Quantifying the Relative-risks of Produced Water Treatment and Reuse: A National Perspective

Texas Water and Energy Institute – Virtual Water Lecture Series
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Presentation Overview

- Trends in system-level considerations and metrics for national energy system design, operation, and performance
- Energy interdependencies with water and other resources, and impacts on future national and regional energy policy
- The role of oil and gas and produced water in the national water and energy dialogue
- Efforts and approaches to quantify the benefits of treating produced water to reduce water stress and support regional economic development and public and environmental health.

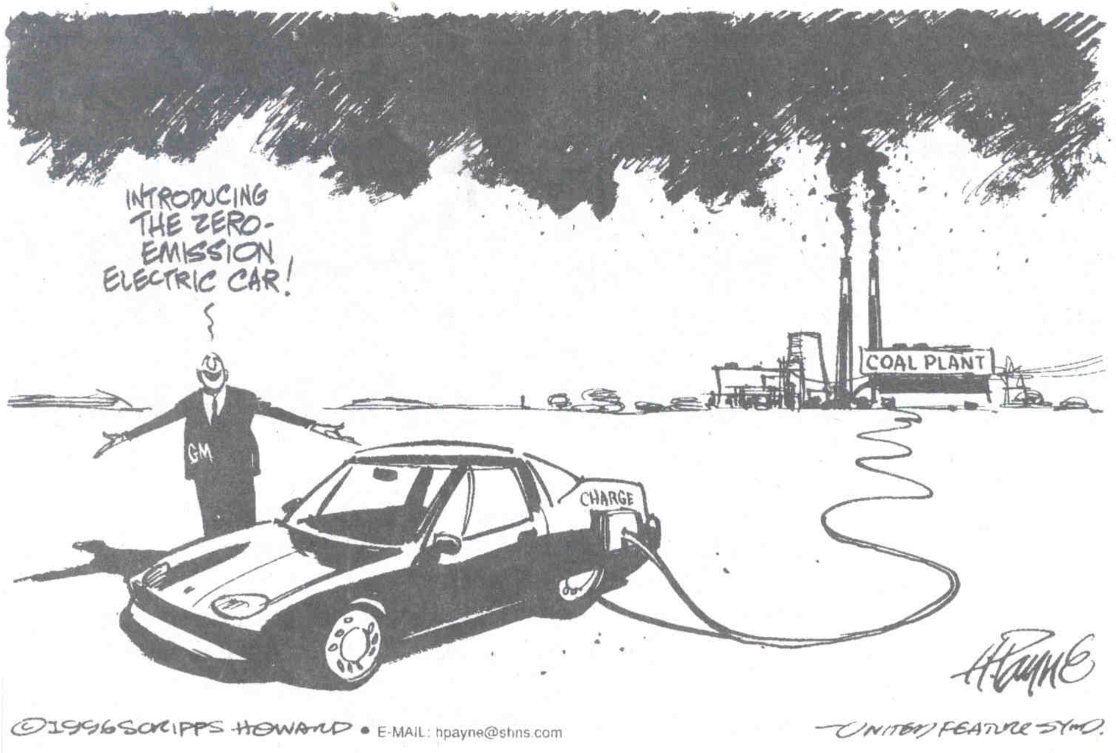
Emerging Energy System Performance Metrics

Performance Characteristic	Definition and Metrics
Safe	Safely supplies energy to end user
Secure	Protection of energy supply infrastructure from intentional disruptions
Reliable	Provides energy when and where needed in spite of small disruptions
Sustainable	Can be maintained indefinitely with minimal impact on natural resources (air, land, water, environment, ecology}
Cost Effective	Provided at affordable cost
Resilient	Ability to prepare for and adapt to changing conditions and withstand and recover rapidly from large disasters or disruptions

Safe, secure, cost-effective, and reliable energy supply for sustained operations and assured system performance

Energy Transition Discussions Not System Focused

Transportation Sustainability

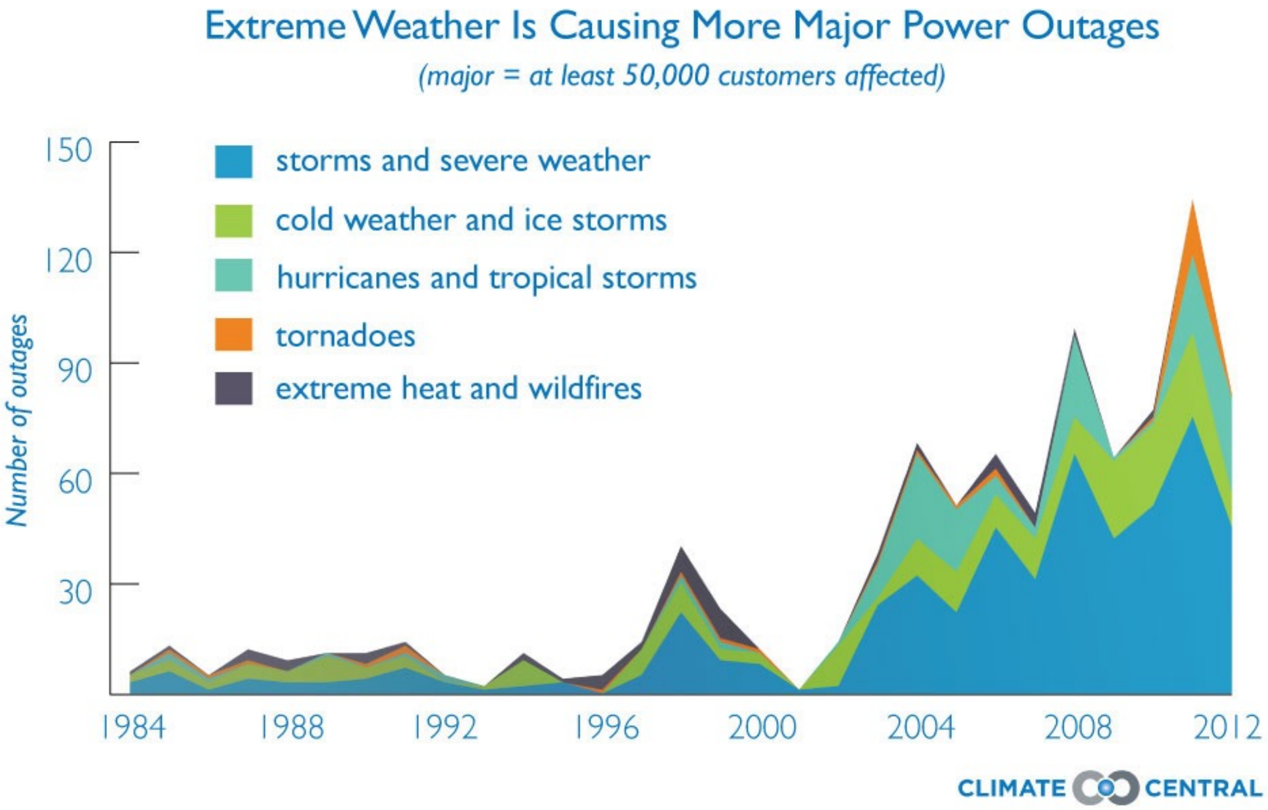


$CH_4 + 2H_2O$ + energy → $4H_2 + CO_2$ (Fuel Cell)

$H_2 + N_2 + O_2$ + heat → energy + $H_2O + NO_x$ (Combustion)

