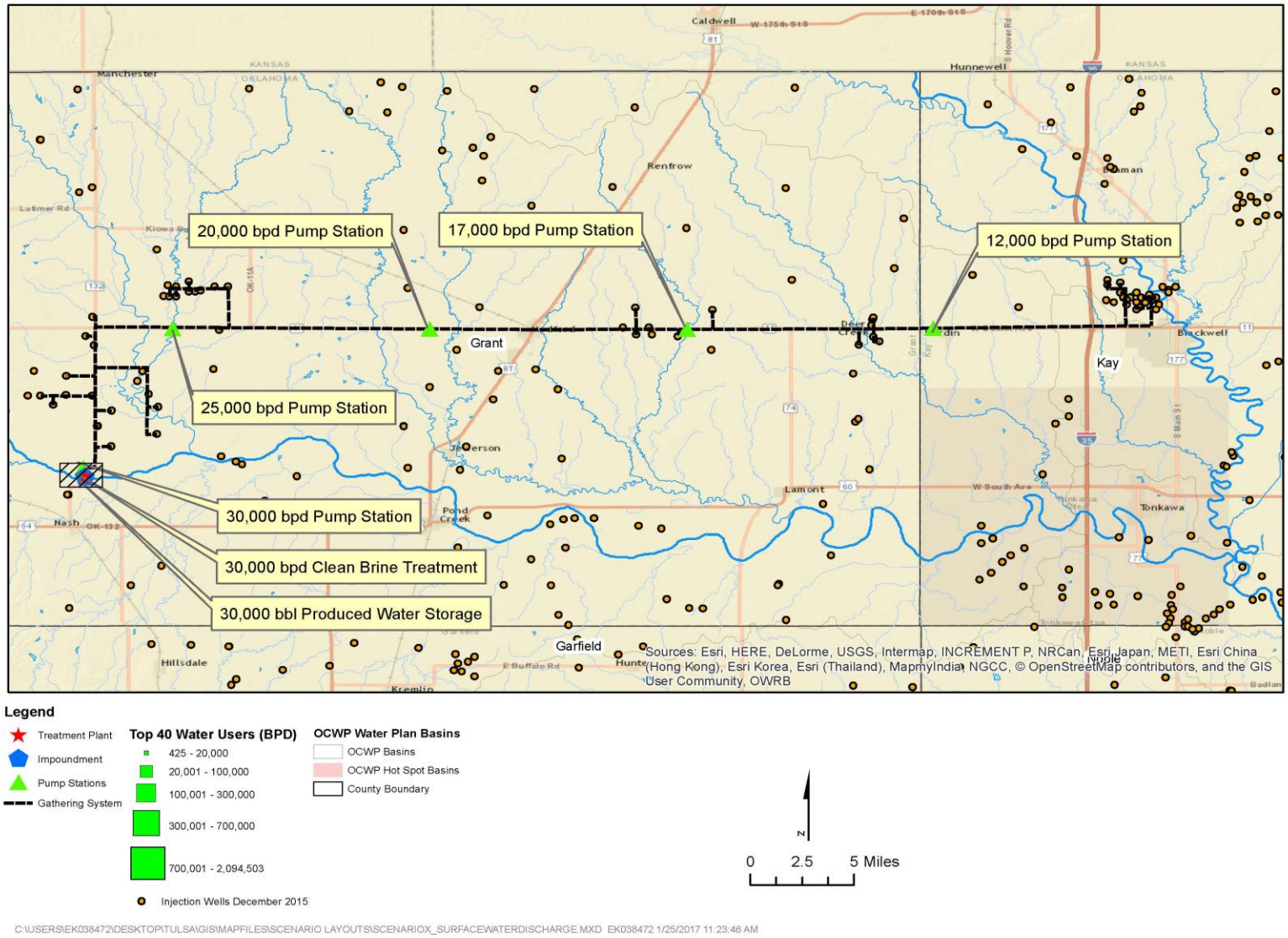


Figure 3-8. Case 10 Layout and Infrastructure

Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

SECTION 4

Estimating Costs

4.1 Methodology (including key financial assumptions)

CH2M used its cost estimating software to estimate screening level capital costs for various pipe sizes, distances, capacities and treatment requirements. The cost estimates used were benchmarked against previous projects where water pipelines were installed in similar geographical areas, giving confidence in the cost estimates. A similar process was used for pump stations and water impoundments.

Water treatment costs were estimated by requesting a variety of cost estimates from leading vendors. These cost estimates are detailed in the section below and summarized in Table 4-1.

A spreadsheet for each case was built using the capital costs, annual treatment costs, and the water volumes to be treated. The spreadsheet discounted future costs and barrels of water at a 10 percent discount rate to establish an overall “Normalized” cost per barrel. When the case involved desalination, the percentage of usable water quality of water was applied so that the costs reflect the usable volumes of water. Often with desalination there is a volume of concentrated water that must still be injected into disposal wells.

4.2 Estimated Cost - Benefit Range(s) (High, Likely, Low)

Water treatment costs were established by soliciting estimates from companies that producers recommended. The eight companies were asked to estimate water treatment costs including their capital cost for equipment, fuel, power and waste removal. The estimates were broken down by the quality of produced water, the quality of the water needed (clean brine or desalinated), project life, and volume treated per day. The cost per barrel of water (BW) is an average of the number of estimates. The column titled “% of inlet wtr recovered” is also an average of how much of the produced water is desalinated and usable. The rest of the water would still have to be disposed of in an injection well. The last two columns of Table 4-1 show the cost estimate Low and High estimates. This information helps understand that a significant variable in the estimates exist.

Table 4-1. Treatment Cost Estimates for Different Cases

Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

Water Treatment Cost Estimates
Summary of Cases

Case #	Barrels per day treated	Contract term (yrs)	Inlet wtr TDS (mg/l)	Wtr quality needed	Cost per BW*	% of inlet wtr recovered	Number of Estimates	Cost Estimates Low	Cost Estimates High
1	20,000	2	30,000	Clean brine	0.66		8	0.30	1.50
2	100,000	2	30,000	Clean brine	0.57		8	0.18	1.50
3	100,000	10	30,000	Clean brine	0.47		8	0.10	1.50
4	20,000	2	150,000	Clean brine	0.69		8	0.30	1.75
5	100,000	2	150,000	Clean brine	0.60		8	0.18	1.75
6	100,000	10	150,000	Clean brine	0.50		8	0.10	1.75
7	20,000	2	10,000	Desalinated	2.58	88%	8	0.95	5.30
8	100,000	2	10,000	Desalinated	2.04	88%	8	0.65	4.25
9	100,000	10	10,000	Desalinated	1.76	88%	8	0.45	4.00
10	20,000	2	30,000	Desalinated	3.05	74%	8	1.45	5.75
11	100,000	2	30,000	Desalinated	2.55	74%	8	1.25	4.70
12	100,000	10	30,000	Desalinated	2.22	74%	8	0.95	4.50
13	20,000	2	150,000	Desalinated	4.58	60%	6	1.46	9.26
14	100,000	2	150,000	Desalinated	3.60	60%	6	1.10	6.91
15	100,000	10	150,000	Desalinated	2.52	60%	6	0.90	5.25
16	20,000	2	30,000	Evaporation	1.66		3		
17	20,000	2	150,000	Evaporation	1.79		3		

SECTION 5

Challenges, Opportunities, and Risks

The committee and its subcommittees have discussed the challenges to re-use and recycling of produced water from oil and gas operations. The group has identified six primary challenges to re-use of produced water that are discussed here.

5.1 Cost to Transport and Treat Water for Re-use and Recycling

Currently, most of produced water from oil and gas in Oklahoma is disposed into Class II disposal wells. This disposal has generally been a safe and low cost method. Typically, the disposal wells can take large volumes of water and there is usually minimal transportation cost since the well is located near the producing wells.

For hydraulic fracturing operations to re-use the produced water, the water must be transported from the tank batteries where the water is gathered, to the new well site. Typically, the produced water must be treated to kill bacteria, reduce suspended solids and any scaling tendencies. Generally, the cost to transport and treat the water for re-use has been higher than the cost to dispose of the water. Thus, produced water re-use has been slow to gain adoption in Oklahoma based on the costs and alternatives.

Due to seismicity, the OCC has limited water disposal in key areas. Normally, this would have the effect of increasing prices for water disposal, but the water disposal restrictions have occurred over a time period of low oil prices and declining produced water volumes. Thus, water disposal prices have remained relatively low in the recent environment. However, when oil prices, drilling, and water production increase in the sector, it is likely that the price of water disposal will increase and begin to tip the cost equation towards produced water re-use.

5.2 Water Treatment Facility Bonding Requirements

The purpose of bonding for water storage is to provide the state with the funds to necessary close down any water impoundments that are left behind in the event of a bankruptcy. The OCC requires bonding of $2 per barrel of water storage capacity at a water treatment facility. The trend in water storage is to construct impoundments of approximately 1 million barrels of water to accommodate the larger hydraulic fracture completions being performed. Thus, one impoundment could lead to $2 million of bonding required. Normally, multiple ponds will be necessary to effectively re-use produced water in a portion of a county, leading to potentially tens of millions of dollars of bonding requirements in a small area.

This bonding requirement has been identified as a deterrent to produced water re-use by several oil and gas producers working with the PWWG committee.

A lower bond requirement, justified by a data-driven assessment of environmental risk based on minimum impoundment design standards would reduce the impact of this financial obligation.

5.3 Ownership and Value of Produced Water

With produced water re-use, the producing company will often have new costs related to water treatment and conveyance. In some cases, one producer may sell treated produced water to another company. Based on the historical and current situation with most unconventional oil and gas plays, the

cost to treat and transport the water will far exceed the value of the water sold. The water sold may only offset about 25 percent of the costs to treat and transport, depending on many factors.

With the emphasis on water re-use, the ownership of the water has been called into question by some surface owners. The surface owners' case is that since most oil and gas leases do not include produced water, then the value from selling produced water should be shared with them.

The oil and gas companies' case is that since the value from the sale of water will not cover the cost of treating and transporting the water, revenue sharing with the surface owner does not make sense. This is amplified by the fact that the surface owner does not have an obligation to pay for produced water disposal.

The concern over the ownership and value of produced water has been discussed regularly at PWWG meetings and highlighted by producing companies as a significant potential impediment. Regulatory and legal clarity is needed so this issue does not slow water re-use.

5.4 Legal Custody of Water as it Relates to Potential Spills

As produced water re-use increases, it is likely that more commercial water treatment facilities and their associated water pipelines become common. It is important to have a clear legal custody and liability transfer to the commercial operator of the water infrastructure. If the oil companies believe that they risk being sued over a spill by the commercial plant, it would be a challenge to moving ahead with this commercial model. This commercial operator model is often going to be the most effective way for multiple producing companies to gain the economies of scale to sustainably develop and operate a produced water re-use system in a given area.

Therefore, laws that support the legal transfer of custody of the water and the associated liability to the commercial water system operator would reduce the uncertainty of this issue. Other states have passed statutes to this effect.

A separate issue about custody of water relates to the legal classification of produced water if it is treated and transferred to another beneficial user. If desalinated produced water is transferred to a power plant, there is some uncertainty whether the power plant's existing permits need to be updated. According to power plant experts and environmental experts on the committee, the plant's existing permits would still apply and no new permits or amendments would be needed. (Note: the power plant would still need to meet all of its existing discharge criteria.) Some on the committee were less confident that the treated produced water loses its classification when it is transferred to another user. The oil and gas producer will want regulatory certainty before transferring water for beneficial re-use.

5.5 Right-of-Way and landowner negotiations

Another significant and often-mentioned challenge to water re-use and recycling is right-of-way (ROW). Water pipelines and impoundments need the authorization of the surface land owners. The challenges for the company installing the infrastructure include needing to negotiate with numerous landowners and payments for the ROWs. Probably little can be done to improve the ROW challenge for produced water re-use. It has been suggested during a PWWG committee meeting that a pipeline can become a common carrier and obtain the power of eminent domain to get ROWs. Even in this eminent domain case, the producer must pay for ROW.

Temporary right-of-way for short term use of layflat lines to move water to the last mile or so to the well site is becoming a more difficult issue. There may be a potential legislative solution to clarify that the payment for the permit for temporary transfer, as well as elimination/reduction of the alternative, utilization of tank trucks to transport the water qualifies as a public good, and therefore does not require landowner authorization.

There are opportunities for landowners to benefit from the process both in the ROW of this infrastructure and by making their groundwater available for purchase for these operations.

5.6 Discharge Permit Challenges Including Timing

The PWWG re-use and recycling study includes scenarios where desalinated produced water is discharged to waterways. The National Pollutant Discharge Elimination System (NPDES) permits have been obtained from the EPA in a small number of cases for highly treated oil and gas produced water. The NPDES permits could be very important in specific cases or in special economic cycles within the oil sector. If oil and gas was reusing a high percentage of produced water in the future and oil prices dropped substantially, the hydraulic fracturing re-use would go away due to the lack of economics and the produced water would need an outlet. If disposal continues to be limited in the state, this sudden reduction in re-use could create a need for NPDES permits to discharge water. The problem is that the current approval cycle for a NPDES permits is much longer than the typical time it takes for oil prices to drop and drilling to stop. Thus, there is a need for a shortened approval time or a way to obtain a permit that might be needed in the future.

Another permitting concept that would add flexibility for a discharge scenario would be to allow permitting of a mobile technology. If this were possible, the producer could potentially deploy a permitted mobile unit in a short period of time, potentially weeks, when the need arose. In the past, NPDES permits were for permanent facilities and tailored to the body of water where the discharge occurred.

State Senate and House bills have been introduced to the current session of the legislature providing that the state apply for delegation authority of NPDES permitting from EPA of produced water with the intent of expediting the process and make a more viable option for water management.

SECTION 6

Implementation

6.1 Implementation Considerations

At a high level, developing a produced water recycle/reuse project needs to achieve the following:

- Reliably balance supply and demand between the oil and gas producing company and the end user, including addressing interruptions on either end and seasonal and market variability
- Finance capital construction of storage, treatment and transport infrastructure
- Provide for effective operations of facilities
- Be financially and operationally sustainable over the duration of the oil and gas operation
- Secure necessary land and right-of-way
- Obtain necessary permits and licensing
- Confirm that water compatibility issues are addressed so that the re-used produced water works effectively

Oil and gas companies have the most direct incentive and leverage to initiate produced water recycling/reuse projects as they face both water sourcing pressures to support development and disposal costs and challenges. The OCC has been restricting water disposal based on the occurrence of seismicity in some cases. Details are available on the OCC's web site at: https://earthquakes.ok.gov/what-we-are-doing/oklahoma-corporation-commission/ If additional disposal restrictions are mandated, or if produced water volumes increase due to oil activity, it is likely that water disposal costs will increase. Increasing water disposal costs will provide economic incentives for oil and gas producers to implement alternatives, including water reuse.

To implement a project related to produced water re-use or recycling, it is likely that the oil and gas producer will initiate the detailed evaluation and sanction the project. It is also possible that a water user could initiate a project, but this seems unlikely as long as there is not a drought. The reason oil companies have and are sponsoring water re-use projects is that they are responsible for the produced water. Several companies refer to water re-use within their public documents and are highlighted in Section 2.2.

It is also possible that a midstream (pipeline) company could initiate a project that requires significant capital for water pipelines. A midstream company would likely be needed to help plan and execute Case 4, where water would be moved across multiple counties.

6.2 Environmental and Stakeholder Considerations

Industrial activity, including oil and gas operations, has a variety of impacts on the environment and stakeholders in the community. Different ways of managing produced water have varying impacts, too. Water injection to dispose of produced water from oil and gas wells has been a safe, reliable and low-cost method. The increase in seismicity in Oklahoma since 2009 has been associated with water injection in some instances by regulators and researchers. Effectively, Case 1 is the status quo of disposal, and its biggest risk may be seismicity.

Case 2 is re-use of the produced water in subsequent hydraulic fracturing stimulations. Oil and gas re-use can have the positive effect of reducing trucking and the associated air emissions, reducing or

eliminating water disposal, and reducing water sourcing requirements. However, the positive aspects may be partially offset by environmental risk transferring high salinity water and required water storage.

Case 3, the inter-county water transfer for oil and gas re-use, is similar to Case 2; however, Case 3 also includes a longer substantial pipeline to transfer water across a few counties. Technologies exist to ensure safe transfer of this type of water, but there is always a very low chance that a spill could occur during the life of the pipeline.

Cases 4 and 5 involve evaporating the produced water. Depending on the type of technology employed, there may be a risk of overspray of the produced water that could risk impacting streams or groundwater. Usually there are solids created during the process that must be hauled to a landfill. Since the solids contain a significant amount of salt, the landfill must not leach any of the salt into groundwater. There are some trials and research ongoing across the United States to study the potential to remove elements from the solids that could be saleable as minerals[2]. Rare Earth [3] Geo news Rare earth

Cases 6 to 10 involve desalination of the produced water for either industrial use or discharge. Although desalination is designed to remove over 99 percent of the TDS, there is still the potential of problematic components of the produced water remaining. In fact, toxicity levels have not been established for all of the potential components in produced water. Thus, additional research is needed to ensure water quality standards are established based on sufficient science. According to The Health Effects Institute[1]: "Adequate toxicity information does not exist for some components of OGD fluids and wastewater." Research goals include: "toxicological evaluations where exposure information suggests that such evaluations would be helpful to decision-making about the protection of human and ecological health" and "determine the potential for impacts from approved disposal of OGD [solid and liquid] wastes and the most effective practices for managing the wastes."

Table 6-1 summarizes the qualitative impacts as either positive or negative for each case. The importance of each factor vary. The table provides a high level prospective of complex issues that will be case dependent.

Table 6-1. Produced Water Use Implementation Opportunities, Challenges, and Impacts
Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

Implementation Opportunities, Challenges and Impacts

Case	Case Description	Limits Water Disposal	Reduce Water Needs	"Create" New Water	Reduce Water Trucking	Water Storage Needed	Water Pipeline Needed	Solid Waste Generated
1	Typical Source and Dispose							
2	Oil and gas re-use							
3	Clean Brine Transfer & treatment							
4	Evaporation - low TDS (SCOOP & STACK)							
5	Evaporation - high TDS (Miss. Lime)							
6	Desalination for Surface Discharge							
7	Desalination for Power Use							
8	Desalination for Power Use							
9	Desalination for Industrial Use							
10	Desalination for Surface Discharge							

Positive opportunity or impact Negative impact or challenge

6.3 Macroeconomic Considerations

Oil and gas operations and production are important economic drivers for Oklahoma's economy. According to a Research Foundation Report in September, 2016:

- In 2015, the oil and gas industry employed 53,500 Oklahomans who earned $5.6 billion
- 95,000 Oklahomans earned $10 billion in self-employment income from oil and gas activity
- In total, nearly 150,000 Oklahomans are either wage and salary workers or self-employed in the oil and gas sector
- Household earnings ($15.6 billion) from the oil and gas sector total 13.2% of total state earnings
- Average wages in the oil and gas sector ($104,000) are more than double the state average ($44,178).

Legislative and regulatory efforts attempt to balance stakeholder concerns with the desire to promote economic growth. Incentives and disincentives for specific oil and gas operations could have the effect of promoting industry activity or potentially shutting in a less economic region. Recent history continues to demonstrate that oil and gas companies drill and complete new wells where their economic results are most favorable, whether within a region in Oklahoma or another country.

A directive that mandates water re-use or significantly increases disposal costs would be highly disruptive to industry and could create incentives for companies to stop drilling in Oklahoma. There may be cases where locally sourced fresh water from landowners is the lowest impact option.

However, the state has demonstrated a desire to control stakeholder impacts, including seismicity. The OCC mandated cut-backs in underground water disposal appear to have reduced the occurrence of seismicity. In the long run, limited disposal options will raise the cost of water disposal and tend to encourage water re-use. Section 2.2 of this report documents recent water infrastructure projects by a number of oil companies.

One objective of the PWWG is to study treating produced water for discharge or beneficial re-use for other industries. This report documents that based on existing costs, beneficial re-use involving desalination is an expensive way to create new water sources based on current commercial technologies and economics.

If these alternatives to disposal are pursued, more study is needed to understand the potential collateral macro and regional economic impacts in order to facilitate a constructive transition. This could include, but is in no way limited to, research and development support to commercialize more cost effective technologies or economic incentives to incentivize project development.

This study finds that beneficial reuse within the oil and gas industry is growing and does appear financially competitive after water infrastructure is in place.

SECTION 7

Conclusions and Recommendations

This study for the PWWG is focused on alternatives to injecting produced water from oil and gas wells into disposal wells. While this study is attempting to find the best short term solutions, clearly the transformation of water management will be a long-term effort.

Key Findings (in order of viability and timeframe)

1. Produced water re-use by the oil and gas industry is the most viable cost-effective alternative due to minimal water treatment needs and thus low treatment costs. Increased inter-organizational planning and sharing of resources to improve re-use viability are required. The oil and gas industry has built limited water pipeline networks to date; however, planned cooperative expansion of the water distribution systems over time would reduce conveyance costs and further facilitate produced water use for hydraulic fracturing.
2. A special case of water re-use was evaluated using surplus produced water from the Mississippi Lime play area around Alfalfa County. This surplus could be gathered and conveyed to sites in Blaine County for oil and gas re-use. Although the project could be technically and commercially complex, the screening analysis shows it has potential to be financially competitive with current disposal methods. A more detailed evaluation is needed.
3. Evaporation techniques for produced water should be further investigated and developed. Due to low water treatment costs and potentially limited water conveyance requirements, evaporation technology could be a viable alternative to disposal.
4. Water treatment and desalination techniques of produced water should be further investigated and developed if the PWWG intends to reduce the majority of water produced in the state. Although current technologies are technically implementable, they appear impractical at this time. The cases presented in this report were found to be the most expensive strategies by more than four times current disposal costs. Water treatment at or near fresh water levels could produce water for power, industry, and other beneficial uses including the potential to be discharged and augment local stream flow; thereby making PW an added benefit rather than a liability.

Recommendations

1. Reduce the challenges to water reuse through targeted regulations and legislation by
    a. Removing legal ambiguity about ownership of produced water when sold or in the event of an environmental impact
    b. Establishing bonding requirements for water impoundments that are appropriate without being an impediment; Evaluate technical standards or other data-driven risk strategies and financial assurance approaches to equitably manage risk and remove financial impediments to reuse project development.
    c. Clarifying rules and ownership when water is transferred from one company to another
    d. Requesting delegation from the U.S. Environmental Protection Agency (EPA) to Oklahoma for permitting the discharge of treated produced water consistent with water quality protections for the receiving stream; including the ability to permit mobile operations
    e. Considering methods that make obtaining right-of-way for pipelines that allow cost-effective transfer of recycled/re-used water easier as an alternative to impacts of trucking.

2. Further investigate methods to facilitate the re-use of produced water in oil and gas operations in a more detailed study.
3. Study further the feasibility of the transferring Miss. Lime produced water to the STACK play (Case 3). The more detailed evaluation could include:
    - Evaluate the commercial challenges and how the many companies can be brought together most effectively.
    - Evaluate the potential water compatibility issues and technical solutions through lab work and collaboration with treatment companies.
    - Provide a more detailed cost estimate of the pipe infrastructure.
    - Evaluate the feasibility of tying into one or more of the existing Mississippi Lime produced water systems as an alternative to building a new one.
    - Assess the potential environmental risks and methods to reduce impacts.
4. Conduct a more detailed evaluation of evaporation as an alternative to injection (Cases 4 and 5). The additional studies could include:
    - Evaluate the technologies available or being developed, their potential economic viability, and their operations.
    - Assess the potential environmental risks and ways to lower possible impacts.
5. Identify research needs and potential funding partnerships to further accomplish the group's goals, e.g.
    - improve the economic feasibility of Cases 6-10;
    - Research new technologies to lower the cost of effective water treatment;
    - identifying toxicological risks and protective water quality targets to ensure that the environment and public health are adequately protected under various reuse scenarios;
    - Research potential agricultural uses for produced water;
    - Research potential for marginal aquifer recharge with produced water;
    - Identify other potential beneficial uses of treated water.
6. Continue the PWWG or subgroups to identify opportunities to continue cooperative planning and development of new techniques, infrastructure, water users, legislation and regulatory structure. A regular dialogue between producing companies, potential water users, regulators, technology providers, researchers, and stakeholders is warranted.
7. Support and build upon the Water for 2060 Advisory Council 2015 energy and industry water use sector water conservation findings and recommendations to the Governor and the Legislature (see further details in the Water for 2060 Report, 2015):
    - Facilitate increased sharing of information and supplies between industrial users
    - Promote industrial use of marginal quality waters

SECTION 8

Literature Cited

Health Effects Institute (HEI) Special Scientific Committee on Unconventional Oil and Gas Development in the Appalachian Basin. 2015. Strategic Research Agenda on the Potential Impacts of 21st Century Oil and Natural Gas Development in the Appalachian Region and Beyond. Boston, MA: Health Effects Institute. October.

University of Wyoming. 2016. *UW, INL Researchers Study Pulling Rare Earth Elements from Industrial Waters.* Accessed February, 2016. http://www.uwyo.edu/uw/news/2016/06/uw,-inl-researchers-study-pulling-rare-earth-elements-from-industrial-waters.html

Kruger, Ned. 2015. A "Rare" Opportunity. North Dakota Geological Survey. January. https://www.dmr.nd.gov/ndgs/documents/newsletter/Winter%202015/A%20Rare%20Opportunity.pdf

Oklahoma Water Resources Board (OWRB). 2012. Update of the Oklahoma Comprehensive Water Plan.

Oklahoma Water Resources Board (OWRB). 2015. Report of the Oklahoma Water for 2060 Advisory Council.

The State of Oklahoma. 2015. *Gov. Fallin Forms Fact-finding Group to Look at Ways 'Produced Water' Can Be Reused*. December 1. Accessed April 2017. https://www.ok.gov/triton/modules/newsroom/newsroom_article.php?id=223&article_id=17069.

Appendix A
Meetings Agenda, Summaries and Presentations

Water for 2060
Produced Water Working Group

March 10, 2017

9:00 a.m.-12:00 p.m.

Oklahoma Water Resources Board

3800 N. Classen Boulevard, Oklahoma City, OK

1.	**Welcome (9:00-9:05)**	**Julie Cunningham, Chairman**
2.	**Vision for Produced Water Working Group (9:05-9:15)**	**Secretary Michael Teague**
3.	**Presentation of Draft Study Results & Draft Recommendations, CH2M (9:15-10:15)**	**Michael Dunkel**
4.	**Questions, Discussion on Recommendations (10:15-10:45)**	**Julie Cunningham** **Michael Dunkel**

BREAK (10:45-10:55)

5.	**Bureau of Reclamation Grant Proposal Ground Water Protection Council (10:55-11:05)**	**Michael Paque**
6.	**Legislative Overview and Discussion (11:05-11:30)**	**Bud Ground** **Julie Cunningham**
7.	**Comments by the Public (time permitting)**	
8.	**Next Steps/Next Meeting (11:45-12:00)**	**Julie Cunningham**
9.	**Adjourn**	

Produced Water Working Group

Meeting Summary of Fifth Meeting, 9:30 am March 10, 2017
OWRB Board Room, 3800 N. Classen Blvd., Oklahoma City, Oklahoma

---

ATTENDEES:

***Produced Water Group Members and representation (from Sign In and/or Introductions)*:**

Michael Teague, Sec. Energy & Environment
Julie Cunningham, Chair/OWRB
Tim Baker, OCC
Fred Fischer, OPAIA
Bud Ground, EFO
Teena Gunter, for OK Sec. of Agriculture
Brent Kisling, Enid Reg. Development Alliance
Dave Lampert, OSU
Mike Mathis, OIPA/Continental
Mike Ming, GE
Mike Paque, GWPC
Alan Riffel, OML
Jesse Sandlin, Devon/OKOGA
Terry Stowers, COSMO
Scott Thompson, ODEQ
Usha Turner, OG&E

***OWRB Staff and Consultants*:**

Mike Dunkel, CH2M
Owen Mills, OWRB
Anna Childers, CH2M

***Other Attendees*:**

Allen, Jon OWRB
Amosu, Ope GE
Black, Galyn White Star
Boehs, Jared Pure Water Services
Boudreau, Donald Veolia
Boyd, Joyce OCC
Bruner, Monty Env. Tech Group
Bruns, Joan GE
Cauthron, Bill OWRB
Cox, Jayme Cimarex
Cravey, CC Reliable One
Cravey, Shannon Reliable One
Downey, Patricia OCC
Erickson, Mike Marathon Oil
Everett, Jeff OG&E
Feezel, Anthony Reliable One
Foltz, Tommy Ecolab
Gibson, Sara OWRB
Hallderson, Brent Fountain Quail Energy
Karges, Arnella OKOGA
Kirk, Lloyd ODEQ
McCurdy, Rick Chesapeake
McElroy, Philip Reliable One
Moore, Trey Logic Energy
Morford, Michael Bison Group
Moss, Justin OSU
Murray, Kyle OGS
Myers, Jeff OCC
Naggs, Veolia
Pearen, Holly EDF
Porter, Monty OWRB
Powell, Tyler OSEE
Rick McCardy, Chesapeake
Robins, Tom OSEE
Saunders, Nicole EDF
Schultz, Brad ONEOK
Singletary, Rob OWRB
Slatton, OCC
Stalling, Rob OWRB Board
Steele, Ed GE
Tahmassebi, Saba ODEQ
Tytanic, Chris Reliable One
Walker, Ella OGS
Ward, Sharissa Reliable One
Wertz, Joe State Impact
Westerheich, John GE OGTC
Whorton, Sherrie Everblue Water Tech
Wilkins, Kent OWRB
Wilmoth, Adam Oklahoman
Yates, Dan GWPC

Welcome and Vision for Produced Water Working Group

Ms. Julie Cunningham, OWRB Interim Executive Director and Produced Water Working Group (PWWG) Interim Chairman, opened the final scheduled PWWG meeting by welcoming the attendees, and held introductions. Ms. Cunningham reviewed the agenda and logistics for the meeting. She also provided a recap of the progress thus far and the PWWG efforts up to now. The primary goal for the meeting was to present the findings and recommendation included in the draft Oklahoma Water for 2060 Produced Water Reuse and Recycling Report (Report) that was provided to the PWWG ahead of the meeting and to solicit input from the PWWG on the findings and make recommendations to include in the final Report. The Oklahoma Secretary of Energy and Environment, Mr. Michael Teague, emphasized the long-term focus with the produced water study efforts. He stated that the produced water re-use will be part of the innovative water use and source picture for Oklahoma. The Secretary stated that the work has just begun by the PWWG's first round of results and recommendations that we will be discussing today.

Presentation of Draft Study Results and Draft Recommendations

Mr. Michael Dunkel provided a PowerPoint presentation of the draft Oklahoma Water for 2060 Produced Water Reuse and Recycling Report. Mr. Dunkel summarized the different produced water use economic scenarios and their rankings based on their cost efficiency. He reminded that the current task is to assess how Oklahoma can reuse produced water most effectively. The cost estimates included in the Report were developed for the most viable scenarios. Followed by the presentation, the PWWG members were provided an opportunity to ask questions and provide feedback on the Report findings. The group discussed the different water use categories. The main comments included the cost comparisons of different scenarios, the different cost assumptions and elements used in developing the costs. The PWWG members recommended that consideration for Aquifer Storage Recovery (ASR) as a potential option to store marginal quality water and the potential for agricultural water use and application of produced water should be addressed in the report. Mr. Dunkel agreed and added that the PWWG should consider providing feedback on all the key findings and recommendations. Secretary Teague emphasized the importance of the report's findings that recommend and identify further research and investigation topics. Mr. Dunkel mentioned that the report will be revised to reflect the comments received during the meeting as well with any comments sent to Owen Mills and Michael Dunkel via email by March 31st, 2017. The comments will be summarized into a separate summary table and will be included in the final Report. The anticipated schedule for the final Report is mid-April, 2017.

Bureau of Reclamation Grant Proposal Ground Water Protection Council

Michael Paque of GWPC briefed the PWWG on the recent submittal for Funding Opportunity with the Bureau of Reclamation (BOR) WaterSMART Title XVI Water Reclamation and Reuse Program grant No. BOR-DO-17-F003. OWRB (applicant on the grant) submitted the proposal on January 5, 2017. The total project cost is $300,000 with a $150,000 Federal share. The total length of the study is 18 months upon issuance of notice to proceed. The study would support the findings and recommendations of the ongoing PWWG effort slated to be completed by June 2017 to search for ways to use produced water as a benefit to the state as a part of the Water for 2060 initiative and to find solutions that reduce deep-well injection volumes. OWRB proposes build on the conclusions of the PWWG initial scoping study and more fully evaluate the most encouraging recommendations. The non-Federal project partners are: Oklahoma Water Resources Board (Applicant), Environmental Defense Fund (EDF), Groundwater Protection Council (GWPC), and Bureau of Economic Geology (UT). The anticipated award date is sometime in May 2017.

Legislative Overview and Discussion

Mr. Bud Ground of EFO provided an overview of the legislative working group efforts and summarized the various bills in the Oklahoma State Legislature that address directly or indirectly produced water. As stated in the previous PWWG meetings, the Oklahoma rules and regulations need to be changed to incentivize and permit PW uses (e.g., water ownership, definition and liability of spills, classification of water once treated, regulatory authority, infrastructure right-of-ways etc.). Incentives for reusing PW coupled with disincentives for not reusing PW will likely be necessary to get large volumes of water recycled. Doing this will support recycling today vs. waiting for the market to force it to happen. The PWWG has been given some of the credit as the impetus for these bills. Through the subcommittee workings, these helped to develop shell bills to advance the PW use. The subcommittee helped to formulate issue / solution pairings.

E.g. HB 1485 on environment and natural resources; state agencies to issue permits for Clean Water Act.
SB 287 on oil and gas; authorizing DEQ and Corporation Commission to administer oil and gas programs.
SB 743 on oil and gas; creating the Oil and Gas Produced Water Recycling Act; instructing Commission to promulgate certain rules; ownership of produced water.
SB 285 on Corporation Commission; Oklahoma Brine and Produced Water Development Act.
SB 475 on gross production tax; manner in which certain payment of tax is allocated; construing application of specified act.

Oklahoma Water for 2060
Produced Water Reuse and Recycling

Produced Water Working Group meeting

March 10, 2017

Report Outline

1. Introduction
2. Produced Water in Oil and Gas Operations
3. Produced Water Re-use Scenarios
4. Feasibility of Broad Scale Implementation
5. Challenges, Opportunities, and Risks
6. Implementation
7. Conclusions and Recommendations

Red River

Executive Summary - Economics

1. Re-use by the oil and gas industry is the most cost-effective alternative to water disposal in disposal wells

2. Surplus produced water in Alfalfa County could be gathered and conveyed to Blaine County for re-use (subset of item 1).

3. Evaporating produced water is the third most cost-effective alternative category of options

4. Cases requiring desalination for power, industrial plants or discharge to rivers are technically implementable, but are the most expensive scenarios

Short term | Medium term | Long term

Executive Summary - Recommendations

1. Reduce the challenges to water re-use through targeted regulations and legislation: water ownership, bonding, water sharing, right-of-way & discharge delegation.

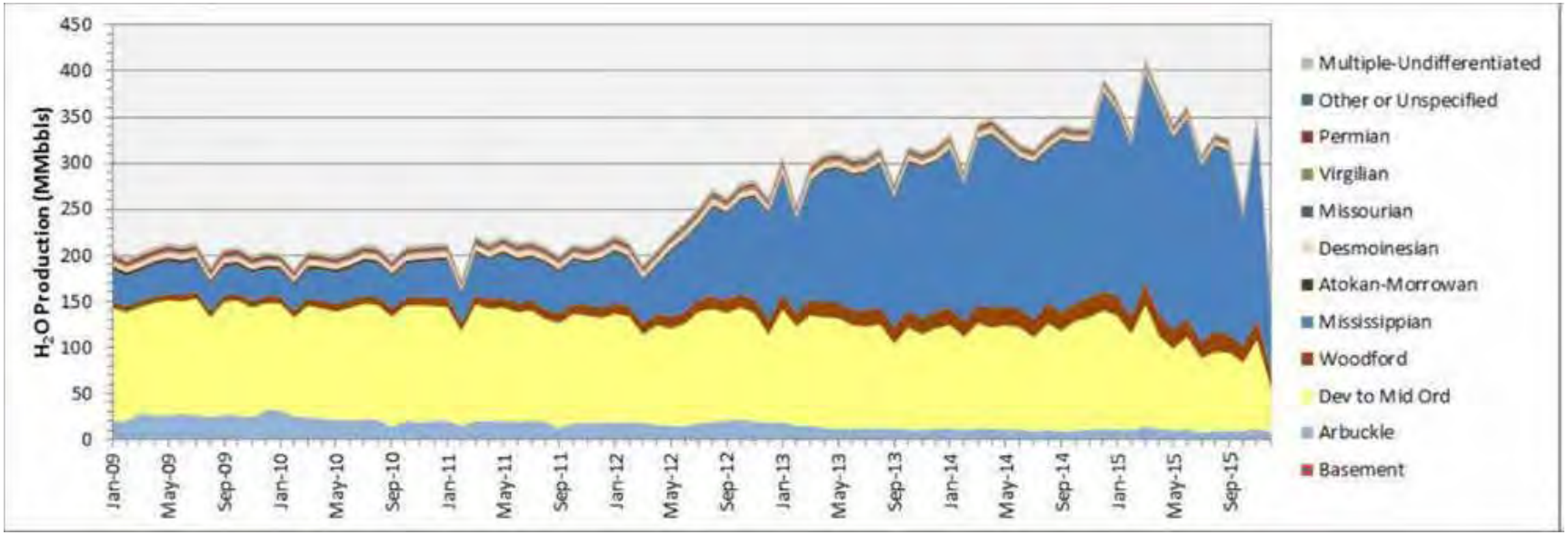
2. Continue to consider how to facilitate the re-use of produced water in oil and gas operations.

3. Continue detailed study of the feasibility of transferring the Mississippi Lime area produced water to the STACK play (Case 3).

4. Continue a detailed evaluation of evaporation as an alternative to injection (Cases 4 and 5).

5. Companies and regulators should consider all negative and positive environmental and stakeholder impacts, as well as any data gaps, before implementing a long-term project.

1. Introduction



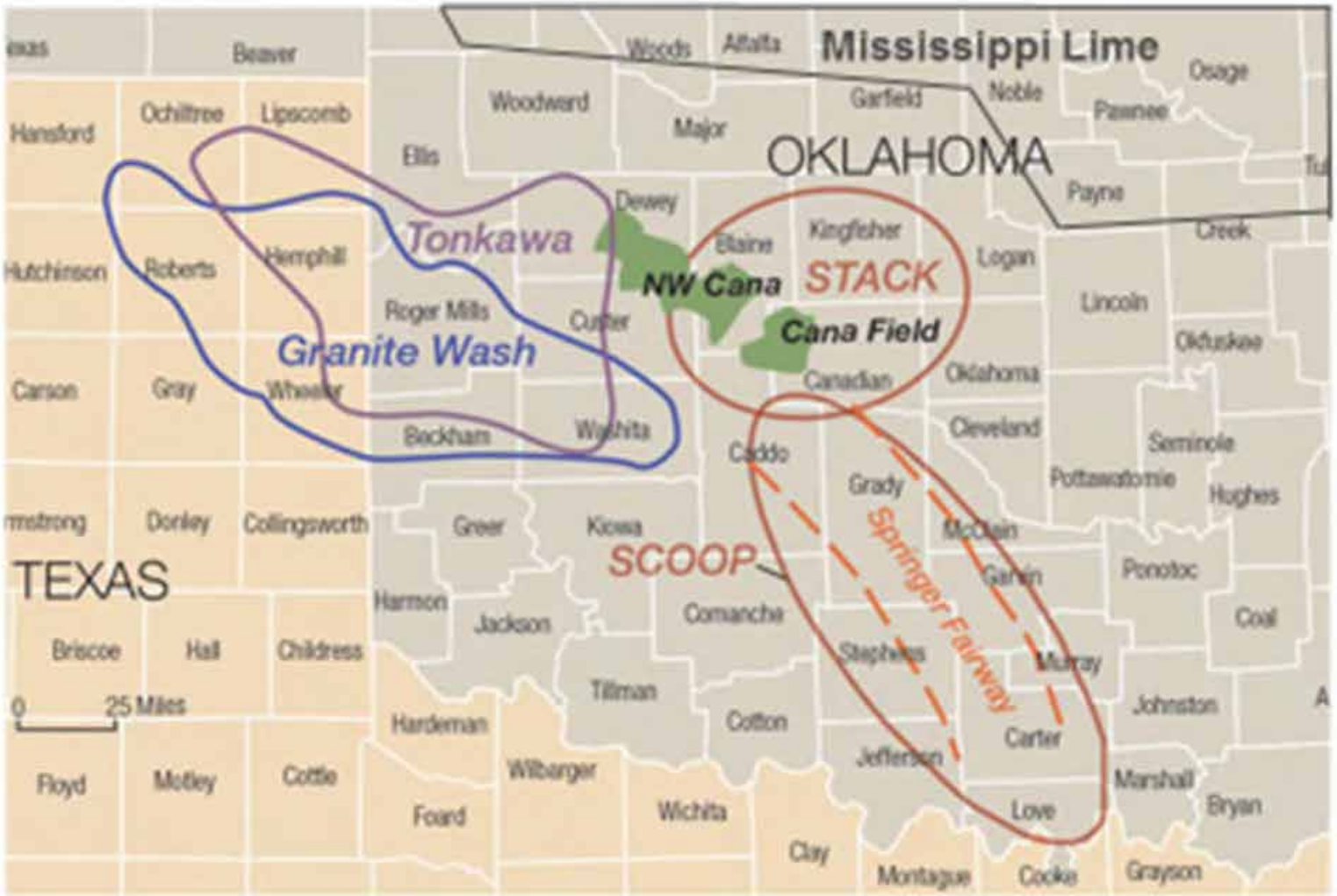
WATER FOR 2060
EFFICIENCY · CONSERVATION · RECYCLING · REUSE

PWWG Meetings:

March 2016, June 2016, August 2016, November 2016 & March 2017

2. Produced Water in Oil and Gas Operations

Main Oil and Gas Areas



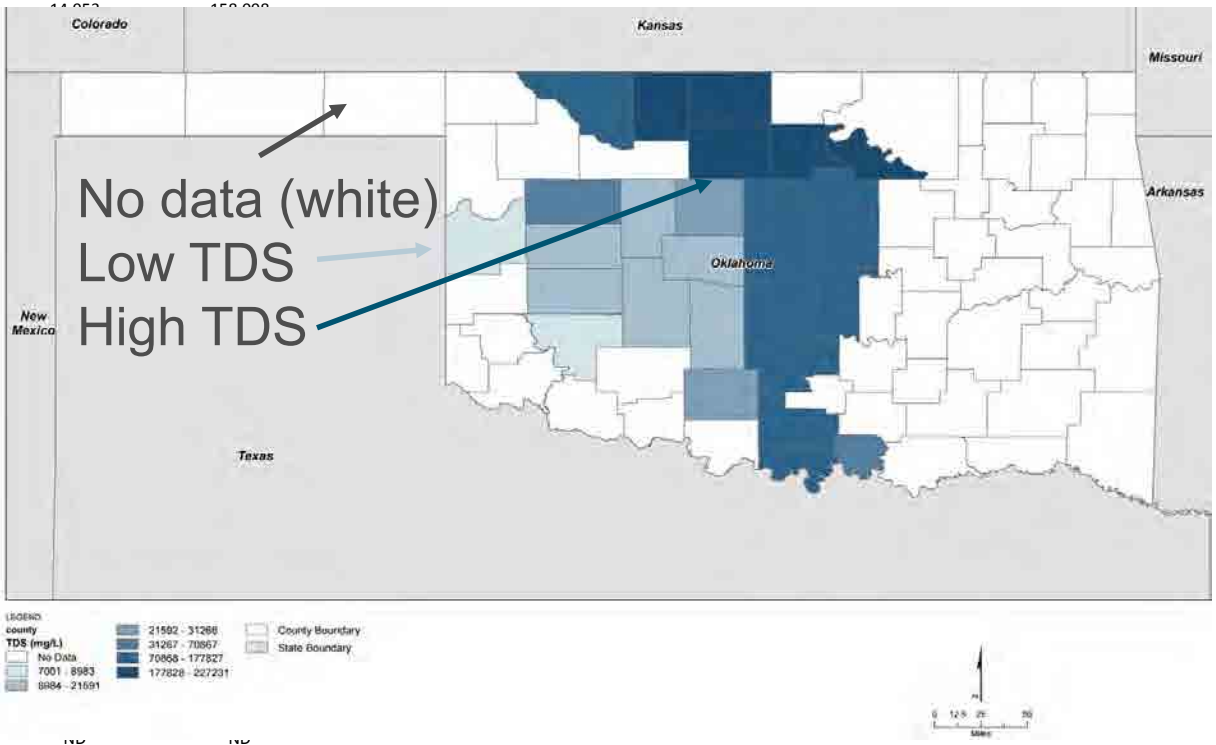
2. Produced Water in Oil and Gas Operations

Produced Water Volume and Quality by County

Table 2-1. Produced Water Volumes Injected and Total Dissolved Solids (TDS) by County in Oklahoma
Oklahoma Water for 2060 Produced Water Re-use and Recycling Report

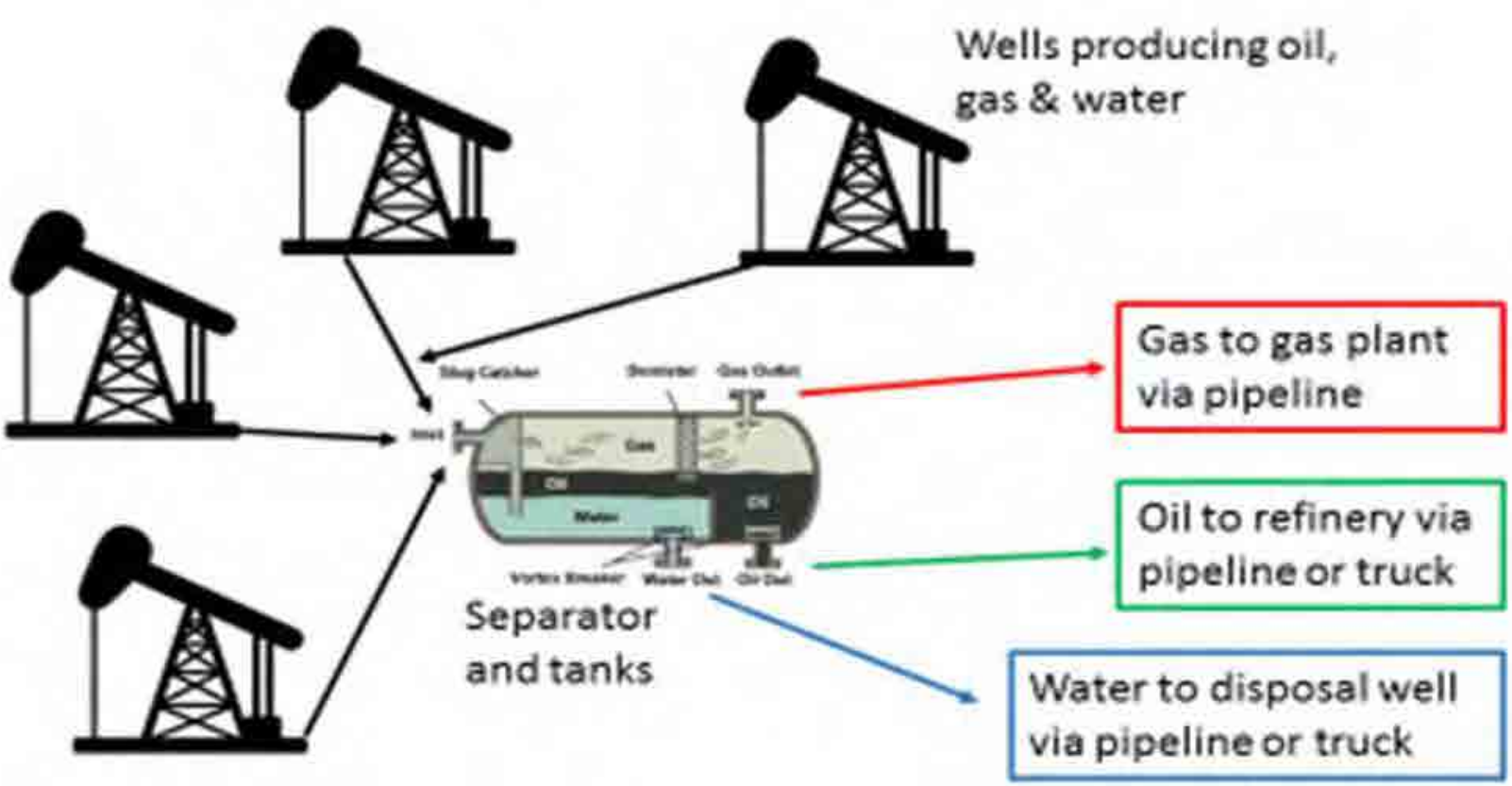
County	Produced Water Injected Barrels Per Day (December 2015)[1]	Minimum TDS (mg/L)[2]	Average TDS (mg/L)	Maximum TDS (mg/L)
ALFALFA	600,559.53	207,133	212,935	217,543
BEAVER	39,458.61	ND	ND	ND
BECKHAM	22,322.81	ND	ND	ND
BLAINE	25,676.97	3,427	16,870	35,202
BRYAN	-	ND	ND	ND
CADDO	36,095.58	2,403	20,369	147,501
CANADIAN	66,147.00	1,373	[illegible]	[illegible]
CARTER[3]	1,041,173.35	95,550	[illegible]	[illegible]
CIMARRON	4,375.68	ND	[illegible]	[illegible]
CLEVELAND[3]	5,597.03	106,738	[illegible]	[illegible]
COAL	22,115.13	ND	[illegible]	[illegible]
COMANCHE	973.42	ND	[illegible]	[illegible]
COTTON	17,468.26	ND	[illegible]	[illegible]
CRAIG	378.19	ND	[illegible]	[illegible]
CREEK	475,327.76	ND	[illegible]	[illegible]
CUSTER	12,675.71	20,261	[illegible]	[illegible]
DEWEY	122,761.81	70,867	[illegible]	[illegible]
ELLIS	29,566.71	ND	[illegible]	[illegible]
GARFIELD	146,793.31	208,250	[illegible]	[illegible]
GARVIN[3]	166,967.78	46,131	[illegible]	[illegible]
GRADY	54,725.17	122	[illegible]	[illegible]
GRANT	109,502.35	217,171	[illegible]	[illegible]
GREER	16.94	ND	[illegible]	[illegible]
HARMON	35.00	ND	[illegible]	[illegible]
HARPER	13,022.42	ND	[illegible]	[illegible]
HASKELL	14.48	ND	[illegible]	[illegible]
HUGHES	71,959.32	ND	[illegible]	[illegible]
JACKSON	4,701.48	ND	[illegible]	[illegible]
JEFFERSON	15,104.94	ND	[illegible]	[illegible]

- Production data from OCC
- TDS from oil companies



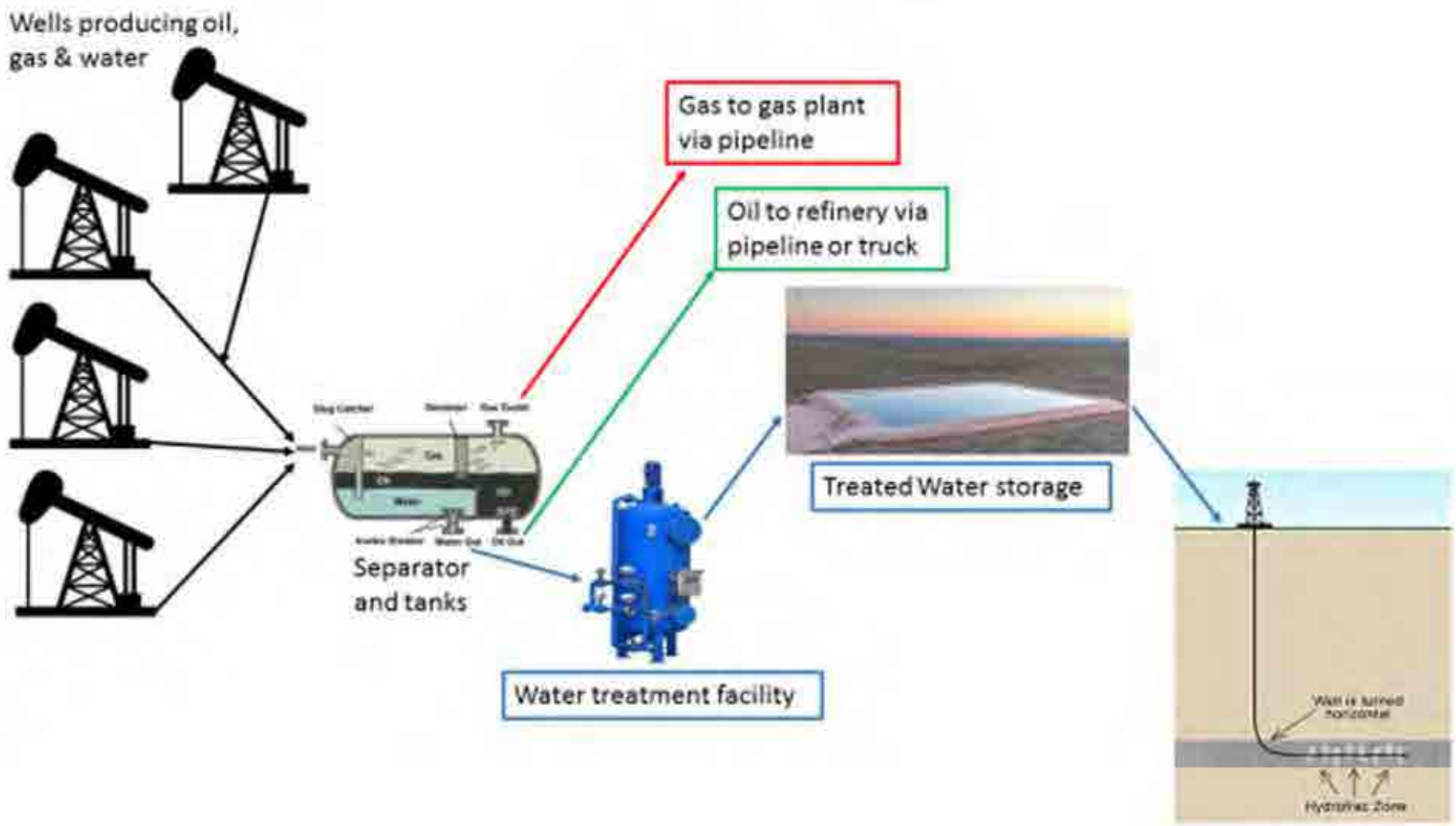
2. Produced Water in Oil and Gas Operations

Typical Simplified Oil, Gas and Water Process



2. Produced Water in Oil and Gas Operations

Simplified Oil, Gas and Water Process with Water Re-use



2. Produced Water in Oil and Gas Operations

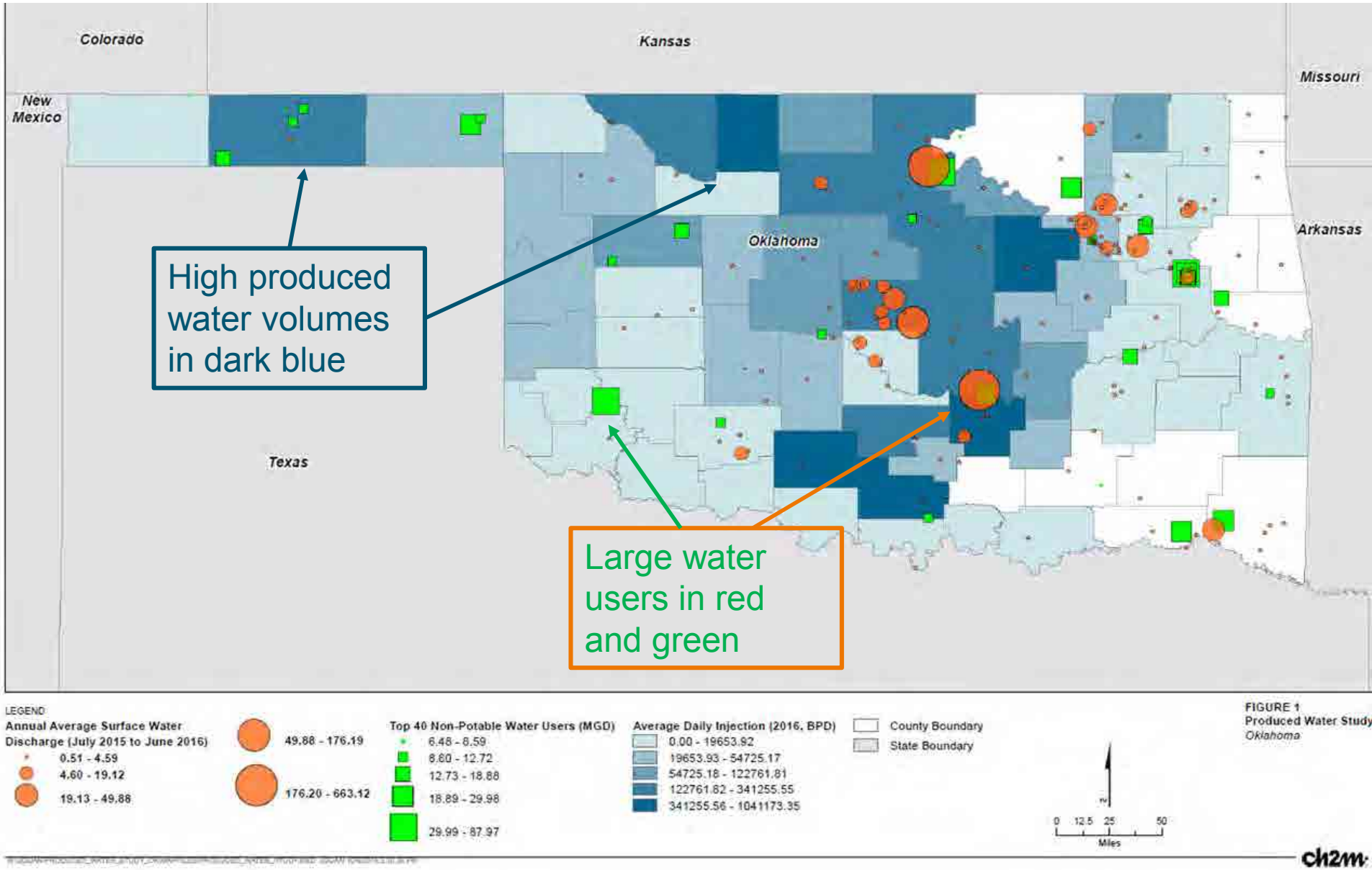
Key points

- Average well in OK in 2016 used ~210,000 barrels for hydraulic fracturing
- PW TDS range: 10,000 to 230,000 milligrams per liter (mg/L) in OK
- Water quality needed for oilfield reuse is flexible. Water standard for other industries or discharge requires desalination.
- Transportation of water can be high cost

Companies mentioned with water infrastructure: Continental, Devon, Newfield & Cimarex.