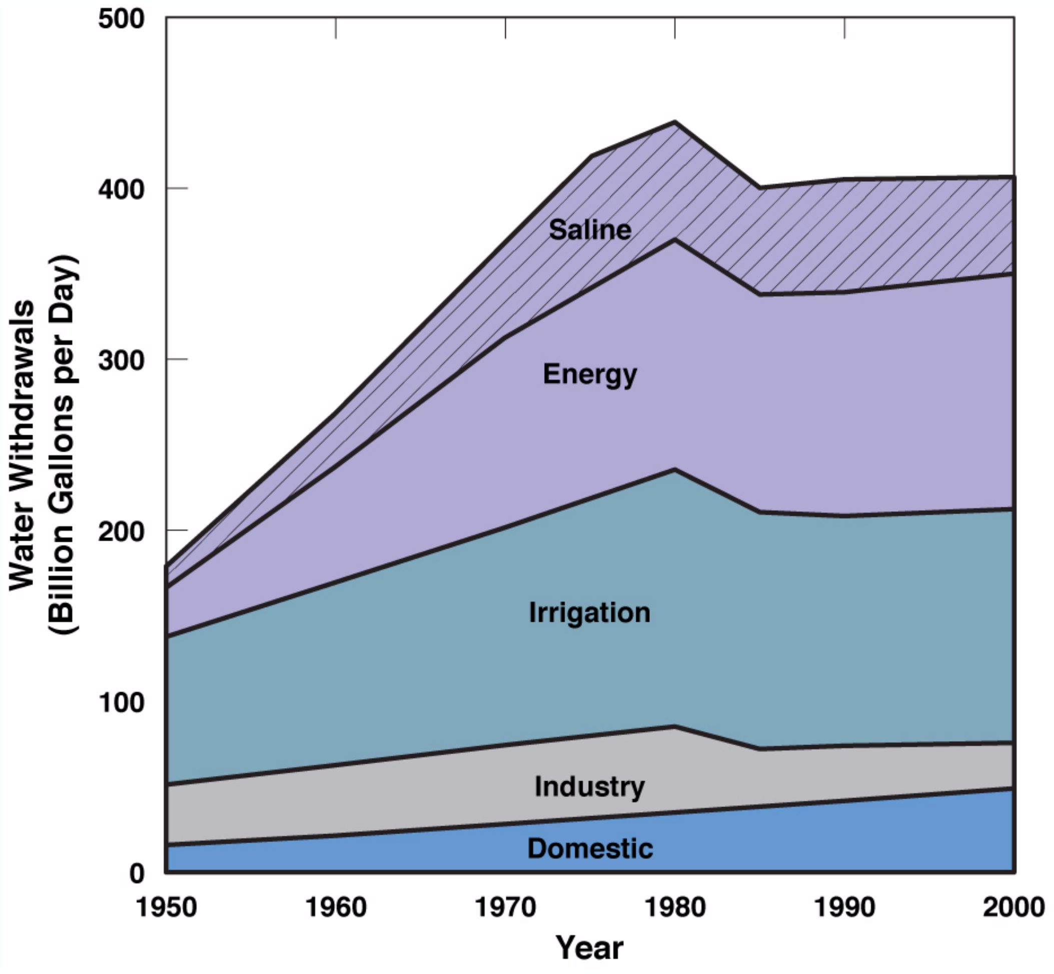
1000 gal of water for 1 gallon of irrigated ethanol

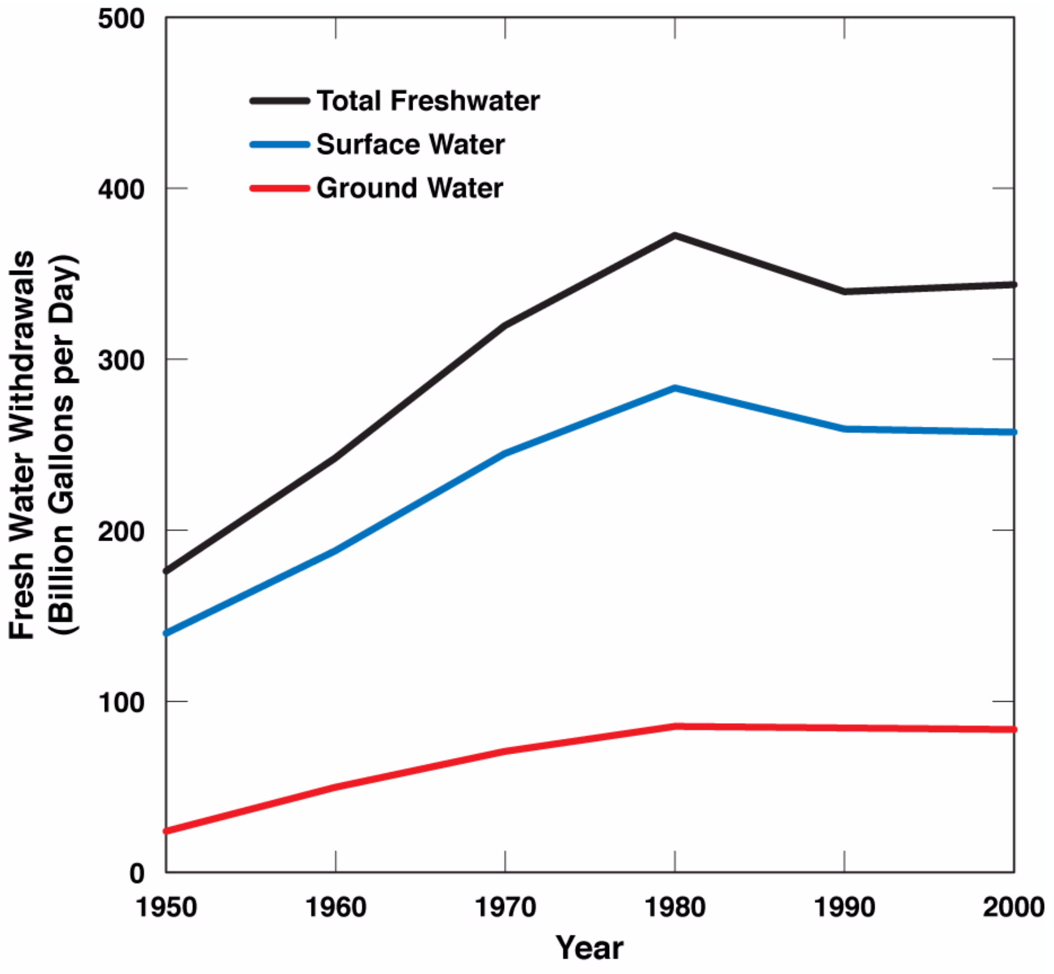
Electric Power Reliability and Resiliency