Photo from Chesapeake.

2. Produced Water in Oil and Gas Operations



Matching Produced Water with potential users.

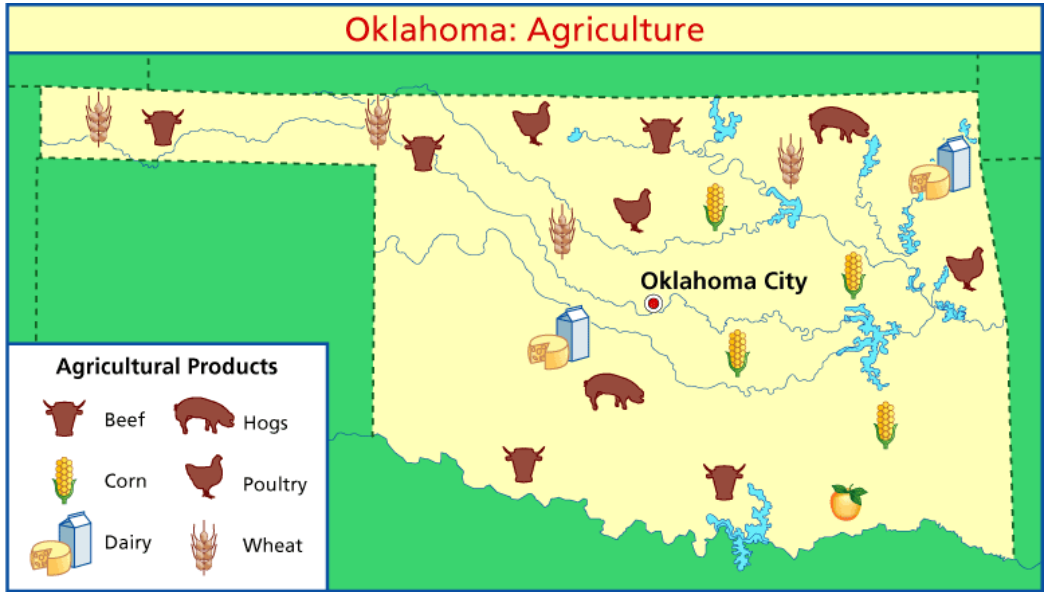
Produced Water in Oil and Gas Operations

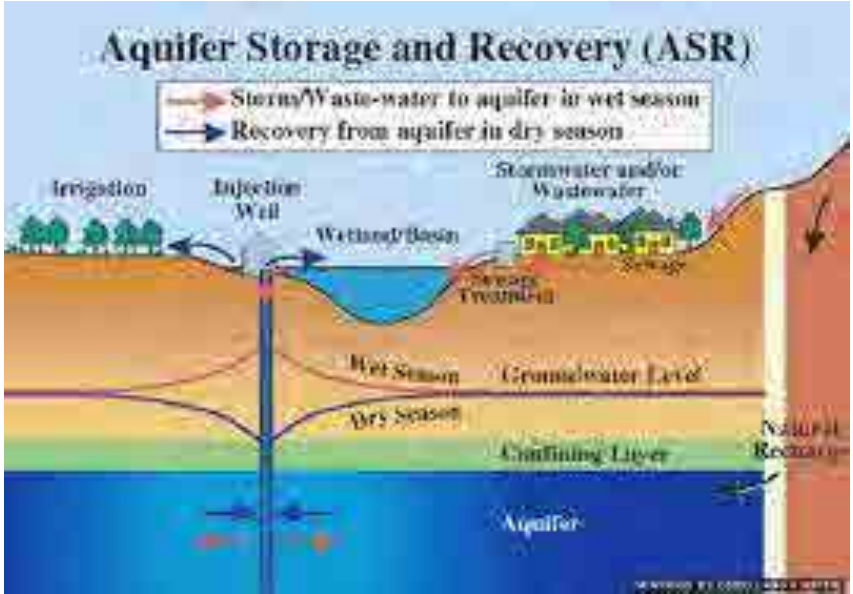
Alternatives Not Evaluated Economically

1. Agriculture – Locations not aligned, seasonality

2. Aquifer Storage & Recovery – lack of regulations currently

3. Mining





3. Produced Water Re-use Scenarios

Cost estimates and economic assumptions

- Capital cost estimates (+50%/-30% accuracy) using CH2M's Parametric Cost Estimating System and benchmarked against other similar projects.
- Water treatment costs based on estimates from selected companies.
- Used 10 year project life for all capital, but project lives could be longer.
- “Normalized” capital, treatment costs and barrels into “today’s dollars” by discounting future costs and barrels at 10% discount rate.

Important points in the fine print.

3. Produced Water Re-use Scenarios

Water Treatment Cost Estimates

Summary of Cases

Case #	Barrels per day treated	Contract term (yrs)	Inlet wtr TDS (mg/l)	Wtr quality needed	Cost per BW*	% of inlet wtr recovered	Number of Estimates	Cost Estimates Low	Cost Estimates High
1	20,000	2	30,000	Clean brine	0.66		8	0.30	1.50
2	100,000	2	30,000	Clean brine	0.57		8	0.18	1.50
3	100,000	10	30,000	Clean brine	0.47		8	0.10	1.50
4	20,000	2	150,000	Clean brine	0.69		8	0.30	1.75
5	100,000	2	150,000	Clean brine	0.60		8	0.18	1.75
6	100,000	10	150,000	Clean brine	0.50		8	0.10	1.75
7	20,000	2	10,000	Desalinated	2.58	88%	8	0.95	5.30
8	100,000	2	10,000	Desalinated	2.04	88%	8	0.65	4.25
9	100,000	10	10,000	Desalinated	1.76	88%	8	0.45	4.00
10	20,000	2	30,000	Desalinated	3.05	74%	8	1.45	5.75
11	100,000	2	30,000	Desalinated	2.55	74%	8	1.25	4.70
12	100,000	10	30,000	Desalinated	2.22	74%	8	0.95	4.50
13	20,000	2	150,000	Desalinated	4.58	60%	6	1.46	9.26
14	100,000	2	150,000	Desalinated	3.60	60%	6	1.10	6.91
15	100,000	10	150,000	Desalinated	2.52	60%	6	0.90	5.25
16	20,000	2	30,000	Evaporation	1.66		3		
17	20,000	2	150,000	Evaporation	1.79		3		

3. Produced Water Re-use Scenarios

New Case	Case Description	Total Capital ($Millions)	Capacity BWPD	County	Assumed Wtr TDS (mg/L)	Normalized $/BW
1	Typical Source and Dispose - STACK & SCOOP	NA	NA	Central OK	NA	1.83
2	Oil and gas re-use (treatment cost only, pipe transfer exists)	NA	NA	State-wide	NA	0.57
3	Clean Brine Transfer & treatment	208	200,000	Alfalfa	213,000	1.03
4	Evaporation - low TDS (SCOOP & STACK)	NA	20,000+	Blaine	17,000	1.66
5	Evaporation - high TDS (Miss. Lime)	NA	20,000+	Alfalfa	213,000	1.79
6	Desalination for Surface Discharge	22	15,000	Beckham	9,000	3.58
7	Desalination for Power Use	88	130,000	Pawnee	125,000	4.37
8	Desalination for Power Use	95	230,000	Seminole	180,000	4.43
9	Desalination for Industrial Use	35	30,000	Grant	227,000	7.41
10	Desalination for Surface Discharge	38	30,000	Grant	227,000	7.49

3. Produced Water Re-use Scenarios

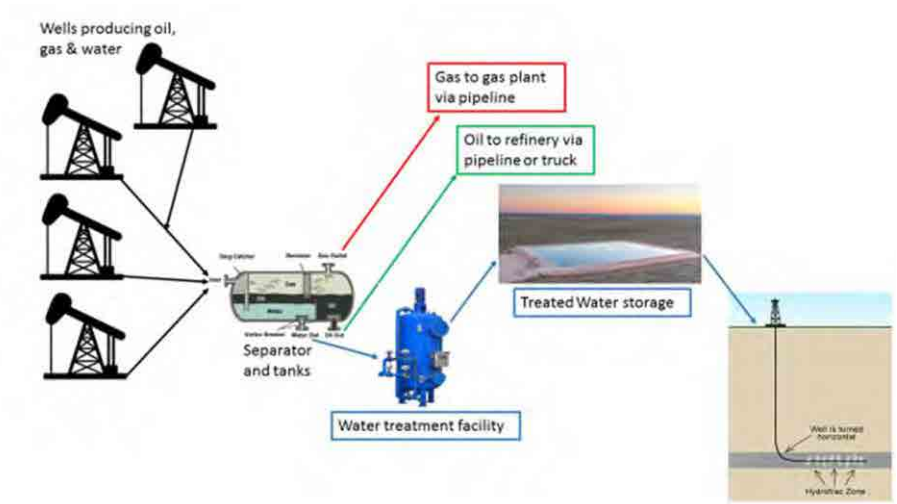
Case 1 – Typical cost to source & dispose in STACK & SCOOP

- Cost is average of estimates from four operators = $1.83/BW
- Trucking costs when applicable are about ½ of this cost.
- Does not include temporary lines to move water to frac site.
- Would like to have more companies input.

3. Produced Water Re-use Scenarios

<u>Case 2</u> – Oil and gas reuse assuming water infrastructure exists

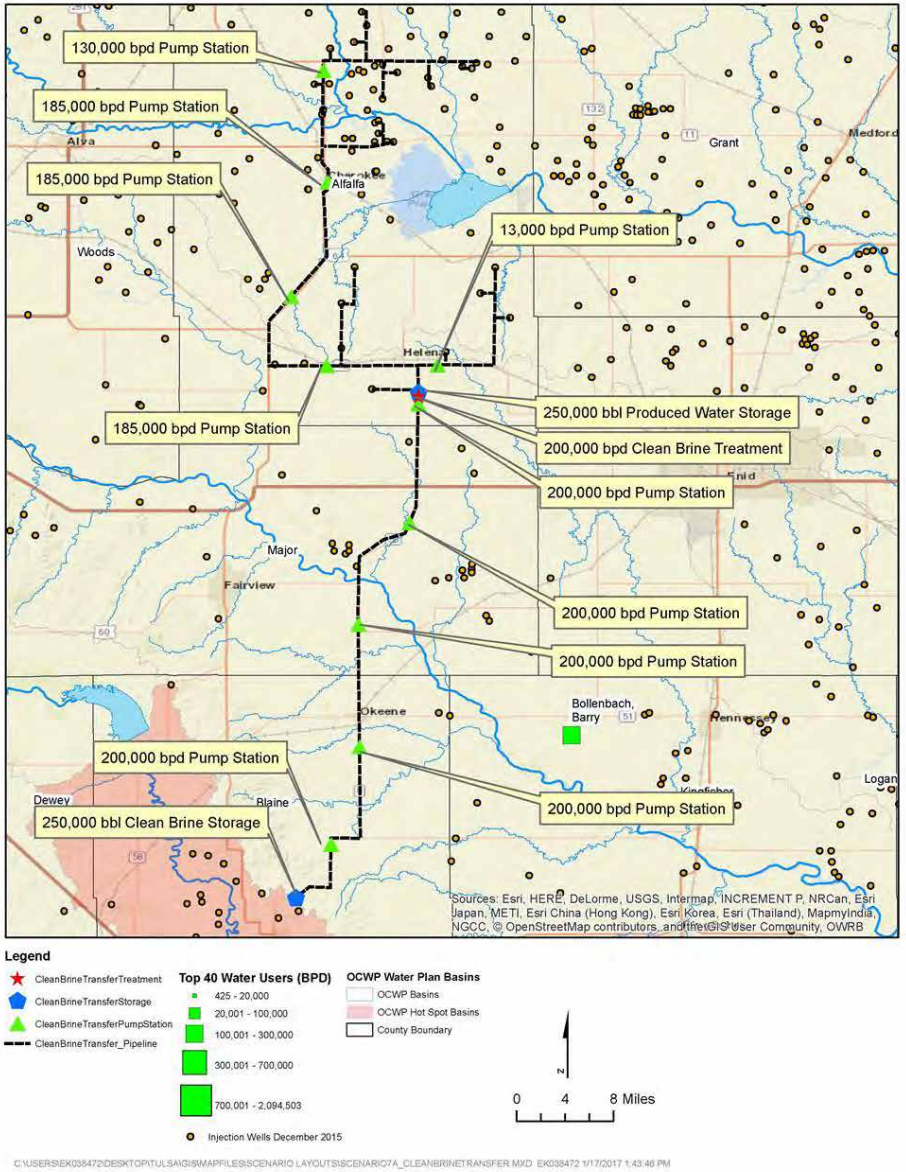
- Cost to treat water for re-use = $0.57/BW
- But, little water infrastructure currently exists
- Infrastructure of water gathering lines, impoundments and delivery lines is needed
- If trucking to and from a treatment facility is required, the two-way trucking cost could be $2 to $6/BW.



3. Produced Water Re-use Scenarios

Case 3 – Inter-county Clean Brine Transfer & Treatment

- Normalized cost for capital & water treatment = $1.03/BW
- Alfalfa Co. PW surplus
- Blaine Co. need for frac'ing
- Cost of 200,000 BWPD gathering lines & transfer is not impediment
- Does not include distribution system in Blaine Co.
- Commercial and technical issues will need to be resolved



3. Produced Water Re-use Scenarios

Case 4 - Forced Evaporation – Low TDS (SCOOP & STACK)

- Evaporation cost = $1.66/BW for 20,000 BWPD facility, 2 year project
- No capital required since assume treatment facility next to disposal well.
- Vendor provides all power needs and disposes of any solid or liquid waste.

3. Produced Water Re-use Scenarios

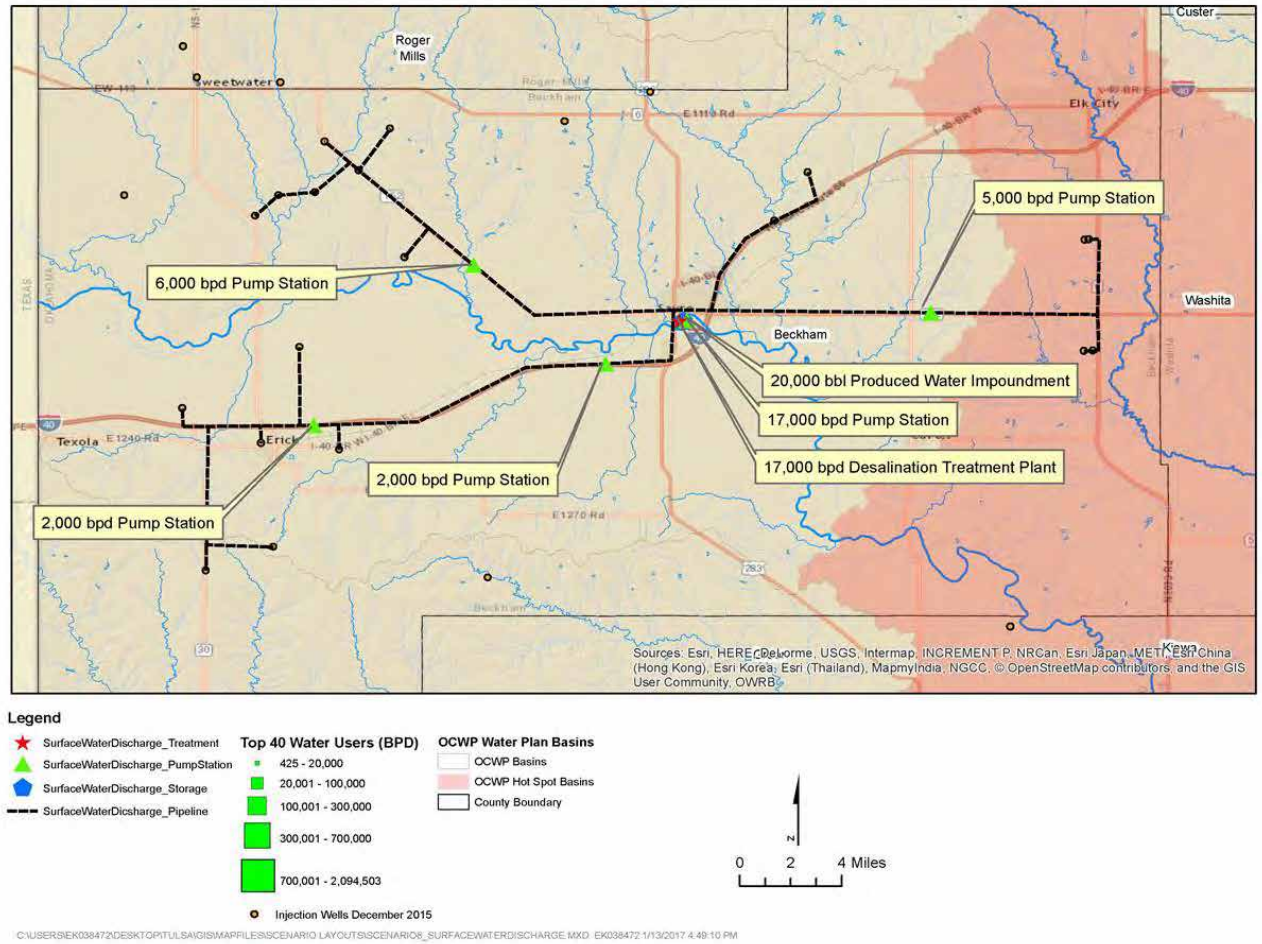
Case 5 - Forced Evaporation – High TDS (Mississippi Lime)

- Evaporation cost = $1.79/BW for 20,000 BWPD facility, 2 year project
- No capital required since assume treatment facility next to disposal well.
- Vendor provides all power needs and disposes of any solid or liquid waste.

3. Produced Water Re-use Scenarios

Case 6 - Desalination for Surface Discharge in Beckham County

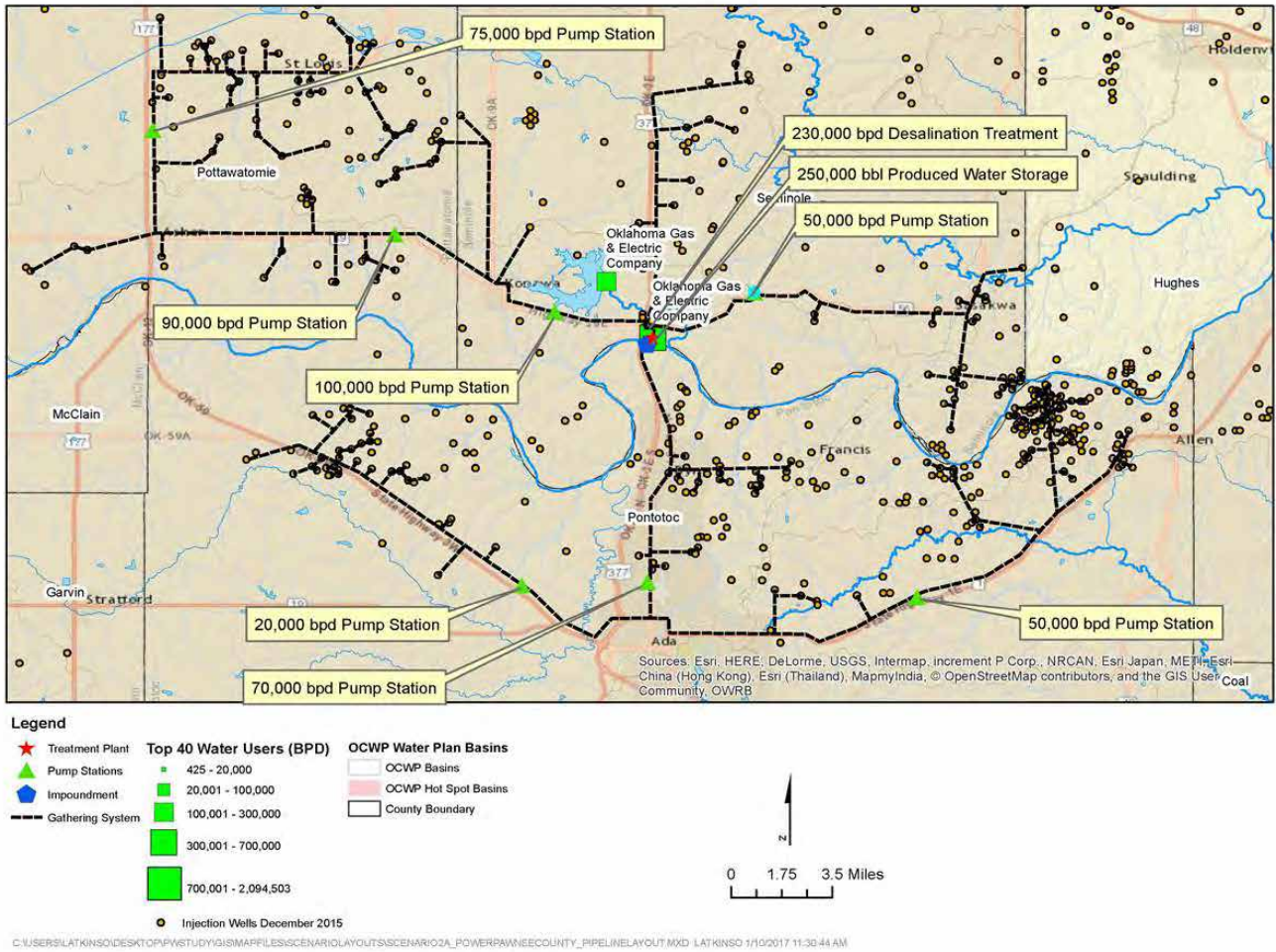
- Normalized cost for gathering lines and treatment = $3.58/BW
- Lowest cost of desalination cases due to unusually low TDS of PW



3. Produced Water Re-use Scenarios

Case 7 - Desalination for Power Use in Seminole County

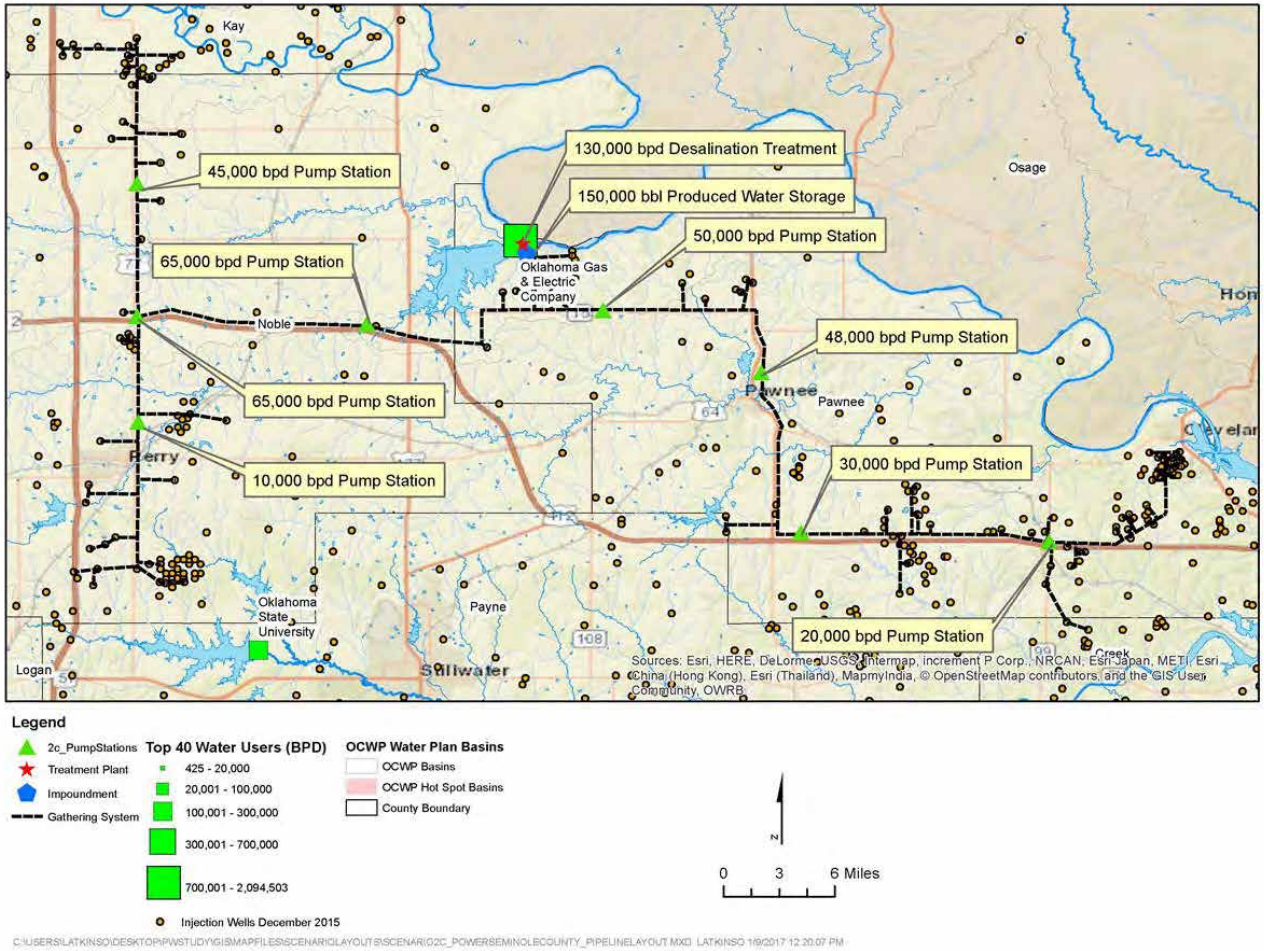
- $4.37/BW cost estimate.
- Power has large, long-term water demand
- 130,000 BWPD capacity for 125,000 TDS water.



3. Produced Water Re-use Scenarios

Case 8 - Desalination for Power Use in Pawnee County

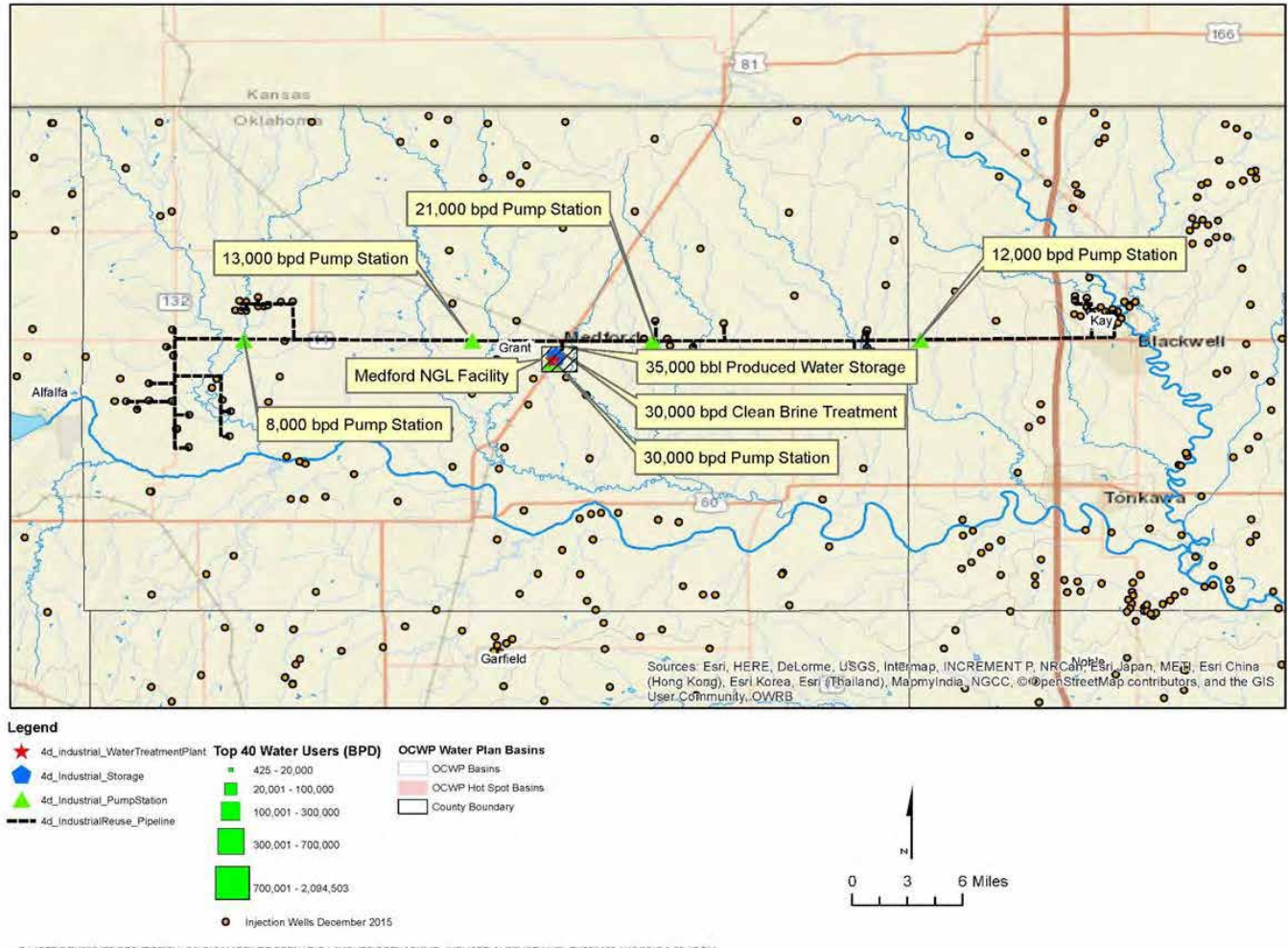
- $4.43/BW cost estimate.
- Power has large, long-term water demand
- 230,000 BWPD capacity for 180,000 TDS water.
- Compared to prior case, higher volume & higher TDS offset.



3. Produced Water Re-use Scenarios

Case 9 - Desalination for Industrial Use in Grant County

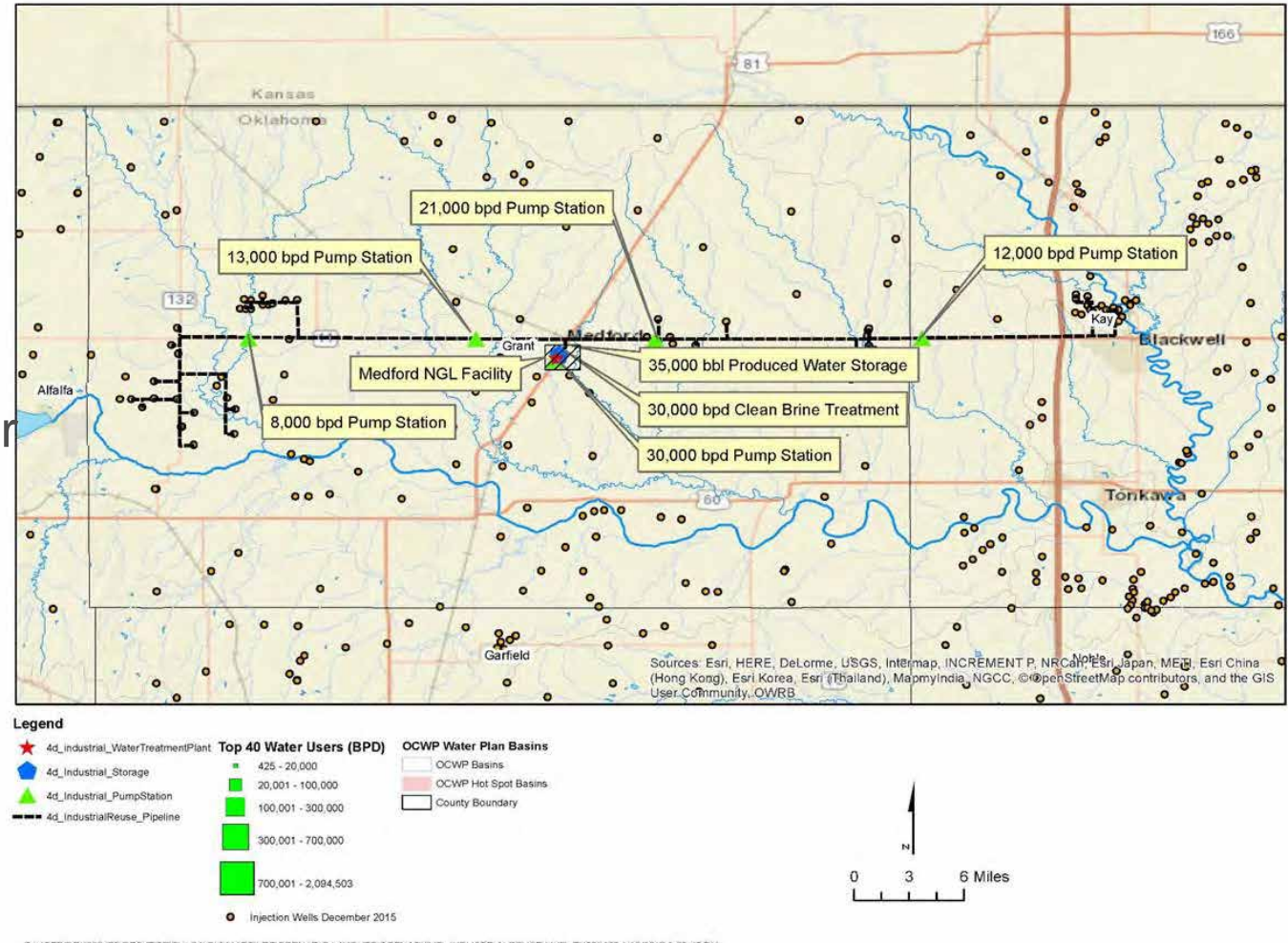
- $7.41/BW cost estimate.
- 30,000 BWPD capacity for 227,000 TDS water.
- Lower volumes & higher TDS increase cost per BW.



3. Produced Water Re-use Scenarios

Case 10 - Desalination for Surface Discharge in Grant County

- $7.49/BW cost estimate.
- 30,000 BWPD capacity for 227,000 TDS water.
- Similar to prior case except slightly higher capital.



5. Challenges, Opportunities, and Risk

Challenges to produced water re-use

1. Cost to Transport and Treat Water for Re-use and Recycling
2. Water Treatment Facility Bonding Requirements
3. Ownership and Value of Produced Water
4. Legal Custody of Water as it Relates to Potential Spills
5. Right-of-Way and landowner negotiations
6. Discharge Permit Challenges Including Timing

6. Implementation

Requirements for success

- Design for water balance
- Financing for capital
- Permits & right-of-way
- Oil and gas companies likely to lead
- Time for projects to develop

6. Implementation

Environmental and Stakeholder Considerations

	Method	Possible risks or issues
1.	Disposal/injection	Potential for seismicity or casing leaks
2.	Re-use	More water transfer & storage; less trucking
3.	Evaporation	Potential for solid waste disposal
4.	Other industries/ Desalination	Maximum solid waste disposal; more transfer/storage

6. Implementation

Environmental and Stakeholder Considerations

Implementation Opportunities, Challenges and Impacts

Case	Case Description	Limits Water Disposal	Reduce Water Needs	"Create" New Water	Reduce Water Trucking	Water Storage Needed	Water Pipeline Needed	Solid Waste Generated
1	Typical Source and Dispose							
2	Oil and gas re-use							
3	Clean Brine Transfer & treatment							
4	Evaporation - low TDS (SCOOP & STACK)							
5	Evaporation - high TDS (Miss. Lime)							
6	Desalination for Surface Discharge							
7	Desalination for Power Use							
8	Desalination for Power Use							
9	Desalination for Industrial Use							
10	Desalination for Surface Discharge							

Positive opportunity or impact

Negative impact or challenge

6. Implementation

Macroeconomic Considerations

- Roughly one-quarter of all jobs in OK are energy related
- Legislative and regulatory efforts attempt to balance stakeholder concerns with the desire to promote economic growth
- Limited disposal options will raise the cost of water disposal and tend to encourage water re-use.

7. Conclusions

1. Re-use by the oil and gas industry is the most cost-effective alternative to water disposal in disposal wells

2. Surplus produced water in Alfalfa County could be gathered and conveyed to Blaine County for re-use (subset of item 1).

3. Evaporating produced water is the third most cost-effective alternative category of options

4. Cases requiring desalination for power, industrial plants or discharge to rivers are technically implementable, but are the most expensive scenarios

7. Recommendations

1. Reduce the challenges to water re-use through targeted regulations and legislation: water ownership, bonding, water sharing, right-of-way & discharge delegation.

2. Continue to consider how to facilitate the re-use of produced water in oil and gas operations.

3. Continue detailed study of the feasibility of transferring the Mississippi Lime area produced water to the STACK play (Case 3).

4. Continue a detailed evaluation of evaporation as an alternative to injection (Cases 4 and 5).

5. Companies and regulators should consider all negative and positive environmental and stakeholder impacts, as well as any data gaps, before implementing a long-term project.

Thank You

ch2m SM

Water for 2060
Produced Water Working Group

November 2, 2016

2:00 p.m.-5:00p.m.

Oklahoma Water Resources Board

3800 N. Classen Boulevard, Oklahoma City, OK

1. **Welcome** — **Julie Cunningham, Chairman**
2. **Produced Water Quality Request** — **Michael Dunkel**
   a. **Where to return the data?**
   b. **Timing**
3. **Summary of Subcommittee Meetings and Conference Calls**
4. **Water treatment status**
5. **Produced Water and Potential User Data in Map Form**
6. **Economic Case Development**
7. **Timing for Draft Report**
8. **Next Steps** — **Julie Cunningham / Michael Dunkel**
9. **Adjourn**

Produced Water Working Group

Meeting Summary of Fourth Meeting, 2 pm November 2, 2016

OWRB Board Room, 3800 N. Classen Blvd., Oklahoma City, Oklahoma

---

ATTENDEES:

***Produced Water Group Members and representation (from Sign In and/or Introductions)*:**

Tim Baker, OCC
Julie Cunningham, OWRB
Mike Dunkel, CH2M
Jeff Everett, OG&E
Fred Fischer, OPAIA
Bud Ground, EFO
Mike Mathis, OIPA/Continental
Mike Ming, GE
Kyle Murray, OGS
Mike Paque, GWPC
Jim Reese, OK Secretary of Agriculture
Alan Riffel, OML
Jesse Sandlin, Devon/OKOGA
Terry Stowers, COSMO
Scott Thompson, ODEQ

***OWRB Staff and Consultants*:**

Owen Mills, OWRB
Anna Childers, CH2M

***Others*:**

Jared Boehs, Pure Water Services
Joyce Boyd, OCC
Jayme Cox, Cimarex
Mike Erickson, Marathon Oil
Lloyd Kirk, ODEQ
Rick McCurdy, Chesapeake
Jeff Myers, OCC
Holly Pearen, EDF
Nicole Sanders, EDF
Brad Schultz, ONEOK
Jana Slatton, OCC
Ed Steele, GE
Saba Tahmassebi, ODEQ
Ella Walker, OGS
John Westerheide, GE OGTC

Introductions and Goals for Today

Ms. Julie Cunningham, OWRB Interim Executive Director and Produced Water Working Group (PWWG) Interim Chairman, opened the meeting by welcoming the attendees, held introductions, provided a brief update on OWRB's recent change of leadership and confirmed that she is going to see the PWWG effort into completion in her role both as the Interim Executive Director as well as the PWWG Interim Chairman. Ms. Cunningham reviewed the agenda and logistics for the meeting. She stated the primary goal for the meeting was to review the PWWG process thus far as well as discuss the ongoing data collection, data gaps and information coordination. Mr. Michael Dunkel led the meeting and started with overview of the previous meetings and subcommittee efforts.

Summary of Subcommittee Meetings and Conference Calls

Based on the feedback received from the previous meetings and coordination with PWWG subcommittees, a common theme emerged suggesting that some rules and regulations might be changed to simplify and incentivize potential PW uses. Some of the difficulties identified were a need for clarification including, water ownership, definition and liability of spills, classification of treated PW, regulatory authorities, infrastructure right-of-ways etc. It was suggested that incentives for reusing PW coupled with disincentives for not reusing PW may be necessary to jumpstart recycling today versus waiting for the market to force it to happen. While there was some agreement to this idea, there were no suggestions offered on how to implement. Additional subcommittee coordination will be needed. To this end, Mr. Bud Ground of EFO offered to communicate with other interested members to develop shell bills to advance PW use. The subcommittee will help to formulate issue / solution pairings. In addition, DEQ is considering request of delegation of EPA NPDES discharge permitting to OPDES delegation. DEQ must satisfy EPA criteria to obtain delegation of authority.

Needs Status of Water Quality Dataset

Mr. Dunkel discussed the ongoing water quality data collection effort. He stressed the need for water quality data for determining both cost and relative waste stream volumes. Rick McCurdy from Chesapeake voiced his concerns of including *all* of the water quality data, relating that inclusion of all the chemistry can reveal multiple substances of concern and yet be naturally occurring. The PWWG decided that there was no need to include anything the firms are not comfortable with reporting. Also, the PWWG agreed that in order to protect the identity of those providing water quality data, it is acceptable to include less specific spatial information for the wells. County level information at a minimum or truncated coordinates on the order of Township and Range should be sufficient. Determined further that there is no need to include API # and suggested to enter "N/A" rather than a 0 (zero) where the data is not known.

GIS data analyses of the produced water volumes, water quality and water users will be included in the draft report.

Produced Water and Potential User Data in Map Form

Mr. Dunkel provided a PowerPoint presentation on PW and potential user data. He summarized the approach of short-listing top 12 non-potable water use candidates in high PW volume counties. This presentation may be found on OWRB's PWWG page.

After reviewing the presentation, the PWWG were provided an opportunity to ask questions and provide feedback on the preliminary findings and the approach. The group discussed the different water use categories and suggested that it would be helpful to define them in the report. The group had question about Osage Co. why that did not have any PW data. Ms. Anna Childers explained that most of the Osage Co. is in BLM in control and accessing data is challenging; however, the project team would look into accessing data for the county. If no data available, it was suggested to include an asterisk to recognize why the county blank in figures.

Speculation arose on using the Great Salt Plains as a potential site for receiving treated PW into the lake. since the lake levels drop dramatically every year and the water is moderately high on TDS (3,600). The general consensus of the group was the idea may not be a feasible option given its unique ecology and sensitive ecosystems.

The group members also discussed Aquifer Storage Recovery (ASR) as a potential option to store marginal quality water. Oklahoma is in the process of developing ASR guidelines however extensive studies may be required for source water compatibility with the local geochemistry and state standards.

Forced evaporation alternative was discussed and the challenges associated with this option, such as the seasonality; e.g., little evaporation in colder months), large volumes of solids disposal can be very difficult, icing issues such as on nearby powerlines and so forth.

Economic Case Development

Michael Dunkel reviewed the planned economic scenarios. He reminded that the current task is to assess how Oklahoma can reuse produced water most effectively. Scott Thompson indicated that existing state rules handle if PW is transferred to a power plant. Ed Steele reminded the group that an evaporation case is important. Mike Ming suggested ranking the options based on their practicality. Holly Pearin suggested reviewing what California is doing with PW re-use. Scott Thompson said that toxicity evaluation of water discharged will need to be assessed for a project. Jim Reese suggested that the Interstate Oil and Gas Commission may have information on water treatment.

The cost estimates will be developed for the study using the most viable scenarios. The goal is to develop preliminary cost estimates and cost scenarios: less than dozen will be developed.

The PWWG concluded that O&G reuse probably would be the lowest cost. However, it is difficult to evaluate oil-and-gas re-use due to the requirements for detailed company drilling plans that are often confidential and changing. This level of planning is being performed internally by many producing companies. The majority of the scenarios evaluated for this report involve more permanent water users that have long term water needs in one location.

CH2M will initiate development of cost per barrel of water upon receipt of water quality data and average cost estimates from treatment companies. The resulting treated water quality will depend on the intended end water use (clean brine, desalinated, evaporation) Also, infrastructure costs would be developed.

Mr. Jesse Sandlin from Devon suggested if a pilot analysis could be done at some point to get cost estimates for treatment. This could include e.g. 30 wells and certain pipeline lengths and configurations

of the infrastructure to get “ballpark” / rough order of magnitude estimates. Those representing O&G industry would follow-up after the meeting and discuss the potential for the concept development.

Bud Ground shared that the proposed “shell” legislative bills are due between mid-November and December 9th and that PW ownership is important to clarify. Michael Dunkel committed to drafting a summary of the challenges to re-use for consideration in the draft bills. There was also a short discussion about writing a summary of the re-use process for oil-and-gas operations.

Timing for Draft Report

Prior to finalizing the report, the PWWG will meet to discuss the report findings and solicit comment and look for recommendations. At the time of this meeting the draft report was anticipated for end of January of 2017.