Number of customers impacted has tripled per major power outage

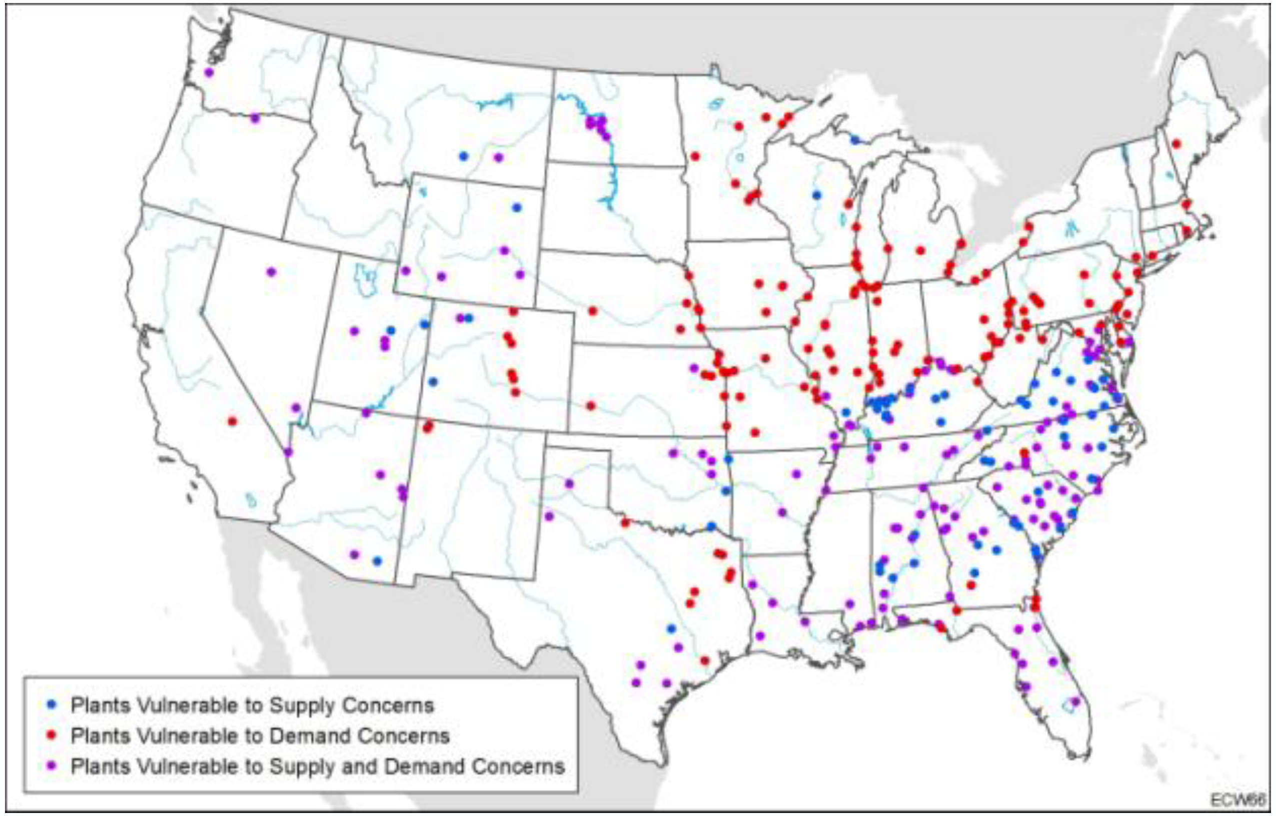
Energy Sector Water Withdrawal Trends



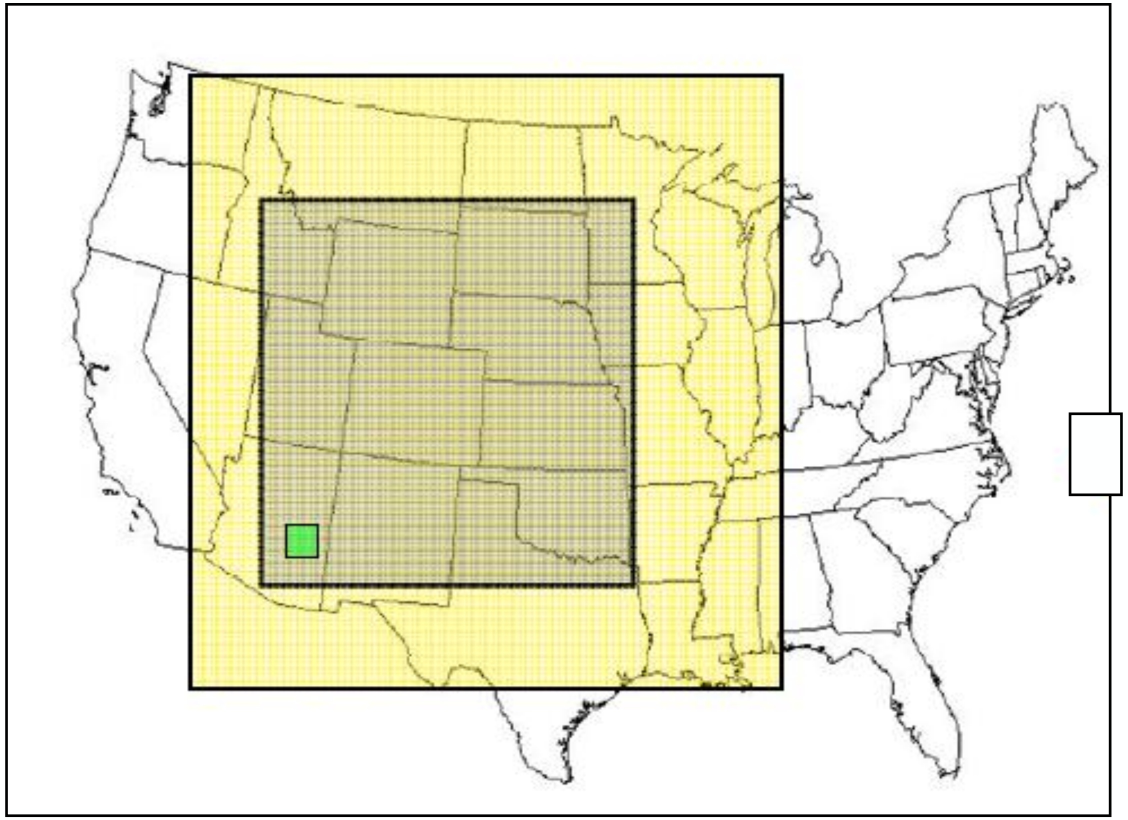


[USGS, 2004, 2013, 2018]

Thermoelectric Power Plants with Water Supply and Demand Concerns



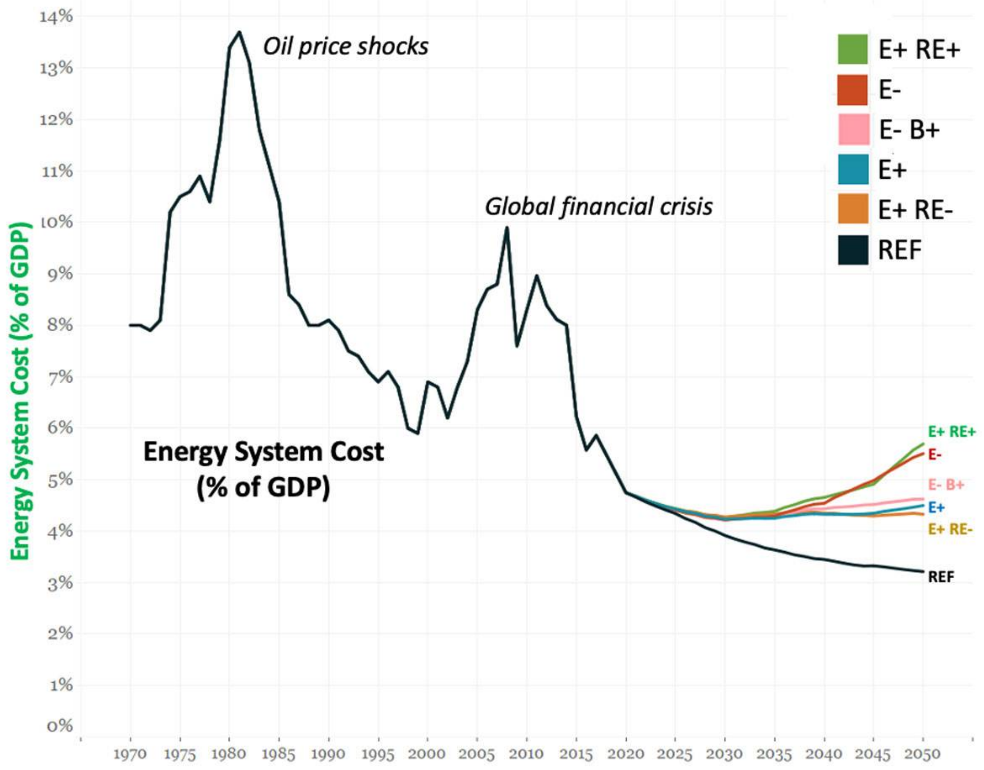
Land Needed for Biofuel to Replace 50% of Current Petroleum/Diesel using: Corn, Soybean, Algae