Action Items and Next Steps

To sum up actions to be taken by the staff:

- Set up next meeting using Doodle-Poll
- Post all meeting items in PWWG website (OWRB’s website)
- Distribute meeting summaries for the PWWG for review
- Complete cost analyses for selected scenarios
- Prepare draft report and distribute the PWWG members

OWRB Produced Water Working Group
November 2, 2016

ch2m SM

Agenda

1. Produced Water Quality Request
   A. Where to return data?
   B. Timing
2. Summary of Subcommittee Meetings and Conference Calls
3. Water treatment status
4. Produced Water and Potential User Data in Map Form
5. Economic Case Development
6. Timing for draft report
7. Next Steps

Julie Cunningham

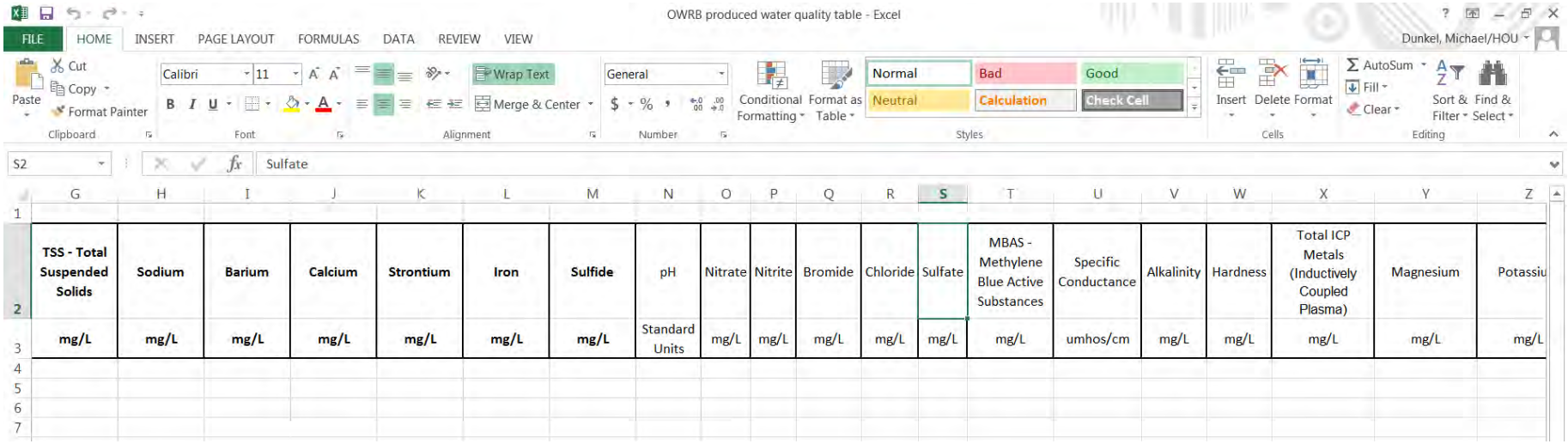
Produced Water Quality Data

1. OWRB (JD Strong) sent letter to OIPA and OOGA in September requesting analyses

2. OIPA sent out request to companies

3. It would be best to send data back to OIPA for aggregation, but it can be sent to me directly.

4. Need for data is urgent



TSS - Total Suspended Solids	Sodium	Barium	Calcium	Strontium	Iron	Sulfide	pH	Nitrate	Nitrite	Bromide	Chloride	Sulfate	MBAS - Methylene Blue Active Substances	Specific Conductance	Alkalinity	Hardness	Total ICP Metals (Inductively Coupled Plasma)	Magnesium	Potassiu
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Standard Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	umhos/cm	mg/L	mg/L	mg/L	mg/L	mg/L

PWWG Subcommittee Overviews

1. Agriculture
   A. Big water use in specific areas
   B. Seasonality for irrigation – does not match with plant output
   C. Chemical spraying volumes are small relative to PW plant
   D. Land use (hay) may compliment some scenarios

2. Water Users and Water Discharge
   A. Power, chemical plants, other
   B. Municipal – probably not a consideration
   C. Discharge to stream – permit timing – talked to EPA
   D. Aquifer Storage & Recovery – no treatment before drinking – State regulatory process is ongoing
      - Inject to marginal quality aquifer
   E. Evaporation – potential to rid water at lower cost

PWWG Subcommittee Overview

1. Oil and Gas
   A. Re-use requires minimal treatment
   B. Industry is working on re-use now
   C. Is there a way to compare to other economic scenarios?
   D. Incentives needed?

2. Regulatory and Challenges
   A. Commercial treatment facility designation - higher bonding
   B. NPDES permits -challenge to obtain, including the timing requirements.
   C. Produced water ownership – Value and liabilities
   D. Right-of-Way (ROW) and landowner negotiations
   E. Costs to re-use vs. disposal
   F. Legal custody of water as it relates to potential spills

Water Treatment Update

1. Six producing companies suggested treatment companies that had delivered in prior projects

2. Plan to send Request For Information (RFI) to 12 treatment companies for cost estimates for a number of treatment scenarios

3. Variables for treatment scenarios

   A. 20,000 Barrels of Water Per Day (BWPD) and 100,000 BWPD

   B. Varying TDS levels: 10,000, 30,000, 150,000 mg/l

   C. Contract term assumption: 2 years and 10 years

   D. Quality needed: “Clean brine” and TDS removal (desalination)

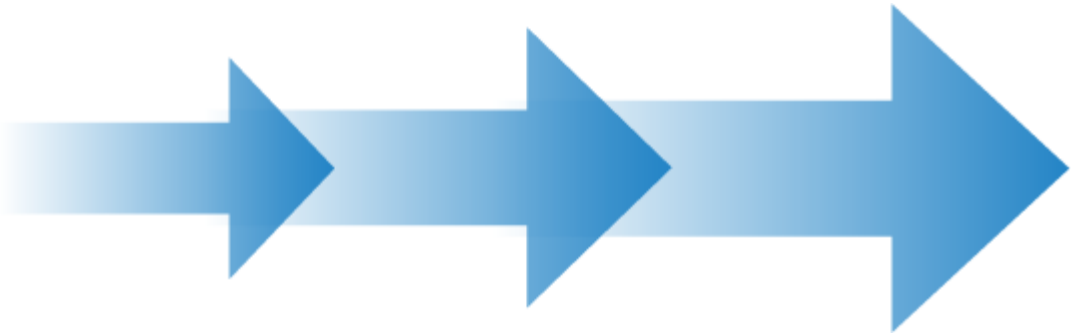
Summary of Data Analysis Completed to Date

1. Quantified/classified water use by county.

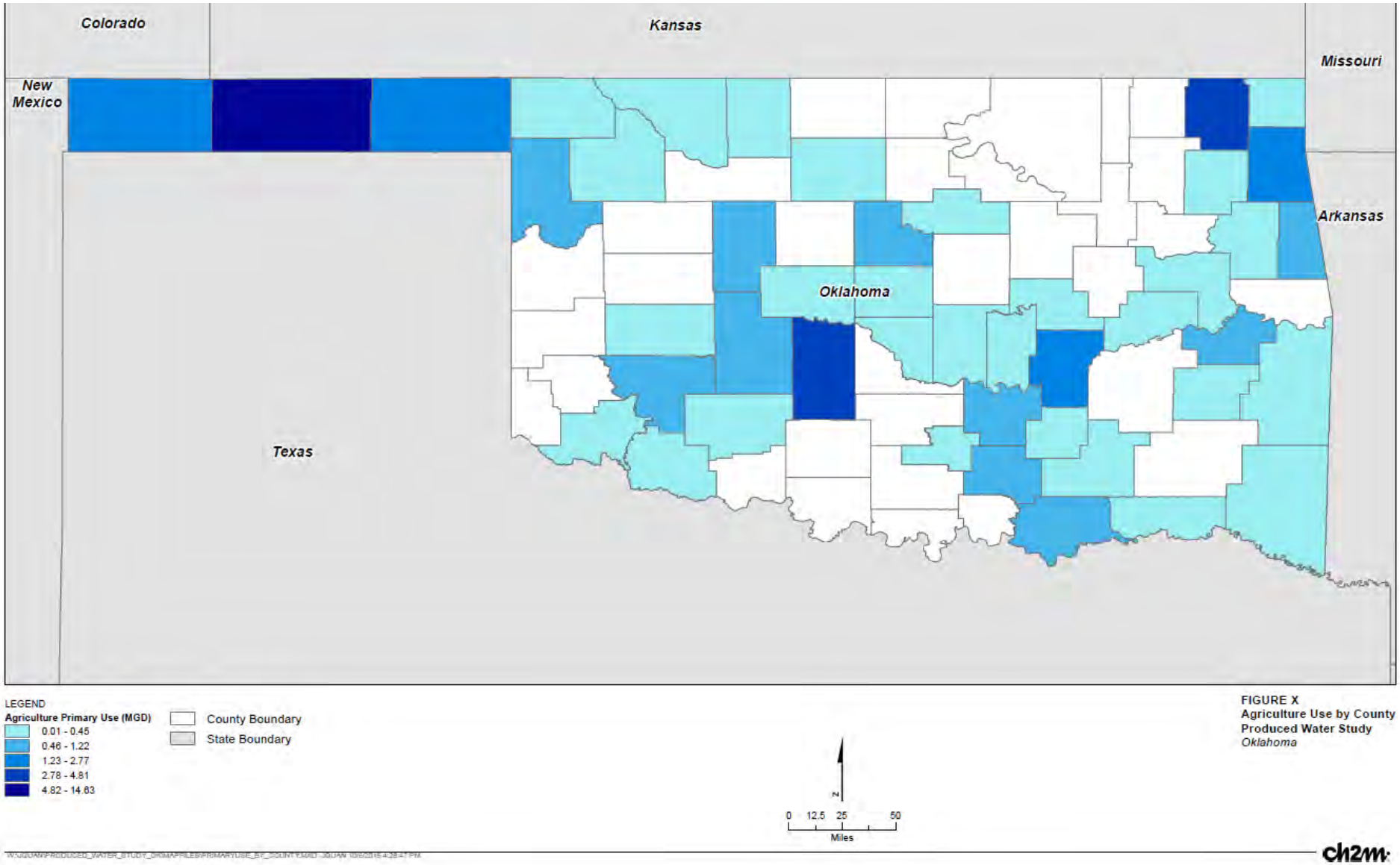
2. Evaluated produced water supply versus demands based on data provided by the PWWG.

3. Identified 16 matches which could be potential economic scenarios.

4. Developed screening matrix to shortlist the 16 potential scenarios down to 7 for further evaluation based on produced water quality data and treatment requirements

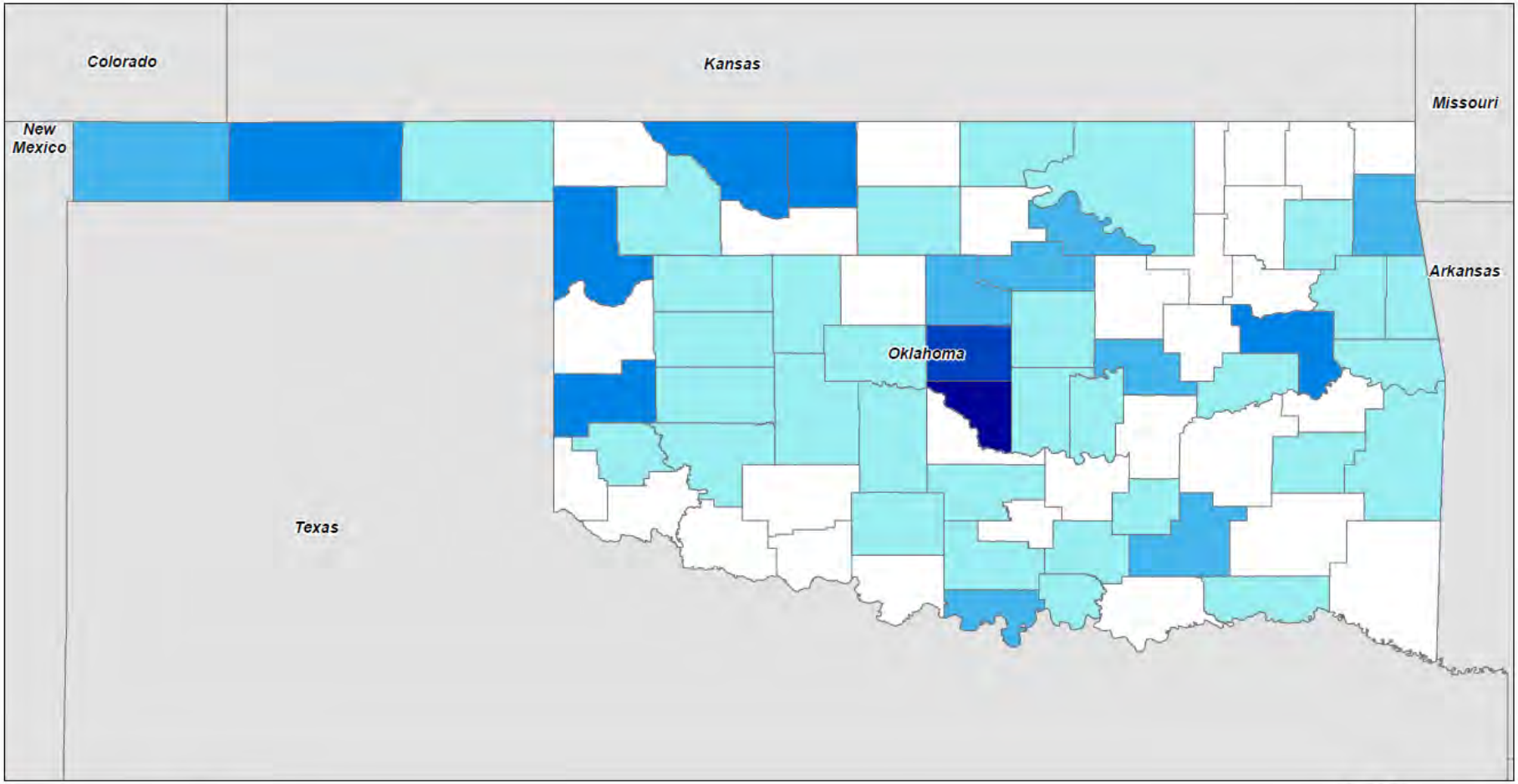


Agricultural Water use by County



Data from ODEQ

Commercial Water use by County



LEGEND

Commercial Primary Use (MGD)

- 0.01 - 0.17
- 0.18 - 0.43
- 0.44 - 1.07
- 1.08 - 2.53
- 2.54 - 6.31

- County Boundary
- State Boundary

N

0 12.5 25 50

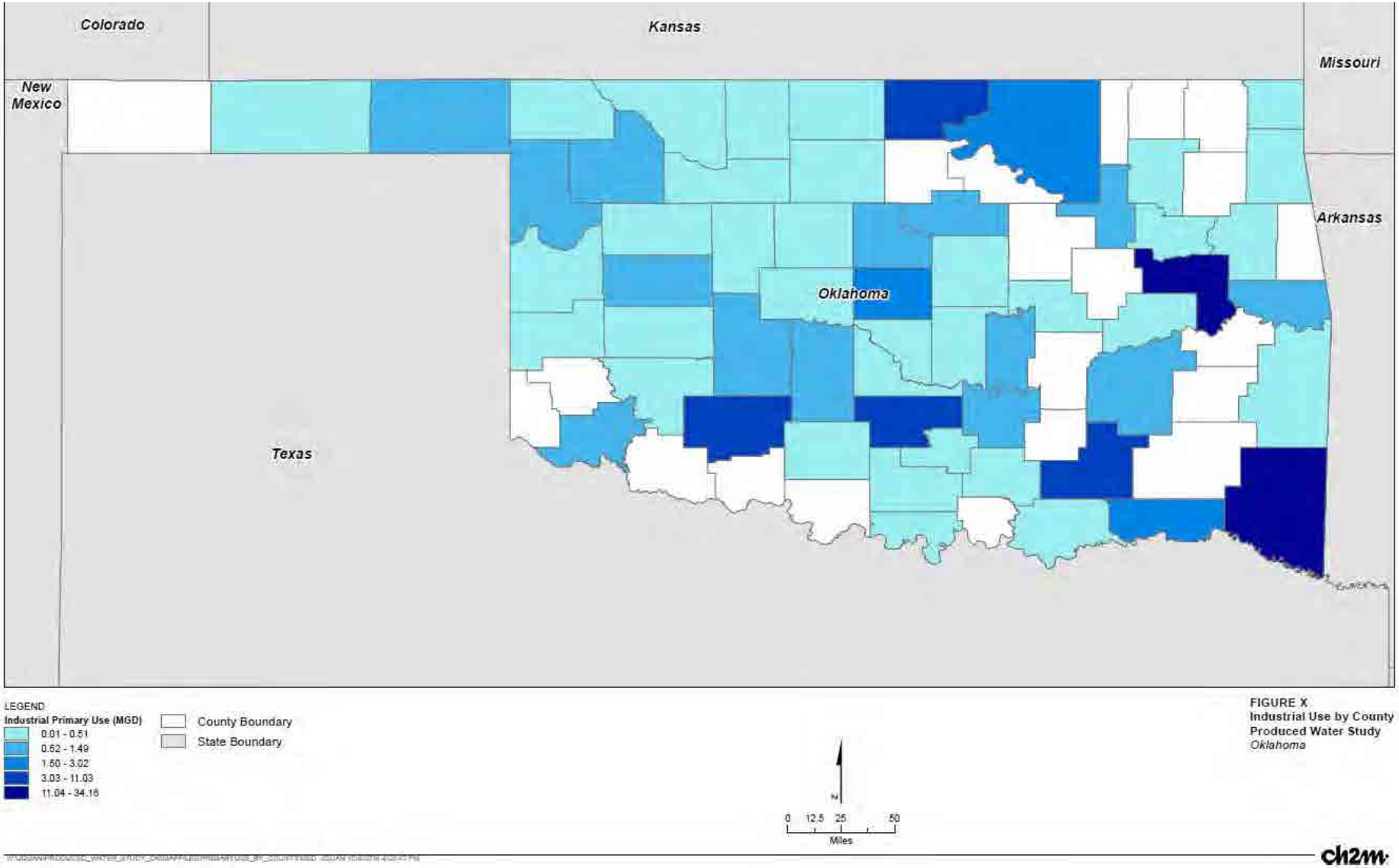
Miles

FIGURE X
Commercial Use by County
Produced Water Study
Oklahoma

ch2m

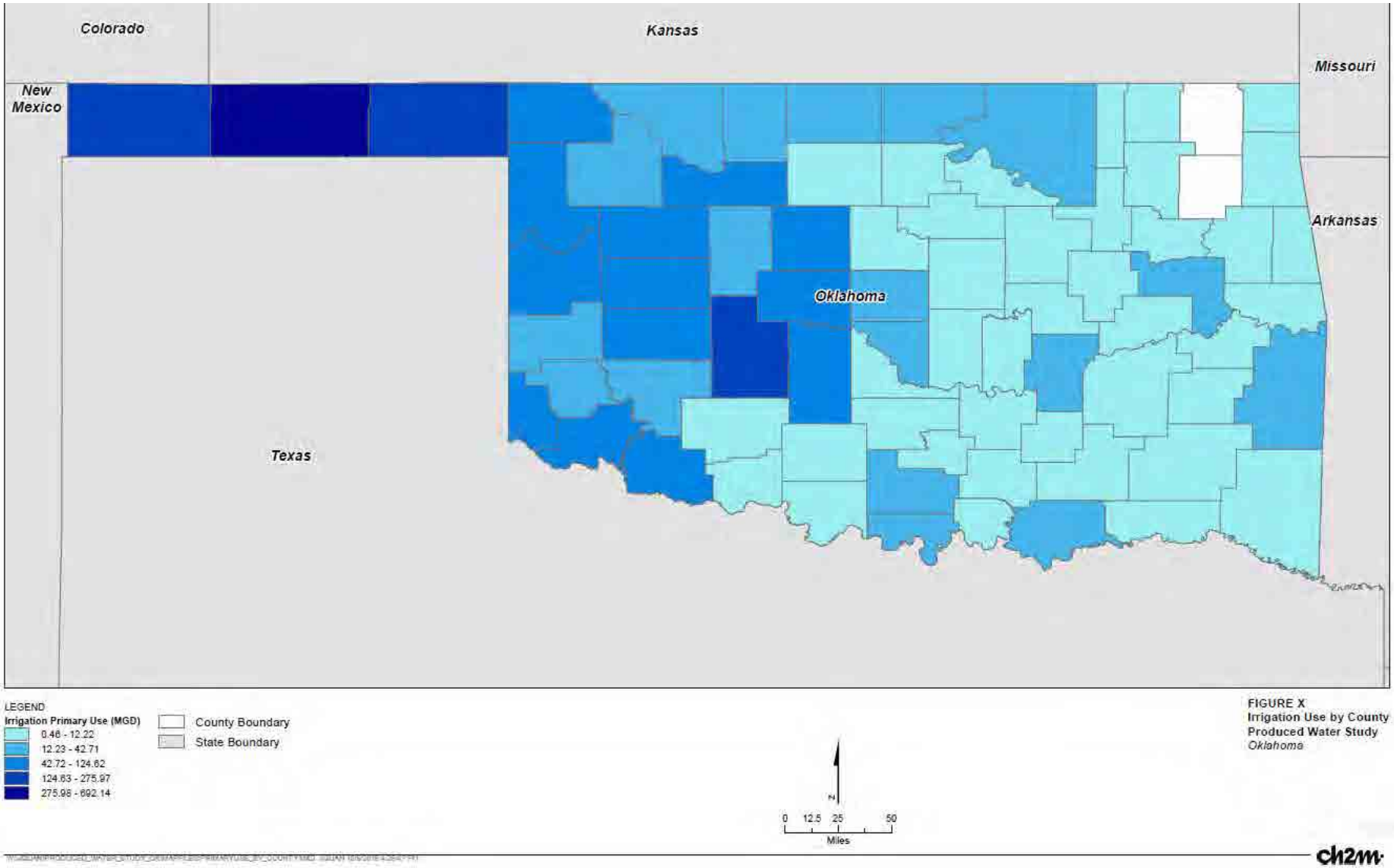
Data from ODEQ

Industrial Water use by County



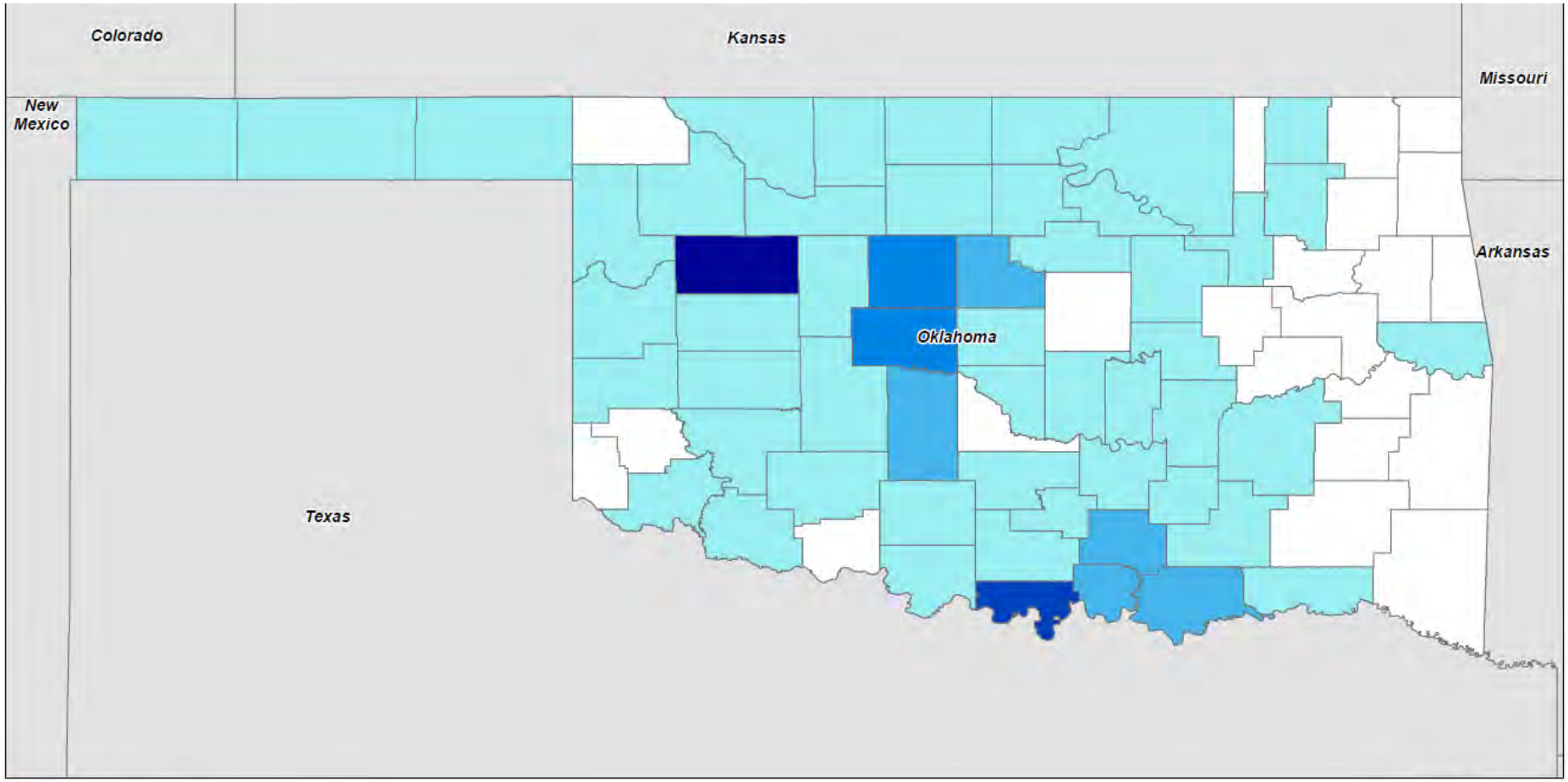
Data from ODEQ

Irrigation Water use by County



Data from ODEQ

Mining Water use by County



LEGEND
Mining Primary Use (MGD)
- 0.002 - 3.72
- 3.73 - 7.45
- 7.46 - 11.17
- 11.18 - 14.89
- 14.90 - 18.62

- County Boundary
- State Boundary

FIGURE X
Mining Use by County
Produced Water Study
Oklahoma

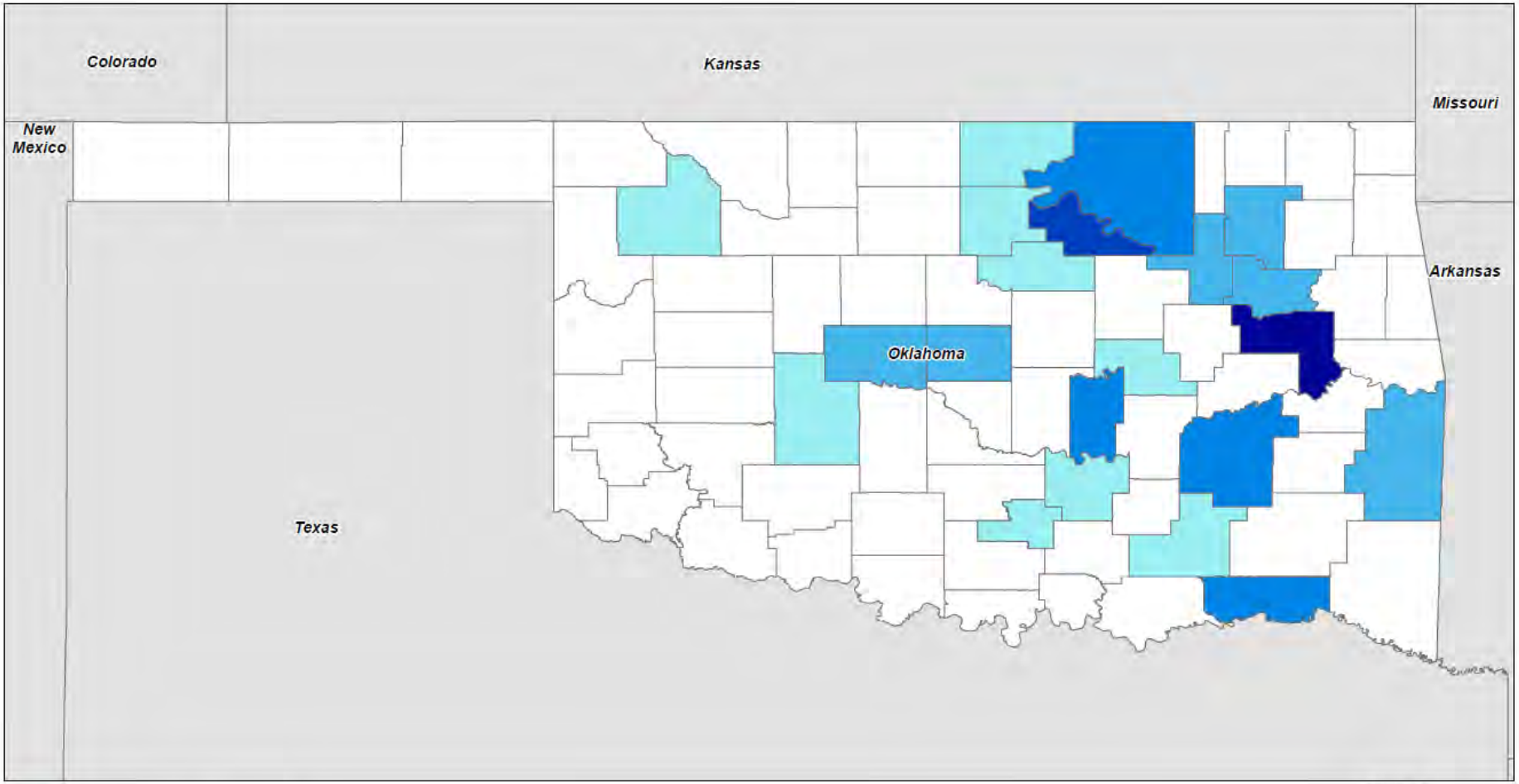
N

0 12.5 25 50
Miles

ch2m

Data from ODEQ

Power Industry's Water use by County



LEGEND

Power Primary Use (MGD)

- 0.04 - 4.68
- 4.69 - 18.35
- 18.36 - 31.31
- 31.32 - 65.13
- 65.14 - 134.54

- County Boundary
- State Boundary

N

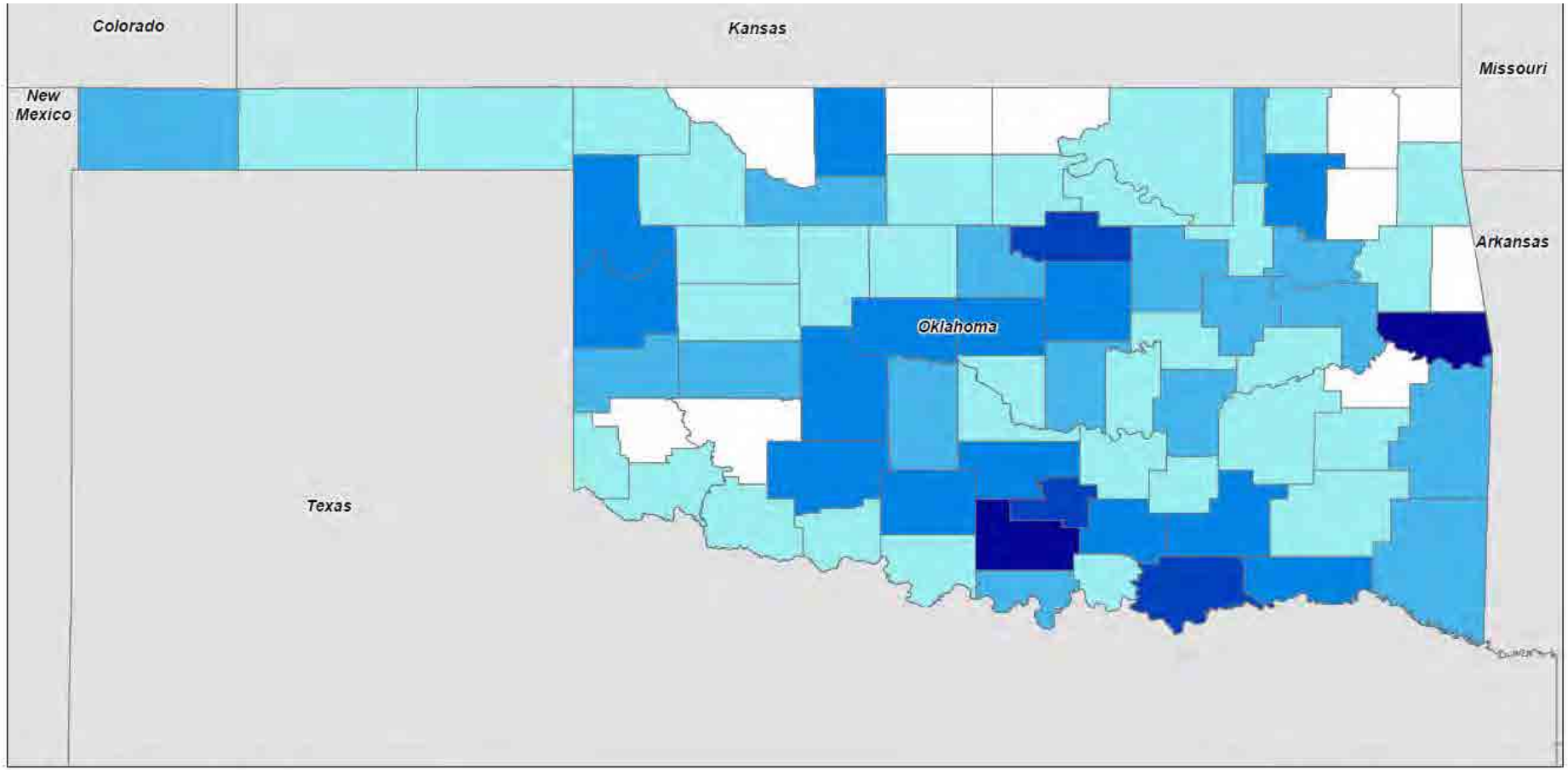
0 12.5 25 50

Miles

FIGURE X
Power Use by County
Produced Water Study
Oklahoma

ch2m

Recreation, Fish & Wildlife - Water use by County



LEGEND

Recreation, Fish and Wildlife Primary Use (MGD)

- 0.001 - 0.46
- 0.47 - 1.43
- 1.44 - 4.24
- 4.25 - 8.85
- 8.86 - 15.75

- County Boundary
- State Boundary

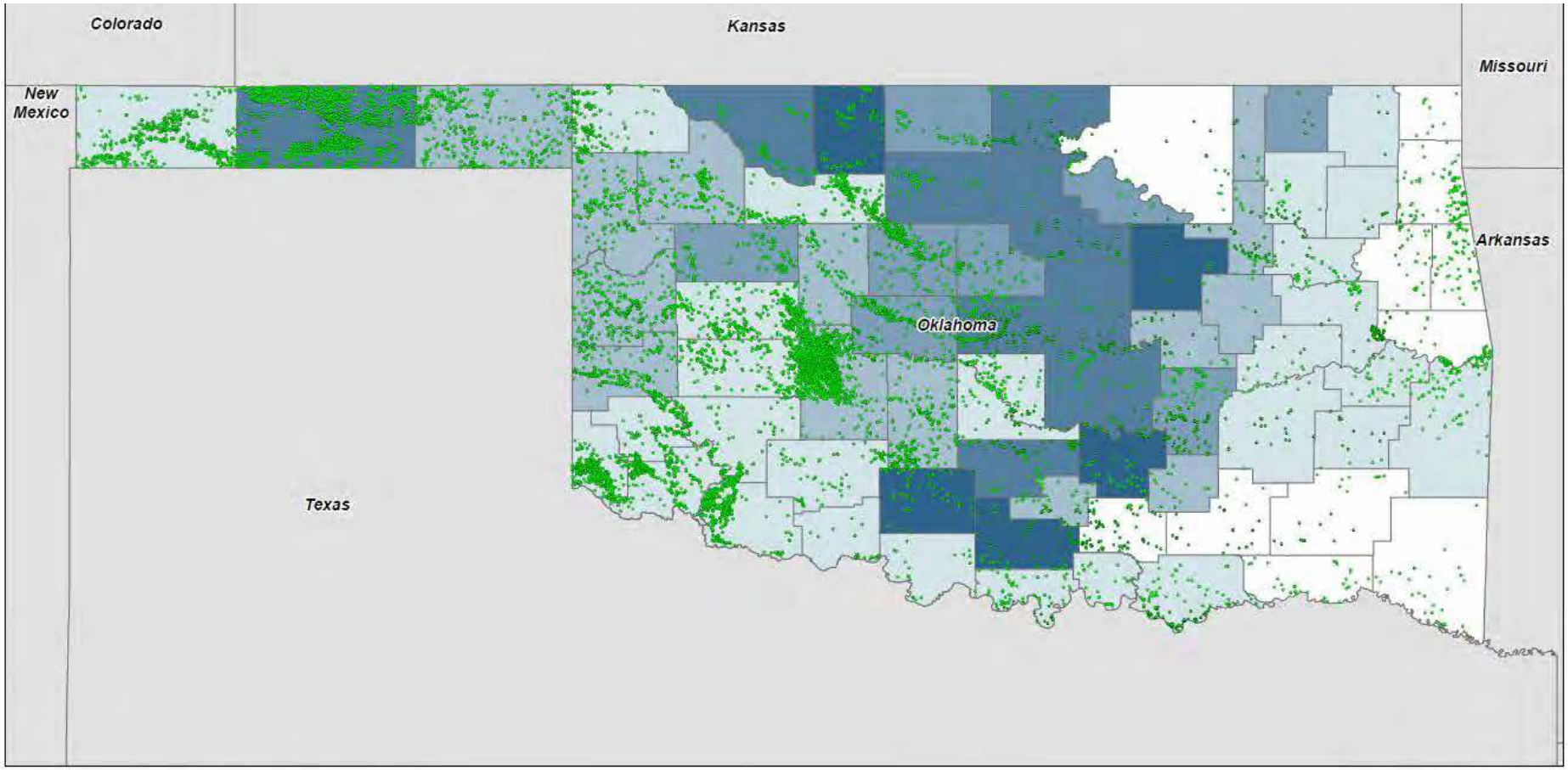
N

0 12.5 25 50
Miles

FIGURE X
Recreation, Fish and Wildlife Use by County
Produced Water Study
Oklahoma

ch2m

Produced Water Disposal & Water Users



LEGEND

Average Daily Injection (2016, BPD)

- 0 - 19654
- 19655 - 54725
- 54726 - 122762
- 122763 - 341256
- 341257 - 1041173

- Water User
- County Boundary
- State Boundary

N

0 12.5 25 50

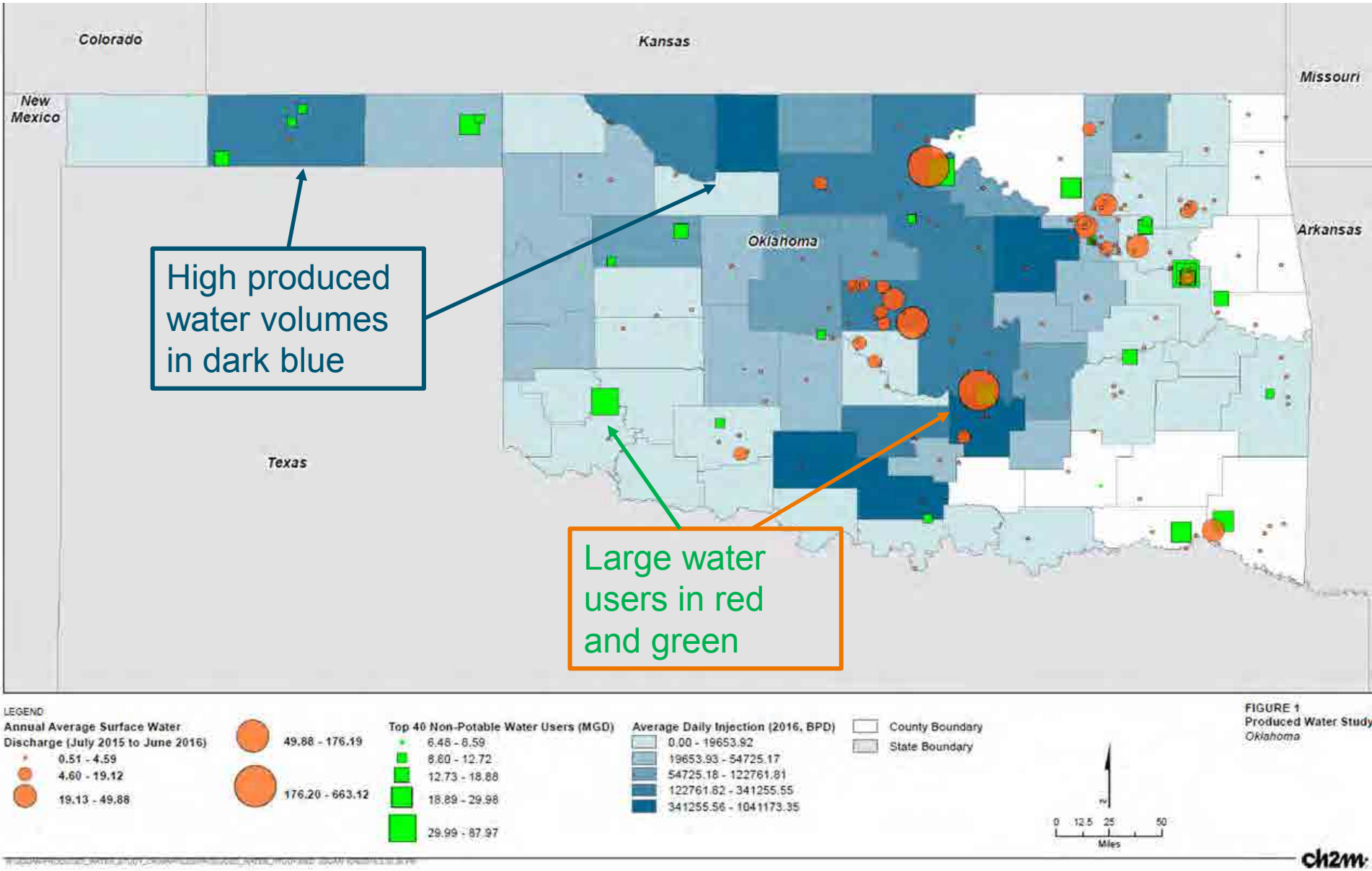
Miles

FIGURE X
Water Users
Produced Water Study
Oklahoma

W:\JQUAN\PRODUCED_WATER_STUDY_OK\MAPFILES\WATER_USERS.MXD JQUAN 10/7/2016 1:34:09 PM

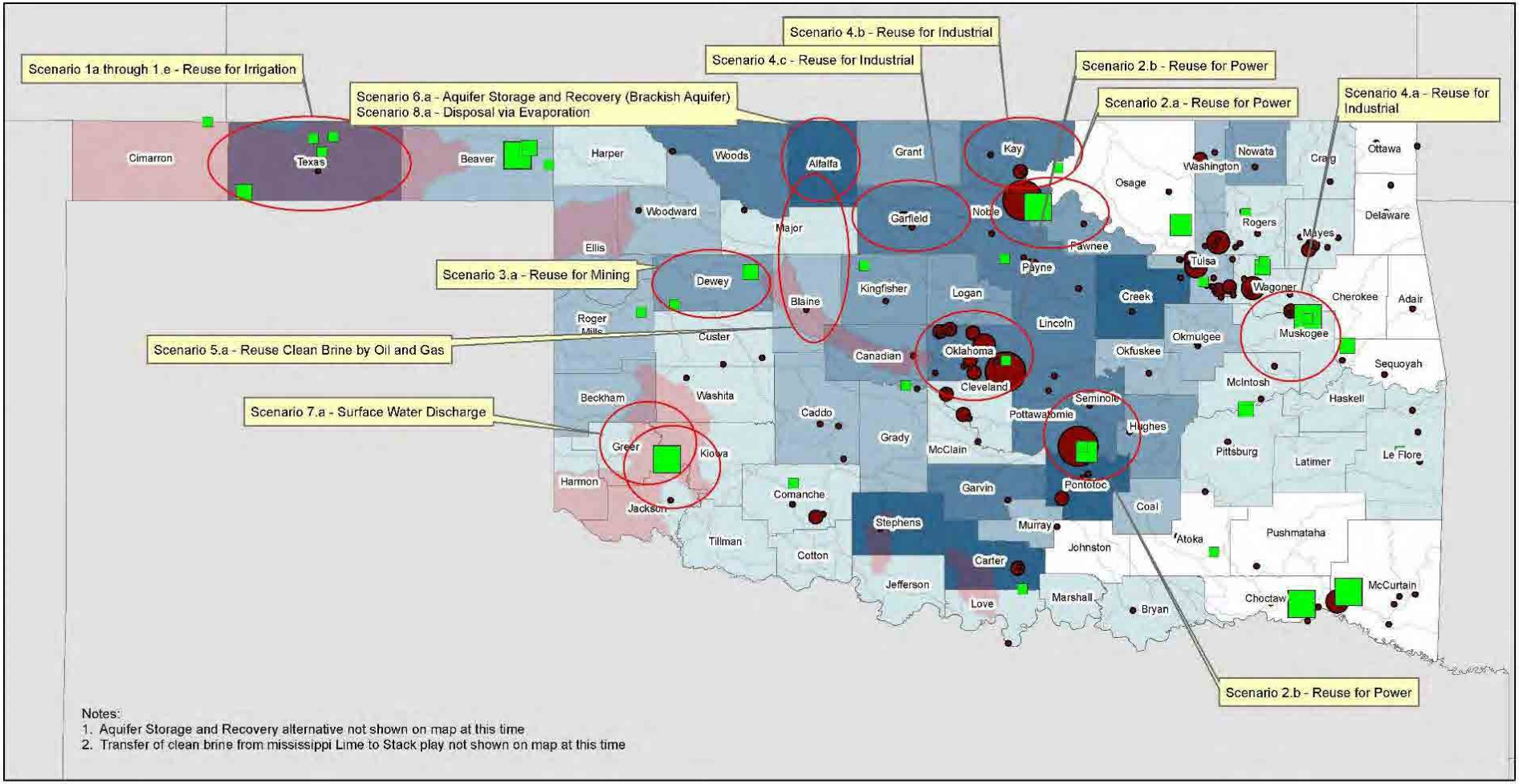
ch2m

Preliminary Matches of PW & Water Users



Data from ODEQ and OCC.

Preliminary Matches of PW & Water Users



LEGEND

Average Daily Injection (2016, BPD)
- 0 - 19654
- 19655 - 54725
- 54726 - 122762
- 122763 - 341256
- 341257 - 1041173
- County Boundary
- State Boundary

Top 40 Water Users (BPD)
- 425 - 150,000
- 150,001 - 300,000
- 300,001 - 450,000
- 450,001 - 600,000
- 600,001 - 2,094,503

Annual Average Surface Water Discharge (BPD) June 2015 to July 2016
- 12,159 - 100,000
- 100,001 - 450,000
- 450,001 - 1,200,000
- 1,200,001 - 4,000,000
- 4,000,001 - 15,788,506

OCWP Water Plan Basins
- OCWP Basins
- OCWP Hot Spot Basins

N

0 12.5 25 50
Miles

FIGURE 1
Overview - Produced Water versus Water Users
Produced Water Study
Oklahoma

Screening Matrix

Scenario	Water Use	County	Potential User(s)	Volume Needed (BPD)	Volume Produced in County (BPD)	Match Supply and Demand	Located in OCWP Hot Spot Basin	Year Around User	Treatment Required	Regulatory Challenges
1.a	Irrigation	Texas	Heimsoth Partners	217,739	149,403	X	X		X	X
1.b		Texas	Russell Family Partnership	449,499	149,403	X	X		X	X
1.c		Texas	Fischer Family Farms LP	227,681	149,403	X	X		X	X
1.d		Texas	Stephens Land & Cattle Co Inc	195,477	149,403	X	X		X	X
1.e		Texas	Chemical Spray for Agriculture/Irrigation	<10,000[2]	149,403		X		X	X
2.a	Power	Pawnee	Oklahoma Gas and Electric Company	1,550,729	93,787			X	X	X
2.b		Oklahoma	Oklahoma Gas and Electric Company	203,617	191,323	X		X	X	X
2.c		Seminole	Oklahoma Gas and Electric Company	743,499	329,065	X		X	X	X
3.a	Mining	Dewey	Kauk Mike and LaDena	223,199	122,762	X		TBD	X	X
4.a	Industrial	Muskogee	Georgia-Pacific Consumer Products	752,741	4,108			X	X	X
4.b		Kay	Phillips Refinery	131,748	173,719	X		X	X	X
4.c		Garfield	Koch (Chemical Manufacturing)[3]	10,000,000	146,793			X	X	X
5.a	Oil and Gas	Alfalfa to Blaine	Transfer Produced Water	250,000	600,560	X	X	X	X	X
6.a	Oil and Gas or Other?	Alfalfa	Aquifer Storage and Recovery - in Saline Aquifer	TBD	600,560	X		X	X	X
7.a	Surface Water Discharge	Beckham	Irrigation - Lugert-Altus Irrigation District	1,819,025	22,323		X	X	X	X
8.a	Evaporation	Alfalfa	None	NA	600,560	X		X		

*Uses highlighted have been shortlisted for further evaluation; assume one from “Power” and one from “Industrial” will be selected based on water quality.

Scenario 1: Irrigation and Chemical Spray

- Not feasible due to seasonal demands for irrigation and small volume of water required for chemical spraying.

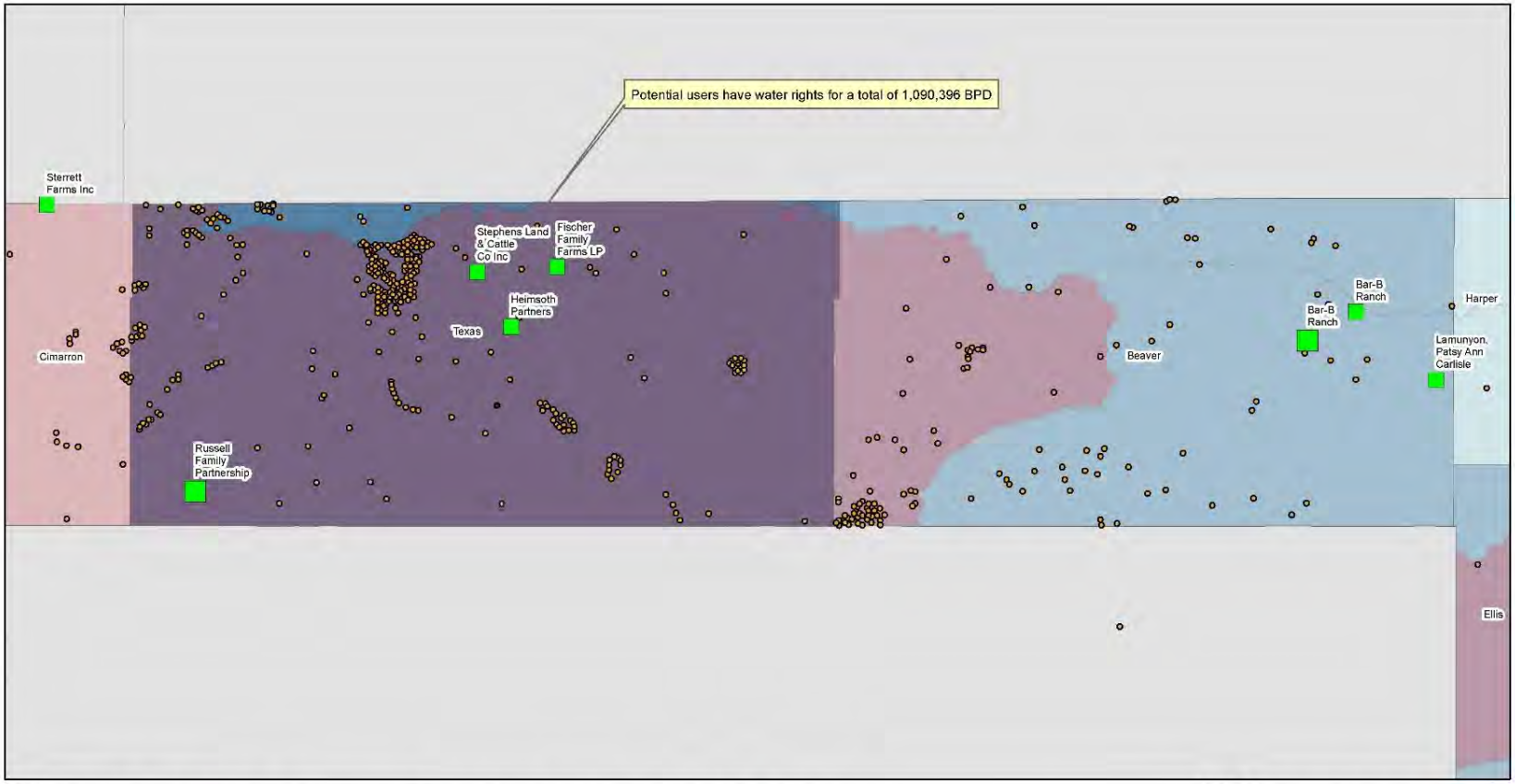
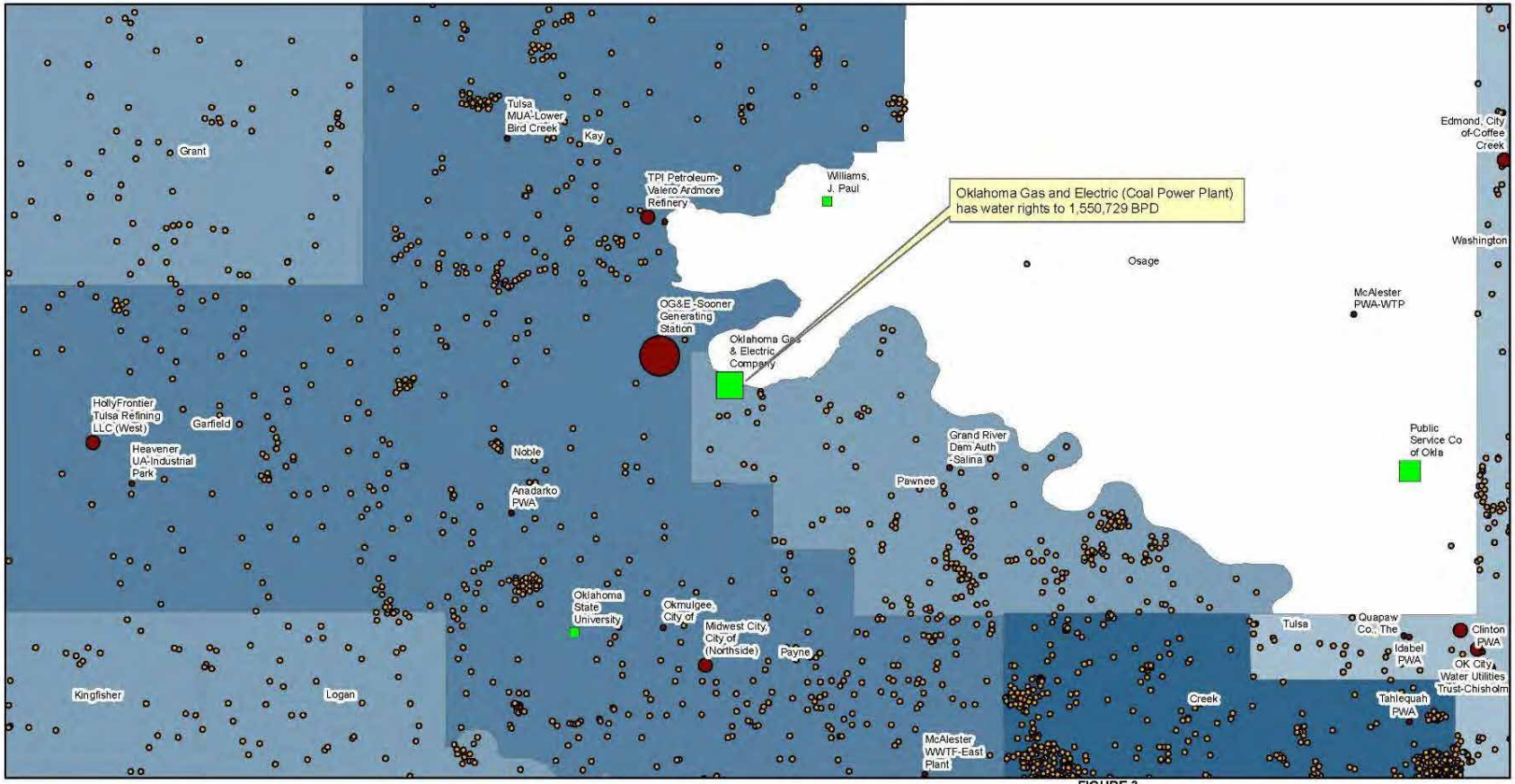


FIGURE 2
Scenario 1.a through 1.e - Produced Water Reuse f
Texas County
Produced Water Study
Oklahoma

Scenario 2.a: Power (Coal Power Plant)

- One alternative match between power plant water demands and an area of high produced water.



LEGEND

Average Daily Injection (2016, BPD)
- 0 - 19654
- 19655 - 54725
- 54726 - 122762
- 122763 - 341256
- 341257 - 1041173

- Injection Wells December 2015
- County Boundary
- State Boundary

Top 40 Water Users (BPD)
- 425 - 150,000
- 150,001 - 300,000
- 300,001 - 450,000
- 450,001 - 600,000
- 600,001 - 2,094,503

Annual Average Surface Water Discharge (BPD) June 2015 to July 2016
- 12,159 - 100,000
- 100,001 - 450,000
- 450,001 - 1,200,000
- 1,200,001 - 4,000,000
- 4,000,001 - 15,788,506

N

0 12.5 25
Miles

FIGURE 3
Scenario 2.a - Produced Water Reuse for Coal Processing Power Plant
Produced Water Study
Oklahoma

Scenario 2.b: Power (Coal Power Plant)

- Second alternative match between power plant water demands and an area of high produced water.

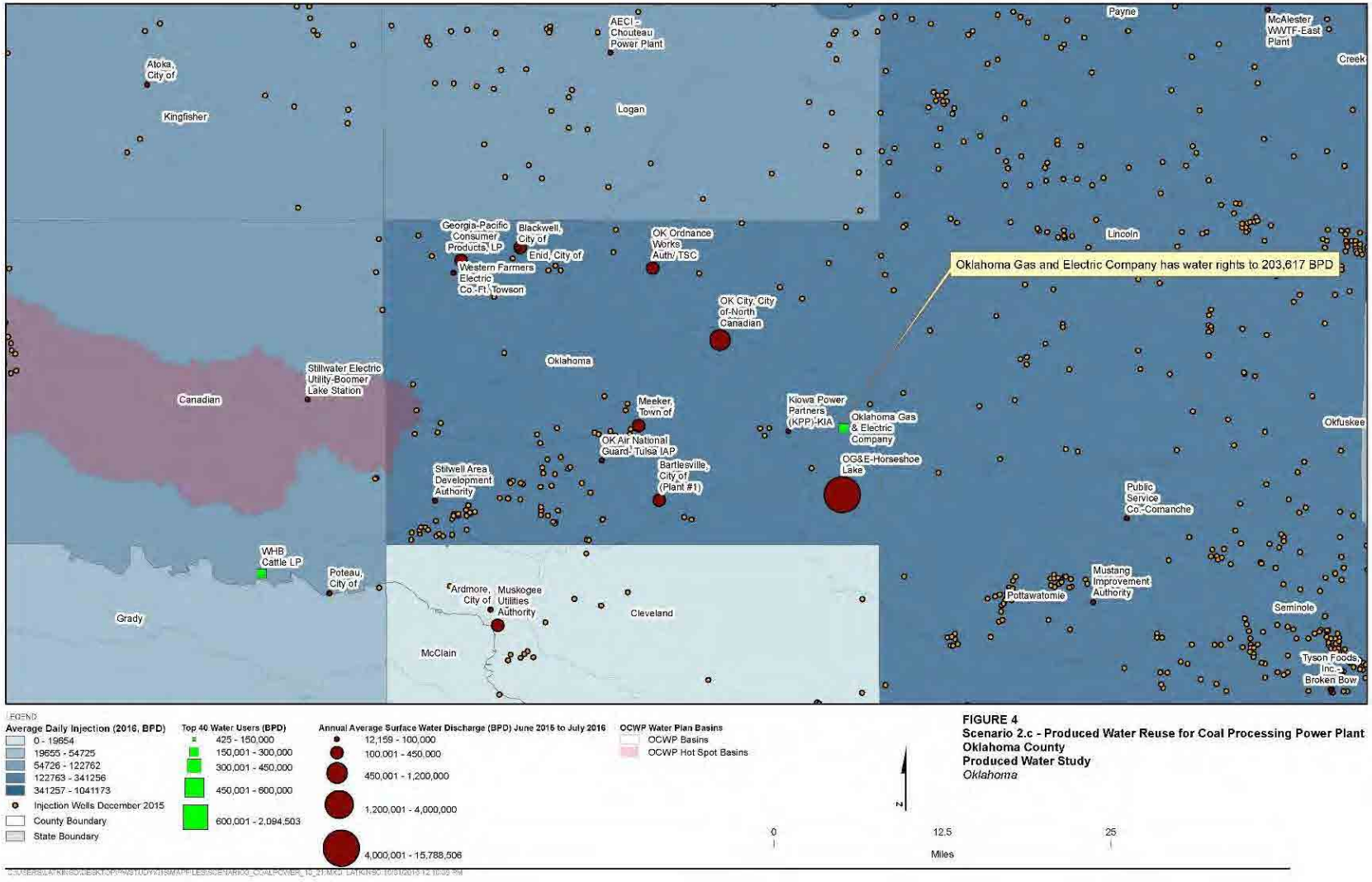


FIGURE 4
Scenario 2.c - Produced Water Reuse for Coal Processing Power Plant
Oklahoma County
Produced Water Study
Oklahoma

Scenario 2.c: Power (Coal Power Plant)

- Third alternative match between power plant water demands and an area of high produced water.
- Assume one of the three power plant alternatives will be further evaluated based on produced water quality data, etc.

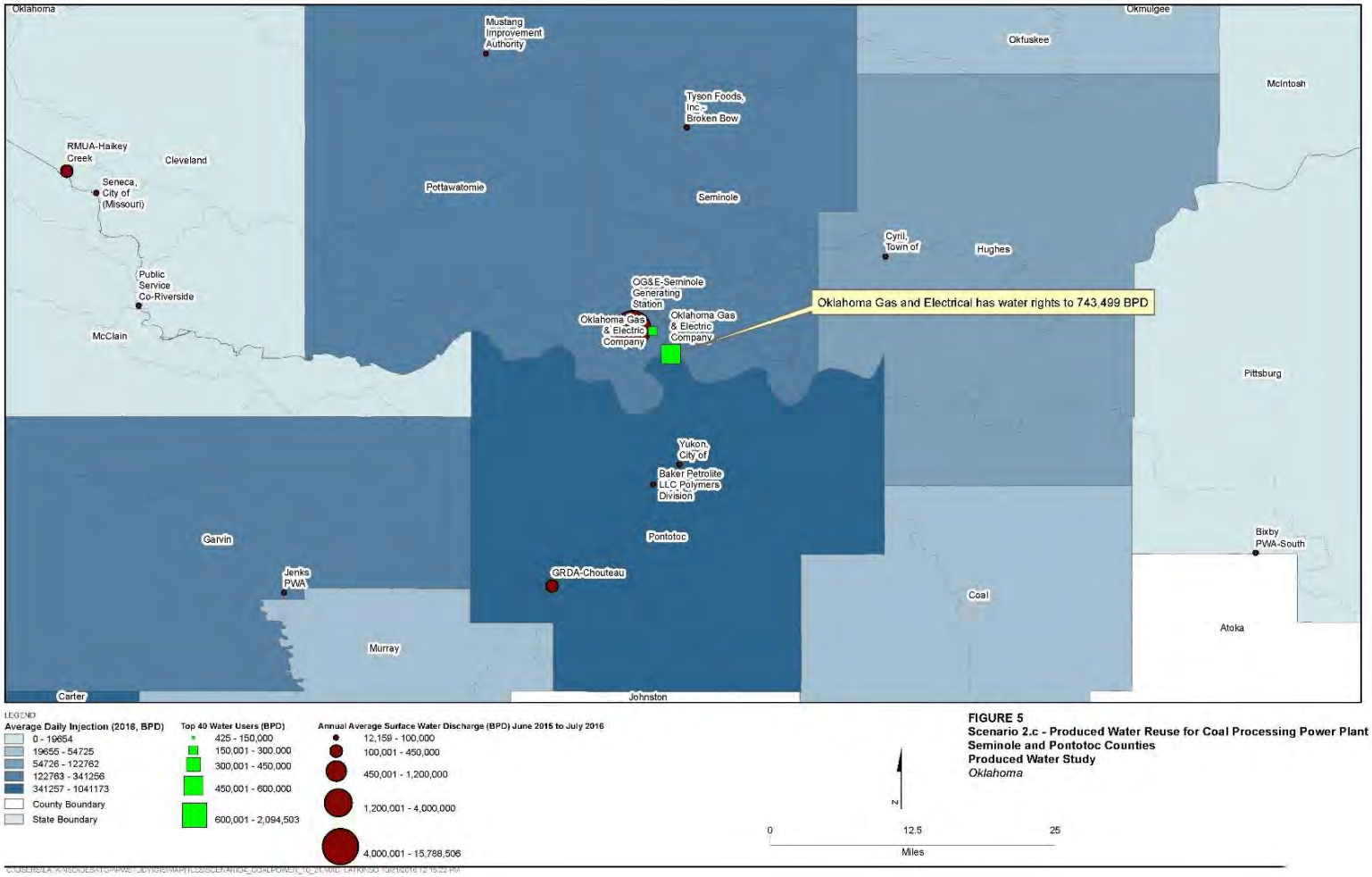


FIGURE 5
Scenario 2.c - Produced Water Reuse for Coal Processing Power Plant
Seminole and Pontotoc Counties
Produced Water Study
Oklahoma

Scenario 3.a: Mining

- Further evaluation is required to determine seasonality of water demands, water quality requirements, etc.

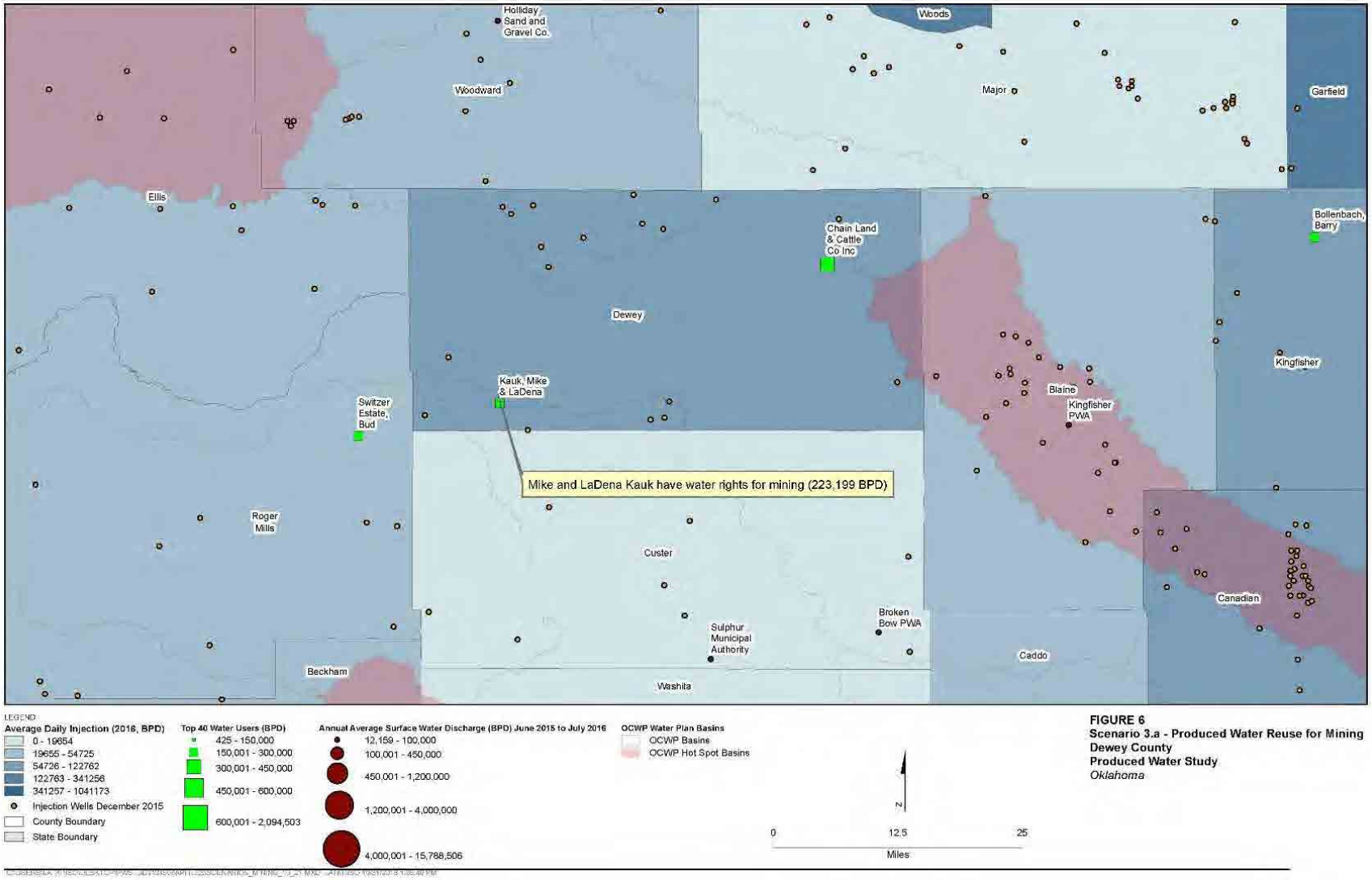


FIGURE 6
Scenario 3.a - Produced Water Reuse for Mining
Dewey County
Produced Water Study
Oklahoma

Scenario 4.a: Industrial (Consumer Products)

- One alternative match between an Industrial user who manufactures consumer products such as tissues and an area of high produced water.
- Further evaluation is required to determine seasonality of water demands, water quality requirements, etc.

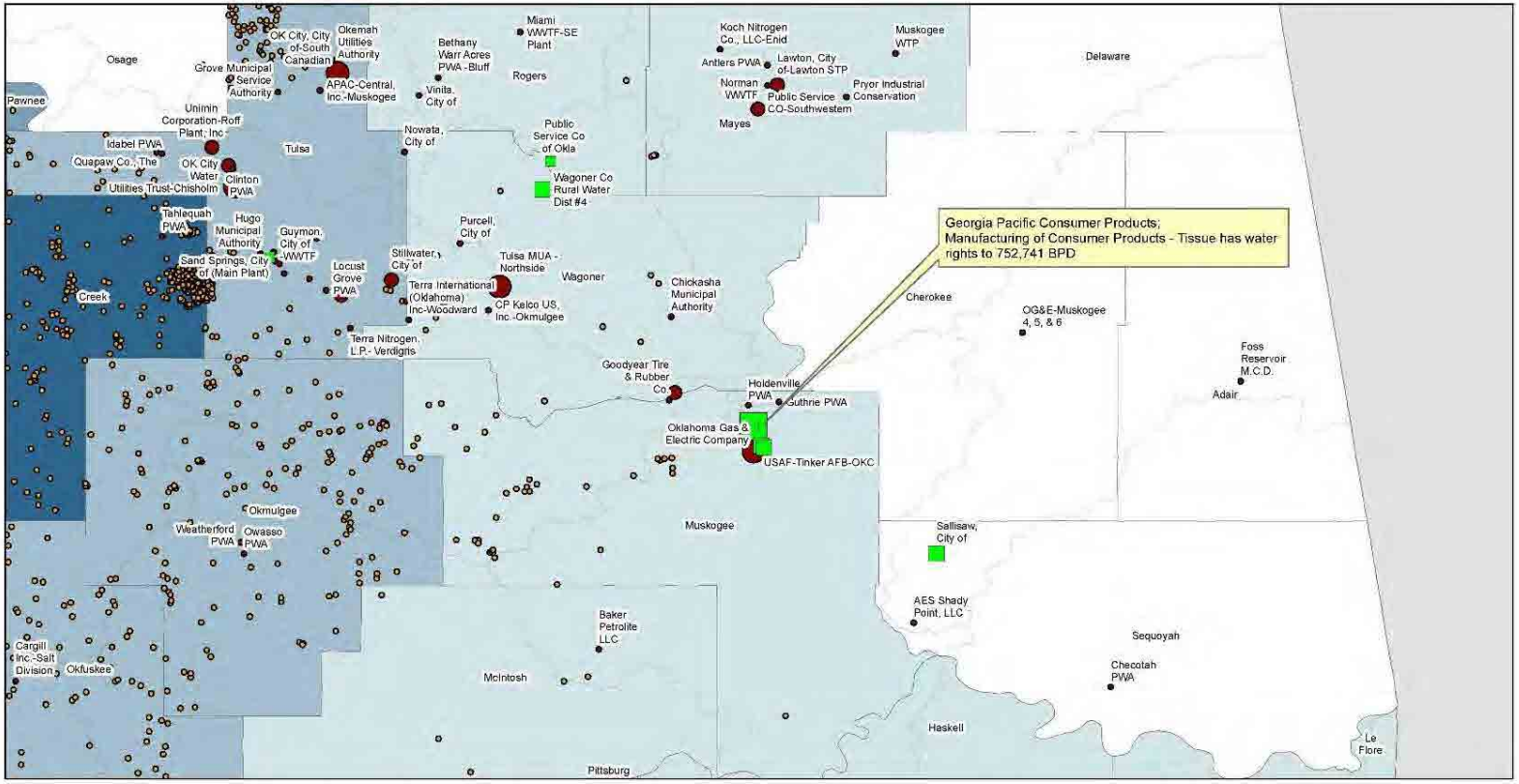
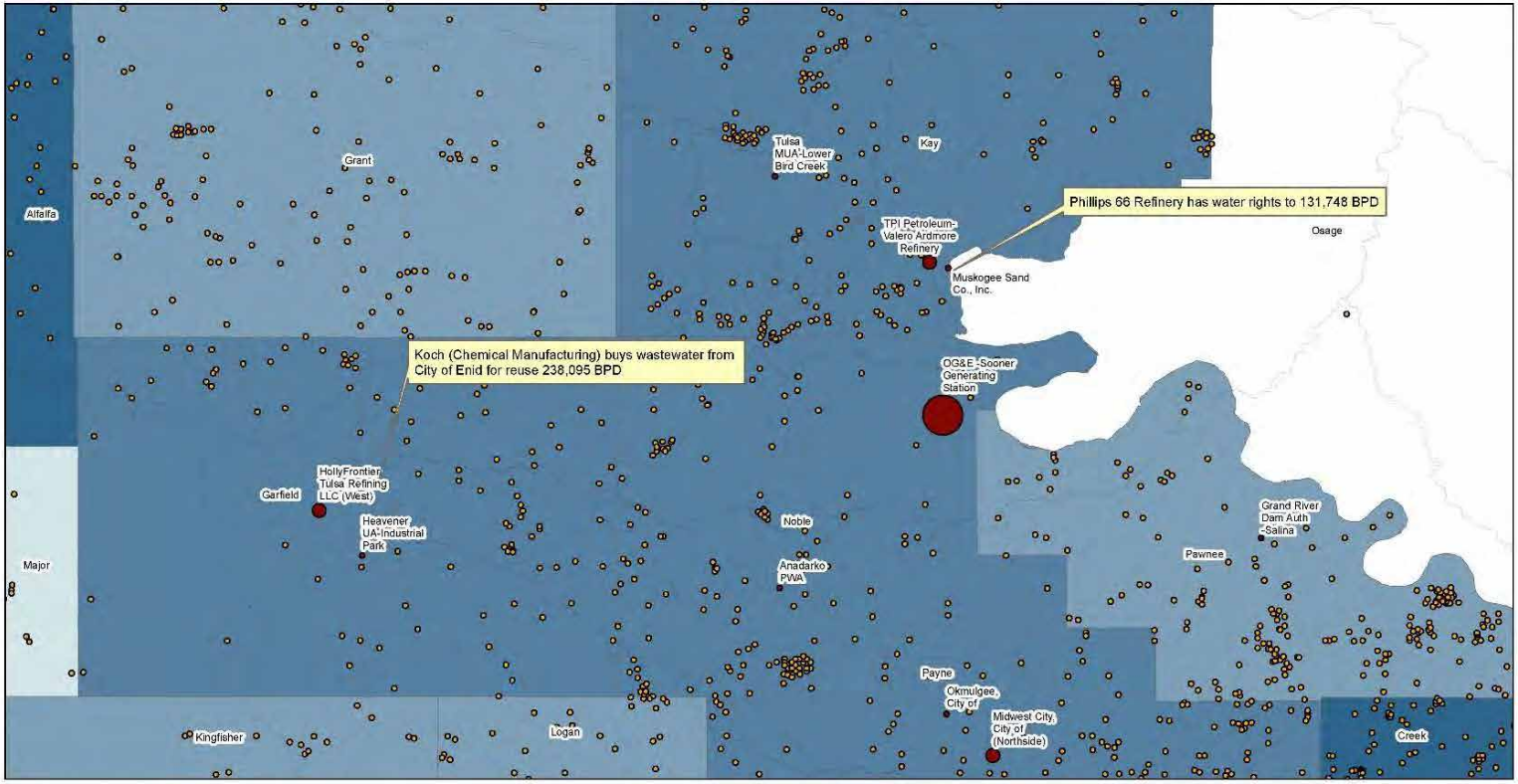


FIGURE 7
Scenario 4.a - Produced Water Reuse for Industrial
Muskogee County
Produced Water Study
Oklahoma

Scenario 4.b and 4.c: Industrial (Refinery and Chemical Manufacturing)

- Two additional alternative matches between an Industrial user – refinery and a chemical manufacturing plant.
- Further evaluation is required to determine seasonality of water demands, water quality requirements, etc.



LEGEND

Average Daily Injection (2016, BPD)
- 0 - 19654
- 19655 - 54725
- 54726 - 122762
- 122763 - 341256
- 341257 - 1041173

Injection Wells December 2015
- County Boundary
- State Boundary

Top 40 Water Users (BPD)
- 154,329 - 150,000
- 150,001 - 300,000
- 300,001 - 450,000
- 450,001 - 600,000
- 600,001 - 2,094,503

Annual Average Surface Water Discharge (BPD) June 2015 to July 2016
- 12,159 - 100,000
- 100,001 - 450,000
- 450,001 - 1,200,000
- 1,200,001 - 4,000,000
- 4,000,001 - 15,788,506

0 12.5 25
Miles

FIGURE 8
Scenario 4.b and 4.c - Produced Water Reuse for Industria
Kay and Garfield Counties
Produced Water Study
Oklahoma

Scenario 5.a: Transfer Clean Brine for O/G

- Transfer clean brine from Mississippi Lime to Stack play for oil and gas use.

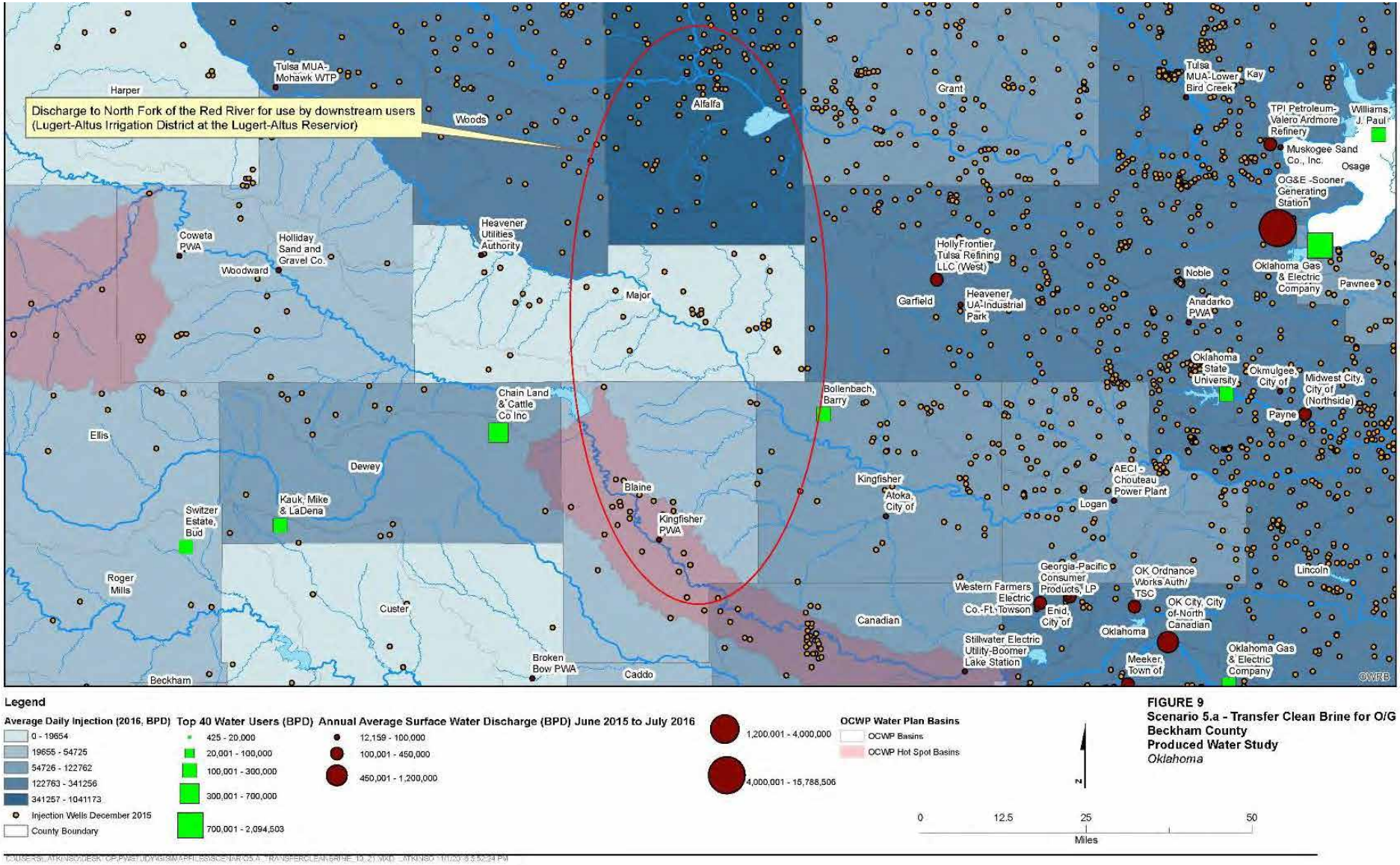


FIGURE 9
Scenario 5.a - Transfer Clean Brine for O/G
Beckham County
Produced Water Study
Oklahoma

Scenario 6.a: Aquifer Storage and Recovery

- Aquifer storage and recovery into a brackish aquifer.
- Higher chloride concentrations around Great Salt Plains Reservoir.
- May be a potential to improve native water quality and provide incentive for ASR.
- Target shallow depth to brackish water.

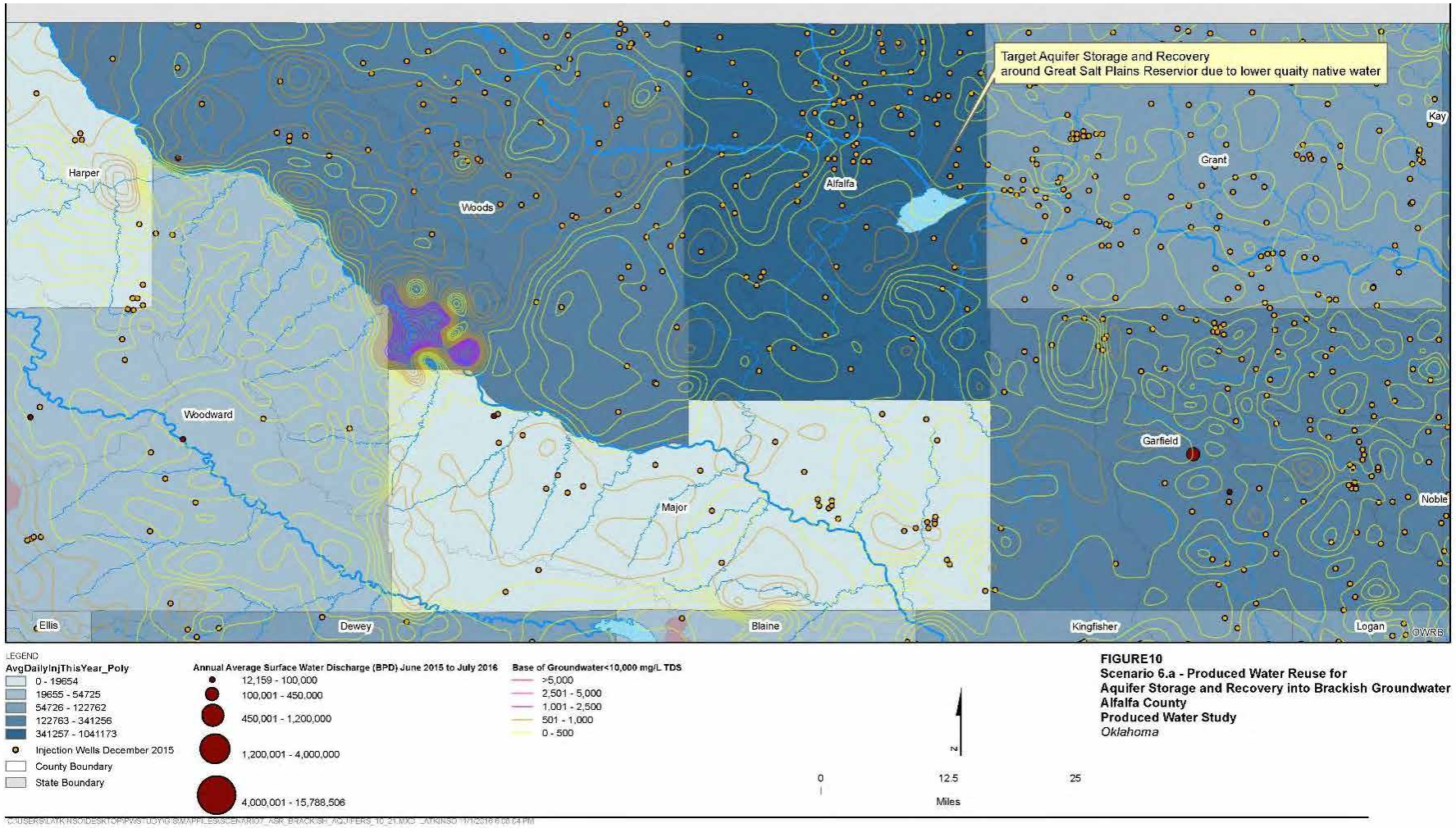
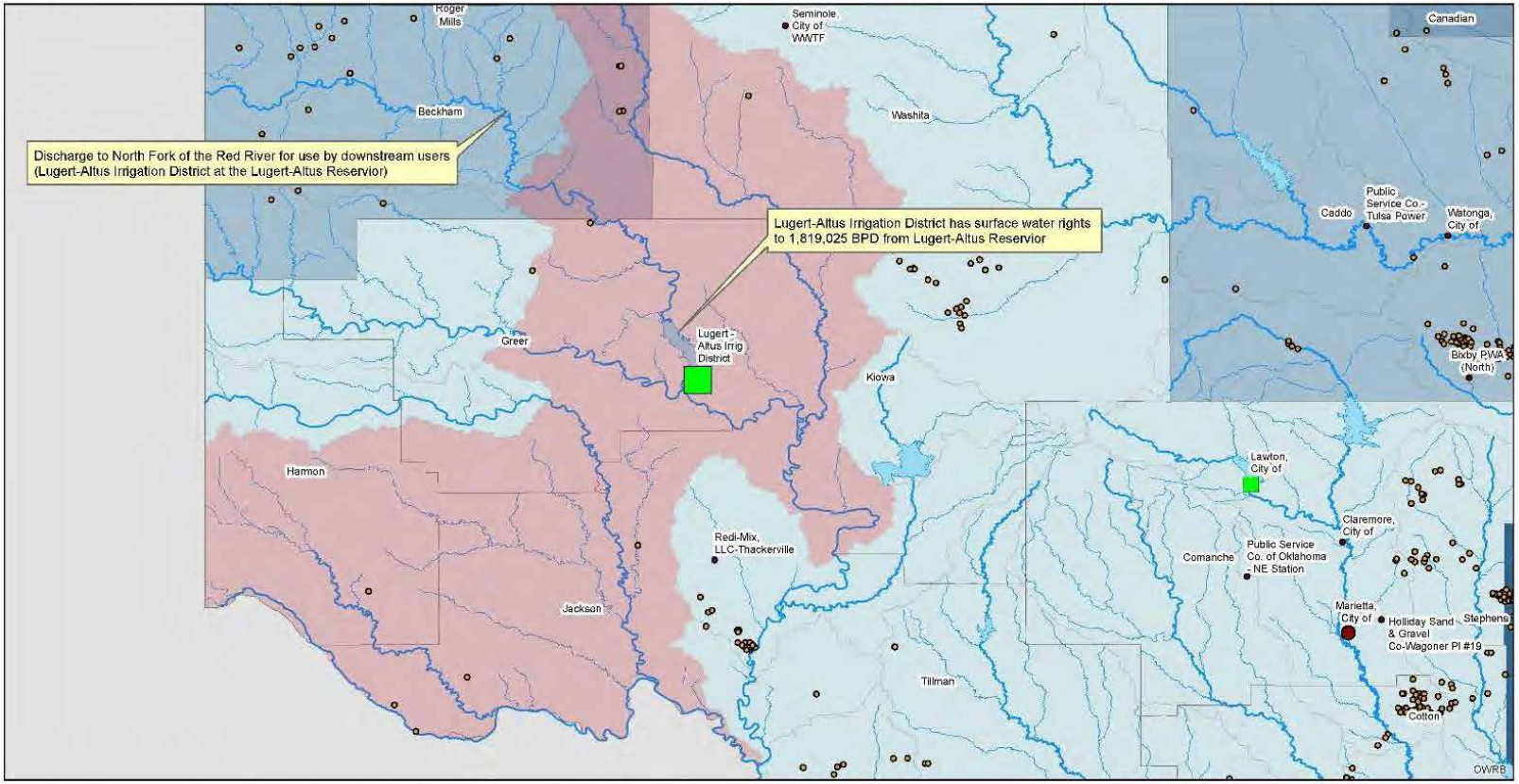


FIGURE10
Scenario 6.a - Produced Water Reuse for Aquifer Storage and Recovery into Brackish Groundwater
Alfalfa County
Produced Water Study
Oklahoma

Scenario 7.a: Surface Water Discharge

- Target hot spot basin.
- Discharge into North Fork of the Red River in Beckham County due to higher produced water volumes.
- North Fork of the Red River supplies the Lugert-Altus Irrigation District Reservoir.



LEGEND

Average Daily Injection (2016, BPD)
- 0 - 19654
- 19655 - 54725
- 54726 - 122762
- 122763 - 341256
- 341257 - 1041173
- Injection Wells December 2015
- County Boundary
- State Boundary

Top 40 Water Users (BPD)
Total_Pe_2
- 425 - 20,000
- 20,001 - 100,000
- 100,001 - 300,000
- 300,001 - 700,000
- 700,001 - 2,094,503

Annual Average Surface Water Discharge (BPD) June 2015 to July 2016
- 12,159 - 100,000
- 100,001 - 450,000
- 450,001 - 1,200,000
- 1,200,001 - 4,000,000
- 4,000,001 - 15,788,506

OCWP Water Plan Basins
- OCWP Basins
- OCWP Hot Spot Basins

N

0 12.5 25 50
Miles

FIGURE 11
Scenario 7.a - Surface Water Discharge
Beckham County
Produced Water Study
Oklahoma

Scenario 8.a: Evaporation

- Evaporation ponds in Alfalfa County due to high volume of produced water and vicinity to oil and gas activity
- Current produced water estimates 600,560 BPD.

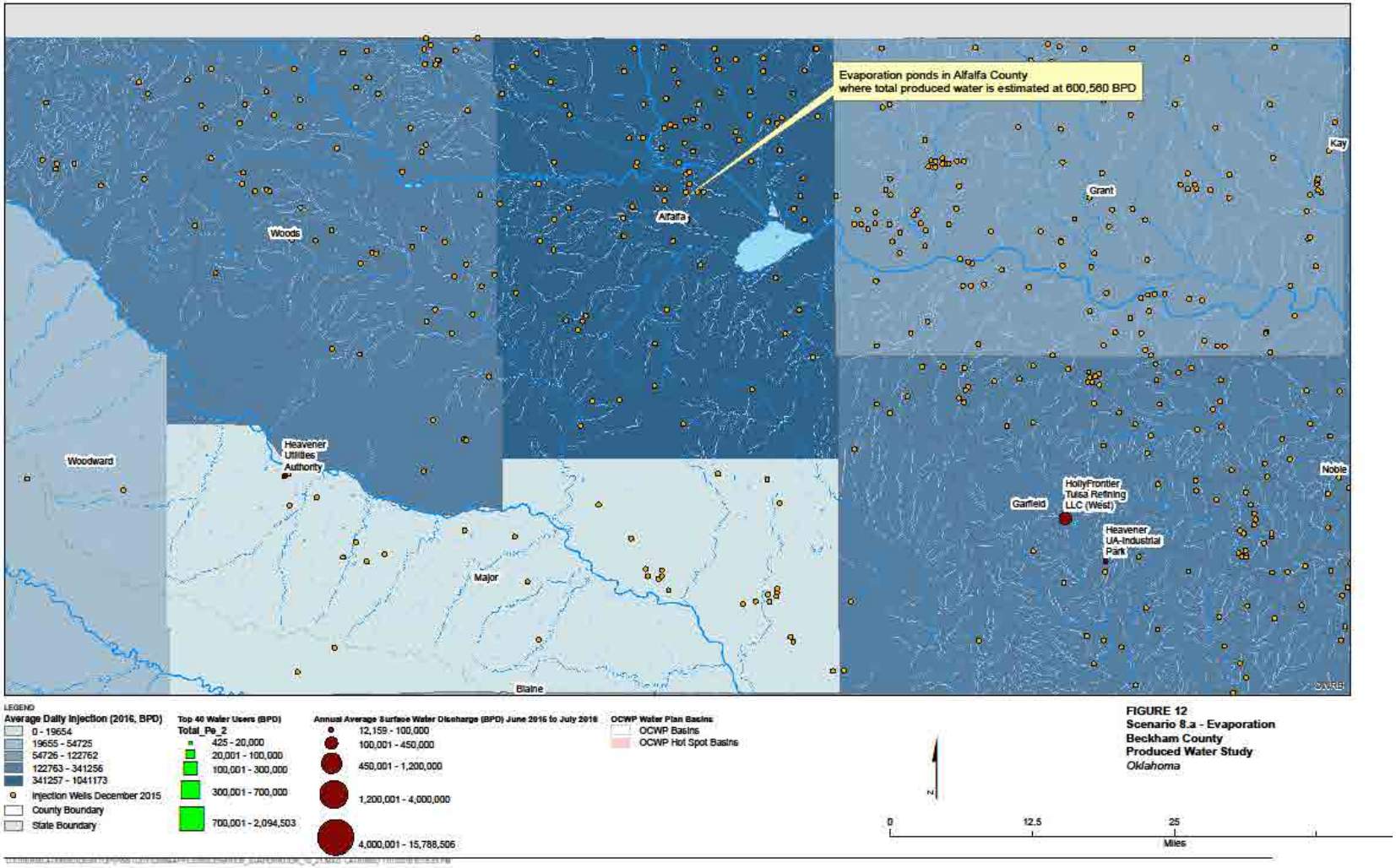


FIGURE 12
Scenario 8.a - Evaporation
Beckham County
Produced Water Study
Oklahoma

Next Steps - Timing

1. Produced water quality is crucial
2. Water treatment cost estimates
3. Cost estimates of economic scenarios
4. Review of economic conclusions
   A. Next meeting in mid-December or January?
   B. Phone meeting?
5. Review of draft report (February?)

Thank You

ch2m SM

Water for 2060
Produced Water Working Group

August 29, 2016

2:00 p.m.

Oklahoma Water Resources Board

3800 N. Classen Boulevard, Oklahoma City, OK

1. **Welcome and Introduction of Workgroup Members** — **J.D. Strong, Chairman**
   a. Overview of Second Meeting — (10 minutes)

2. **Re-use/Recycling Study Kickoff and Discussion** — **Michael Dunkel, CH2M**
   a. Coordination of work (establish subcommittees)
   b. Water source data and water quality data
   c. Identify water users
   d. Water treatment
   e. Economics
   f. Timing
   (50 minutes)

3. **Produced Water Survey of Other States** — **Saba Tahmassebi, Department of Environmental Quality** (20 minutes)

4. **Commercial Recycling Facilities** — **Tim Baker, Oklahoma Corporation Commission** (30 minutes)

5. **Next Steps** — **J.D. Strong**
   a. Wrap-up, Future Workgroup Meeting — **Michael Dunkel** (10 minutes)

6. **Adjourn**

Produced Water Working Group

Meeting Summary of Third Meeting, 10:30 am August 29, 2016

OWRB Board Room, 3800 N. Classen Blvd., Oklahoma City, Oklahoma

---

ATTENDEES:

***Produced Water Group Members and representation (from Sign In and/or Introductions)*:**

J.D. Strong, OWRB, Chair
Tim Baker, OCC
Mike Dunkel, CH2M
Bud Ground, EFO
Mike Mathis, OP8A/Continental
Mike Ming, GE
Mike Paque, GWPC
Jim Reese, OK Secretary of Agriculture
Alan Riffel, OML
Jesse Sandlin, Devon/OKOGA
Terry Stowers, COSMO
Usha Turner, OG&E
Scott Thompson, DEQ

***OWRB Staff and Consultants*:**

Owen Mills, OWRB
Anna Childers, CH2M

Speakers:

Saba Tahmassebbi, ODEQ
Tim Baker, OCC

***Others*:**

Jared Boehs, Pure Water Services
Joyce Boyd, OK Corp Com
Jeff Everett, OG&E
Lloyd Kirk, DEQ
Nicole Sanders, EDF
Adam Shupe, Burns & McDonnell
Jana Slatton, OCC
Terry Stowers, COSMO
John Westerheich, GE OGTC
Dan Yates, GWPC

Introductions and Goals for Today

Mr. J.D. Strong, OWRB Executive Director and Produced Water Working Group (PWWG) Chairman, opened the meeting by welcoming the attendees, held introductions, provided a brief background of the Group's responsibilities and goals, and gave an overview of previous PWWG meetings held in March and June 2016. Mr. Michael Dunkel facilitated the meeting. He reviewed the agenda and logistics for the meeting, noting that the primary goal for today's meeting was to gain insights and ideas from PWWG regarding available data on produced water quality, volumes, production areas and potential end-users for the produced water.

Mr. Dunkel informed the PWWG that four subcommittee meetings would also be held. The four subcommittees include: 1) Agriculture; 2) Oil and Gas; 3) Water Users - Demand & Discharge, and 4) Regulatory, Legal and Challenges to reuse/recycling. The intent of forming these groups was to allow stakeholders to develop recommendations specific to their issues and better inform the PWWG study of their specific needs and concerns that should be considered.Mr. Strong emphasized that everyone was encouraged to join the subcommittee meetings if they had not already joined and would need to let Michael Dunkel know. The dates and times of the subcommittee meetings were as follows:

- Agriculture: August 30th at 8:30 am
- Oil and Gas: August 30th at 2:30 pm
- Water Users and Demand: August 31st at 10:30
- Regulatory, Legal and Other Challenges to use/recycling: August 31st at 2:20 pm

OWRB has a PWWGweb page providing the group with easy access to meeting notes and other information that might be of interest. The page maybe found at:
http://www.owrb.ok.gov/2060/pwwg.php

Information and Data Needs

Mr. Dunkel emphasized the importance of obtaining valid data to initiate the work. Mr. Dunkel informed the group Charles Lord at OCC had provided him with the Arbuckle water injection volumes and geospatial information for each well. Mr. Lord is working on extracting total injection volumes. Using the data, Mr. Dunkel had calculated the total disposal volumes by county.

In order for the study to find economic ways to use produced water for reuse and recycling, Mr. Dunkel summarized the key data categories and some criteria for the types of data that would be beneficial to the study. Scott Thompson highlighted that it would be important to characterize the data, capture what we do not know, and to assess data gaps. He also emphasized that established regulatory standards do not exist for all applications and those need to be addressed by detail analysis later on. The member from the general audience recommended to use GIS to demonstrate the reuse potential.

Mr. Dunkel Emphasized that identification of potential users of marginal quality waters was crucial to the study. Discussion ensuedas to how best to find such users. He also expressed the problem of a continually changing landscape to keeping water recycling viable

Water Quality

Source water (supply)

- WQ is crucial for determining both cost and relative waste stream volumes.
- Salinity generally ranges from 40,000 to 300,000 ppm TDS but commonly found at 100,000-200,000 ppm in some plays.
- The Study will characterize general WQ by county if possible with a target of one dozen samples .
- Oil & gas firms offered to share blind water analyses data. ?? (Maybe OCC?) has complete water analysis from the O&G companies.
- Action item is for the project team to prepare request letter to oil and gas associations. Each company will contribute data in a tabular format that will be aggregated by the association, preserving the identity of the contributing company.
- Group mentioned other metadata is important such as when the sample was taken relative to the life of the well, as water quality usually changes over the first weeks of production.

Water use sectors (demand)

- Subcommittees will explore this in-depth for agriculture and oil and gas

Water Availability and Needs

Source water (supply)

- Interested in those counties that produce the most water: Bigger volumes, lower cost.
- Per OCC data: Arbuckle injection approx. 68% of total water injected in the state. Mr. Dunkel is working on getting the rest.
- OGS has data that includes some analysis data per county (not per well-basis) volume of water injected.

Water use sectors (demand)

- Very important to identify potential users, those with who has major plans: e.g. industry, agriculture.
- OWRB has information on current self-supplied permitted water use and users.
- DEQ can identify potential water-users around the state via discharge permits. CH2M will work with DEQ to obtain the discharge permit data.
- Terry Stowers suggested that oil and gas reuse is preferential to recycling to another industry standard based on costs.
- Volume of produced water is so high that there is likely going to be more produced water than oil and gas can reuse for the foreseeable future.
- Power generation industry is the third largest user in the State and should be included in the Study analysis. Water quality is an essential consideration though.
- Water for 2060 (OWRB) final report has self-supplied water users by type; however, did not include individual industries that buy water from a municipality (e.g. Koch in Enid would not be included. Koch uses 5 mgd of Enid municipal waste water).

- Municipalities using non-potable water for irigation of parks or golf courses should be a viable option for this marginal quality water. \
- The idea of basin to basin produced water transfer for oil and gas reuse was discussed.
- Discussion on wastestream volumes and fate is a necessary consideration of any reuse/recycle program. Must consider receiving and discharging water quality.

Water Treatment Technologies

- No separate water treatment subcommittee set up.
- OWRB has received a lot of solicitations from many companies wanting to promote their product. After analyzing the source and user data, the project team will define scenarios for estimating water treatment costs.
- A number of members said that water treatment is complicated by the number of companies operating in this area.
- Mike Paque said that North Dakota hopes to establish a web site that has vetted water treatment companies.
- Mike Ming suggested that water treatment should be done after the baseline data have been gathered. Risk assessment need to be completed fist: need to address legal and regulatory issues. Need to consider what treatment options are available and needed.
- Michael Dunkel reminded of the current task to assess how Oklahoma can reuse produced water most effectively.

Economics

- The cost estimates should be developed for the most viable scenarios for non-oil and gas industries.
- The goal is to develop preliminary cost estimates and cost scenarios: maybe less than dozen will be developed.
- Risk and risk mitigation will be included for qualifying different scenarios (e.g. regulatory analysis).

Timing

- The project team reminded the group about the aggressive schedule for the project: the final report is targeted for the kick off of the OK legislative season in Feb. 2017.

Presentations:

Next, invited speakers provided presentations on produced water management and treatment.

Saba Tahmassebi, Oklahoma Department of Environmental Quality, gave a PowerPoint presentation on ODEQ"s Produced Water Management Survey of 26 States. The presentation emphasized the significance of the 98th Meridian where no discharge east of the line is allowed. The summary highlighted the various method of managing produced water. In addition, the study developed recommendations to help promote produced water reuse/recycling. It also identified possible next steps, including identification of potential reuse options ("Fit for use" –criteria); how to develop standards for intended use; identify obstacles regarding water rights/ownership/recommend actions (regulatory, statutory) to address obstacles, and work with federal agencies / counterparts in addressing produced regulatory issues. The PowerPoint presentation accessible on the OWRB's Produced Water Working Group website: http://www.owrb.ok.gov/2060/pwwg.php

Tim Baker, Oklahoma Corporation Commission, provided an overview about commercial recycling facilities classification and requirements. Commercial recycling was identified as a regulatory challenge by a few producing companies. Additional information is included in the PowerPoint presentation available on OWRB's website: http://www.owrb.ok.gov/2060/pwwg.php

The speakers each answered questions from the PWWG and other meeting participants through the course of their presentations.

Action Items and Next Steps

Michael Dunkel will be contacting some PWWG members individually on data needs and share the meeting summaries and reports with the PWWG members and their representatives. Mr. Strong encouraged the PWWG for an early brainstorming of ideas and recommendations that they want to champion for. One group member suggested to use the policy, regulatory and legal recommendations to guide some the findings outlined in Mr. Tahmasebbi's presentation.