System Evaluation of 100% Renewable Energy by 2050

	REF ~AEO 2019	E+ high electrification	E- less-high electrification	E- B+ high biomass	E+ RE- renewable constrained	E+ RE+ 100% renewable
CO_2 emissions target		- 0.17 $GtCO_2$ in 2050				
Electrification	Low	High	Less high	Less high	High	High
Wind/solar annual build	n/a	10%/y growth limit	10%/y growth limit	10%/y growth limit	Recent GW/y limit	10%/y growth limit
Existing nuclear	50% → 80-y life	50% → 80-y life	50% → 80-y life	50% → 80-y life	50% → 80-y life	Retire @ 60 years
New nuclear	Disallow in CA	Disallow in CA	Disallow in CA	Disallow in CA	Disallow in CA	Disallowed
Fossil fuel use	Allow	Allow	Allow	Allow	Allow	None by 2050
Maximum CO_2 storage	n/a	1.8 Gt/y in 2050	1.8 Gt/y in 2050	1.8 Gt/y in 2050	3 Gt/y in 2050	Not allowed
Biomass supply limit	n/a	13 EJ/y by 2050 (0.7 Gt/y biomass) *[No new land converted to bioenergy]*		23 EJ/y by 2050 (1.3 Gt/y biomass)	13 EJ/y by 2050 (0.7 Gt/y biomass) *[No new land converted to bioenergy]*	

PRINCETON UNIVERSITY



PRINCETON UNIVERSITY

Included – air, CO2 storage, more land, energy mix, more transmission and batteries, cost

Not included – water, security, resiliency, socio-economic impacts, other CO2 sources

System Performance Optimized 2050 Energy Portfolio

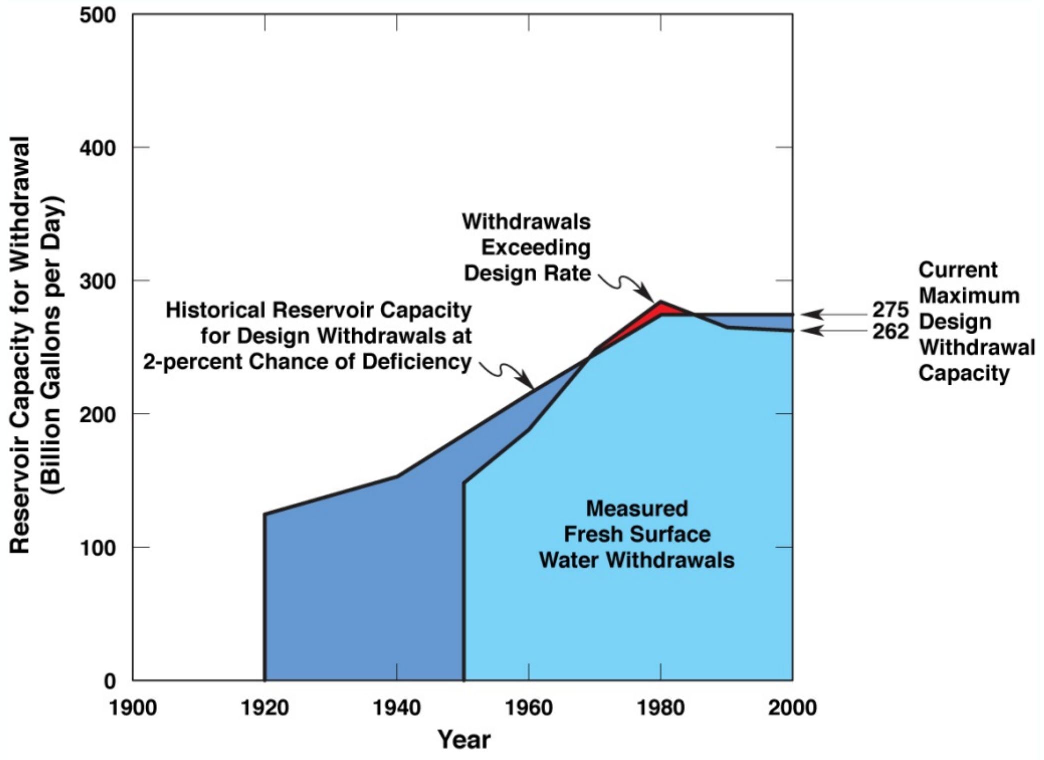
- Collectively, EEI's member companies are on a path to reduce their carbon emissions at least 80% by 2050, compared with 2005 levels.
  - The switch from coal to natural gas and renewable energy has been the single most effective tool over the past decade for reducing carbon emissions
  - all of this has been done while keeping rates steady and while ensuring that electricity remains affordable and reliable.
- It is important to us that we lead on clean energy in a way that gives us all the options, including making sure that we maintain existing nuclear and that we are still able to use natural gas to help achieve our clean energy targets.
- To eliminate the last 10% to 20% of emissions. …. we need advanced renewables, long-duration energy storage and demand efficiency, advanced nuclear, hydrogen, carbon- capture, use, and storage, … and getting critical transmission and energy grid infrastructure built more quickly.

Tom Kuhn, president of the Edison Electric Institute, the association of U.S. investor-owned electric companies. Jan. 26, 2021

2050 Electric Power Targets Based on System Performance Optimization

10% Coal
30% Natural gas
15% Nuclear
45% Renewables
(Wind, Solar, Hydro, Biomass)