To sum up actions to be taken by the staff:

1. Set up next meeting using Doodle-Poll
2. Post all meeting items in PWWG website (OWRB's website)
3. Distribute meeting summaries for the PWWG for review
4. Data items:
    a. Water Quality Data: Letters from OWRB/CH2M to industry groups will be prepared, including formatted table for input
    b. Water Well Production: Expect to get additional data from OCC and/or Kyle Murray
    c. Water users information: OWRB will provide water user information and identify water users and ODEQ
    d. CH2M will provide GIS data analyses of the produced water volumes, water quality and water users: and present the data to PWWG

Oklahoma Corporation Commission

Oil and Gas Conservation Division
Tim Baker
Director

Commercial Recycling

- OAC 165: 10-9-4 " Commercial Recycling Facilities"
- Definition: " A commercial recycling facility is a facility which is authorized by Commission order to recycle materials defined as "deleterious substance"… Such substances must undergo at least one treatment process and must be recycled into a marketable product for resale and/or have some beneficial use.

Commercial Recycling Requirements

- Owner of the land for the site.
- Test borings
- Topographic maps / soil surveys
- Site construction drawings
- Closure Plan:

  Reclamation Costs

  Volume and fate of disposal of any wastes

  Post closure monitoring plan

  Post closure monitoring plan

Commercial Facilities Public Notice

- Publication in the Co. in which the facility is located and in OK Co.
- Two publications required in both Counties.
- Minimum 30 day comment/protest period from last date of publication.

Commercial Facilities Site Restrictions

- 100 yr. flood plain.
- Strip pits, abandoned mines, rock quarries.
- Within one mile of a public water supply well or Wellhead protection area.

Commercial Facilities Site Restrictions

- Facilities with pits larger than 50,000 bbls. are restricted:

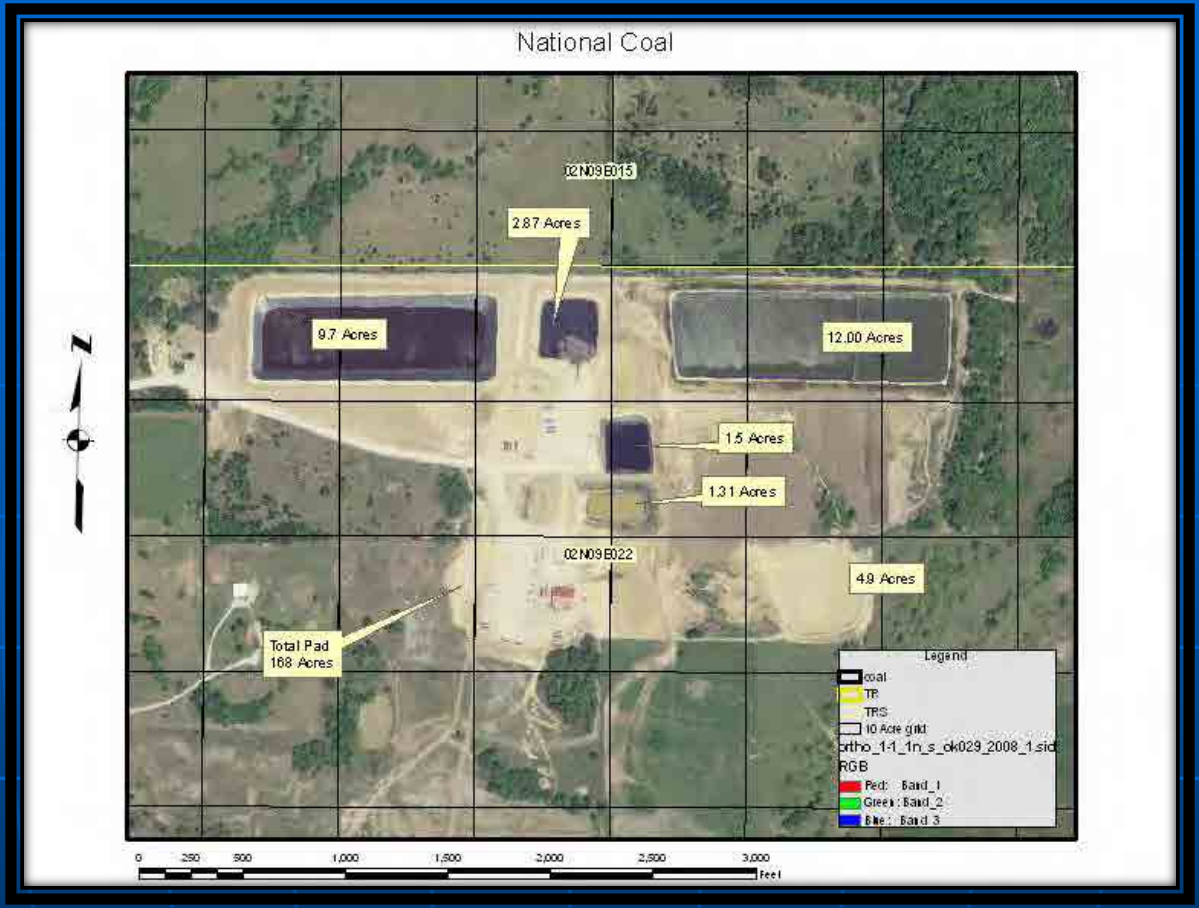
Incorporated municipalities with populations:

1. Greater than 20,000 minimum 5 miles.
2. Populations less than 20,000 minimum 3 miles.

Commercial Recycling

- Bonding

The amount of the bond shall be established based upon the Commission's estimates of closure, which includes trucking costs, post closure monitoring, plugging of monitor wells, etc.



Commercial Water Recycling Facility

National Coal Facility

Commercial Recycling

- National Coal
- Permitted 2006 under existing "Commercial Rules"
- Recycled over 8,000,000 bbls. – 336,000,000 gals. water.
- Currently being converted to mud disposal.

Noncommercial Recycling

- “Recycling Pit” “..a pit that is used for the recycling or reuse of deleterious substances, is located off-site, and is operated by the generator of the waste.
- Note: “Off Site” is interpreted to mean off of the drilling location.

Noncommercial Recycling

- Construction Requirements are the same.
- Notice requirements are less stringent.
- The rules have changed to allow multiple operators to use the same facility.
- Eight facilities have been approved.

Commercial Recycling Facilities

Tim Baker

Oil and Gas Conservation Division

PRODUCED WATER MANAGEMENT SURVEY OF STATES

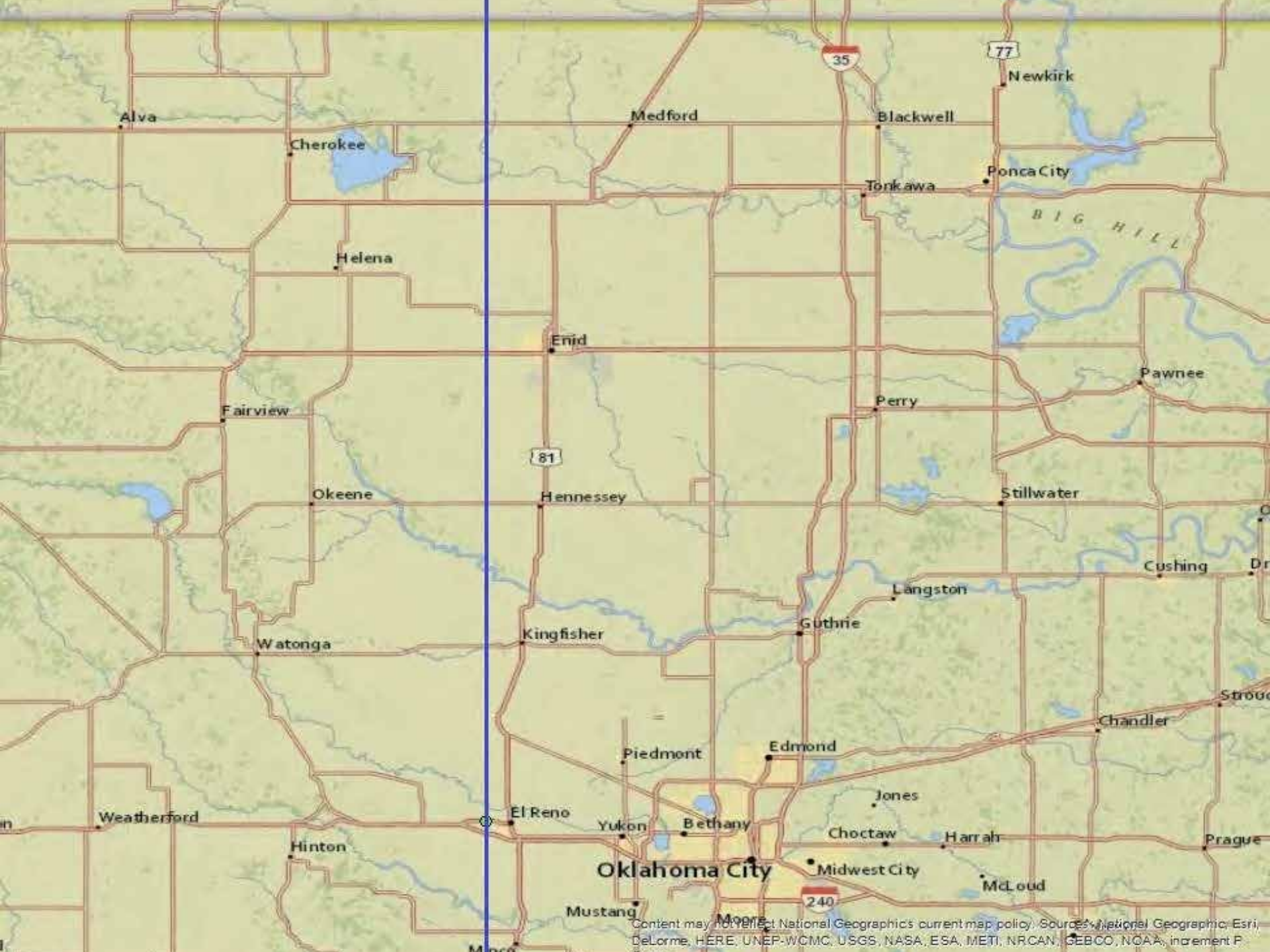
Produced Water Working Group - Aug 29, 2016

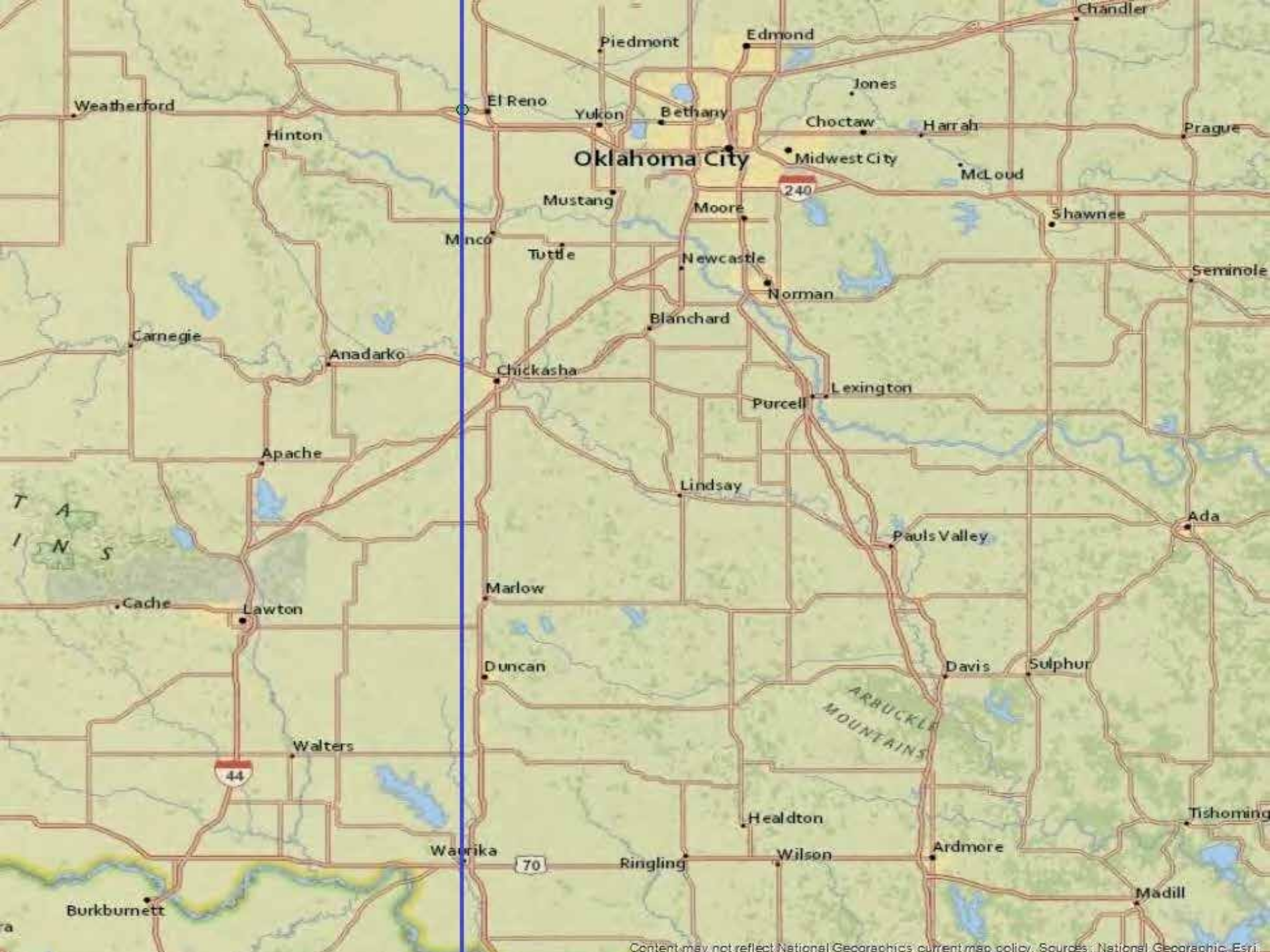
26 States Contacted

- Alaska
- Arkansas
- California
- Colorado
- Idaho
- Illinois
- Indiana
- Kansas
- Kentucky
- Louisiana
- Michigan
- Mississippi
- Missouri
- Montana
- Nebraska
- New Mexico
- North Dakota
- Ohio
- Oklahoma
- Pennsylvania
- South Dakota
- Tennessee
- Texas
- Utah
- Virginia
- Wyoming

98TH Meridian

Source: www.permaculturemarin.org (modified), retrieved from bing.com/images


35
77
Newkirk
Alva
Medford
Blackwell
Cherokee
Ponca City
Tonkawa
BIG HILL
Helena
Enid
Pawnee
Fairview
Perry
81
Okeene
Hennessey
Stillwater
Cushing
Langston
Guthrie
Kingfisher
Watonga
Chandler
Edmond
Piedmont
Jones
Weatherford
El Reno
Yukon
Bethany
Choctaw
Harrah
Prague
Hinton
Oklahoma City
Midwest City
McLoud
240
Mustang
Content may not reflect National Geographic's current map policy. Sources: National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P



Content may not reflect National Geographics current map policy. Sources: National Geographic, Esri

Section I: Discharge

1. How is produced water managed in your state? (e.g., deep well injection, discharge, reuse, etc.)

2. Do you allow direct discharge of treated produced water?

3. Is produced water discharged indirectly through a Publicly Owned Treatment Works (POTW)?

4. How are water rights/ownership addressed for the treated produced water in your area?

   - Property owner has rights/ownership; mineral owner; operator, state

5. Is discharge pursuant to state authority or EPA?

   - State authority; EPA [40 CFR 435: Oil and Gas Extraction Point Source; 40 CFR 437: Centralized Waste Treatment]

6. Does your agency have additional requirements beyond what is required by federal regulations?

7. Is produced water discharged in areas of the state to benefit agriculture and/or wildlife?

8. Do you allow discharges East/West of the 98th Meridian?

9. What agency(s) have permitting authority for discharge of produced water?

10. Does your agency have monitoring requirements for discharge of produced water?

11. If your state permits discharge of produced water, what pollutants are regulated within the permits?

    - Hydrocarbons; Metals; Radionuclides; Minerals/Total Dissolved Solids (TDS); Toxic Organics/Toxic Inorganics; Whole Effluent Toxicity (WET); Other (please specify)

12. Approximately what volume fraction of the produced water is from unconventional activities? (e.g., fracking, horizontal drilling, etc.)

13. What technologies have been used in treating produced water in your state?

Section II: Deep Well Injection

14. Is deep well injection used to dispose of produced water in your state?

15. Is induced seismicity an issue in your state?

Section III: Reuse

16. Is produced water reused?

17. For what applications is produced water used? (e.g., industrial, agricultural, aquifer storage and recovery (ASR), etc.)

18. Does your agency have technical standards for reuse of produced water?

19. For applications other than E&P, after reuse, does the produced water retain its regulatory status as produced water?

20. After reuse does produced water get discharged?

Section IV: Radioactivity

21. Are there any considerations for dealing with radioactive produced water or treatment residuals?

- Section V: Contact Information

Summary of Responses

1. PW is managed by:
   - Deep well disposal/injection
   - Surface water discharge
   - Regional disposal facilities
   - Hauling to a CWT
   - Recycling
   - Reuse
   - Evaporation
   - Discharge overboard

2. Direct/Indirect discharge:
   - No state discharges east of the 98th (except per Part 437)
   - Some states discharge west of the 98th
   - Some states have permits for centralized waste treatment
   - Some states claim to indirectly discharge through a POTW

3. Water rights/ownership for the treated PW
   - In some states the property owner has rights/ownership
   - In some states the operator has rights/ownership
   - In MOST states water rights/ownership is unknown or not addressed

4. In some states, discharge/management is pursuant to state authority, in others EPA

5. Some states have monitoring requirements and limits beyond 40CFR. Monitoring parameters include:
   - Hydrocarbons, minerals/TDS, metals, radionuclides, whole effluent toxicity, toxic organics and inorganics

6. Other limits and parameters in state permits:
   - pH, DO, oil and grease, flow rate, total alkalinity, conductivity, chloride, sulfate, temperature, hardness, radium, strontium, thallium, beta radiation

7. Volume fraction of PW from unconventional activities ranges from <10% to >75%

8. Various technologies have been used for treating PW

9. Several states use deep well injection to dispose of PW

10. Induced seismicity is a concern for seven states

11. PW is reused in several states

    - EOR/water flood, Oil & Gas production operations/well stimulation, fracking, recharge, drilling fluid for oil/gas wells, beneficial reuse: dust suppression, ice control, livestock watering, agriculture/irrigation, wildlife, land farming

12. Some states have technical standards for reuse

13. PW retaining its regulatory status as produced water after reuse

    - Yes, No, Unknown

14. Discharging produced water after reuse

    - Yes, No, Unknown

15. In some states there are considerations for dealing with radioactive produced water or treatment residuals

    - Monitoring, effluent limits, limits based on reuse, disposal of residuals

Conclusions

- The survey generated detailed primary data from the responding states.
- The results could be used to help us chart some of our future activities.
- Based on the survey results, we may want to consider forming subcommittees to address the following areas.

Possible next steps for regulators

- Identify and remove regulatory/administrative obstacles for the reuse of PW in the field.
- Identify all possible reuse options. Recommend ways of developing a "fit for use" criteria. Recommend how PW standards may be developed for the intended reuse. Case-by-case basis?
- Identify obstacles regarding water rights/ownership. Recommend actions (regulatory, statutory) to address the obstacles.
- Work with federal counterparts to help define the regulatory status of PW after reuse.

Possible next steps…

- Work on easing federal regulatory obstacles for discharges east of the 98th (perhaps work with ECOS? Start with R6?)
- Work on removing the designated use restrictions for discharges west of the 98th.
- Seek NPDES delegation from EPA for the discharge of produced water.
- Recommend administrative ways of handling prospective NPDES applications by agencies.
- Come up with ideas for technology evaluations.

Questions – Feedback?

Water for 2060
Produced Water Working Group

June 7, 2016

1:30 p.m.

Oklahoma Water Resources Board

3800 N. Classen Boulevard, Oklahoma City, OK

1. Welcome and Introduction of Workgroup Members a. Responsibilities of the Workgroup b. Goals and Overall Timeline c. Overview of First Meeting	**J.D. Strong, Chairman** **OWRB**
2. Quantity and Quality of Produced Water in Oklahoma	**Kyle E. Murray** **OK Geological Survey**
3. Challenges of Recycling Produced Water in Oklahoma	**Lloyd Hetrick** **Newfield Exploration**
4. Proposed Scoping Evaluation and Funding Opportunities	**Michael Dunkel** **CH2M**
5. Next Steps a. Wrap-up b. Future Workgroup Meetings	**J.D. Strong**
6. Adjourn	

MEETING NOTES

WATER FOR 2060
PRODUCED WATER WORKING GROUP

Meeting #2
June 7, 2016
1:30 p.m.
Oklahoma Water Resources Board
3800 N. Classen Boulevard, Oklahoma City, OK 73118

J.D. Strong, Executive Director of the Oklahoma Water Resources Board, and Chairman of the Water for 2060 Produced Water Working Group (PWWG), welcomed the members and attendees to the first meeting of the Group. He stated Governor Fallin had announced establishment of the PWWG on December 1, 2015, and charged the Group with discussing opportunities and challenges associated with treating produced water for beneficial uses to save fresh water by reusing and recycling oil and gas produced water, particularly alternatives to deep well disposal.

Chairman Strong gave a short review of PWWG responsibilities, goals, expected timeline, and highlights of the previous meeting in March and presented an outline of what his office has been doing in the interim, specifically, developing with both the Oklahoma Office of the Secretary of Energy and the Environment and CH2M a study proposal for a federally funded grant to evaluate potential challenges and solutions to a statewide beneficial alternative to produced water disposal.

Members of the PWWG in attendance were: Bud Ground, Environmental Federation of Oklahoma; Jeff Everett (for Usha Turner), OG&E Energy Corporation; Jesse Sandlin, Oklahoma Oil & Gas Association; A.J. Ferate (for Mike Mathis), Oklahoma Independent Petroleum Association; Michael Dunkel, CH2M; Mike Ming, GE Global Research; Dan Yates (for Mike Paque), Groundwater Protection Council; Fred Fischer, Oklahoma Panhandle Agriculture & Irrigation Association; Tina Gunter (for Secretary of Agriculture Jim Reese); Tim Baker (for Tim Rhodes), Oklahoma Corporation Commission; Scott Thompson, Oklahoma Department of Environmental Quality; Brent Kisling, Enid Regional Development Alliance; Alan Riffel, Oklahoma Municipal League; Dr. Garey Fox, Oklahoma State University; and Terry Stowers, Coalition of Oklahoma Surface & Mineral Owners.

Kyle Murray, OGS, presented on his recent studies related to quantity and quality of and produced water. Some highlights from the presentation:

- Seismic activity is a little lower since the OCC cut back injection by 40% in some key areas.
- OGS is tracking disposal volumes to estimate produced water volumes geographically by county.
- The USGS has water quality data available, but it may be dated.
- Disposal well applications have water quality on the form, but this has yet to be captured in a database anywhere at the state.
- The average produced water (PW) TDS across OK is about 150,000 mg/l.
- Could more produced water be recycled for oil and gas EOR (Enhance oil recovery)?

* This presentation is on PWWG web page in PDF format.

Mr. Lloyd Hetrick, Newfield Exploration, presented on the challenges of recycling produced water in Oklahoma. Some highlights from the presentation:

- Newfield has designed their own recycling plant for Kingfisher County, but has put off plans to build it.
- Newfield wants to cooperatively share water facilities, transportation, and storage, with other operators and share water volumes for re-use. The next step is for the operators to gather and discuss a plan forward.
- Newfield thinks a coop is the best commercial model.
- Mr. Hetrick highlighted that regulatory structure creates substantive barriers to the coop concept, especially in areas of ownership/responsibility/liability.
- Mr. Hetrick highlighted the ownership issue of produced water and which led to a lengthy discussion involving the larger group.

Mr. Michael Dunkel, CH2M, presented his grant proposal to evaluate multiple scenarios for reuse solutions. Some highlights and comments from the presentation follow:

- Mike Ming from GE thought that a risk analyses should be included in the study as a deliverable.
- Discussion about potentially focusing on Oil and gas reuse as much as possible; Mr. Dunkel stated that Oil and Gas reuse is in the work plan; however, the non-oil and gas re-use has not been comprehensively studied previously and there is far more PW than oil and gas reuse can use.

* This presentation is on PWWG web page in PDF format.

Other group discussion that followed:

- Aquifer storage and water flooding was mentioned as a possible PW use.
- Scott Thompson from DEQ suggested setting up subcommittees to consider parameters for water quality analyses, and a second subcommittee about legal/regulatory issues.
- Chad Warmington from OKOGA suggested possibly getting research funds from OSU's NESI.

Chairman Strong concluded the meeting stating he anticipated the group would meet again this summer and he thanked everyone for their participation and attention.

OWRB Produced Water Group - Proposal to Evaluate Solutions

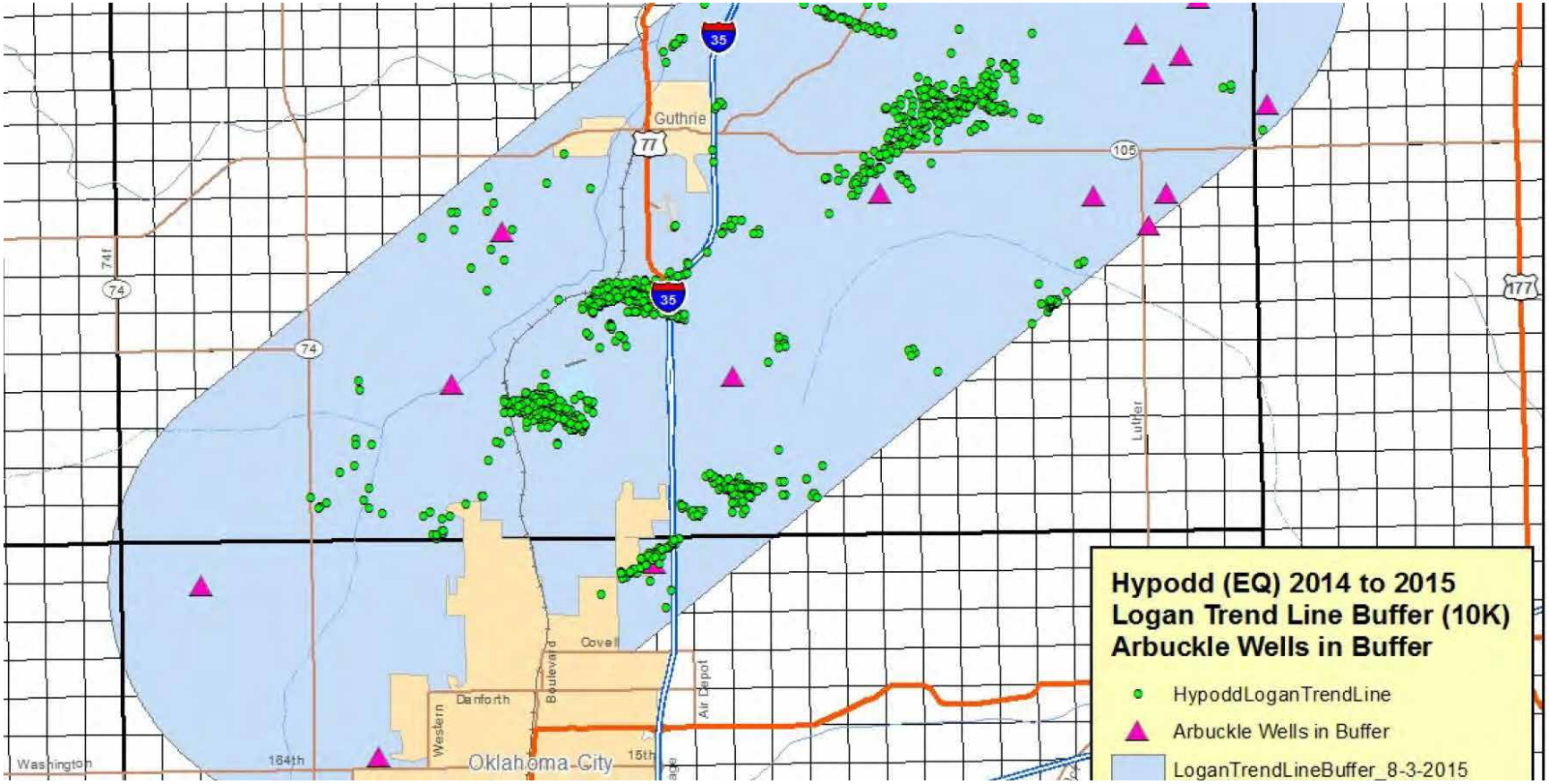
June 7th, 2016

ch2m SM

Defining the Problem

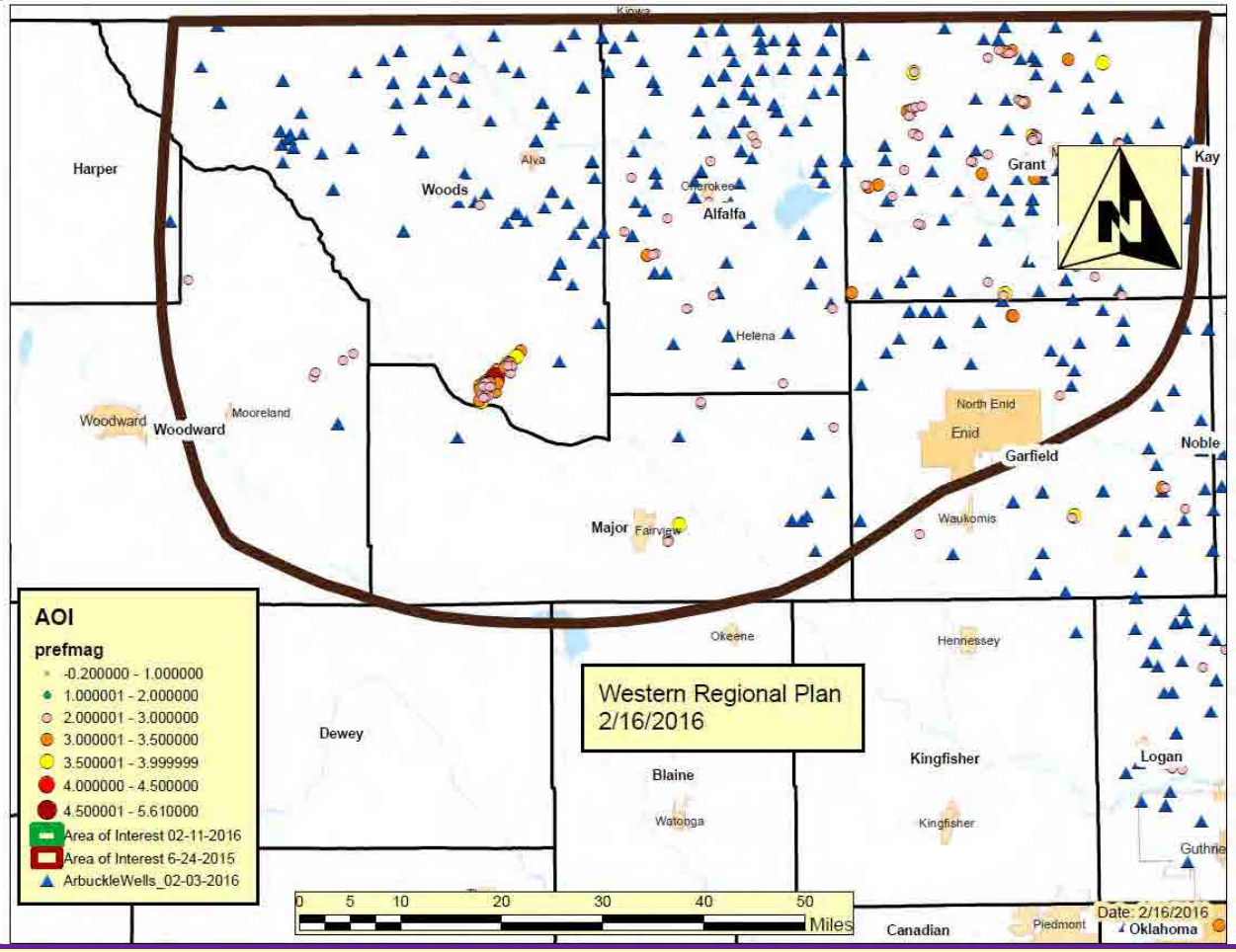
- **Too much produced water compared to limited underground injection capacity (disposal)**
- Long term need to conserve fresh water sources
- What are the economically viable alternatives for produced water reuse or recycling?

OCC –Water Disposal Reduction #1



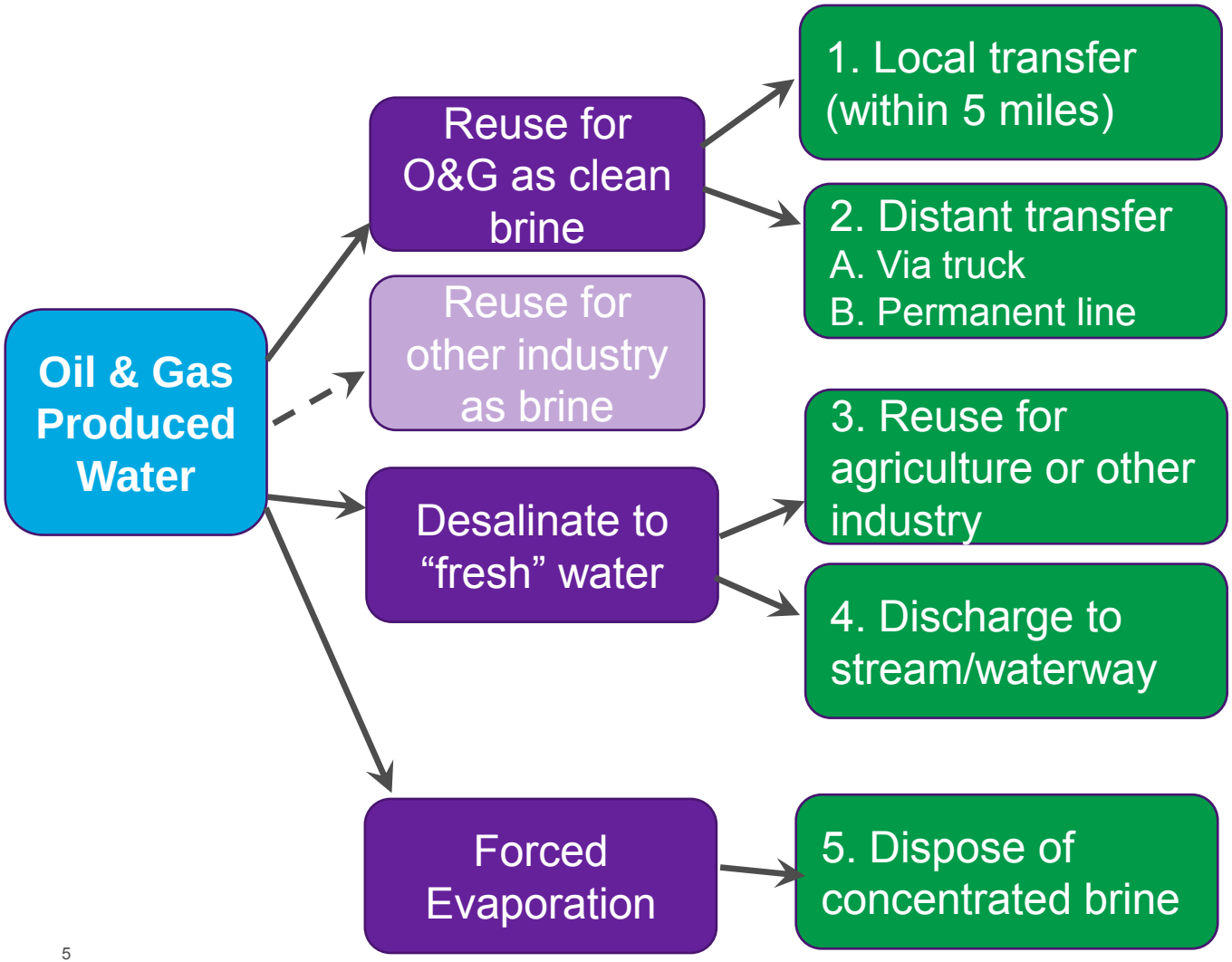
- First Disposal reduction occurred in August 2015 in northern Oklahoma County and southern Logan County
- Reduced injection by about 38%.

OCC –Water Disposal Reduction #2



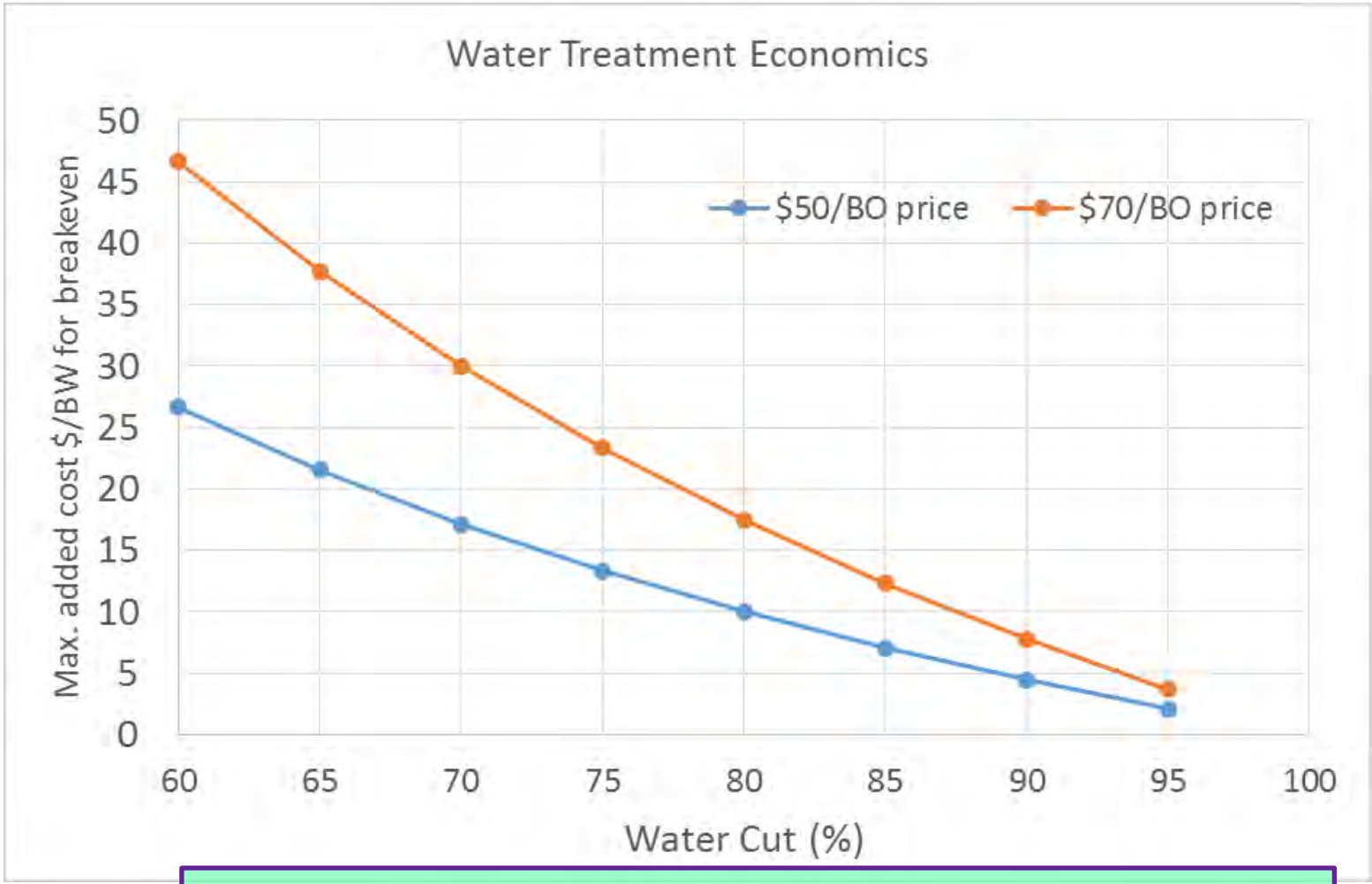
- Second water injection reduced by 40% from 245 wells in area above
  - Took effect from Feb to April 2016
  - Approximately 500,000 Barrels of Water Per Day (BWPD) shut-in

Options Overview (from March meeting)



	Cost $/BW	Other
1. Local transfer (within 5 miles)	2 – 4	Limited volume
2. Distant transfer A. Via truck	4 – 10	Trucking impact
2. Distant transfer B. Permanent line	2 – 6	Lg. vol. needed
3. Reuse for agriculture or other industry	4 – 10	Solid waste, Regulations
4. Discharge to stream/waterway	4 – 10	Solid waste
5. Dispose of concentrated brine	3 – 6	Untried, overspray, lost water

How Much Additional Water Cost is Economically Possible?



- Conclusion: Wells with water cuts less than 90% that are shut-in due to limited disposal capacity could potentially carry higher costs of treatment and transportation.

Assumes well is otherwise shut-in without disposal option

Assumes existing operating cost is $10/BO

Scope of Work - Proposal to DOE

1. Gather data about produced water and users of water
   A. Volumes of water by region (county)
   B. Produced water quality and quality needed by users
   C. Create database; Focus on large volumes and proximity

2. Evaluate appropriate water treatment technologies
   A. Solicit cost estimates from vendors (group thoughts?)
   B. Prepare conceptual designs for treatment cases

3. Evaluate economic options and order of magnitude costs for selected scenarios

4. Prepare Final Study Report
   A. Document methods, data and findings
   B. Recommendations to support future discussion, planning and policymaking

Study Deliverables

1. Database of produced water volumes and water quality data
2. Database of potential users of water, their location and volumes and quality needed
3. Cost evaluation of top scenarios
4. Identification of potential obstacles
5. Recommendations and conclusions
6. Final report for public release

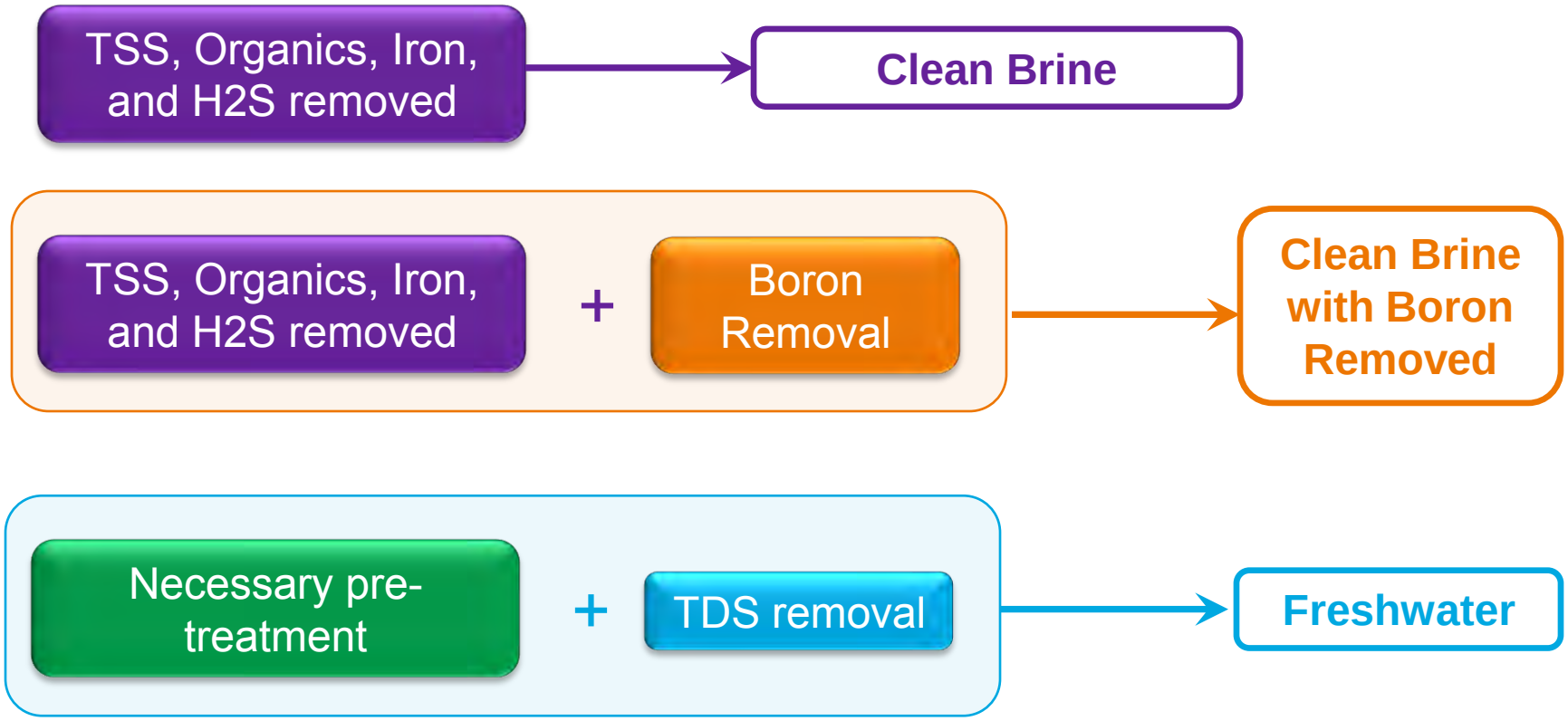
Proposal to DOE – Summary Points

1. $200,000 proposal approved by DOE
2. Expect to start work in July or later
3. Hope to finish by December 2016.
4. Portion of funding will be for in-kind effort by OWRB and balance for third party
5. Emphasis on scoping evaluation of possibilities, rather than focusing too much in in a limited area.
6. PWWG is resource to study effort

Thank You

ch2m SM

Types of produced water treatment



June 20, 2016

Julie Cunningham
Chief
Planning & Management Division
Oklahoma Water Resources Board (OWRB)
3800 N. Classen
Oklahoma City, OK 73118

Subject: CH2M ROM for Produced Water Recycling Opportunities Scoping Evaluation

Dear Ms. Cunningham,

CH2M HILL, Inc. (CH2M) is pleased to provide the attached indicative scope and rough order of magnitude (ROM) estimate to the Oklahoma Water Resources Board (OWRB) to perform the above referenced study. This draft was prepared based on our recent discussions and is intended to support OWRB in seeking matching funds through the U.S. Department of Energy to (USDOE).

The OWRB Produced Water Working Group is interested to evaluate options to beneficially reuse produced water from oil and gas exploration and production activities as an alternatives to disposal. CH2M's approach to this study is to identify representative opportunities to "match" localized produced water sources with potential beneficial reuse demands, and to evaluate the associated treatment and conveyance costs. We will compare these costs to the cost to dispose of the equivalent volume of produced water through forced evaporation. From these representative comparative cases, our objective would be to then draw some generalized conclusions about the opportunity, cost and benefit of extrapolating such a strategy state wide and what the potential impact might be on the individual operator's cost of production.

If you have questions, please contact Michael Dunkel at (469) 585-6468 or Michael.Dunkel@ch2m.com. We look forward to supporting you on this important project.

Regards,

CH2M HILL, Inc.

Michael Dunkel
Vice President
Principal Investigator

Bruce Thomas-Benke
Market Delivery Leader | Water for Upstream Oil & Gas

C: Anna Childers

Draft Statement of Work -

Produced Water Recycling Opportunities Scoping Evaluation

Project Understanding

The Oklahoma Water Resources Board's (OWRB) Produced Water Work Group is charged with investigating solutions to promote recycling of produced water related to oil and gas production. As the oil and gas industry represents a significant portion of Oklahoma's economy, the state is interested in identifying sustainable alternatives to reduce the industry's reliance on deep well disposal while still balancing public interest and continued beneficial development of the state's valuable oil and gas resources.

One potential strategy is beneficial reuse of produced water from oil and gas operations. The objective of this proposed study is to investigate produced water reuse and recycling, including evaluating potential costs to treat and deliver produced water for alternative uses, compared to deep well injection and alternate disposal methods, namely, forced evaporation.

Scope of Services

Task 1 – Coordinate the Produced Water Work Group (PWWG)

Objectives

Coordinate the PWWG meetings in conjunction with the OWRB. Establish subcommittees and working meetings as needed. Coordinate the agenda for the PWWG meetings with OWRB. Use the expertise assembled with the PWWG to execute the study of produced water reuse, recycling and forced evaporation to reduce deep well water disposal.

Activities

1. Establish agenda's for each of the PWWG meetings to make the best use of members' expertise. Use input from the group as a resource for the study.
2. Plans are to establish a legal/regulatory subcommittee to identify obstacles to the various options being evaluated for reuse, recycling and reducing water disposal. The identified obstacles will be included in the final report. Other subcommittees may be created as needed.
3. Coordinate with PWWG members and other experts as each option is investigated. Meetings by industry are likely to better understand potential users of the treated produced water.

Task 2 – Estimate Produced Water Supply and Demands

Objectives

Identify produced water generators and potential users, categorized by water quality and organized by geographic area as a basis for prioritization, supply/demand matching, and routing and sizing of produced water recycling infrastructure. A significant focus being oil and gas reuse of produced water for other oil and gas hydraulic fracturing or water flooding operations.

Activities

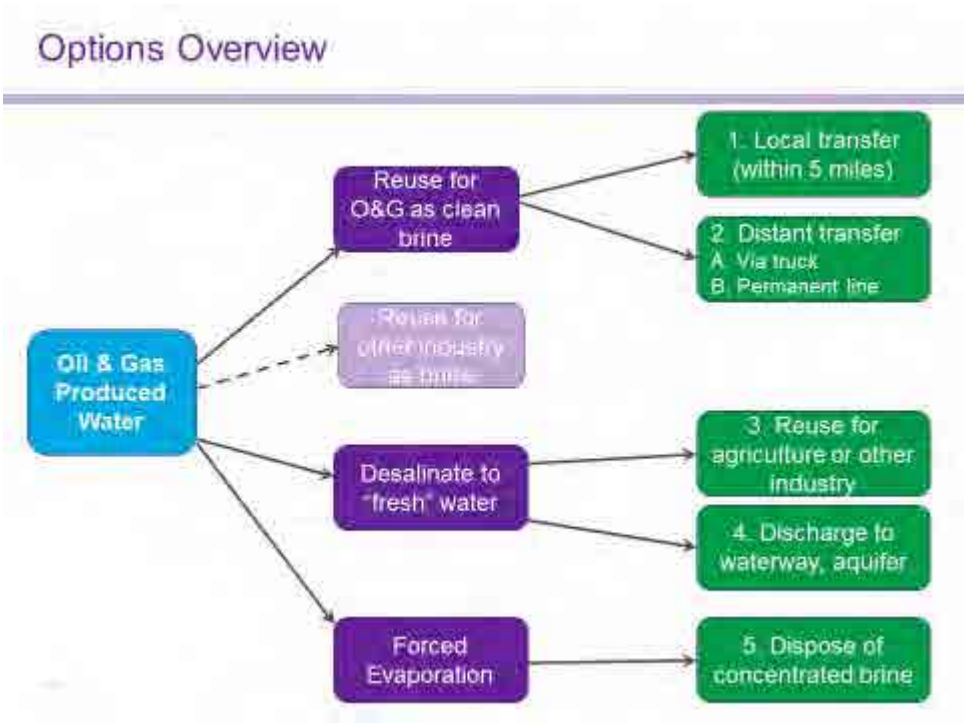
1. Gather produced water volumes by geographical area and associated water quality: We will develop estimates of potential produced water generation, including volumes over time, and water quality. We believe the following steps will be involved:
    a. Review potential data sources and develop estimate methodology. This is likely to be based upon direct and inferred reference information including reserve estimates and historic produced water production based on literature review and other available resources. Propose an estimating methodology based on available references and review with OWRB stakeholders
    b. Aggregate the selected data, develop the estimates and document the methodology by produced water generation over time and by county, including estimated water quality.
    c. Summarize estimates of produced water generation in tabular and GIS format
2. Determine largest users of water by geographical area, including agriculture and specific companies. The following activities are anticipated:
    a. Review the potential data sources. Possible data sources may include water rights databases and industrial wastewater discharge and pretreatment permit iEcoomicsnformation (i.e., big industrial dischargers are likely to be also big water users) and other publically available state water use references. Propose an estimating methodology based on available references and review with OWRB stakeholders.
    b. Aggregate the selected data, develop the estimates and document the methodology by produced water generation over time and by county, including estimated water quality requirements.
    c. Summarize estimates of water demand in tabular and GIS format. Based on the availability of location coordinate information, we will attempt to map specific facility locations for large, acute demands.
3. Prioritize supply/demand matches: Using the produced water supply/demand GIS information developed in the previous activities, we will identify, prioritize and recommend up to 10 matches where reusing produced water has the potential to meet demand and offset produced water disposal, taking into account water quality, proximity of the facility, sustainability of the arrangement over time, and proximity to areas of known induced seismic activity. We will use this to estimate the total potential for beneficial reuse to reduce produced water deep well disposal in these areas. We will identify and recommend up to three (3) example matches, taking into account capacity and treatment requirements to meet the demand water quality requirements. These will be used as a basis for design in the next task.
4. Progress presentation to review and endorse estimates and example match design basis: We will facilitate a discussion with OWRB stakeholders to review the methods, findings and recommendations from this task before moving on to the next task.