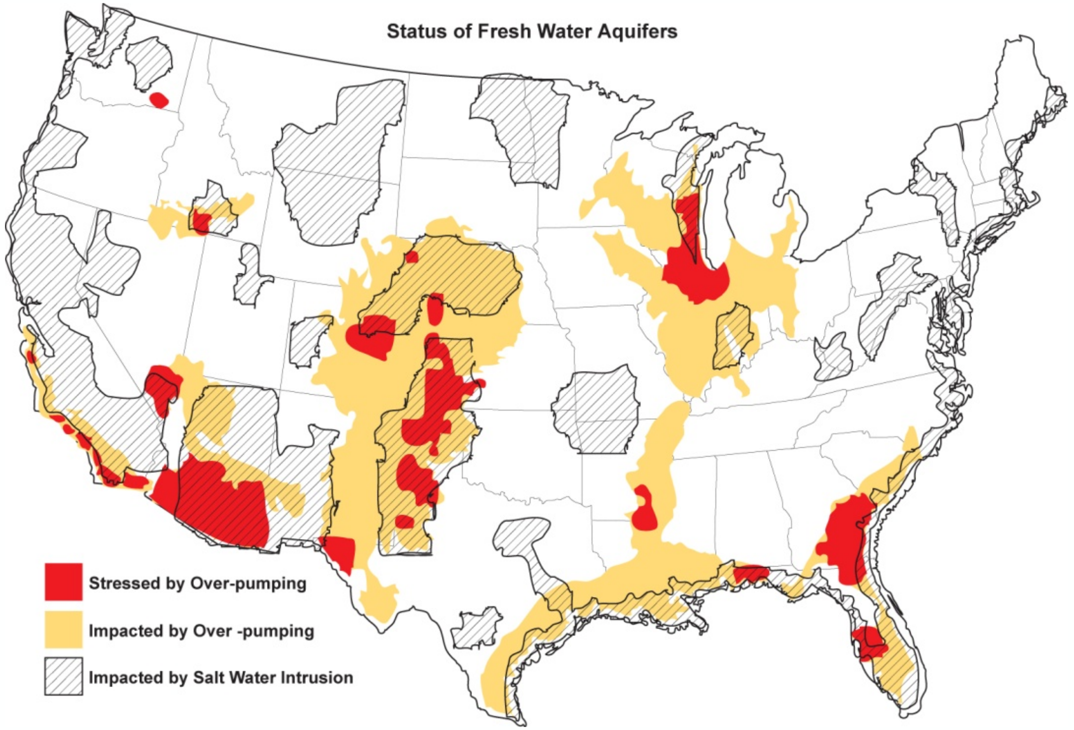
Fresh Water Availability Issues Driving Non-traditional Water Use



(Based on USGS WSP-2250 1984 and Alley 2007)

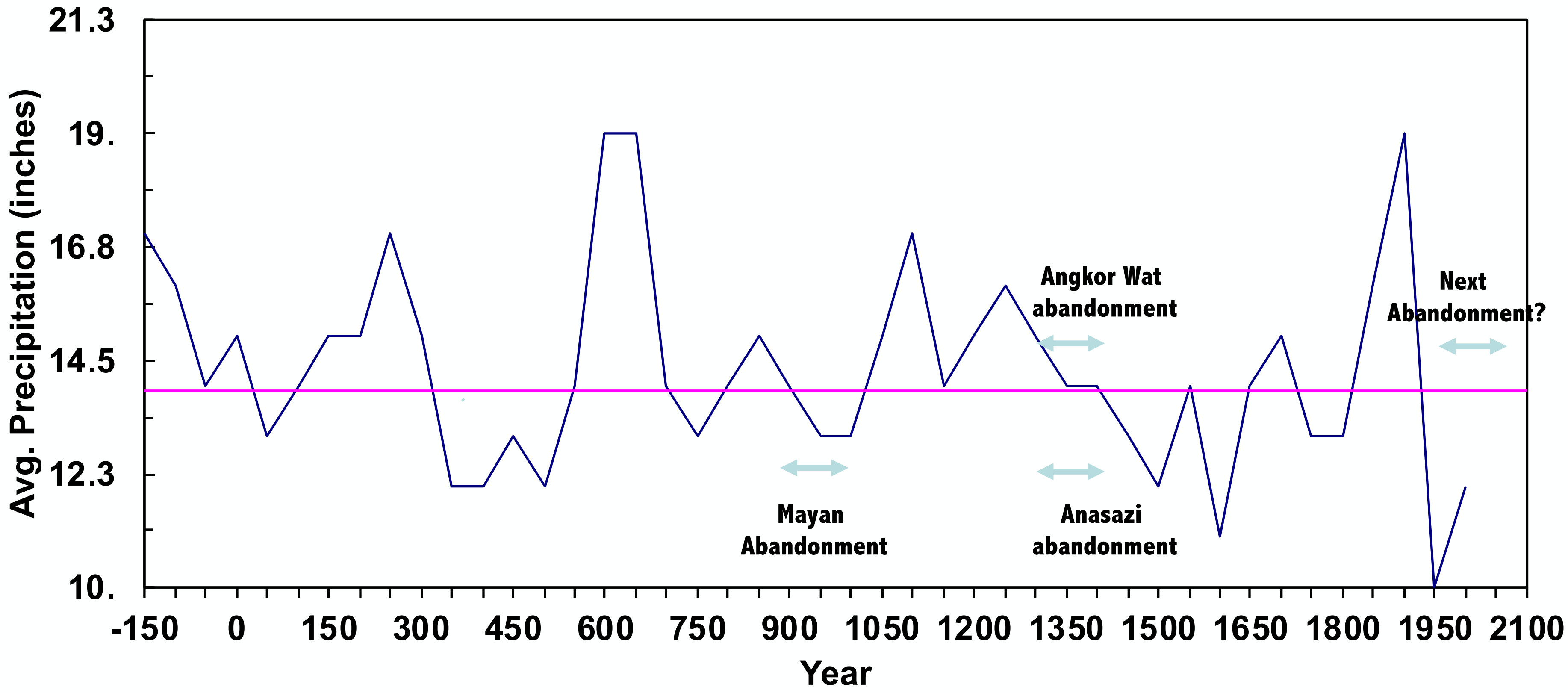
- No new surface water storage capacity since 1980

- All major groundwater aquifers overstressed



(Shannon 2007)

Southwest Climate History from Tree Ring Data



Univ. of Arizona – Tree Ring Lab – 50 year averages

The southern U.S. and the mid-latitudes are in the 130th year of a 300 year arid cycle - not a drought

When Hope was Alive!

Hope, New Mexico 88540,
2020 Population 100

Settled by sheepherders in the 1870s, Hope had 2,000 people when it incorporated in 1910 with a bank, four general stores, three churches, three hotels, two doctors, two barber shops, a saloon, dentists, jewelers, blacksmiths and a newspaper.

In the early 1900s when the river flowed year-round, 20 square miles were in cultivation and orchards produced $200 to $500 per acre. They were served by miles of irrigation ditches .

Hope has been dying since 1912. The biggest reason Hope withered away was because the Peñasco River dried up.

Water-related Economic Concerns by 2030

Today one in five people live in areas of water stress.

This is expected to rise to two in three.

Demand for water is set to outstrip supply by 40%.

Business as usual water management will put at risk $63trillion or 1.5 times today's entire global economy.

Water will have more rapid and unavoidable consequences for some businesses than carbon