Assumptions and Clarifications

- We will host an up to 2 hour web conference to discuss and agree on the produced water generation and water demand estimating methodologies with stakeholders.
- The findings from this task will be summarized in presentation format and presented at a regular OWRB Produced Water Committee meeting.
- Final methods and results from this test, incorporating stakeholder input from the presentation in Activity 4 stated above will be documented in the final report in Task 4.

Deliverables

- Produced water generation estimate and maps
- Water demand estimate and maps
- Progress presentation to be presented at a regular OWRB meeting as described in Activity 4.



Task 3 – Evaluate Treatment

Objectives

Evaluate produced water treatment technologies and prepare conceptual designs for i) produced water treatment for beneficial recycling, and ii) produced water disposal via forced evaporation as a basis for comparison to deep well injection disposal.

Activities

1. Develop desalination conceptual designs and cost estimates: For each of the three (3) representative produced water supply/demand matches identified and agreed in Task 1, CH2M will develop a conceptual design for treatment and conveyance and associated order of magnitude capital and operating cost estimate for the purpose of estimating a lifecycle, present worth cost for comparison to other options. The objective is not to optimize the treatment strategy; rather, to evaluate costs based on a representative treatment approach based on CH2M's professional judgment and other input form OWRB stakeholders. For each of the three selected scenarios, we anticipate the following activities:

   Scenario 1

   a. Summarize design basis

   b. Prepare conceptual design, consisting of:

      i. Block flow diagram

ii. Material and energy balance

iii. Major equipment list

iv. General arrangement

v. Utility and reagent summary

vi. Operating labor requirements

vii. Capital Expenditure (CAPEX) estimate (Class 5[1], +75%/-50% accuracy)

viii. Annualized Operation Expenditure (OPEX) estimate (Class 5[1], +75%/-50% accuracy)

c. Prepare cost sensitivity analysis: The objective here is to generate cost versus capacity estimates for the proposed example system, based on a factored estimate of those original project cost elements which are sensitive to capacity/size. The cost versus capacity relationships will be used in the subsequent task.

Scenario 2 – same as above

Scenario 3 – same as above

2. Develop forced evaporation disposal conceptual designs and cost estimates: We will evaluate large-scale forced evaporation disposal: CH2M will prepare conceptual design and cost estimates for the same three (3) scenarios evaluated under the previous activity for direct comparison. Again, the objective is to base the evaluation on a representative technical approach based on CH2M professional judgment and input from stakeholders. For each of the three (3) selected scenarios, we anticipate the following similar concept definition activities:

Scenario 1

a. Summarize design basis (adapted from associated desalination evaluation for same scenario)

b. Prepare conceptual design, consisting of:

i. Block flow diagram

ii. Material and energy balance

iii. Major equipment list

iv. General arrangement

v. Utility and reagent summary

vi. Operating labor requirements

vii. Capital Expenditure (CAPEX) estimate (Class 5[1], +75%/-50% accuracy)

viii. Annualized Operation Expenditure (OPEX) estimate (Class 5[1], +75%/-50% accuracy)

c. Prepare cost sensitivity analysis: The objective here is to generate cost versus capacity estimates for the proposed example system, based on a factored estimate of those original project cost elements which are sensitive to capacity/size. The cost versus capacity relationships will be used in the subsequent task.

Scenario 2 – same as above

[1] Based on Association for the Advancement of Cost Engineering recommended practices.

Scenario 3 – same as above

3. Progress presentation to review and endorse conceptual designs and estimates for the desalination/reuse and forced evaporation disposal scenarios: We will facilitate a discussion with OWRB stakeholders to review concepts and findings from this task before moving on to the next task.

Assumptions and Clarifications

- We are assuming that for a particular beneficial reuse scenario to be viable in markedly reducing dependence on deep well injection disposal and to be a viable replacement for current water supplies, they will inherently need to be larger capacity, permanent facilities. Therefore we have assumed the technical concepts defined herein will necessarily be customized, fit for purpose facilities, for the purpose of this study, rather than modular/mobile treatment units. CH2M will leverage its own parametric design and cost estimating tools to the extent practicable to complete this task.
- We will assume some limited acceptable level of deep inject well use for concentrated waste disposal in developing the concepts, to be agreed in advance with OWRB.
- The findings from this task will be summarized in presentation format and presented at a regular OWRB Produced Water Committee meeting.
- Final methods and results from this task, incorporating stakeholder input from the presentation described in Activity 3 will be documented in the final report in Task 4.

Deliverables

- Desalination concept design narrative description, basis of estimate (i.e., design criteria and assumptions, concept definition drawings/exhibits), CAPEX/OPEX estimate and cost curves (included in final report)
- Forced evaporation disposal concept design narrative description, basis of estimate (i.e., design criteria and assumptions, concept definition drawings/exhibits), CAPEX/OPEX estimate and cost curves (included in final report)
- Progress presentation to be presented at a regular OWRB meeting as described in Activity 3.

Task 4 – Evaluate Economics

Objectives

For select, representative produced water recycling and disposal scenarios, evaluate economic options and order of magnitude costs in order to assess the conceptual feasibility of said scenarios. This comparative feasibility assessment, in turn, will be used to evaluate risks, barriers, priorities and other recommendations with respect to these alternatives to deep well injection produced water disposal.

Activities

1. Summarize existing public funding sources: CH2M will explore potential sources of funding for CAPEX and OPEX for conveyance and treatment facilities that would be required to implement the technical strategies developed in the previous task. This could include speaking to investment banking firms and reviewing public funding and incentive programs. The objectives of this activity are twofold:
    - Develop assumptions for financial modeling and analysis
    - To the extent practicable, identify funding gaps that may need to be addressed to incentivize execution of the strategy

2. Evaluate feasibility of produced water beneficial reuse: Develop comparative feasibility assessment of beneficial reuse versus forced evaporation disposal of produced water. The representative scenario costs developed in the previous task will be used to prepare both a project level direct comparison of the strategies as well as to extrapolate potential cost-benefit impacts of broadly applying the strategy in Oklahoma to mitigate produced water disposal-induced seismicity risk and occurrences. This activity is anticipated to include:
   a. Compare economic feasibility of desalination versus forced evaporation disposal for each scenario
   b. Develop estimate of state-level implementation. This is expected to take the form of a parametric extrapolation based on the results of item (a), above. CH2M will assess other methodologies including numeric modeling optimization with input from OWRB.
   c. Develop a risk and opportunities assessment which may influence the outcome of the analysis, focusing on:
      - Technical risk
      - Financial/economic risk
      - Implementation risk
   d. Prepare draft conclusions and recommendations, including additional data gathering and studies necessary to quantify and/or mitigate opportunities and risks in the analysis and to inform decision making.
3. Progress presentation to review financial assumptions and evaluation conclusions and recommendations: We will facilitate a discussion with OWRB stakeholders to review assumptions and findings from this task before finalizing the study report in the next task.

Assumptions and Clarifications

- The findings from this task will be summarized in presentation format and presented at a regular OWRB Produced Water Committee meeting.
- Final methods and results from this task, incorporating stakeholder input from the presentation described in Activity 3 will be documented in the final report in Task 4.

Deliverables

- Desalination concept design narrative description, basis of estimate (i.e., design criteria and assumptions, concept definition drawings/exhibits), CAPEX/OPEX estimate and cost curves (included in final report)
- Forced evaporation disposal concept design narrative description, basis of estimate (i.e., design criteria and assumptions, concept definition drawings/exhibits), CAPEX/OPEX estimate and cost curves (included in final report)
- Progress presentation to be presented at a regular OWRB meeting as described in Activity 3.

Task 5 – Prepare Final Study Report

Objective

Prepare a Final Study Report documenting the methods, data, findings and recommendations developed and endorsed by OWRB in previous tasks, to support future discussion, planning and policymaking.

Activities

1. Prepare Final Study report: We will prepare a Final Study report documenting the findings of the study.
    a. CH2M will prepare a draft report.
    b. After OWRB has reviewed the draft report, we will facilitate an up to two hour web conference with interested stakeholders to review and adjudicate comments.
    c. The report will be finalized based on OWRB comments. Responses to individual, material (i.e., non-typographic or formatting) comments will be documented in CH2M's Quality Review Form (QRF) for tracking and closeout purposes.

    Tentative outline includes:

        a. Executive Summary
        b. Introduction and Study Objectives
        c. Produced water estimate
            i. Methods
            ii. Findings
        d. Potential reuse estimates
            iii. Methods
            iv. Findings
        e. Representative Recycling Scenarios
            v. Methodology
            vi. Scenario 1:
                1. Beneficial reuse description
                2. Forced evaporation disposal description
                3. Cost and benefits
            vii. Scenario 2 – same as above
            viii. Scenario 3 – same as above
        f. Feasibility of broad scale implementation
            ix. Methodology (including key financial assumptions)
            x. Estimated cost - benefit range(s) (high, likely, low)
            xi. Opportunities, Barriers and Risks:
                1. Technical
                2. Financial/economic
                3. Implementation (including policy gaps)
        g. Conclusions and Recommendations
            xii. Conclusions and recommendations
            xiii. Recommended Studies

xiv. Next Steps

h. References

Appendices:

A – Produced water data and estimate detail

B – Water demand data and estimate detail

C – Desalination conceptual design and cost estimate detail

D – Forced evaporation disposal conceptual design and cost estimate detail

E – Broad scale implementation estimates and financial analysis detail

2. Prepare Executive Summary Presentation: We will prepare an executive summary presentation of the final report findings and recommendations that the OWRB Produced Water Committee can use/adapt to communicate to stakeholders and third parties. We will target a 20 to 30 minute presentation duration targeted towards general audiences. We will submit a draft presentation along with the draft Final Study Report described in the previous activity. We will review and adjudicate OWRB's comments at the same review web conference as well and will finalize and submit the final presentation along with the Final Study Report.

Deliverables

- Final Study report (draft and final)
- QRF table documenting adjudication of reviewer comments
- Executive Summary Presentation (draft and final)

Assumptions and Clarifications

- Draft report will be submitted in MS Word 2013 read-write format to facilitate electronic editing/comments. The final report will be submitted in Adobe PDF read-only format. The Executive Summary Presentation will be submitted in MS PowerPoint 2013.
- An allowance of 20 business days is included for OWRB's review of the draft report. OWRB will establish an internal "chain of command" to conduct the review, and, prioritize its comments, and will provide one consolidated set of written comments on CH2M's QRF or similar mutually agreed format to facilitate tracking and adjudication of comments.

Project Management and Administration

Objective

Provide management, coordination and project controls to deliver the work in accordance with the project objectives, schedule and budget.

Activities

1. Project kickoff: CH2M will facilitate a project kickoff web conference with ORWB Produced Water Committee members and other stakeholders invited by OWRB. The kickoff is assumed to last two hours or less. Agenda will include but not be limited to:
   - Confirm objectives, requirements and other critical success factors
   - Confirm stakeholders
   - Review scope and approach
   - Review information furnished by OWRB and confirm other assumptions
   - Review schedule and milestones

- Quality assurance/review strategy
- Project communications/meetings

2. Project management and administration:
   a. Charter project team: CH2M will prepare project instructions, including the project quality plan, and charter team members for efficient and effective delivery of the work. Draft project instructions will be reviewed with OWRB at the first kickoff/status call insofar as it addresses interfaces/coordination between OWRB and CH2M.
   b. Project status meetings: CH2M will facilitate a weekly project status call with OWRB representative to review progress, actions and interim deliverables as required.
   c. Change management: CH2M will evaluate trends and scope change, maintain a project change/trend register, and work proactively with OWRB representatives to mitigate or reduce impacts of change on the schedule and budget to the extent practicable.
3. Project controls: CH2M will develop baseline budget and schedule, track performance and trends against baseline, prepare forecasts, and prepare monthly reports.

Deliverables

- Project Change Log
- Action Register

Assumptions and Clarifications

- This is budgeted as a level of effort task assuming a project duration of 28 weeks.
- CH2M will use its own systems and tools for project controls and reporting. If OWRB has specific requirements they will provide this at the beginning of the project. Deviation from CH2M project control standards may result in a project change.

General Assumptions and Clarifications

The following general assumptions were made during the preparation of this ROM:

- We anticipate hosting regular progress calls with OWRB stakeholders to address data gaps and review/collaborate and endorse key approaches, assumptions and findings.
- The success of the study will depend on constructive and timely collaboration by OWRB and its individual Produced Water Committee members to develop and implement the approach to this study to maximize the technical veracity of the methods and findings and optimize usefulness of the study to inform constructive debate and policymaking.
- OWRB and individual Produced Water Committee members and stakeholders will provide data in their possession relevant to the study in a usable format to CH2M.
- As required, the OWRB Produced Water Committee will afford sufficient agenda time at their scheduled meetings to review study materials. CH2M will coordinate this in advance with the committee chair.

Project Team

CH2M's project manager and primary point of contact is:

Anna Childers
CH2M HILL Engineering, Inc.
401 S. Boston Ave.
Suite 330
Tulsa, OK 74103-44253
USA
C +1 918 607 3647
Anna.Childers@CH2M.com

CH2M's Principal Investigator is:

Michael Dunkel
CH2M HILL Engineering, Inc.
14701 St. Mary's Lane
Suite 300
Houston, TX 77079-2923
USA
C +1 469 585 6468
Michael.Dunkel@CH2M.com

Subject matter experts and other project support staff will be engaged as needed. Resumes are available upon request.

Commercial Proposal

Schedule

CH2M understands that the ORWB would like to demonstrate progress on the subject of beneficial produced water reuse/alternate disposal and to plan follow-on actions prior to the end of 2016. We stand ready to begin work upon authorization.

The estimated time for the project is 28 weeks. Assuming a start date of June 6, the estimated completion would be approximately December 16th, 2016. A preliminary schedule is included in Attachment A.

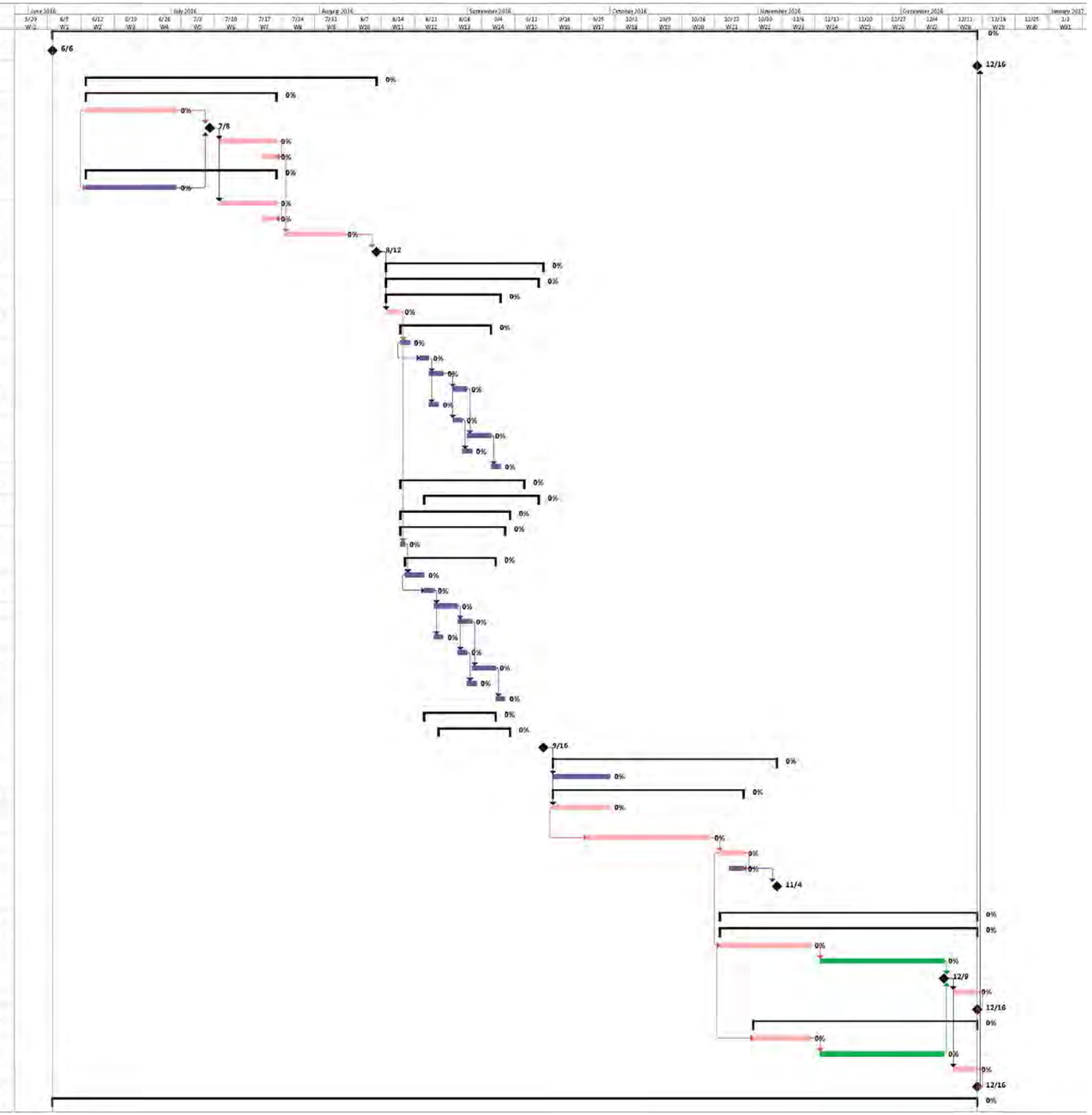
Target milestones are:

- Kickoff web conference — June 10, 2016
- Meet to review Produced water supply and reuse demand estimates — August 12
- Review representative treatment/disposal estimates — September 16
- Review preliminary findings — November 4
- Submit draft report/presentation for final review — November 11
- Issue final report/presentation — December 16, 2016

The main schedule risks are identifying and obtaining necessary data in useful format in a timely manner, scheduling of progress meetings to obtain necessary direction and endorsement from OWRB, and OWRB's efficient and effective review of the final report and presentation to close out the study.

ATTACHMENT A – Proposed Project Schedule

ID	Task Name	Duration	Start	Finish
1	**OWRB - PRODUCED WATER RECYCLING OPPORTUNITIES SCOPING EVALUATION**	**140 days**	**Mon 6/6/16**	**Fri 12/16/16**
2	Notice to proceed	0 days	Mon 6/6/16	Mon 6/6/16
3	Study completion	0 days	Fri 12/16/16	Fri 12/16/16
4	**TASK 1 - ESTIMATE PW SUPPLY AND DEMANDS**	**45 days**	**Mon 6/13/16**	**Fri 8/12/16**
5	**1. Estimate PW volumes/quality by geog. Area**	**30 days**	**Mon 6/13/16**	**Fri 7/22/16**
6	a. Review data sources and develop estimate methodology	15 days	Mon 6/13/16	Fri 7/1/16
7	OWRB review - Endorse PW estimate methodology	0 days	Fri 7/8/16	Fri 7/8/16
8	b. Aggregate data and develop estimates	10 days	Mon 7/11/16	Fri 7/22/16
9	c. Summarize data	3 days	Wed 7/20/16	Fri 7/22/16
10	**2. Determine largest water users by geographical area**	**30 days**	**Mon 6/13/16**	**Fri 7/22/16**
11	a. Review data sources and develop estimate methodology	15 days	Mon 6/13/16	Fri 7/1/16
12	b. Aggregate data and develop estimates	10 days	Mon 7/11/16	Fri 7/22/16
13	c. Summarize data	3 days	Wed 7/20/16	Fri 7/22/16
14	3. Prioritize Supply/demand matches	10 days	Mon 7/25/16	Fri 8/5/16
15	4. Review and endorse estimates and example match design bases	0 days	Fri 8/12/16	Fri 8/12/16
16	**TASK 2 - EVALUATE TREATMENT**	**25 days**	**Mon 8/15/16**	**Fri 9/16/16**
17	**1. Develop desalination conceptual designs and cost estimates**	**24 days**	**Mon 8/15/16**	**Thu 9/15/16**
18	**Scenario 1**	**18 days**	**Mon 8/15/16**	**Wed 9/7/16**
19	a. Summarize design basis	3 days	Mon 8/15/16	Wed 8/17/16
20	**b. Prepare conceptual design**	**13 days**	**Thu 8/18/16**	**Mon 9/5/16**
21	i. Block flow diagram	2 days	Thu 8/18/16	Fri 8/19/16
22	ii. Material and energy balance	2 days	Mon 8/22/16	Tue 8/23/16
23	iii. Major equipment list	3 days	Wed 8/24/16	Fri 8/26/16
24	iv. General arrangement	3 days	Mon 8/29/16	Wed 8/31/16
25	v. Utility and reagent summary	2 days	Wed 8/24/16	Thu 8/25/16
26	vi. Operating labor requirements	2 days	Mon 8/29/16	Tue 8/30/16
27	vii. CAPEX estimate	3 days	Thu 9/1/16	Mon 9/5/16
28	viii. OPEX estimate	2 days	Wed 8/31/16	Thu 9/1/16
29	c. Cost sensitivity analysis and cost curves	2 days	Tue 9/6/16	Wed 9/7/16
30	**Scenario 2**	**18 days**	**Thu 8/18/16**	**Mon 9/12/16**
42	**Scenario 3**	**18 days**	**Tue 8/23/16**	**Thu 9/15/16**
54	**2. Develop forced evaporation disposal conceptual designs and cost estimates**	**17 days**	**Thu 8/18/16**	**Fri 9/9/16**
55	**Scenario 1**	**16 days**	**Thu 8/18/16**	**Thu 9/8/16**
56	a. Summarize design basis	1 day	Thu 8/18/16	Thu 8/18/16
57	**b. Prepare conceptual design**	**13 days**	**Fri 8/19/16**	**Tue 9/6/16**
58	i. Block flow diagram	2 days	Fri 8/19/16	Mon 8/22/16
59	ii. Material and energy balance	2 days	Tue 8/23/16	Wed 8/24/16
60	iii. Major equipment list	3 days	Thu 8/25/16	Mon 8/29/16
61	iv. General arrangement	3 days	Tue 8/30/16	Thu 9/1/16
62	v. Utility and reagent summary	2 days	Thu 8/25/16	Fri 8/26/16
63	vi. Operating labor requirements	2 days	Tue 8/30/16	Wed 8/31/16
64	vii. CAPEX estimate	3 days	Fri 9/2/16	Tue 9/6/16
65	viii. OPEX estimate	2 days	Thu 9/1/16	Fri 9/2/16
66	c. Cost sensitivity analysis and cost curves	2 days	Wed 9/7/16	Thu 9/8/16
67	**Scenario 2**	**11 days**	**Tue 8/23/16**	**Tue 9/6/16**
78	**Scenario 3**	**11 days**	**Fri 8/26/16**	**Fri 9/9/16**
91	3. Review and endorse conceptual design and estimates	0 days	Fri 9/16/16	Fri 9/16/16
92	**TASK 3 - EVALUATE ECONOMICS**	**35 days**	**Mon 9/19/16**	**Fri 11/4/16**
93	1. Research commercial structures and potential sources of funding	10 days	Mon 9/19/16	Fri 9/30/16
94	**2. Develop comparative feasibility assessment**	**30 days**	**Mon 9/19/16**	**Fri 10/28/16**
95	a. Compare economic feasibility of desal vs. forced evap. disposal for three scenarios	10 days	Mon 9/19/16	Fri 9/30/16
96	b. Develop estimate of state-level implementation	20 days	Mon 9/26/16	Fri 10/21/16
97	c. Develop risk and opportunities assessment	5 days	Mon 10/24/16	Fri 10/28/16
98	d. Prepare draft conclusions and recommendations	3 days	Wed 10/26/16	Fri 10/28/16
99	3. Review and endorse financial assumptions and evaluation conclusions and recommendations	0 days	Fri 11/4/16	Fri 11/4/16
100	**TASK 4 - PREPARE FINAL STUDY REPORT**	**40 days**	**Mon 10/24/16**	**Fri 12/16/16**
101	**1. Prepare final study report**	**40 days**	**Mon 10/24/16**	**Fri 12/16/16**
102	a. Prepare draft	15 days	Mon 10/24/16	Fri 11/11/16
103	- OWRB review	20 days	Mon 11/14/16	Fri 12/9/16
104	b. Review workshop	0 days	Fri 12/9/16	Fri 12/9/16
105	c. Prepare final report	5 days	Mon 12/12/16	Fri 12/16/16
106	- Issue final report	0 days	Fri 12/16/16	Fri 12/16/16
107	**2. Prepare executive summary presentation**	**35 days**	**Mon 10/31/16**	**Fri 12/16/16**
108	a. Prepare draft	10 days	Mon 10/31/16	Fri 11/11/16
109	- OWRB review	20 days	Mon 11/14/16	Fri 12/9/16
110	b. Prepare final presentation	5 days	Mon 12/12/16	Fri 12/16/16
111	- Issue final presentation	0 days	Fri 12/16/16	Fri 12/16/16
112	**PROJECT MANAGEMENT AND ADMINISTRATION**	**140 days**	**Mon 6/6/16**	**Fri 12/16/16**



Kyle E. Murray, PhD, Hydrogeologist

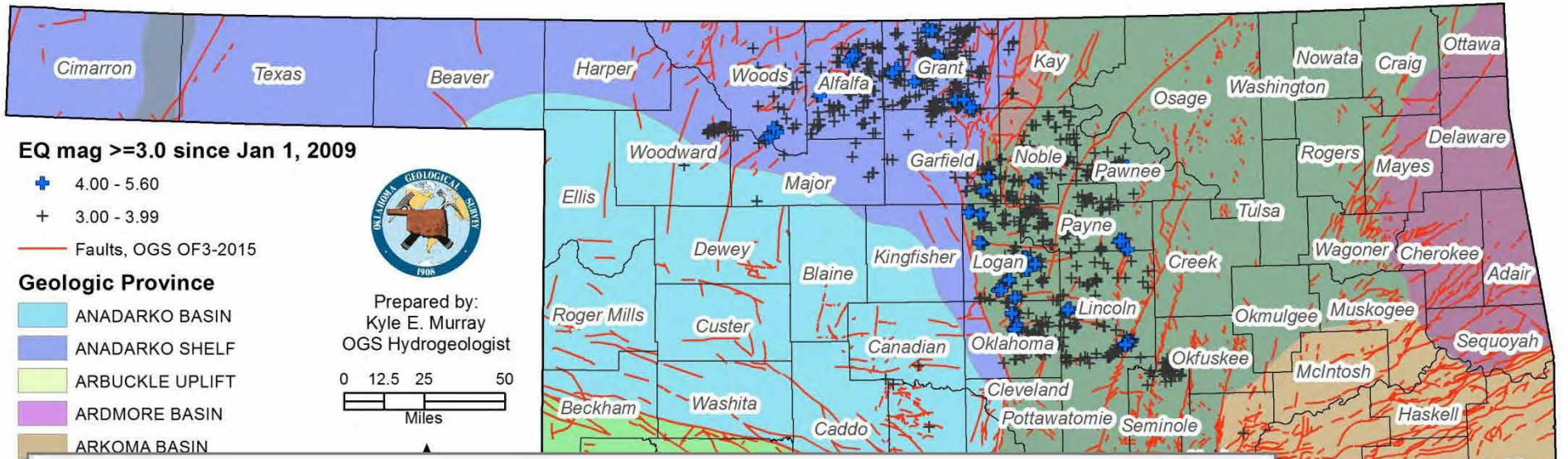
Presents:

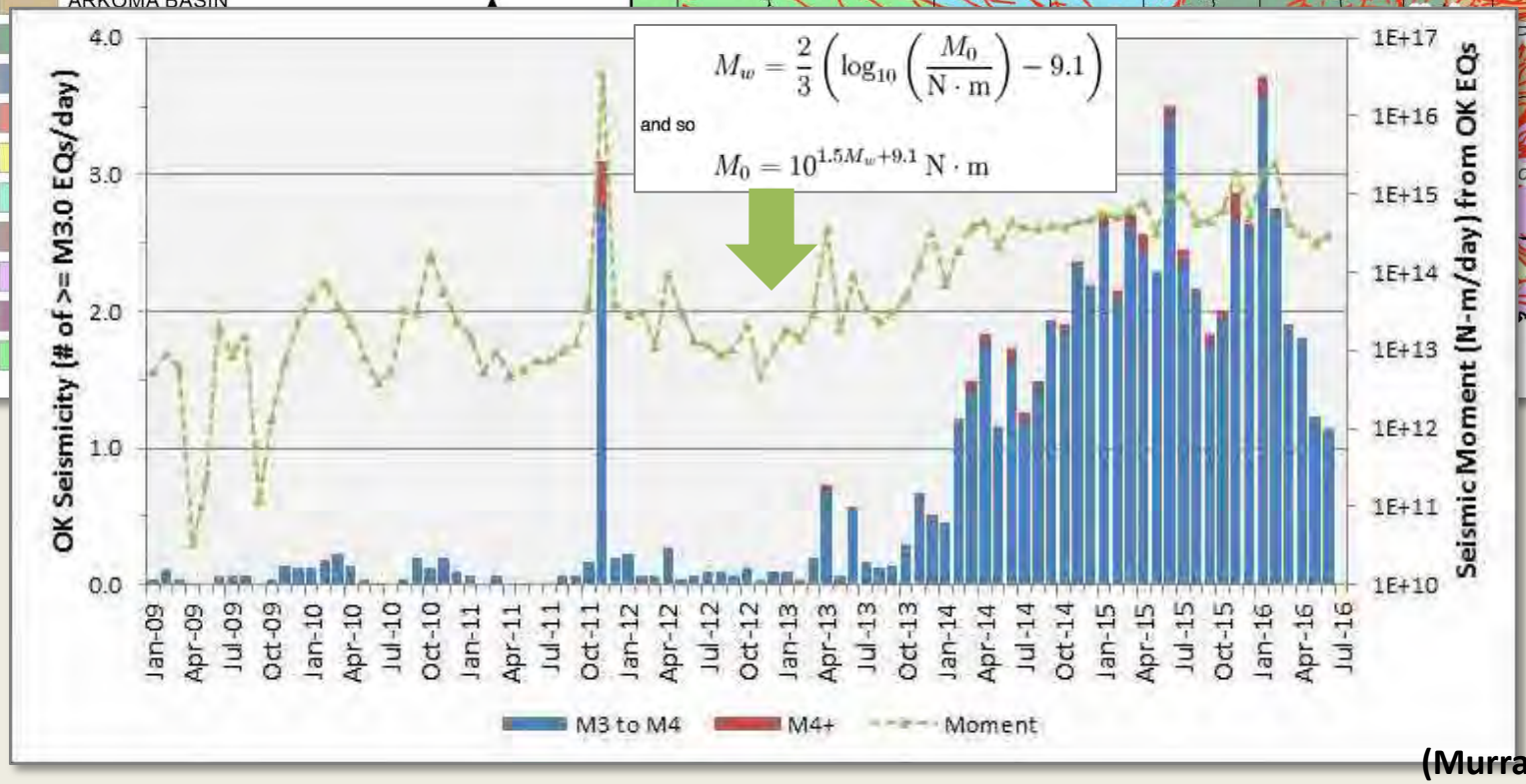
Quantity and Quality of Produced Water in Oklahoma

Water for 2060
Produced Water Working Group

Oklahoma City, OK
Jun 7, 2016

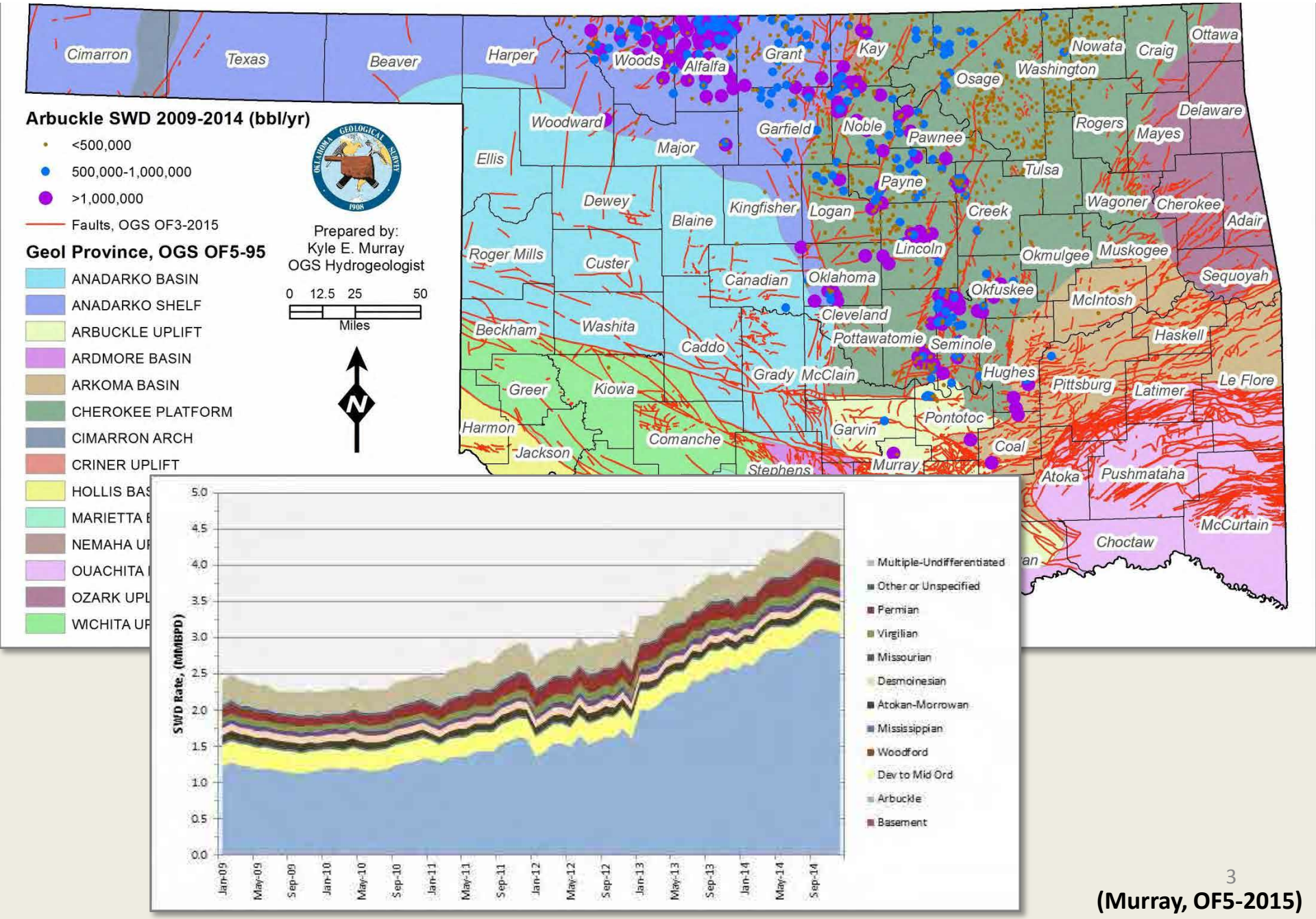
Earthquakes Mag >=3.0, Jan 1, 2009–Jun 7, 2016





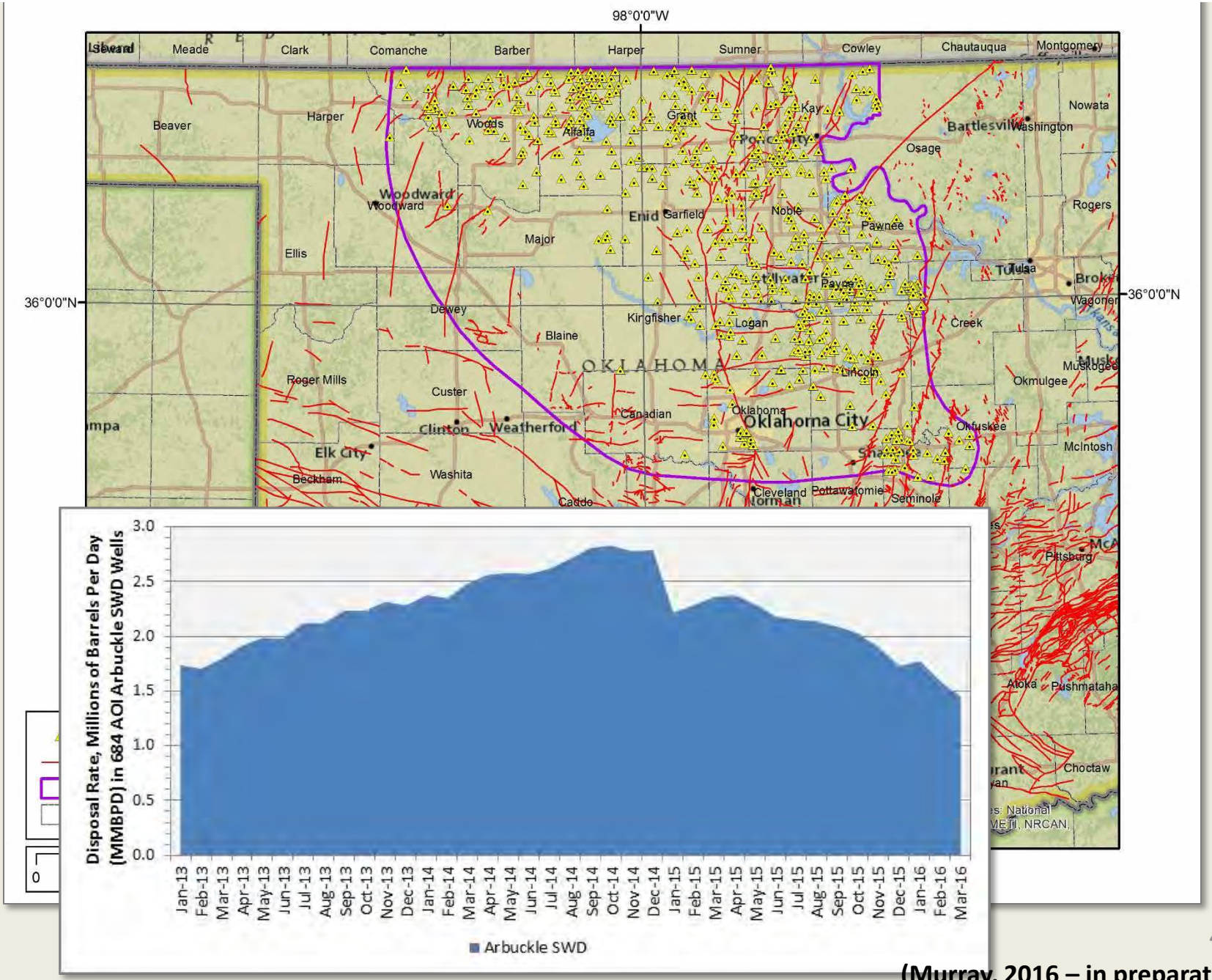
(Murray, 2016 in preparation)

Arbuckle SWD in Oklahoma, 2009–2014



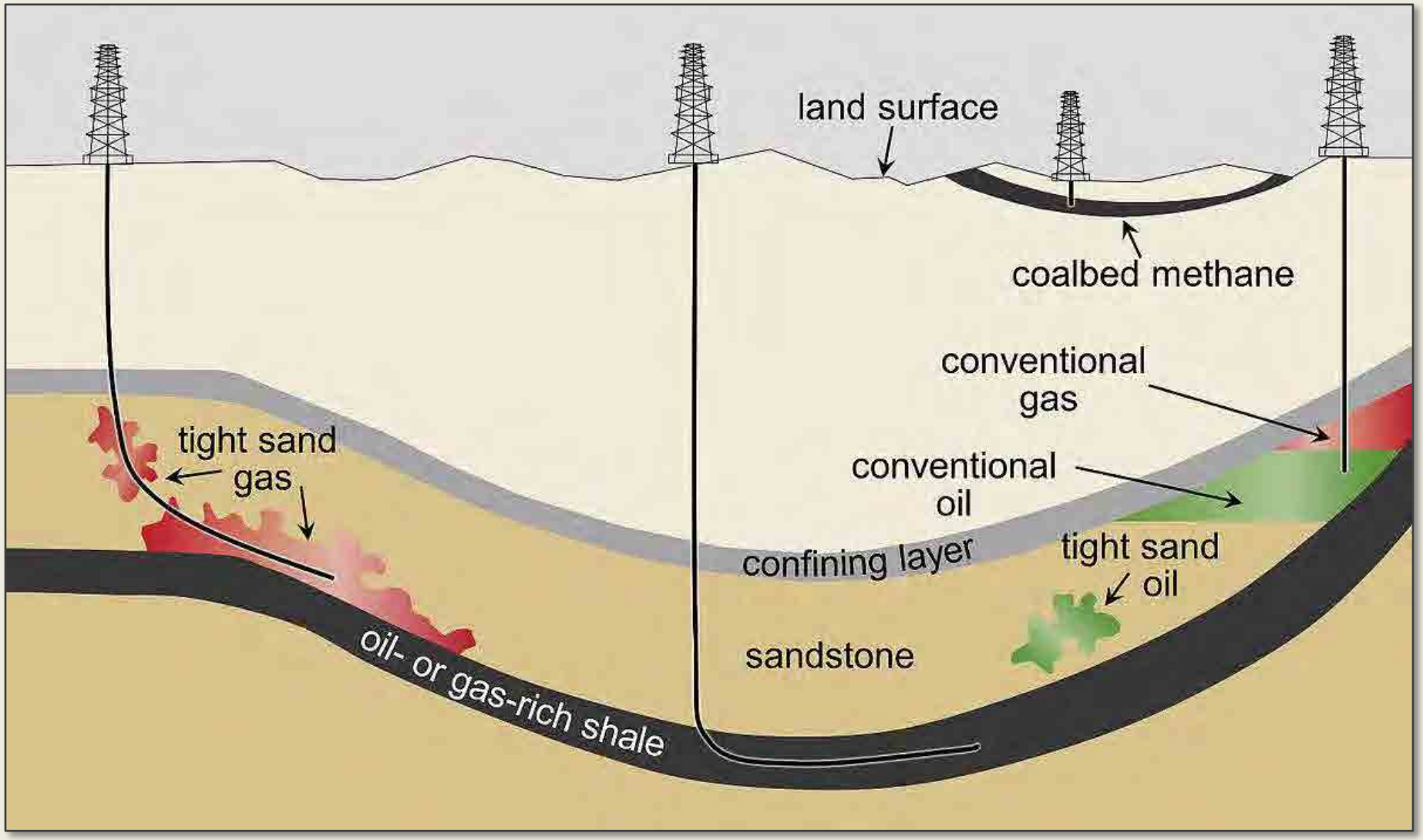
(Murray, OF5-2015)

Arbuckle SWD in Area of Interest (AOI) Jan 2013–Mar 2016



(Murray, 2016 – in preparation)

Conventional vs. Unconventional Production

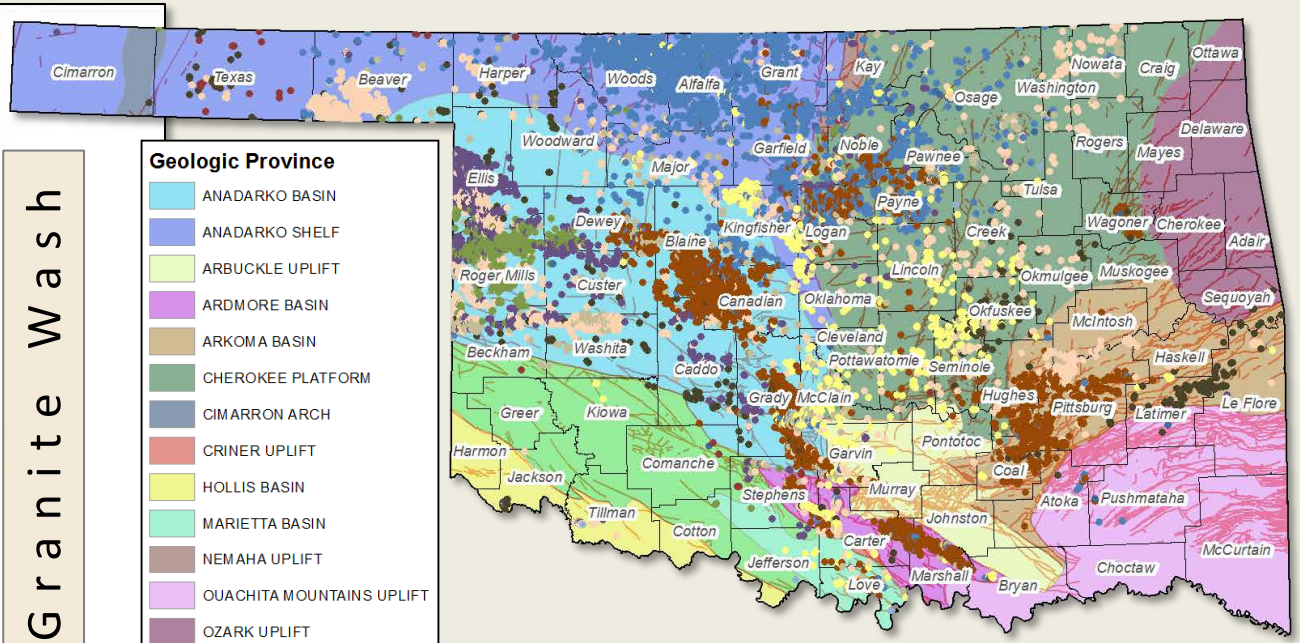


Tight Oil, from Wikipedia

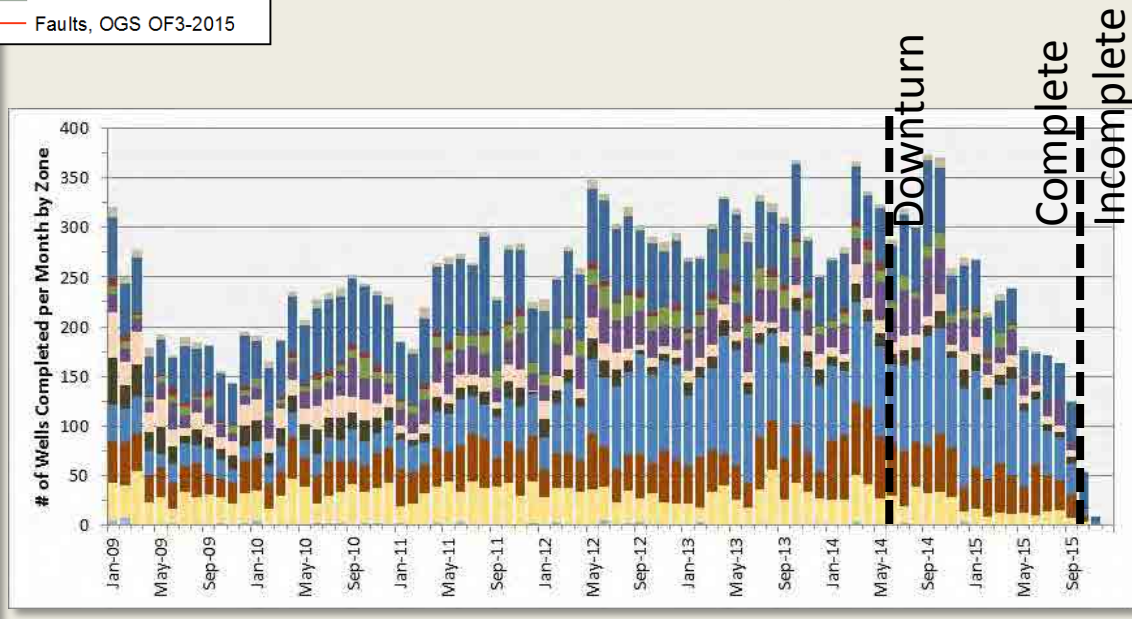
Zone	Group	Formation
Multiple-Undiff		
Other or Unspec.		
Permian		Garber
	Chase	Brown Dolomite
	Council Grove	Pontotoc
	Admire	Belveal
Virgilian	Wabaunsee	Cisco Lime
	Shawnee	Pawhuska
		Endicott
	Douglas	Tonkawa
Missourian	Hoxbar	Lansing
		Cottage Grove
		Kansas City
		Hogshooter
		Layton
		Cleveland
Desmoinesian	Marmaton - Deese	Oswego
	Cabaniss - Deese	Skinner
	Krebs - Deese	Red Fork
		Burbank
		Bartlesville
		Hartshorne
Atokan-Morrowan	Atoka	Gilcrease
		Dutcher
	Morrow	Cromwell
	Springer	Wamsley
Mississippian	Chester	Manning
		Caney
	Meramec	Miss Lime
		Miss Chat
		St. Louis
		Mayes
	Osage	Sycamore
	Kinderhook	Kinderhook
Woodford	Upper Devonian	Woodford
Dev to Mid Ord	Middle Devonian	Misener
	Hunton	Frisco
		Bois d'Arc
		Henryhouse
		Chimneyhill
	Cincinnatian	Sylvan
		Viola
	Simpson	Bromide
		Wilcox
		McLish
		Oil Creek
Arbuckle	Arbuckle Group	West Spring Creek
		Kindblade
		Cool Creek
		McKenzie Hill
		Butterly dolomite
		Signal mountain
		Royer dolomite
		Fort sill limestone
Basement & Crystalline Rock	Cambrian	Reagan
	Pre-Cambrian	Granite

Granite Wash

Key to Symbols
Sandstone
Carbonate
Shale
Coal
Granite



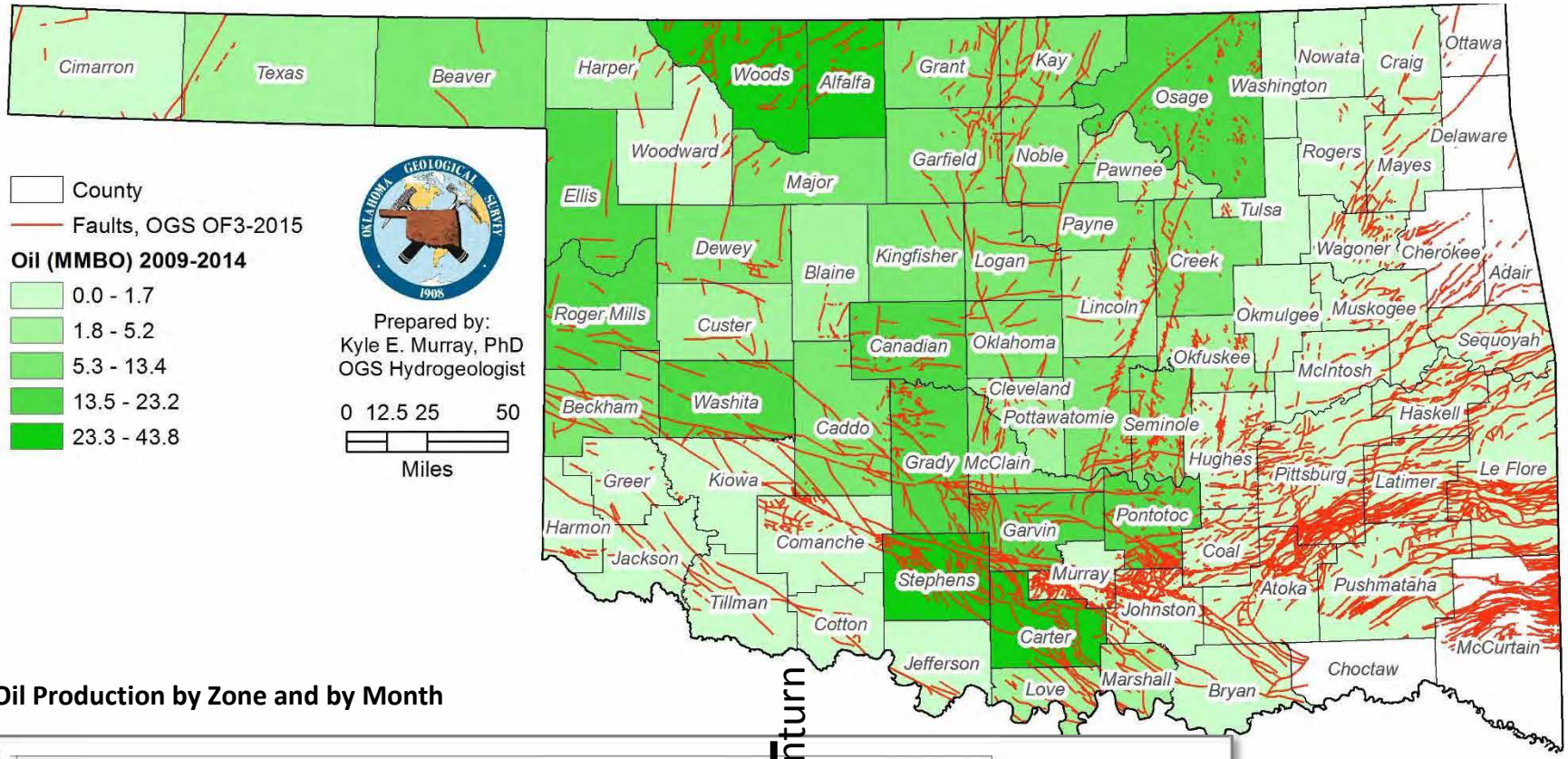
Wells that Started Producing from 2009–2015