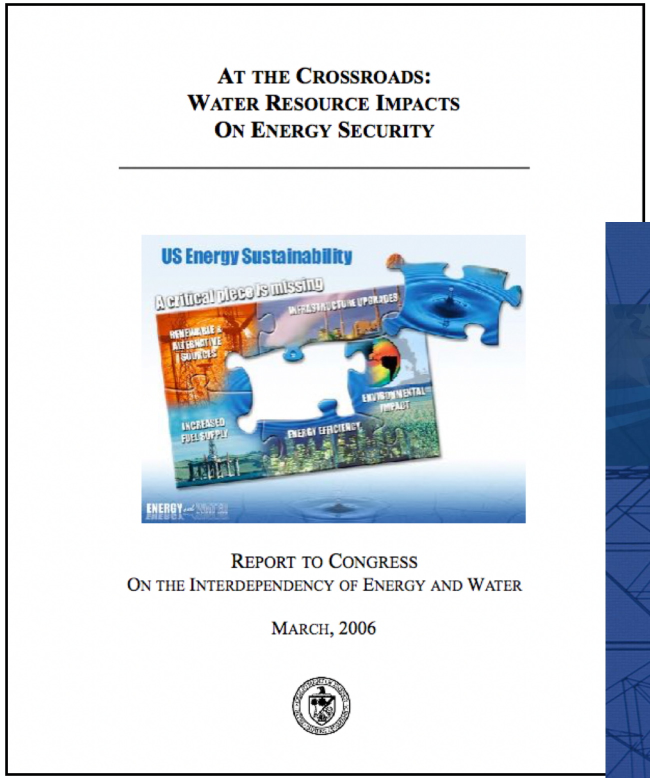
Goldman Sachs

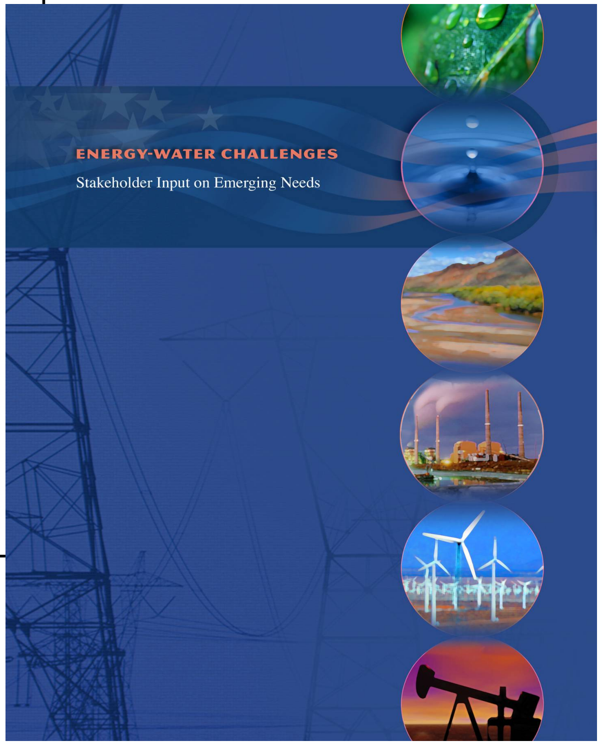
" Investors know how damaging inaction, inappropriate action or delaying interventions on water-related issues can be… The global economy will favor business that take a pro-active approach to water stewardship."

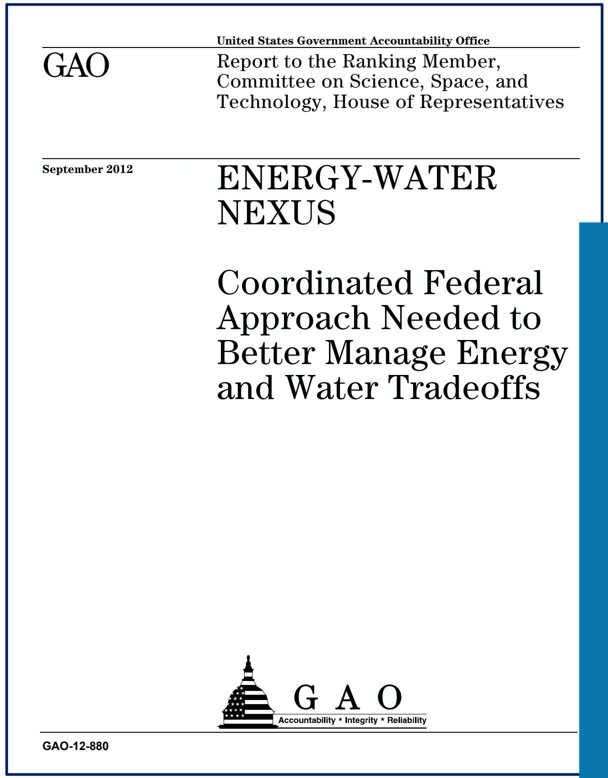
- **Eurizon Capital**

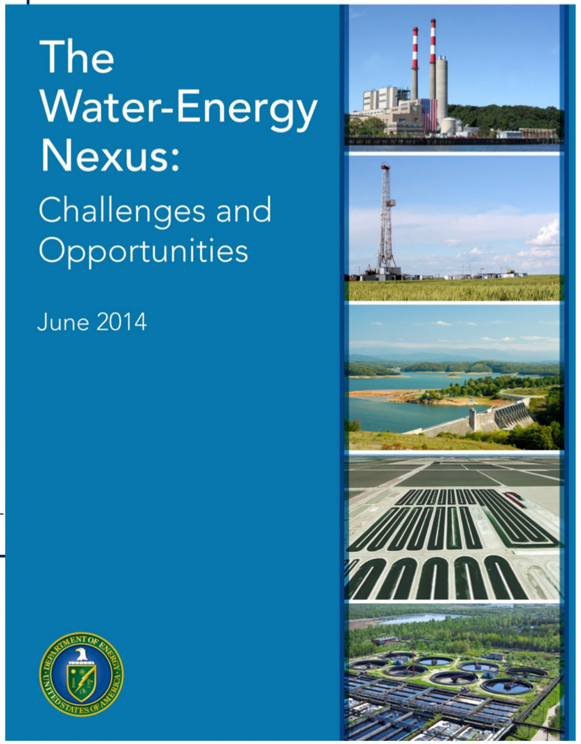
CDP

Water Impacts on Energy Security and Reliability and Energy Impacts on Water Security and Reliability









Water Use and Consumption for Electric Power Generation

Plant-type	Cooling Process	Water Use Intensity (gal/MWh_e)		
		Steam Condensing		Other Uses
		Withdrawal	Consumption	Consumption
Fossil/ biomass steam turbine	Open-loop	20,000–50,000	~200-300	~30
	Closed-loop	300–600	300–480	
Nuclear steam turbine	Open-loop	25,000–60,000	~400	~30
	Closed-loop	500–1,100	400–720	
Natural Gas Combined-Cycle	Open-loop	7,500–20,000	100	7–10
	Closed-loop	230	180	
Integrated Gasification Combined-Cycle	Closed-loop	200	180	150
Carbon sequestration for fossil energy generation	~80% increase in water withdrawal and consumption			
Geothermal Steam	Closed-loop	2000	1350	50
Concentrating Solar	Closed-loop	750	740	10
Wind and Solar Photovoltaic	N/A	0	0	1-2

Water Demand/Impact of Transportation Fuels

Fuel Type and Process	Relationship to Water Quantity	Relationship to Water Quality	Water Consumption	
			Water consumed per-unit-energy [gal / MMBTU] †	Average gal water consumed per gal fuel
Conventional Oil & Gas	Water needed to extract and refine; Water produced from extraction	Produced water generated from extraction; Wastewater generated from processing;		
- Oil Refining			7 – 20	~ 1.5
- NG extraction/Processing			2 – 3	~ 1.5
Biofuels	Water needed for growing feedstock and for fuel processing;	Wastewater generated from processing; Agricultural irrigation runoff and infiltration contaminated with fertilizer, herbicide, and pesticide compounds		
- Grain Ethanol Processing			12 - 160	~ 4
- Corn Irrigation for EtOH			2500 - 31600	~ 980*
- Biodiesel Processing			4 – 5	~ 1
- Soy Irrigation for Biodiesel			13800 – 60000	~ 6500*
- Lignocellulosic Ethanol and other synthesized Biomass to Liquid (BTL) fuels	Water for processing; Energy crop impacts on hydrologic flows	Wastewater generated; Water quality benefits of perennial energy crops	24 – 150 ‡§ (ethanol) 14 – 90 ‡§ (diesel)	~ 2 - 6 ‡§ ~ 2 - 6 ‡§
Oil Shale	Water needed to Extract / Refine	Wastewater generated; In-situ impact uncertain; Surface leachate runoff		
- In situ retort			1 – 9 ‡	~ 2 ‡
- Ex situ retort			15 - 40 ‡	~ 3 ‡
Oil Sands	Water needed to Extract / Refine	Wastewater generated; Leachate runoff	20 - 50	~ 4 - 6
Synthetic Fuels	Water needed for synthesis and/or steam reforming of natural gas (NG)			
- Coal to Liquid (CTL)		Wastewater generated from coal mining and CTL processing	35 - 70	~ 4.5- 9.0
- Hydrogen RE Electrolysis			20 – 24 ‡	~ 3 ‡
- Hydrogen (NG Reforming)			40 – 50 ‡	~ 7 ‡

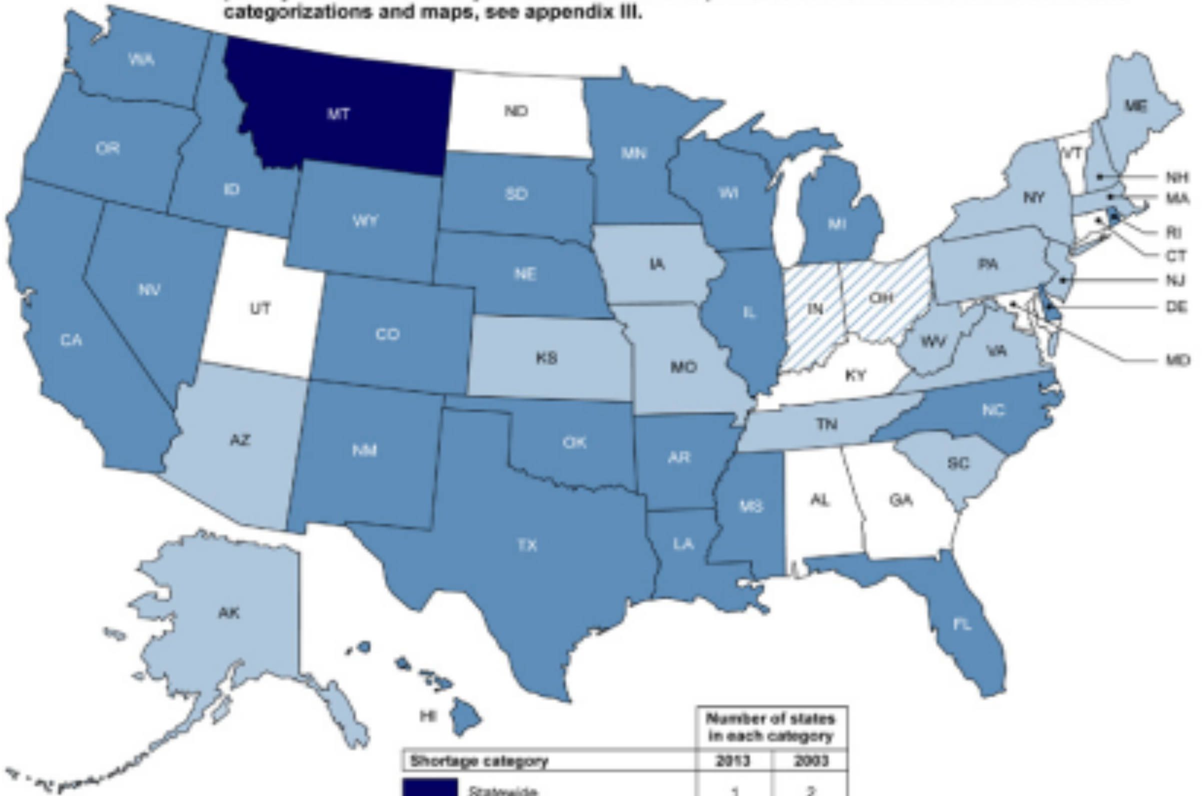
† Ranges of water use per unit energy largely based on data taken from the Energy-Water Report to Congress (DOE, 2007)
* Conservative estimates of water use intensity for irrigated feedstock production based on per-acre crop water demand and fuel yield
‡ Estimates based on unvalidated projections for commercial processing; § Assuming rain-fed biomass feedstock production

Part 1: Questions and Answers

National Initiative in Non-traditional Water Reuse

GAO 2003 and 2013

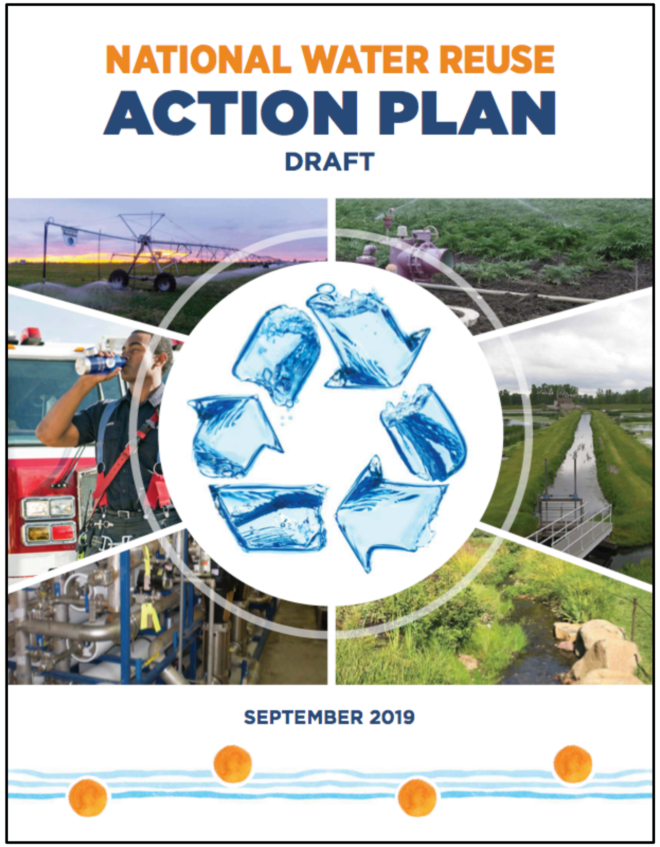
Interactive Graphic **Instructions:** This base map displays 2013 categories. To view 2003 to 2013 category comparisons, place your cursor over any individual state. For a printable version of the 2003 and 2013 state categorizations and maps, see appendix III.



Shortage category	Number of states in each category 2013	2003
Statewide	1	2
Regional	24	16
Local	15	18
None	8	9
No response or uncertain	2	5

Sources: GAO analysis of state water managers' responses to GAO survey; Map Resources (map).