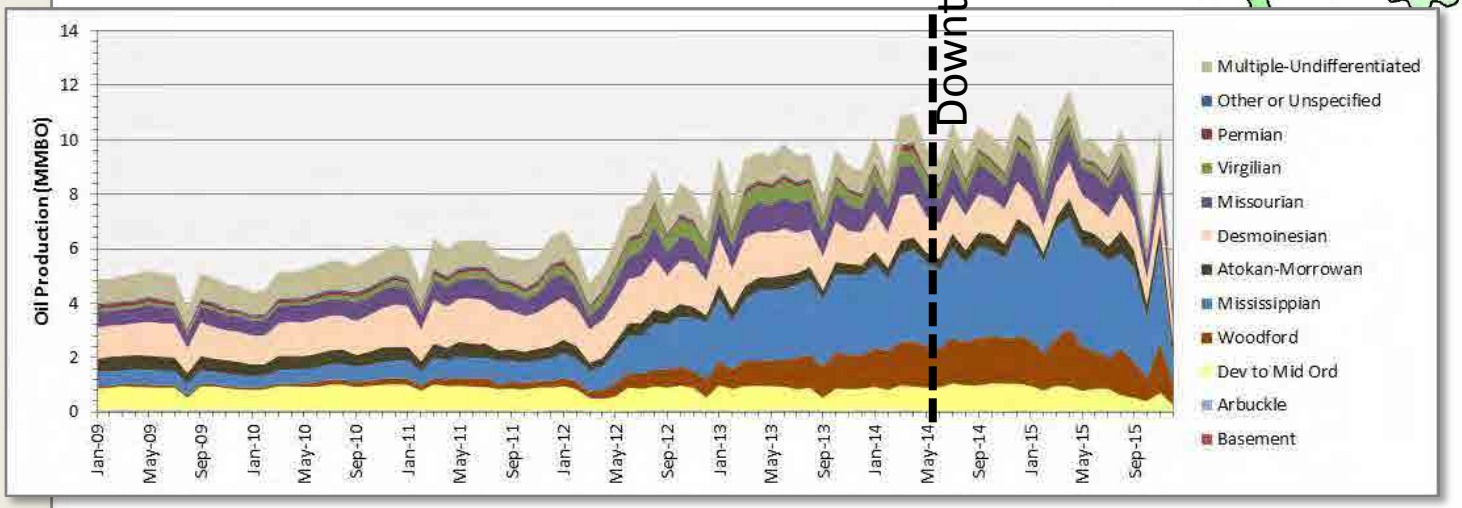
Completions by Zone and by Month, 2009–2015

(Murray, 2016 – in preparation)

Oil Production by County 2009–2014 and by Zone 2009–2015

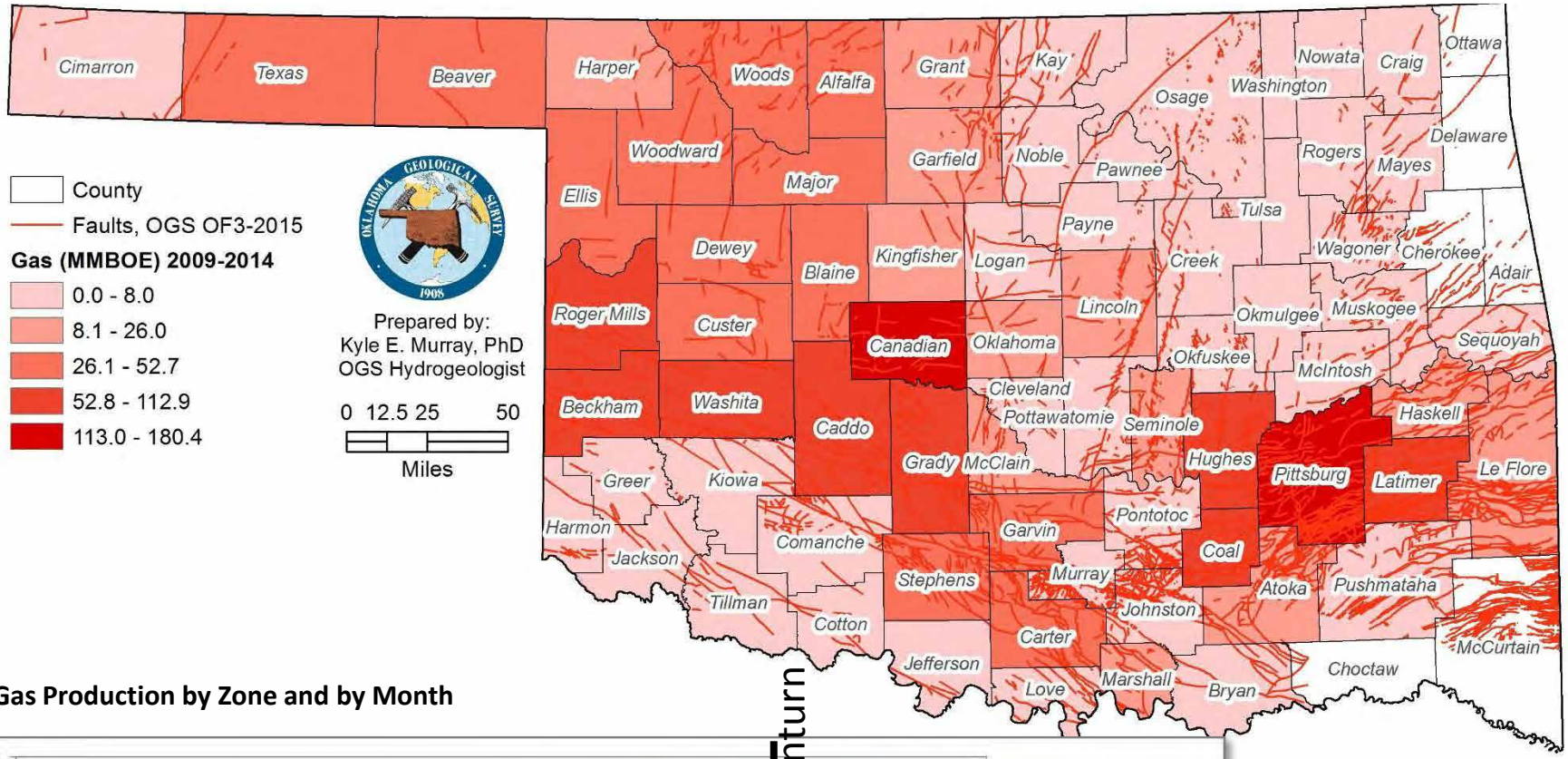


Oil Production by Zone and by Month

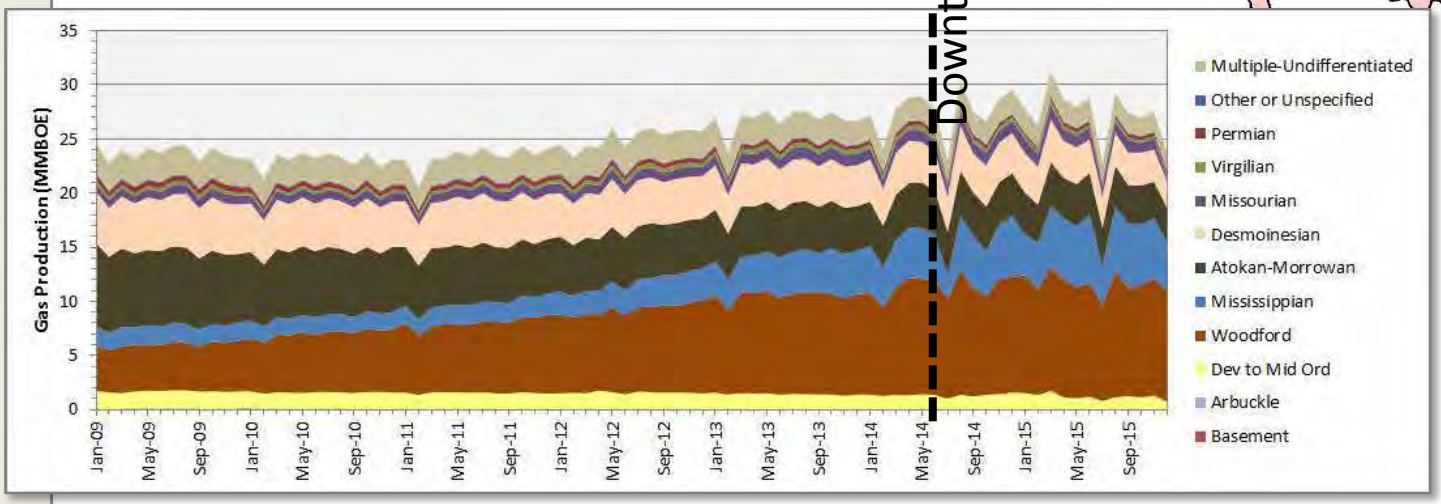


(Murray, 2016 – in preparation)

Gas Production by County 2009–2014 and by Zone 2009–2015

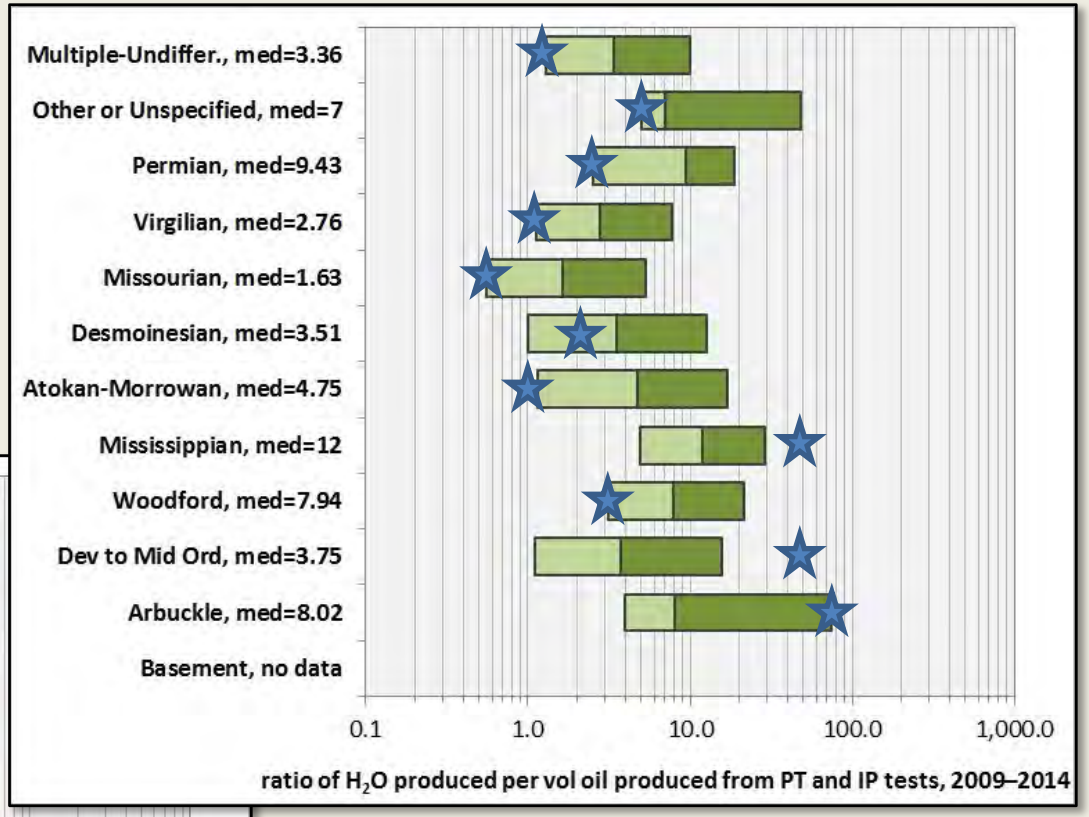


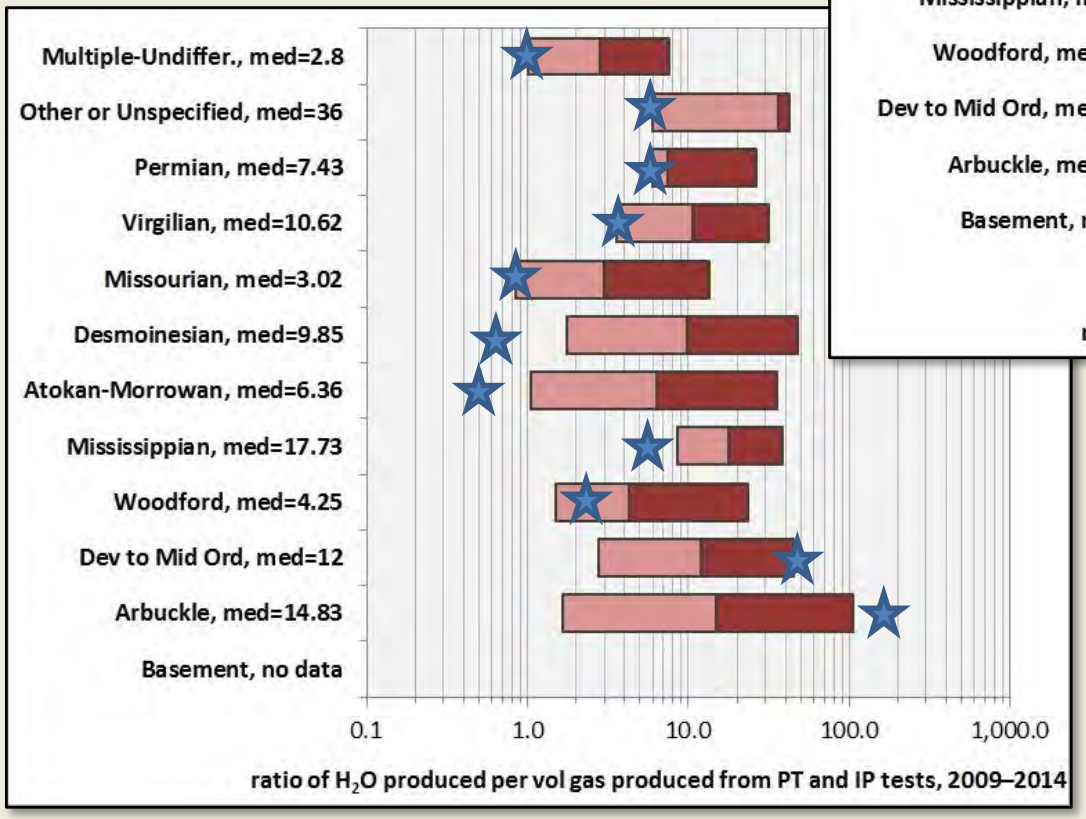
Gas Production by Zone and by Month



(Murray, 2016 – in preparation)

"Calibrated" ratios used to calculate produced H_2O from 2009–2015

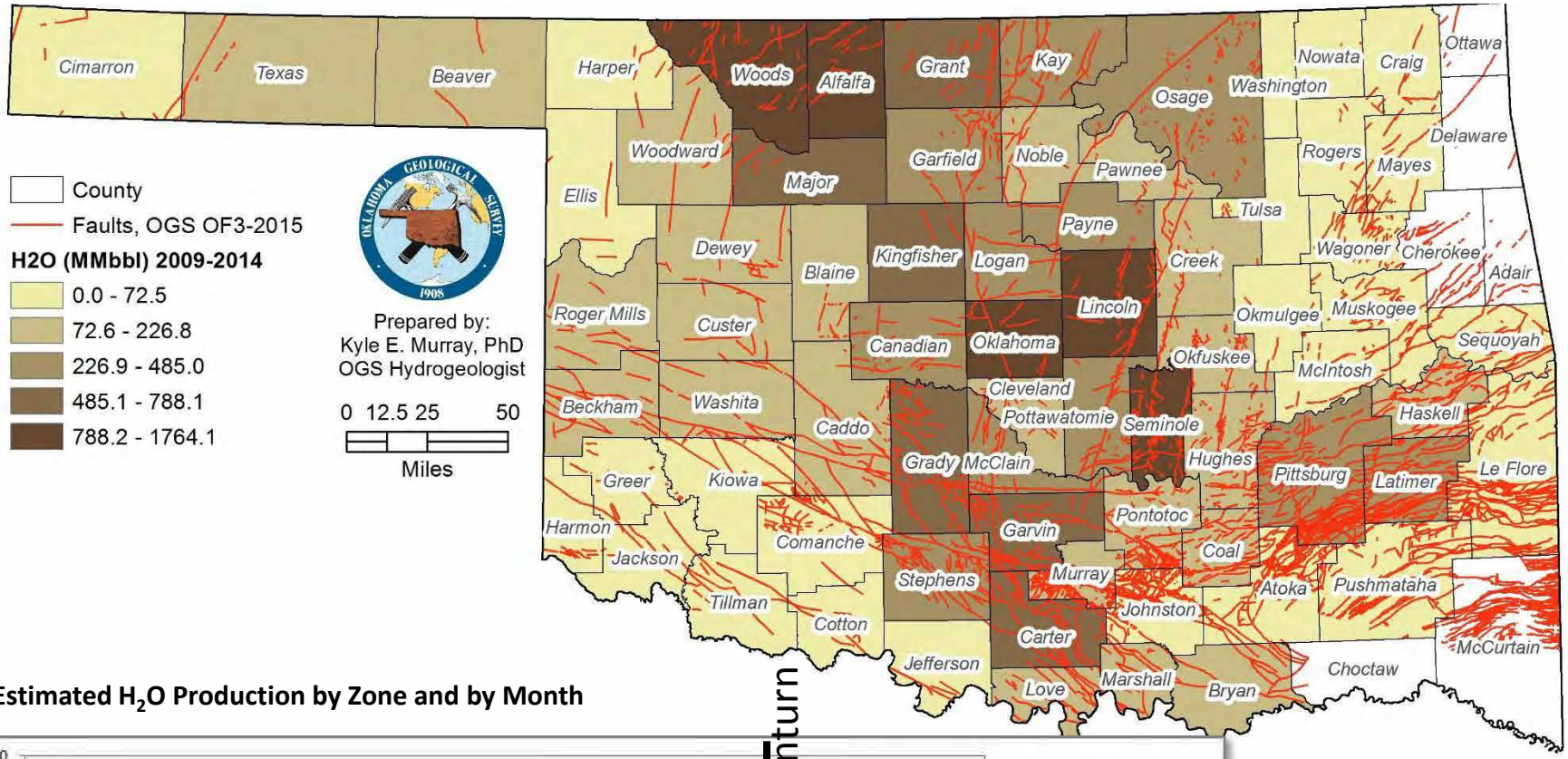




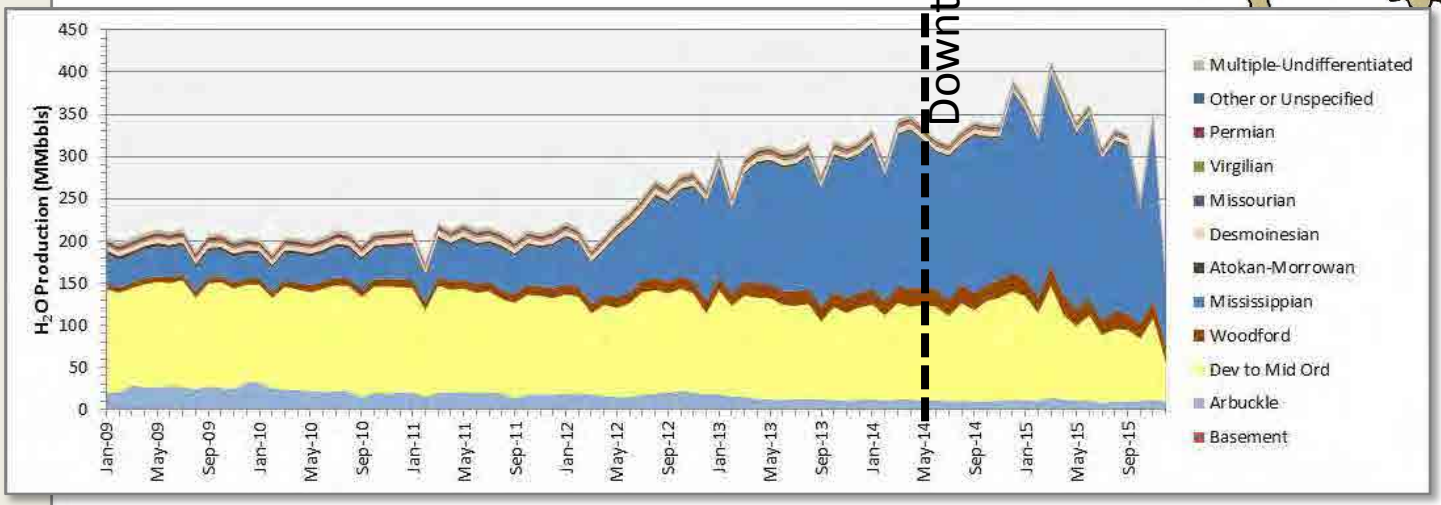
- Assume produced H_2O from County X is disposed into County X
- Compare produced H_2O vs. SWD
- Adjust H_2O:oil and H_2O:gas by zone to maximize r^2 value of produced H_2O vs SWD volume

(Murray, 2016 – in preparation)

Produced H_2O by County 2009–2014, and by Zone 2009–2015



Estimated H_2O Production by Zone and by Month



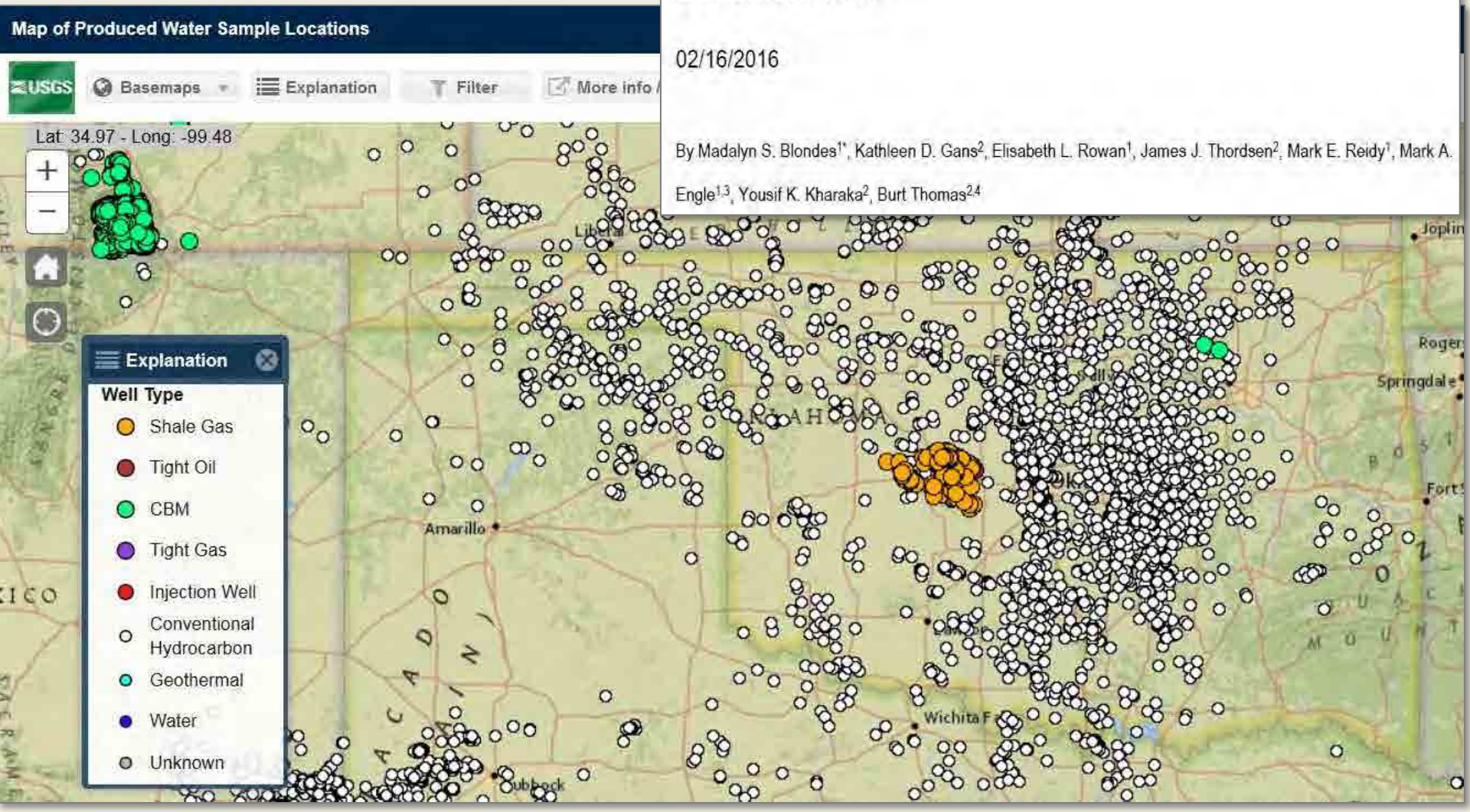
(Murray, 2016 – in preparation)

http://eerscmap.usgs.gov/pwapp/

U.S. Geological Survey National Produced Waters Geochemical Database v2.2 (PROVISIONAL) Documentation

02/16/2016

By Madalyn S. Blondes[1*], Kathleen D. Gans[2], Elisabeth L. Rowan[1], James J. Thordsen[2], Mark E. Reidy[1], Mark A. Engle[1,3], Yousif K. Kharaka[2], Burt Thomas[2,4]



TDS Concentrations in H_2O Produced from Oil & Gas Wells

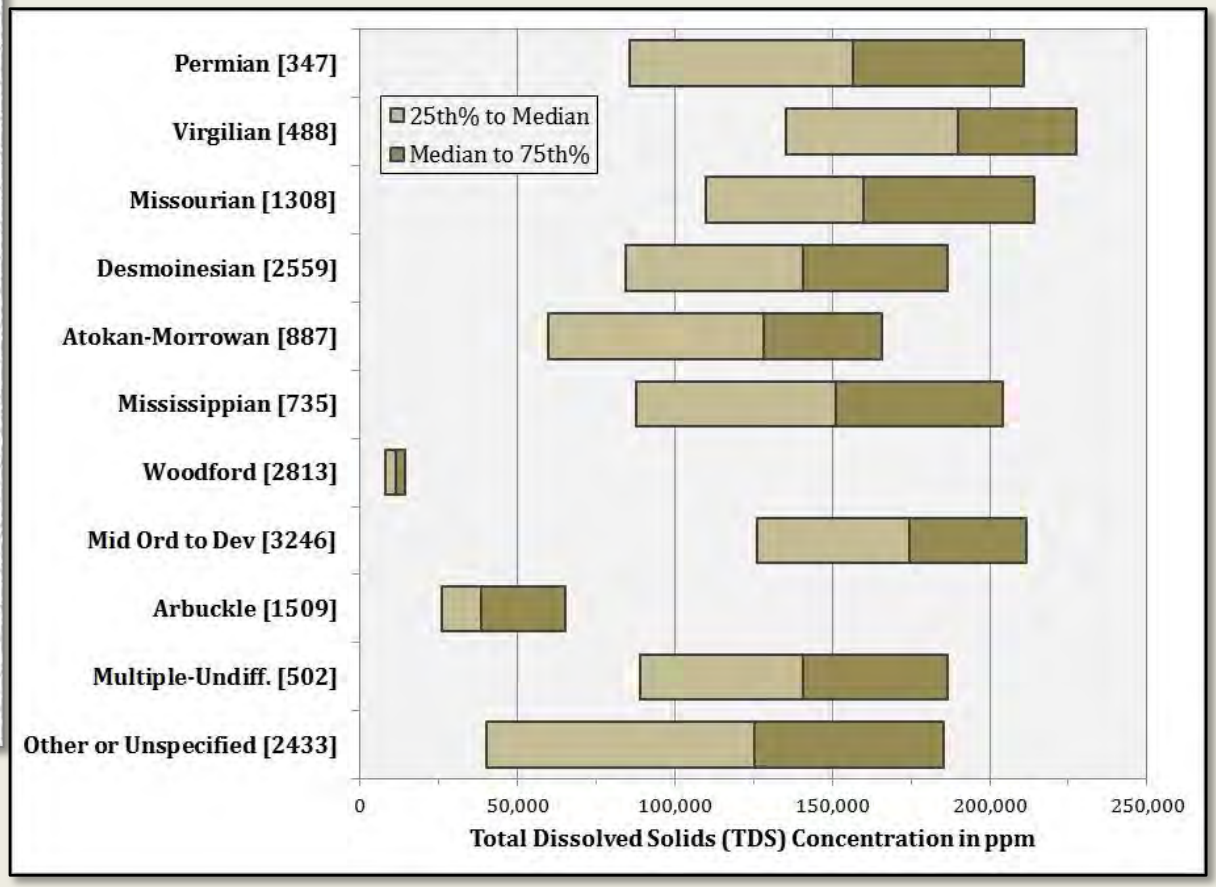
numWells	COUNTY	meanTDS	meanFe	meanCl
985	OSAGE	131478	59	80772
822	SEMINOLE	147630	34	90864
538	CREEK	139251	76	85743
507	OKLAHOMA	211358	161	129614
461	KAY	217863	145	134411
377	POTTAWATOMIE	154386	47	94441
319	STEPHENS	121926	57	74978
300	LINCOLN	181306	36	111673
297	BEAVER	95535	43	58522
265	GARVIN	164799	145	101382
255	NOBLE	229277	82	141757
251	LOGAN	213835	129	131787
232	CARTER	119608	24	73887
212	PONTOTOC	77727	37	47273
205	GARFIELD	228332	79	141576
200	OKFUSKEE	147245	107	90742
189	HARPER	193125	19	118811
171	BECKHAM	35597	110	20908
169	CADDO	128381	32	78786
155	HUGHES	142650	15	87675
152	MCCLAIN	220134	76	134795
150	KINGFISHER	143350	149	88221
148	PAWNEE	160483	38	98337
136	GRANT	231095	130	142478
133	PAYNE	190767	81	118758
131	CLEVELAND	198612	79	121555
111	GRADY	151809	119	93382

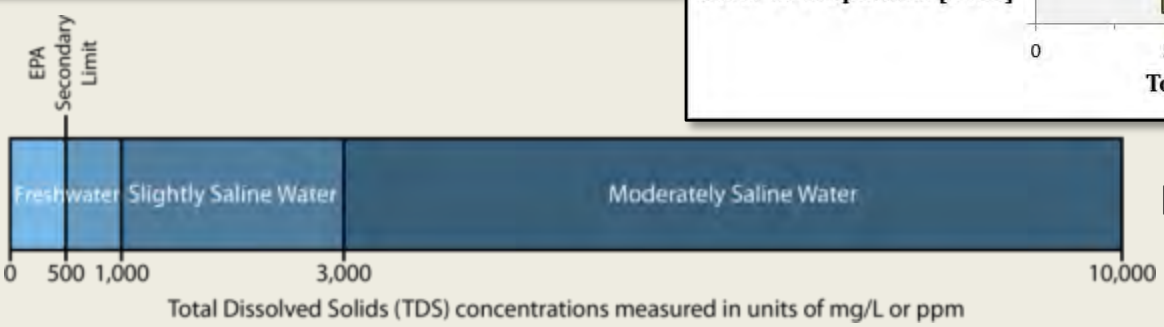
Data for:

pH, TDS, TSS, Ag, Al, As, Au, B, BO3, Ba, Be, Bi, Br

BrO_3, CO_2, CO_3, HCO_3, Ca, Cd, Ce, ClO_3, ClO_4, Cl, ClO_2, ClO

Co, Cr, Cs, Cu, F, FeTot, FeIII, FeII, FeS, FeAl, $FeAl_2O_3$, Ga…





BRINE

(Murray, 2016 – in preparation)

Comparison of Desalination Technologies

Technology	Feed Quality TDS (mg/L)	Process Recovery (%)	Energy Consumption (kWh/m^3)	Energy Cost ($/bbl)*	Product Quality TDS (mg/L)
Reverse Osmosis (RO)	< 45,000[b,e]	40–65[b]	4–6[d]	0.04–0.06	< 250[f]
Membrane Distillation (MD)	> 50,000[i]	65–95[g]	20.5–66.7[j]	0.19–0.63	< 50[i]
Multi-Effect Distillation (MED)	< 100,000[e]	20–35[b]	14–21[d]	0.13–0.20	< 10[d]
Multi-Stage Flash (MSF)	< 100,000[b]	10–20[b]	19–27[d]	0.18–0.25	< 10[d]
Mechanical Vapor Compression (MVC)	< 200,000[c]	40[a,b]	10.4–13.6[a]	0.10–0.13	< 10[b]

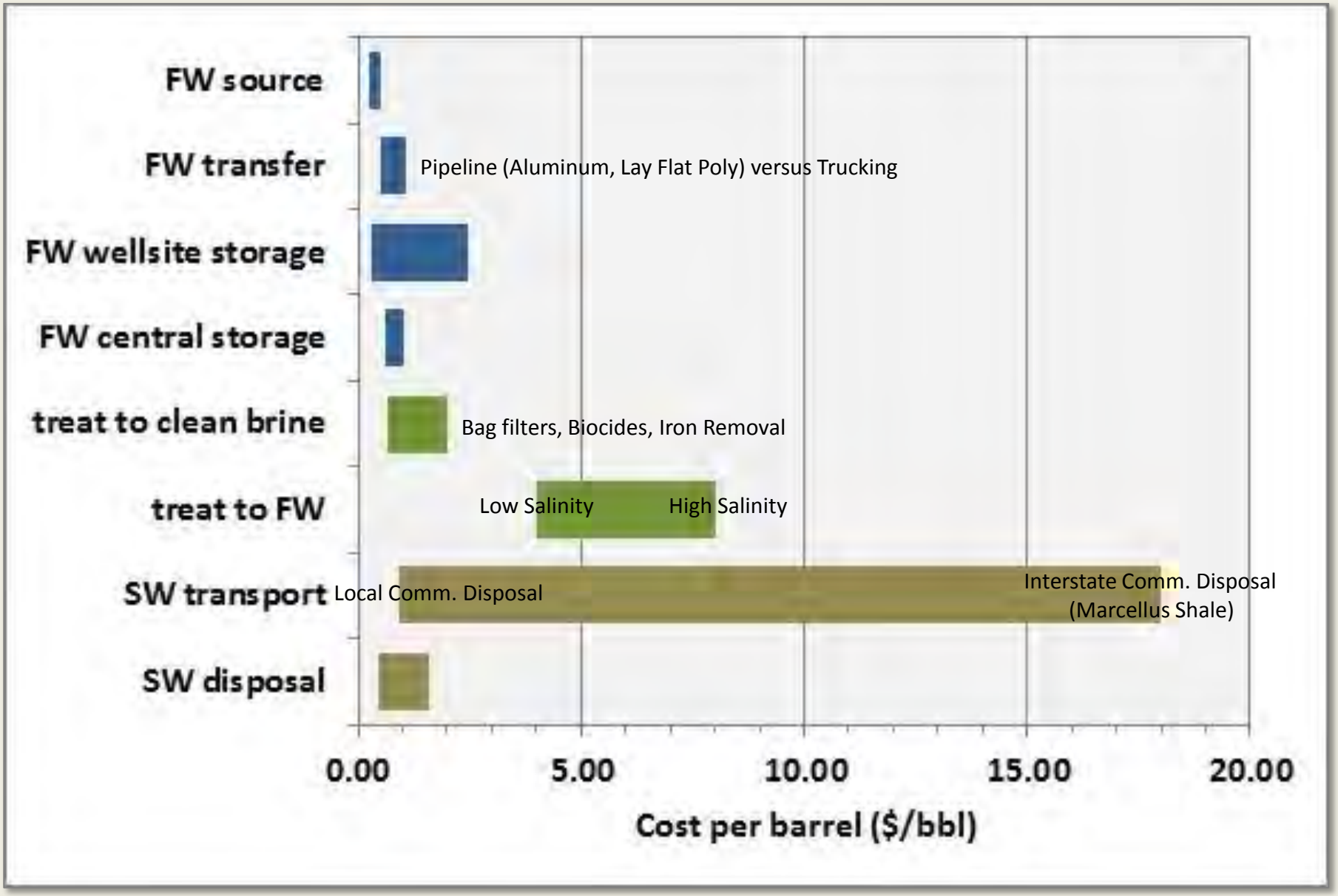
*Estimate based on industrial electricity cost: 5.92 cents/kWh[10]

References

a. Koren 1994
b. Watson et al. 2003
c. Shaffer et al. 2013
d. Al-Karaghouli et al. 2012
e. Fritzmann et al. 2007
f. Tonner 2008
g. Camacho et al. 2013
h. Colorado School of Mines 2009
i. U.S. Energy Information Administration 2014
j. Tarnacki et al. 2012

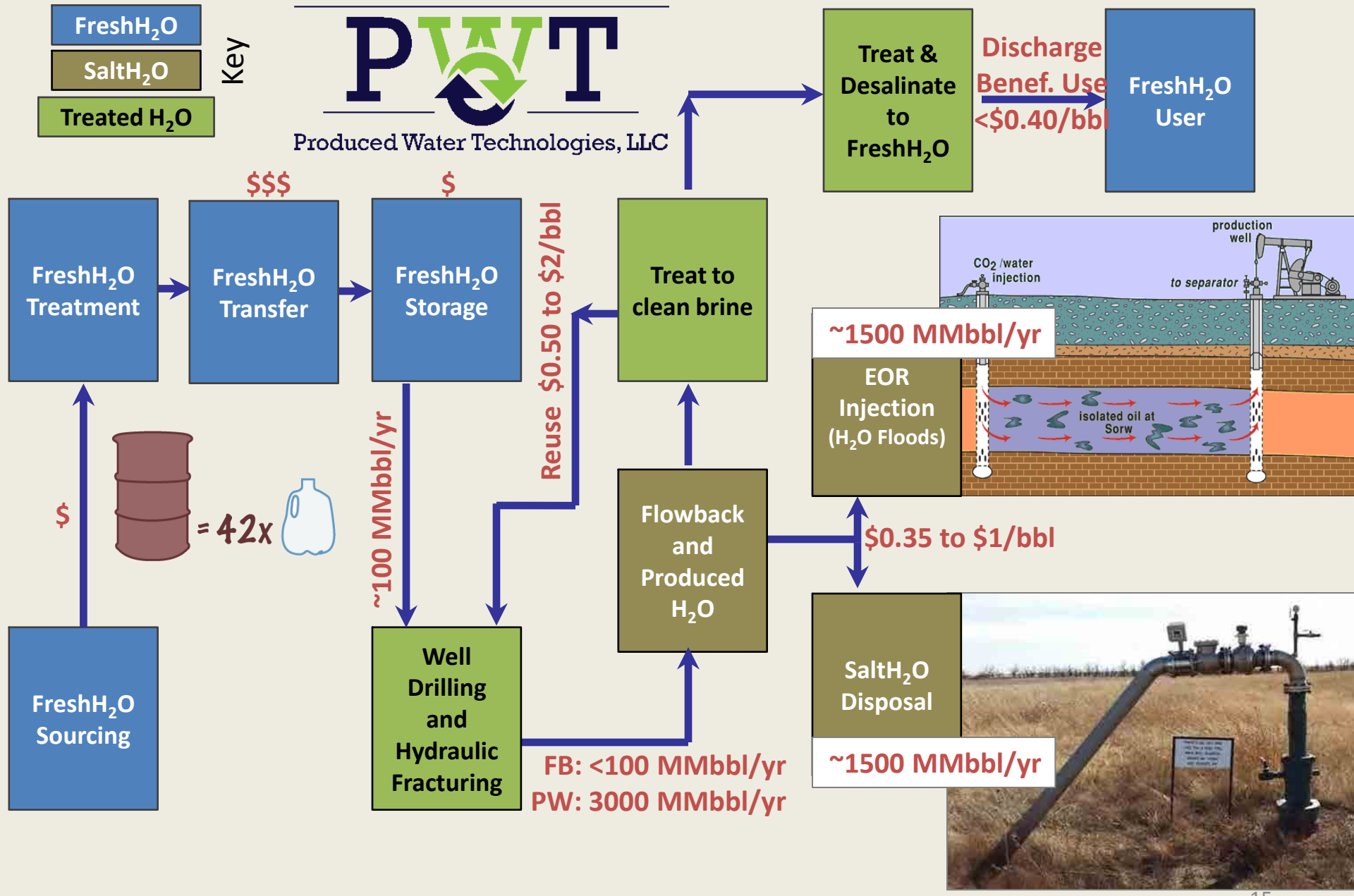
Murray et al, *in preparation*

Water Sourcing, Transfer, Treatment, and Disposal Costs in O&G



(from Kyle Murray presented on Sep 28, 2015 at Ground Water Protection Council meeting, Oklahoma City, OK)

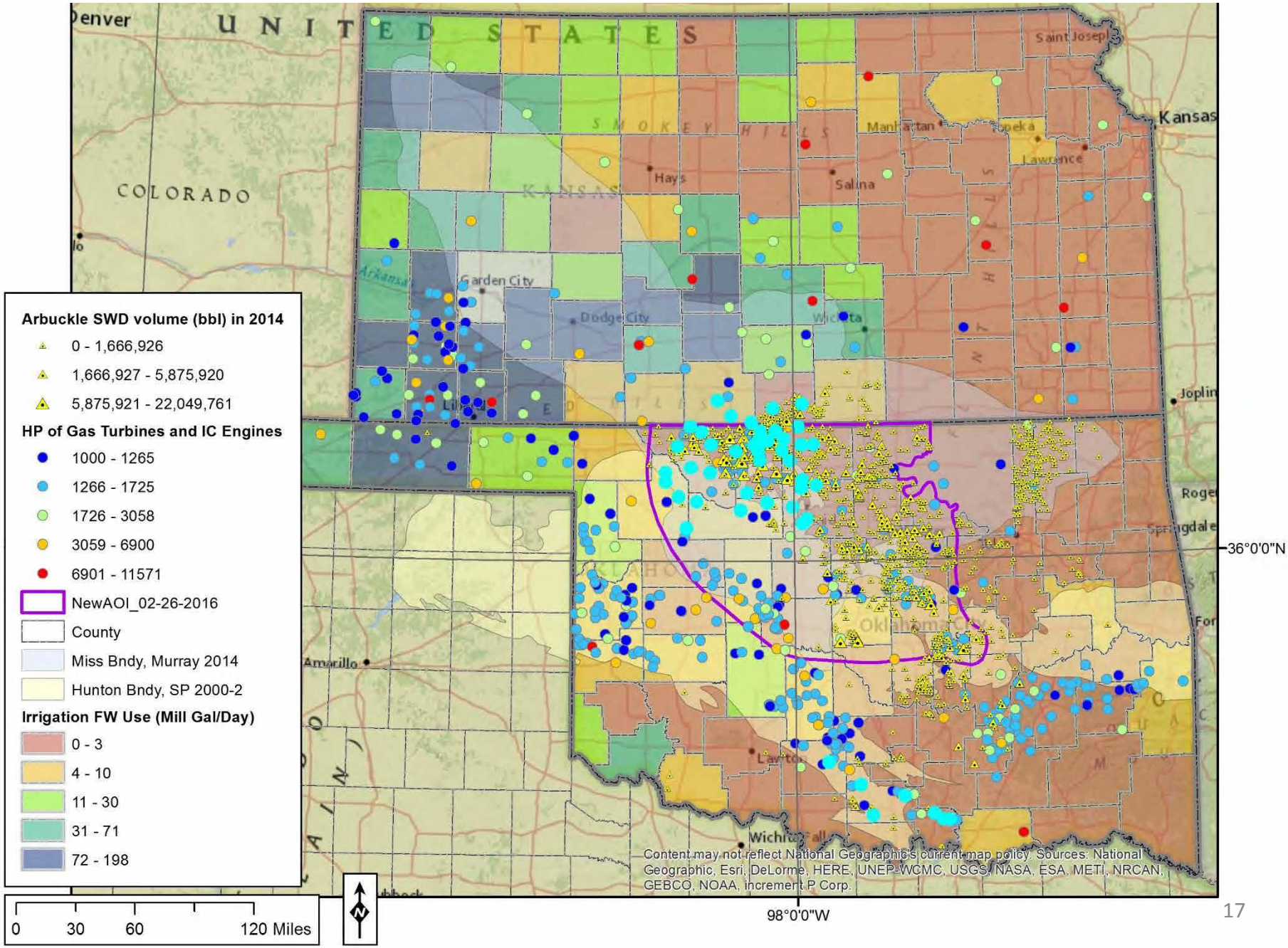
Water Sourcing, Transfer, Treatment, Reuse, & Disposal Flowchart



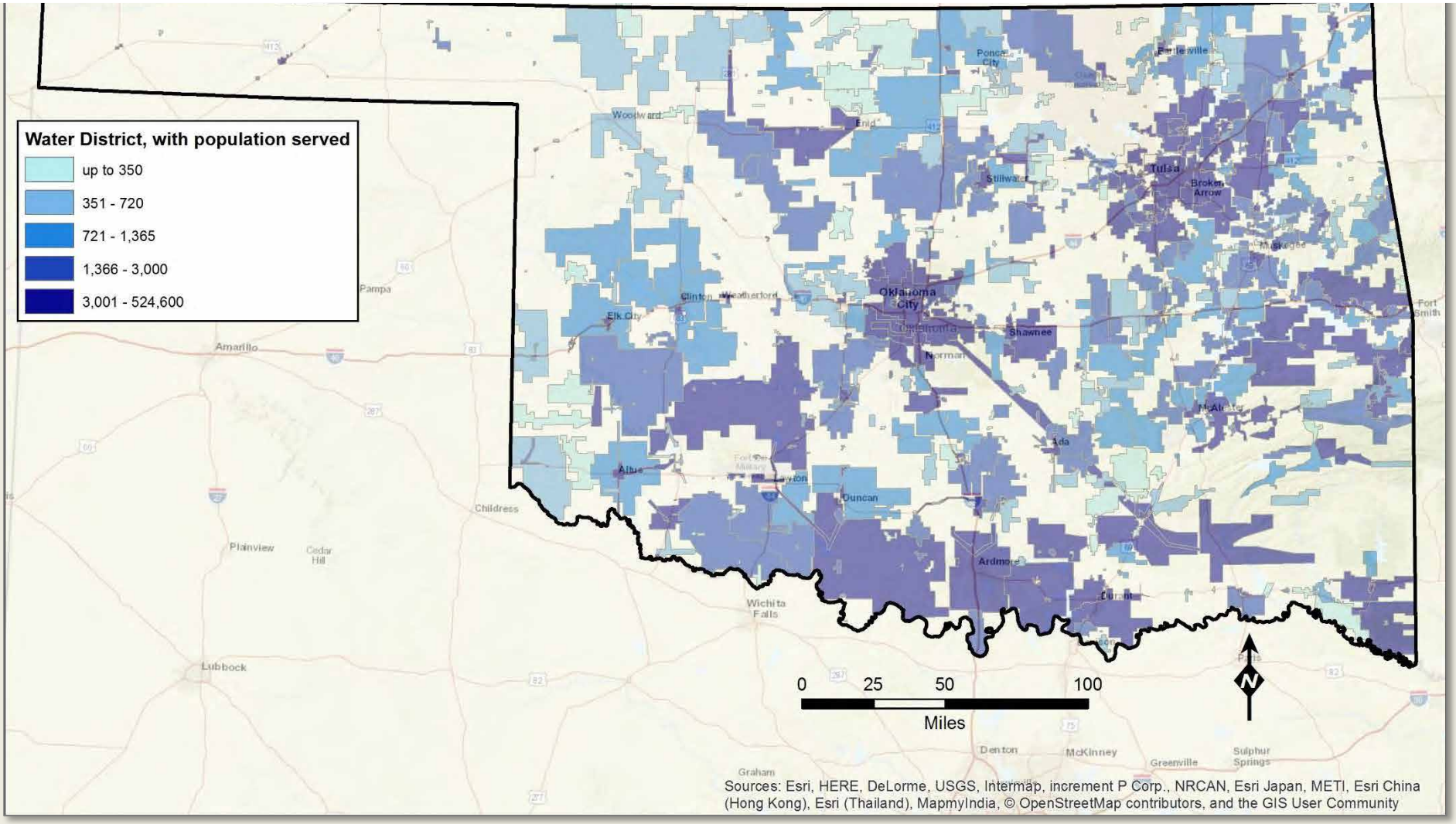
Multiple Stakeholders Must Cooperate/Collaborate

- SWD Operators (aka Oil, Gas, H_2O Producers)
- Mid-Stream Companies
- End Users of Treated/Distilled H_2O (aka Irrigated Agric., Water Districts, or Water Flood Operators)
- Produced H_2O Transfer Company (aka Service Companies)

Targa Compressors and Engines, freshwater Irrigation by County



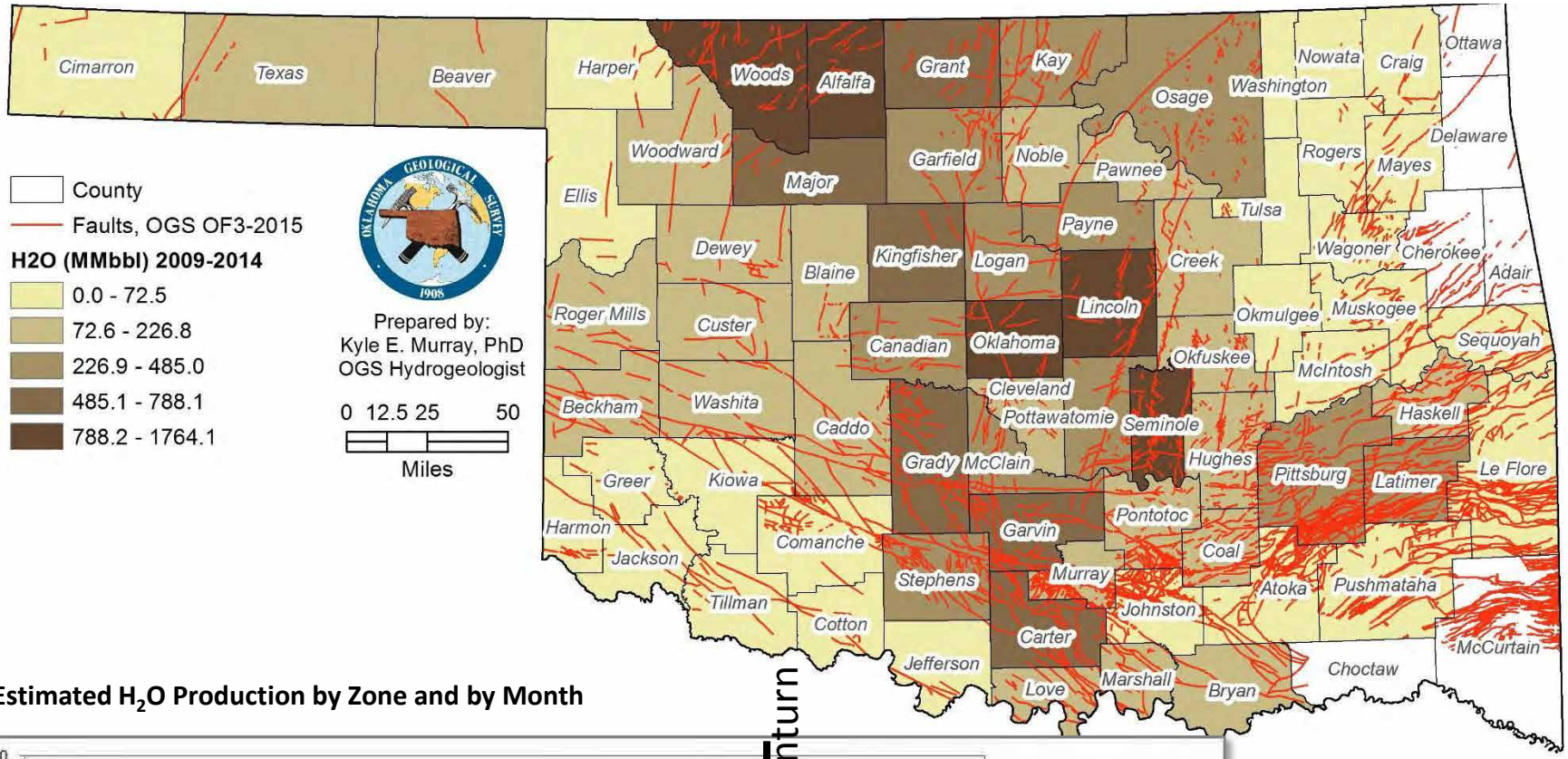
Oklahoma Water Districts



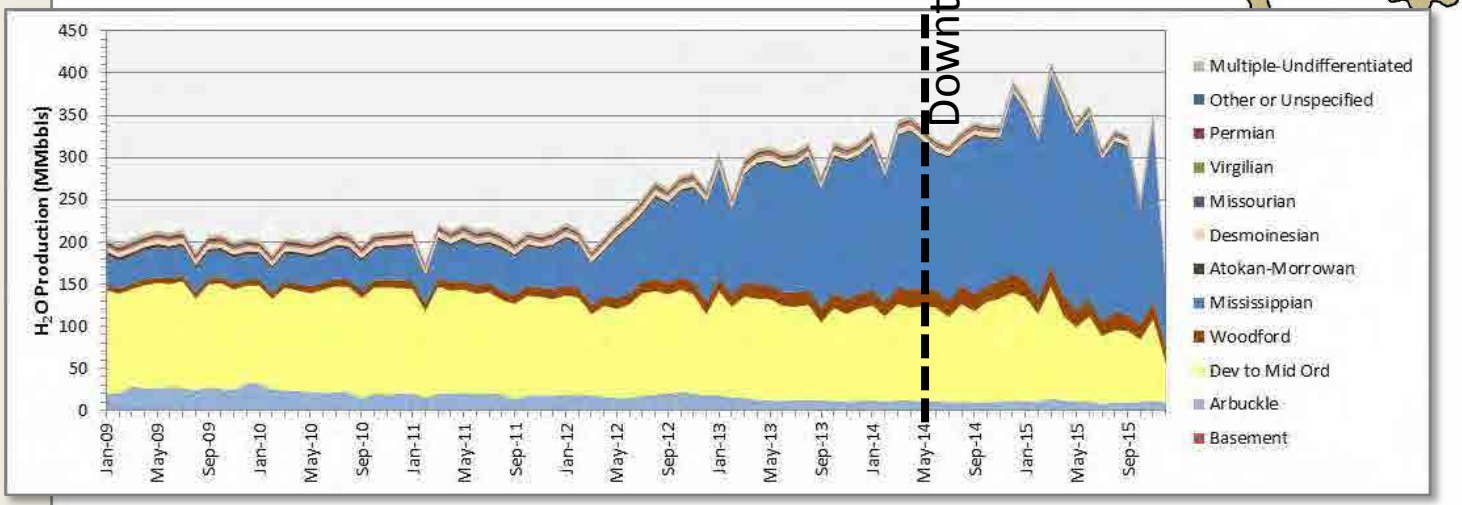
Countless Stakeholders Will Benefit

- SWD Operators (aka Oil, Gas, H_2O Producers)
- Mid-Stream Companies
- End Users of Treated/Distilled H_2O
- Produced H_2O Transfer Company (aka Service Companies)
- Drought-Prone Regions of Oklahoma
- Private Citizens & Public Health
- Oklahoma Economy

Produced H_2O by County 2009–2014, and by Zone 2009–2015



Estimated H_2O Production by Zone and by Month



(Murray, 2016 – in preparation)

Water for 2060
Produced Water Working Group

March 3, 2016

2:00 p.m.

Oklahoma Water Resources Board
3800 N. Classen Boulevard, Oklahoma City, OK

1. **Welcome and Introduction of Workgroup Members** — **J.D. Strong, Chairman**
   a. Responsibilities of the Workgroup
   b. Goals and Overall Timeline
   c. Overview of Path to Achieving Goals

2. **Energy Water Initiative Report: Recycling Flowback and Produced Water** — **Michael Dunkel, CH2M**
   a. Defining the problem

3. **Innovation Challenge at Cost and Scale** — **Michael Ming, GE Global Research**
   a. Structured approach to decision making

4. **Next Steps** — **J.D. Strong**
   a. Content Timing, Location of Future Workgroup Meetings

5. **Adjourn**

MEETING NOTES

WATER FOR 2060
PRODUCED WATER WORKING GROUP

Meeting #1 March 3, 2016
2:00 p.m.
Oklahoma Water Resources Board
3800 N. Classen Boulevard, Oklahoma City, OK 73118

J.D. Strong, Executive Director of the Oklahoma Water Resources Board, and Chairman of the Water for 2060 Produced Water Working Group (PWWG), welcomed the members and attendees to the first meeting of the Group. He stated Governor Fallin had announced establishment of the PWWG on December 1, 2015, and charged the Group with discussing opportunities and challenges associated with treating produced water for beneficial uses to save fresh water by reusing and recycling oil and gas produced water, particularly alternatives to deep well disposal.

Chairman Strong set the stage for the Group's work saying members will meet to solve problems in a relaxed atmosphere, there is no schedule to meet, nor reporting requirements. He distributed copies of the "Water for 2060" brochure and noted the Water for 2060 Advisory Council's "Energy and Industry Recommendation 3: Promote Industrial Use of Marginal Quality Water" with the goal of increasing the use of marginal quality water supplies in industrial application. There is no legislative action required, and costs are associated with state agency staff time. The effort of the PWWG is a step toward implementing this recommendation, and with the current decline in the industry, the challenge will be to recommend reuse and recycling produced water while minimizing cost to the industry. The Group will be looking at gathering information and input on technological processes and barriers, as well state and federal regulatory structures for produced water.

Chairman Strong asked everyone to make self-introductions. Members of the PWWG in attendance were: Bud Ground, Environmental Federation of Oklahoma; Jeff Everett (for Usha Turner), OG&E Energy Corporation; Jesse Sandlin, Oklahoma Oil & Gas Association; Mike Mathis, Oklahoma Independent Petroleum Association; Michael Dunkel, CH2M; Mike Ming, GE Global Research; Mike Paque, Groundwater Protection Council; Fred Fischer, Oklahoma Panhandle Agriculture & Irrigation Association; Secretary of Agriculture Jim Reese; Tim Rhodes, Oklahoma Corporation Commission; Scott Thompson, Oklahoma Department of Environmental Quality; Brent Kisling, Enid Regional Development Alliance; Alan Riffel, Oklahoma Municipal League; Mark Matheson, Oklahoma Rural Water Association; Chad Penn, Oklahoma State University; and Terry Stowers, Coalition of Oklahoma Surface & Mineral Owners.

Mr. Michael Dunkel, CH2M, presented to the Group "Options to Produced Water Disposal" defining the problem of too much produced water, cutbacks to injections, and needing to explore economically viable alternatives. He provided conversions for consideration, and discussed in detail with members the current options for dealing with produced water and associated results: reuse for oil and gas as clean brine →transfer (transportation by truck and pipeline) and storage; reuse for other industry as brine; desalinate to "fresh water" →reuse for agriculture or other industry; discharge; and forced evaporation which creates a need to dispose of concentrated brine. Concluding his presentation, he talked about the information needed for moving forward, i.e., water quantity and quality, identifying industries that could use water, costs for permanent pipe volumes and distances, costs for trucking and transfer lines, and assessment of regulatory and legal issues, and what help the State and regulators can do.

Mr. Mike Ming, GE Global Research, presented to the Group "Innovated Challenge to Cost and Scale" which concerned finding ways to use the water, a comparison of water needs and produced water generation, noting not all use is needed in the same quality. He emphasized the problem needs to be assessed by breaking it down into manageable pieces. Fossil fuel and hydrocarbons still provide the largest amount of energy in the world; fresh water is drying up, energy is needed for desalination, shale gas in North America is in water constrained areas, coal-fired energy requires a lot of water to cool, so the needs for water is not decreasing and in Oklahoma drought is a major consideration. Water management technology strategies should be developed for the purpose of the water, and to meet short term needs while ensuring a long-term reliable water-energy supply. Factors to consider are risk, cost, energy, food, water, with outcomes being actionable. The response to market challenges is to develop the roadmap for moving forward by considering technology and design, extending digital industrial capabilities, and creating appropriate business models. Technology management is key to determining what will be done and what won't through feasibility, viability and desirability, and developing policy for innovative management to create new markets for production while meeting the Water for 2060 goals.

Following the presentations, the members discussed options in technology, current processes and uses, the value of aquifer storage recovery, and what information would be useful in developing a strategy forward. Summarizing, Mr. Strong said the OWRB will provide a webpage for the PWWG under its current "Water for 2060" page and include the presentations from today's meeting, as well as other pertinent presentations from GWPC's recent UIC conference in Denver, and the Energy Water Initiative by CH2M:

- U.S. Onshore Unconventional Exploration and Production Water Management Case Studies (Prepared for the Energy Water Initiative)
- Produced Water Reuse and Recycling: Role in Long-term Water Sustainability
- Agricultural Reuse of Treated Produced Water
- Water Associated with Oil & Gas Development and Long Term Water Sustainability Strategies. (Environmental Defense Fund)

Information/tasks the group will be gathering for future presentations include:

- Survey of what other states are doing
- Assess volume and quality of what water is being produced (invite Kyle Murray at the Oklahoma Geological Survey to make a presentation at the next meeting)
- Inventory potential users/uses of produced water; DEQ's GIS-based tool showing available quantities of municipal waste water as a model
- What is the current cost to oil and gas industry for produced water disposal.
- Landowner/ownership and liability issues (in regard to aquifer storage and recovery)
- Assessment of state and national situation, current regulatory framework and what is needed to bring the companies together (barriers).

Chairman Strong concluded the meeting stating he anticipated the group would meet in about two months, and he thanked everyone for their participation and attention.

OWRB Produced Water Group - Options to Produced Water Disposal

March 3, 2016

ch2m SM

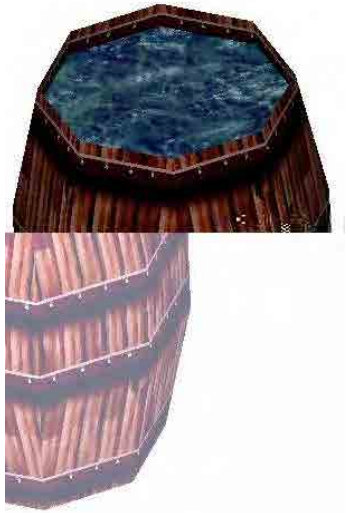
Defining the Problem

- Too much produced water compared to underground injection capacity (disposal)
- Oil and Gas - economic pressure from low prices
- Cutbacks to produced water injection may impact companies, jobs and the state's revenue
- What are the economically viable alternatives?

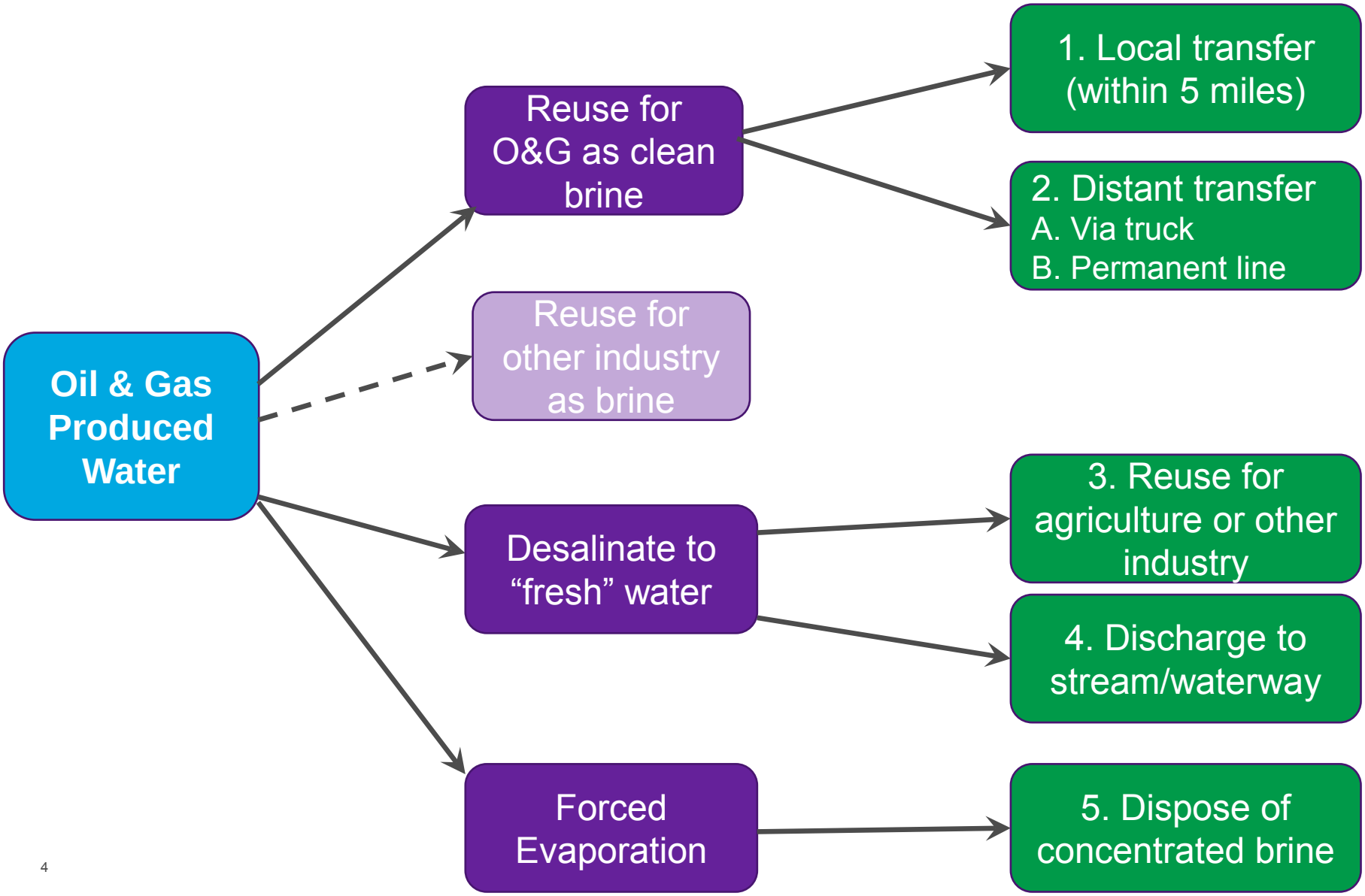
Conversions for Consideration

Various water group sectors use different water quantity metrics:
1 barrel of water (BW) = 42 Gallons
1,000 BW = 42,000 Gallons
10,000 BWPD = 0.42 Million Gallons per Day (MGD)
10,000 BWPD = 40.1 Cubic Feet per Second (CFS)
10,0000 BW = 1.29 Acre-Feet (AF)
1,000 Gallons = 23.8 BW
1,000 Gallons per day = 1,858 CFS
100,0000 gallons = 0.309 AF

1 Ton of water = 1 Ton of cotton



Options Overview



1. O&G Reuse within 5 miles

Process

- Treat water for-purpose (clean brine)
- Transfer water via temporary line on surface
- Store water at well site
- Total cost: $2 to $4/BW*

Viability

- Limited to rig activity within about 5 miles
- This is already being done where possible

*Disclaimer: All costs are conceptual and for internal comparison only. More detailed analyses needed.

2A. O&G re-use - Distant Transfer via Truck

Process

- Treat water for-purpose (clean brine)
- Transfer water via truck
- Store water at well site
- Total cost: $4 to $10/BW

Viability

- Costly due to treatment and trucking
- More trucks on roads create other problems

2B. O&G Re-use Distant Transfer via Permanent Line

Process

- Treat water for-purpose (clean brine)
- Transfer water via buried line
- Store water at well site
- Total cost: $2 to $6/BW

Viability

- Large volumes needed to make permanent lines pay out
- Multi-company network could improve economics with larger volumes

3. Desalinate – Use for Ag or Other Industries

Process

- Desalinate to “fresh” water standard
- Transfer water via temporary or permanent line
- Total cost: $4 to $10/BW

Viability

- Plant cost is high, or per barrel treatment high
- Generates solid waste removed from brine
- Regulatory issues?
- Commercial complexity

Top Industries in Oklahoma*

1. Energy – 20% Oil & Gas; Wind energy
   A. Refinery at Ponca City
2. Information & Finance – 70+ Data Centers, Software
3. Transportation & Distribution – Railroads, airports…
4. Agriculture & Bioscience – Food manufacturing, R&D, fertilizer manufacturing
   A. Koch fertilizer plant in Enid
5. Aerospace & Defense –
   A. Tinker Air Base (OKC),
   B. American Air in Tulsa
   C. Vance Air Base near Enid
6. Other –
   A. OSU in Stillwater

© Infobase Learning

*Source – Oklahoma Dept. of Commerce & Wikipedia

4. Desalinate and Discharge to Waterway

Process

- Desalinate to “fresh” water standard
- Discharge to waterway (NPDES permit)
- Total cost: $4 to $8/BW

Viability

- Plant cost is high, or per barrel treatment high
- Generates solid waste removed from brine
- Removes transport to user, but also removes value due to no water buyer

5. Forced Evaporation & Concentrated Brine Disposal

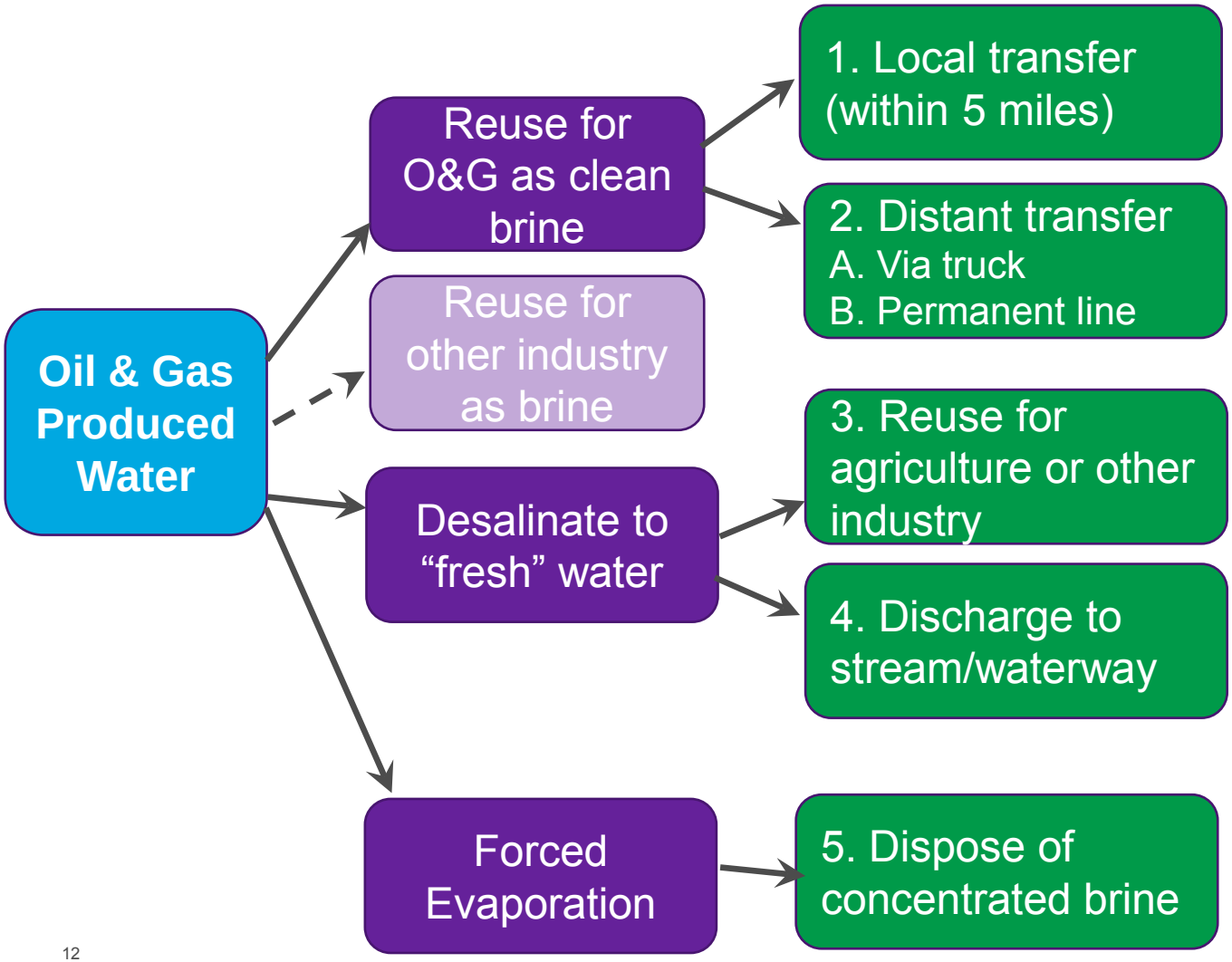
Process

- Forced evaporation reduces volume
- Significant storage area needed
- Concentrated brine still must be disposed
- Total cost: $3 to $6/BW

Viability

- Has not been performed on large scale
- Overspray of produced water is hazard
- No value generated from evaporated water

Options Overview



	Cost $/BW	Other
1. Local transfer (within 5 miles)	2 – 4	Limited volume
2. Distant transfer A. Via truck	4 – 10	Trucking impact
2. Distant transfer B. Permanent line	2 – 6	Lg. vol. needed
3. Reuse for agriculture or other industry	4 – 10	Solid waste, Regulations
4. Discharge to stream/waterway	4 – 10	Solid waste
5. Dispose of concentrated brine	3 – 6	Untried, overspray, lost water

Information Needed for Assessment

1. Water quantity & quality available from O&G
2. Industries in north central OK that could use water
   A. Quantity and quality needed
3. Costs for permanent pipe volumes and distances
4. Costs for trucking and temporary lines
5. Assessment of regulatory and legal issues

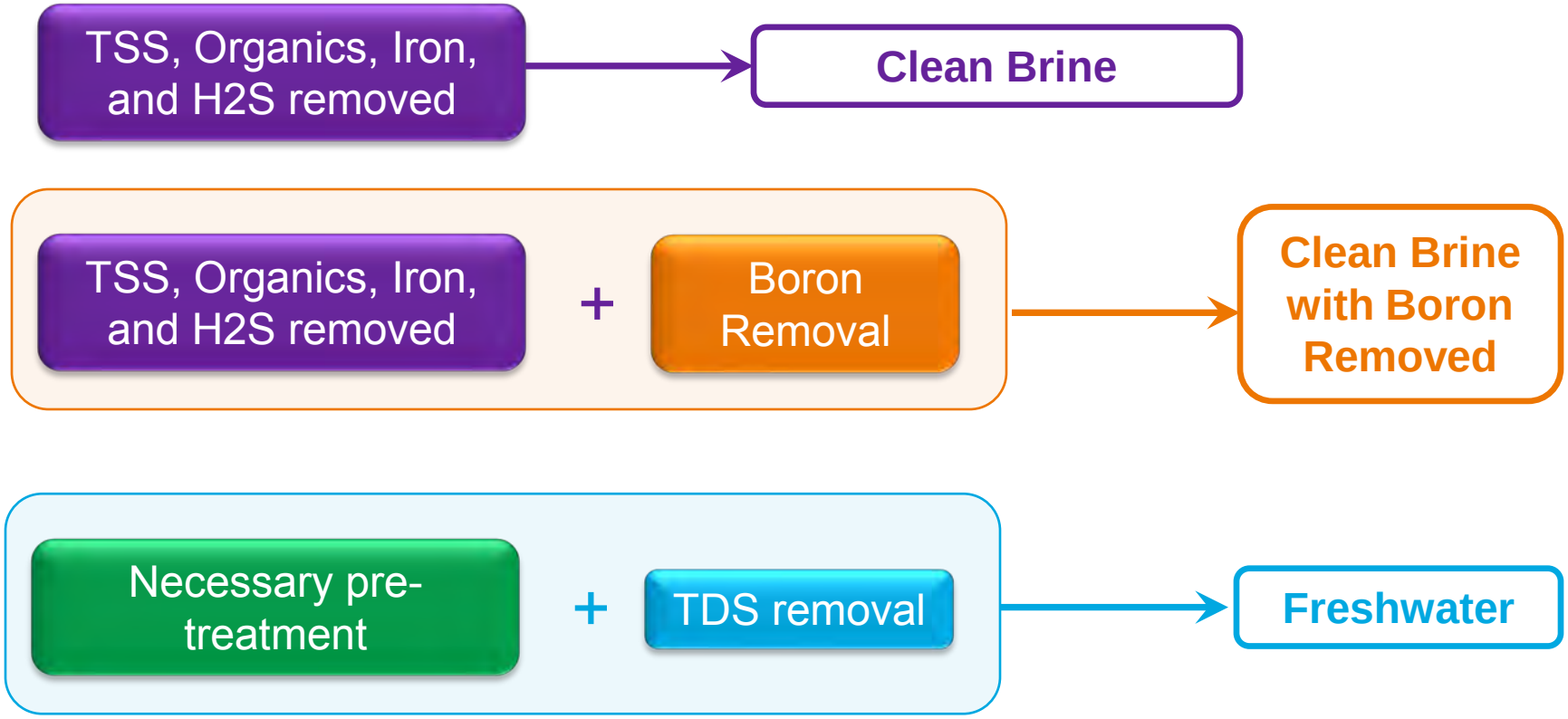
© Infobase Learning

How can the State help?

1. Help gather basic data
2. Assessment of state and national oil & gas water management
3. Bring companies together for opportunities
4. Regulatory framework

Thank You

Types of produced water treatment



Innovation Challenges at Cost & Scale

GE Oil & Gas Technology Center
March 3, 2016

Imagination at work.

Innovation Challenges at Cost and Scale

Water for 2060 Initiative

Comparison of water needs & produced water generation

By Sector

- **Oil & gas**
- Thermo-electric
- Agriculture
- Manufacturing
- Municipalities

By Region

- Infrastructure
- Logistics
- Energy mix
- Waste mgt.
- Regulatory/legal

© 2016 General Electric Company - All rights reserved

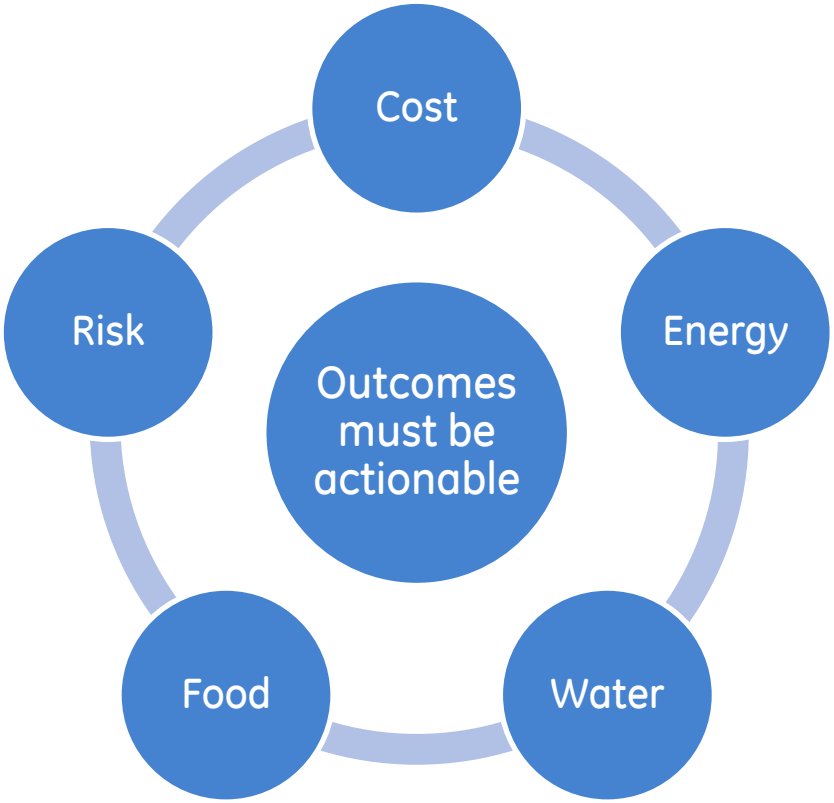
Fit-for-Purpose Strategy

Water management technologies and strategies[1]

Tier 1: Minimize the volume of produced water volumes brought to surface

Tier 2: Reuse and repurpose produced water

Tier 3: Reduce disposal to Class II SWD wells



Water Conservation | Energy Consumption Reduction & Efficiency | Industrial-Scale Solutions | Statewide Resource Transformation

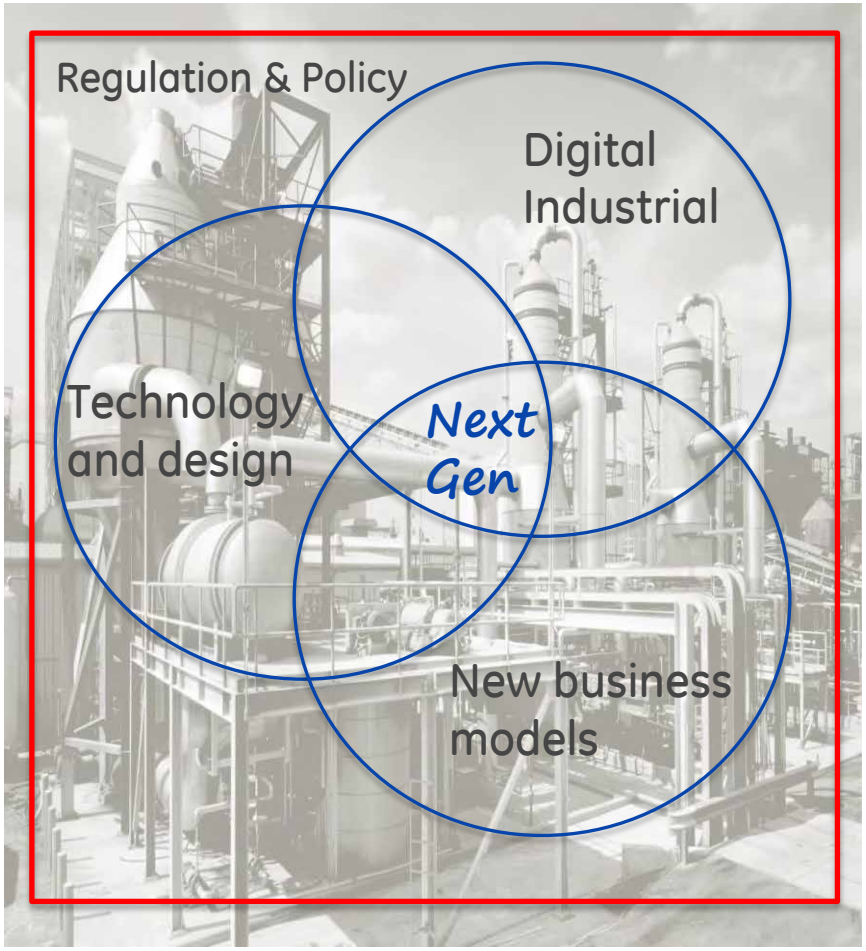
Meet short-term needs and ensure long-term reliable water-energy supply.

1: U.S. Produced water volume and management practices in 2012 (Veil, 2015)

© 2016 General Electric Company - All rights reserved

GE Response to Market Challenges

Innovation pillars



Roadmap & path forward

Technology & Design

- Modularization and structuring footprint and cost reduction
- Process optimization
- Advanced materials, robotics, additive manufacturing

Extending Digital Industrial

- Automation and robotics
- Remote/unmanned operations
- Process/production flexibility
- Prediction/optimization

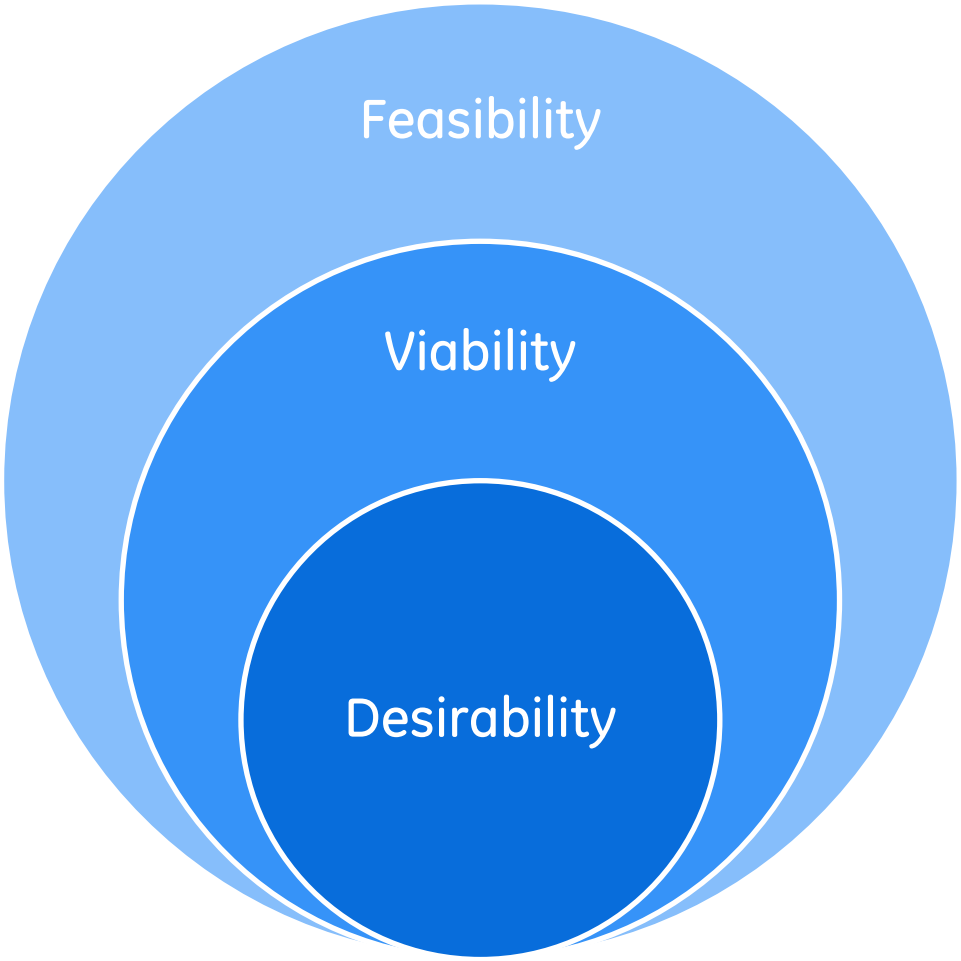
Business model (e.g.)

- BOO, leased equipment, service
- Pay for performance

© 2016 General Electric Company - All rights reserved

Technology Management

Determining what we will and won't do and why



Feasibility

- Technical Reality

Viability

- Commercial Value
- Willing Stakeholders
- Commercial Plan

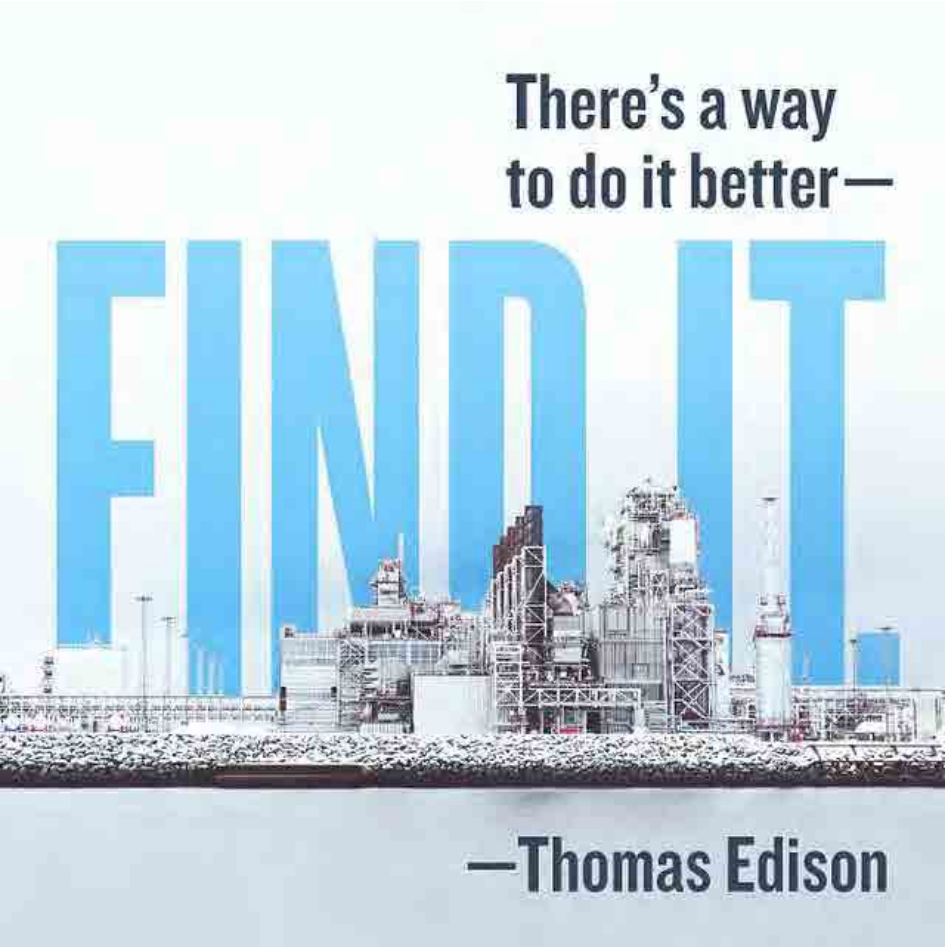
Desirability

- Enabling the Digital Age
- Optimizing Industry Operations
- Transforming the Industry
- Maintaining Industry's Social License to Operate
- Enhancing the Value of Oil & Gas in the Energy System
- Creating New Markets for Production

imagination at work

© 2016 General Electric Company - All rights reserved

Fall in love with the *Problem*, not the solution….



MISSION

Use no more fresh water in 2060 than was used in 2012, while supporting Oklahoma's continued growth and prosperity.

© 2016 General Electric Company - All rights reserved

Appendix B
Produced Water Data and Estimate Detail

Produced Water Injected Per County

Source: 2015 UIC Injection Volumes Report_Incomplete.xlsx

County	Total Barrels of Produced Water Injected (December 2015)	Produced Water Injected Barrels Per Day (December 2015)
ALFALFA	18617345.53	600,559.53
BEAVER	1223217	39,458.61
BECKHAM	692007	22,322.81
BLAINE	795986.16	25,676.97
BRYAN	0	-
CADDO	1118963	36,095.58
CANADIAN	2050557	66,147.00
CARTER	32276374	1,041,173.35
CIMARRON	135646	4,375.68
CLEVELAND	173508	5,597.03
COAL	685569	22,115.13
COMANCHE	30176	973.42
COTTON	541516	17,468.26
CRAIG	11724	378.19
CREEK	14735160.55	475,327.76
CUSTER	392947	12,675.71
DEWEY	3805616	122,761.81
ELLIS	916568	29,566.71
GARFIELD	4550592.5	146,793.31
GARVIN	5176001.24	166,967.78
GRADY	1696480.3	54,725.17
GRANT	3394572.91	109,502.35
GREER	525	16.94
HARMON	1085	35.00
HARPER	403695	13,022.42
HASKELL	449	14.48
HUGHES	2230739	71,959.32
JACKSON	145746	4,701.48
JEFFERSON	468253	15,104.94
KAY	5385286	173,718.90
KINGFISHER	2008227	64,781.52
KIOWA	12925	416.94
LATIMER	63716	2,055.35
LEFLORE	20678	667.03
LINCOLN	4645787	149,864.10
LOGAN	2039600.14	65,793.55
LOVE	342203	11,038.81
MAJOR	609271.5	19,653.92
MARSHALL	28651	924.23
MAYES	10297	332.16

Produced Water Injected Per County

Source: 2015 UIC Injection Volumes Report_Incomplete.xlsx

County	Total Barrels of Produced Water Injected (December 2015)	Produced Water Injected Barrels Per Day (December 2015)
MCCLAIN	422204.9	13,619.51
MCINTOSH	289679	9,344.48
MURRAY	1606092	51,809.42
MUSKOGEE	127333	4,107.52
NOBLE	5067459.66	163,466.44
NOWATA	2492686	80,409.23
OKFUSKEE	1279092	41,261.03
OKLAHOMA	5931000	191,322.58
OKMULGEE	880043.5	28,388.50
PAWNEE	2907390	93,786.77
PAYNE	5464415	176,271.45
PITTSBURG	467478	15,079.94
PONTOTOC	13312350	429,430.65
POTTAWATOMIE	4471924.5	144,255.63
ROGER MILLS	724954	23,385.61
ROGERS	92297	2,977.32
SEMINOLE	10201020.75	329,065.19
STEPHENS	14138536	456,081.81
TEXAS	4631488.65	149,402.86
TILLMAN	180512	5,822.97
TULSA	1212893.16	39,125.59
WAGONER	263990	8,515.81
WASHINGTON	1132098	36,519.29
WASHITA	229063	7,389.13
WOODS	10578922	341,255.55
WOODWARD	953843	30,769.13

Appendix C
Water Demand Data and Estimate Detail

Summary of Water Use by County versus Produced Water Injected

Source: PWWG_Permits_NonPot_Users - cleaned.xlsx

		Water Use By County (BPD)[1]								
County	Produced Water Injected (December 2015 BPD)	Agriculture	Commercial	Industrial	Irrigation	Mining	Other	Power	Recreation, Fish, Wildlife	Grand Total
ADAIR	0	14073	531		34626					49230
ALFALFA	600560	7223	14658	425	406159	42135			87563	558162
ATOKA	0	157	8336	255339	48243	49829		4758	44589	411251
BEAVER	39459	65959	3165	16276	5089068	35949			10118	5220536
BECKHAM	22323		18042	5234	1016900	35724			30127	1106026
BLAINE	25677	29139	1115	4482	501295	77579			7223	620833
BRYAN	0	12778		4735	693123	121745			146087	978467
CADDO	36096	12508	319	29194	4455239	20606		111376	55809	4685051
CANADIAN	66147	2677	616	6120	1220717	197346		251430	47032	1725938
CARTER	1041173		1487	3526	433921	41424			277283	757641
CHEROKEE	0	6267	1487	2018	106384				9177	125333
CHOCTAW	0	425	425	58858	271671	6373		651497	39299	1028547
CIMARRON	4376	47093	7201		6570796	3250			13595	6641936
CLEVELAND	5597	404	150134	1814	335862	13829	170		9411	511624
COAL	22115	765	42		44504	44610			21	89942
COMANCHE	973	2762		262674	236951	6808			49241	558436
COTTON	17468				43272				807	44079
CRAIG	378	114541								114541
CREEK	475328				39357	42			13538	52937
CUSTER	12676		1013	24627	2258400	77218			8773	2370032
DELAWARE	0	61951	5818	552	11068		425		21	79835
DEWEY	122762		166	4036	1298550	443253			5778	1751784
ELLIS	29567	14279	14275	13880	1286712	7987			39448	1376582
GARFIELD	146793	1976	3894	2443	203558	56430			10902	279201
GARVIN	166968		1043	201191	191526	73706			50622	518088
GRADY	54725	95742	514	15720	1258087	144090			29166	1543319
GRANT	109502			6437	342293	21158				369887
GREER	17		53		560913					560967
HARMON	35				1897720		42486		3548	1943753
HARPER	13022	2116		21	1525477				3718	1531332
HASKELL	14	29166			72874					102040
HUGHES	71959	50558			315747	1976			17823	386104
JACKSON	4701	382		23346	2967143	14700			1196	3006767
JEFFERSON	15105				81658	5098			3824	90580
JOHNSTON	0	23401	93	6224	164921	89781			70424	354845
KAY	173719		149	172632	424228	15911		1062		613982
KINGFISHER	64782			12125	1354094	228348			3633	1598200
KIOWA	417	23716	4079	382	390648	5353				424177
LATIMER	2055	2592	319		17886				10260	31057
LEFLORE	667	8191	59	6160	464692			427555	27318	933976
LINCOLN	149864		659	446	42613				43059	86777
LOGAN	65794	16463	10197	28997	132264	144451			14530	346902

Summary of Water Use by County versus Produced Water Injected

Source: PWWG_Permits_NonPot_Users - cleaned.xlsx

		Water Use By County (BPD)[1]								
County	Produced Water Injected (December 2015 BPD)	Agriculture	Commercial	Industrial	Irrigation	Mining	Other	Power	Recreation, Fish, Wildlife	Grand Total
LOVE	11039		6883	616	555269	299482			16455	878704
MAJOR	19654			650	1391936	8816			33946	1435348
MARSHALL	924		38		157065	99098			2124	258326
MAYES	332	3696	64							3760
MCCLAIN	13620			42	213988				2146	216176
MCCURTAIN	0	722		813319	69910				17154	901105
MCINTOSH	9344	9963	2847	85	15667				6267	34828
MURRAY	51809	10621		6058	53107	6861		47032	149698	273379
MUSKOGEE	4108	637	25564	752741	435283			3203219	14233	4431676
NOBLE	163466				80595	1381		76474	8703	167154
NOWATA	80409				15698	4886			5842	26426
OKFUSKEE	41261	7084	6798	8285	67943	18864		10621	2018	121613
OKLAHOMA	191323	7138	60291	71913	415160	19161	6798	315371	100880	996713
OKMULGEE	28389				31758				28529	60287
OSAGE	0		276	49326	351506	8901		531071	2337	943417
OTTAWA	0	2294		4780	19238					26311
PAWNEE	93787		6352		21392	5948		1550729	3399	1587819
PAYNE	176271	127	10235	20860	141860	27297		27106	210814	438300
PITTSBURG	15080			19607	161934	1912		701864	8497	893814
PONTOTOC	429431	14424		22624	223301	16230		55231	3038	334847
POTTAWATOMIE	144256	2231	2163	6685	290904	2466			14519	318968
PUSHMATAHA	0				47183				5098	52281
ROGER MILLS	23386		0	7010	2798373	70471			46118	2921972
ROGERS	2977			361	144112	1593		436859	51733	634658
SEMINOLE	329065	2549	204	13391	36746	28404		745412	10664	837370
SEQUOYAH	0		595	35433	244414	5035			375021	660498
STEPHENS	456082		2791	888	86858	12909			56718	160165
TEXAS	149403	348430	15762	4108	16479548	28126			6522	16882495
TILLMAN	5823	10197			1177277	2549			319	1190341
TULSA	39126			33224	279535	1657		364583	871	679869
WAGONER	8516			1846	267709		15295	382053	13489	680392
WASHINGTON	36519				62242				17249	79491
WASHITA	7389	7647	1168	212	1104813	75540			13338	1202720
WOODS	341256	6798	13765	425	488352	39920				549260
WOODWARD	30769	7499	3718	15106	907907	3620		102051	467	1040367

Notes:

[1]From Non-Potable Permits

Appendix D
Alternatives Screening Matrix

Scenario	Water Use	County	Potential User(s)	Volume of Water Needed (bpd)	Volume of Water Produced in County (bpd)	Match Between Supply and Demand	Located in an OCWP Hot Spot Basin	Year Around User	Treatment Required	Regulatory Challenges	Selected for Economic Evaluation	Notes
1.a	Agriculture/ Irrigation	Texas	Heimsoth Partners	217,739	149,403	X	X		X	X	N	Seasonality challenges
1.b		Texas	Russell Family Partnership	449,499	149,403	X	X		X	X	N	
1.c		Texas	Fischer Family Farms LP	227,681	149,403	X	X		X	X	N	
1.d		Texas	Stephens Land & Cattle Co Inc.	195,477	149,403	X	X		X	X	N	
1.e		Texas	Chemical Spray for Agriculture/Irrigation	<10,000[2]	149,403		X		X	X	N	
2.a	Power	Pawnee	Oklahoma Gas and Electric Company	1,550,729	93,787	X		X	X	X	Y	Large volumes of produced water generated in adjacent counties Kay and Noble
2.b		Oklahoma	Oklahoma Gas and Electric Company	203,617	191,323	X		X	X	X	N	
2.c		Seminole	Oklahoma Gas and Electric Company	743,499	329,065	X		X	X	X	Y	Large volumes of produced water generated in adjacent county Pontotoc
3.a	Mining	Dewey	Kauk Mike and LaDena	223,199	122,762	X			X	X	N	Seasonality of use is unknown; assumed to require similar treatment as Power and Industrial users

Scenario	Water Use	County	Potential User(s)	Volume of Water Needed (bpd)	Volume of Water Produced in County (bpd)	Match Between Supply and Demand	Located in an OCWP Hot Spot Basin	Year Around User	Treatment Required	Regulatory Challenges	Selected for Economic Evaluation	Notes
4.a	Industrial	Muskogee	Georgia-Pacific Consumer Products (Manufacturing of Consumer Products, Tissue)	752,741	4,108			X	X	X	N	Small volumes of produced water in adjacent counties Wagoner, Okmulgee
4.b		Kay	Phillips Refinery	131,748	173,719	X		X	X	X	N	
4.c		Garfield	Koch (Chemical Manufacturing)[3]	238,095	146,793	X		X	X	X	N	
4.d		Grant	Medford OK Natural Gas Liquids Fractionator	30,000	109,502	X		X	X	X	Y	Added as a result of 11/02/2016 Meeting; Facility is uniquely positioned in Mississippi Lime Play and has several existing lined pits to store water;
5.a	Re-use Clean Brine - Oil and Gas	Alfalfa to Blaine	Oil and Gas - Transfer Produced Water from Mississippi Lime to Stack Play	250,000	600,560	X	X	X	X	X	Y (Case 3)	
6.a	Aquifer Storage and Recovery - Oil and Gas	Alfalfa	Oil and Gas - Store treated produced water in saline aquifer	TBD	600,560	X		X	X	X	N	Regulatory challenges and water quality issues make this scenario unfeasible

Scenario	Water Use	County	Potential User(s)	Volume of Water Needed (bpd)	Volume of Water Produced in County (bpd)	Match Between Supply and Demand	Located in an OCWP Hot Spot Basin	Year Around User	Treatment Required	Regulatory Challenges	Selected for Economic Evaluation	Notes
7.a	Surface Water Discharge	Beckham	Irrigation - Lugert-Altus Irrigation District	1,819,025	22,323		X	X	X	X	Y	Added as a result of 11/02/2016 Meeting
7.b		Grant	Salt Fork Arkansas River (downstream of Great Salt Plains Lake)	NA	109,502			X	X	X	Y	Not feasible to discharge into the Great Salt Plains Lake due to the sensitive ecosystem; TDS<4000; national reserve for threatened and endangered species; alternatively looked at a surface water discharge point along the Salt Fork Arkansas River downstream of the Lake.

Appendix E
Cost Estimate Assumptions

APPENDIX E

Cost Estimate Assumptions

Conceptual Design Assumptions:

- Pipeline diameters were estimated based on a velocity of 7 fps.
- Pipelines are assumed to be HDPE DR11.
- Pump stations were located approximately every 10 miles; detailed hydraulic analysis was not performed at this time.
- Impoundment volumes were assumed to be 20% greater than the estimated treatment volume.

The following markups were assumed on all unit costs:

- Contractor overhead – 10%
- Contractor profit – 5%
- Mob/Bonds/Insurance – 5%
- Contingency for items without vendor quotes – 30%
- Contingency for items with vendor quotes and labor – 10%
- Engineering – 10%
- Service During Construction – 7%
- Commissioning and Startup – 2%
- Land Acquisition – 10%
- Permitting – no additional markups were added specifically for permitting at this level of design. Permitting costs are assumed to be covered in the markups identified above.