EPA 2019

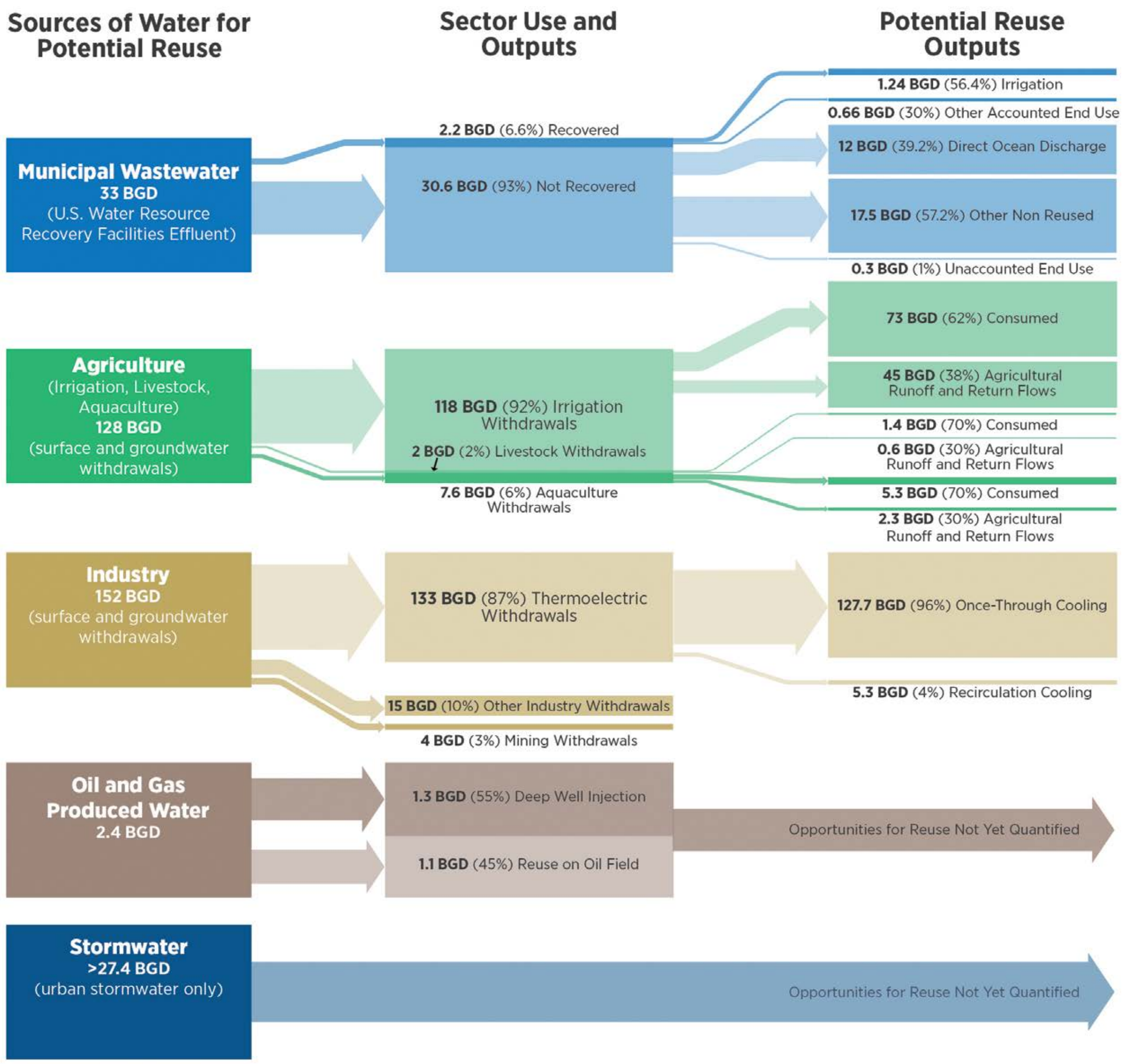


NM STATE BE BOLD. Shape the Future.

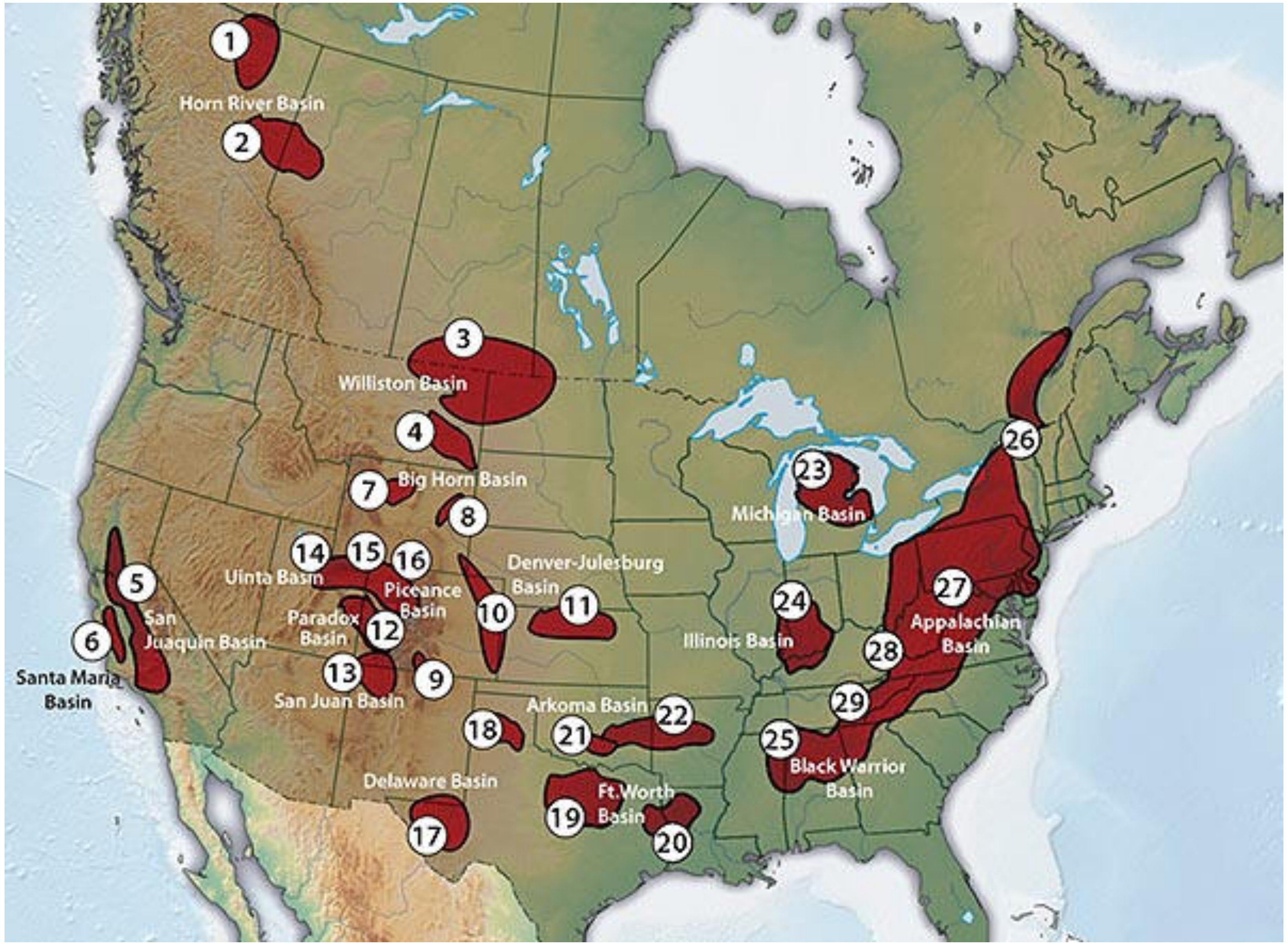
NEW MEXICO PRODUCED WATER RESEARCH CONSORTIUM

EPA National Water Reuse Action Plan Focus Areas

- Clear potential to reclaim more waste waters for beneficial use
- Sources of water for priority reuse:
  - ➢ 33 BGD - Municipal wastewater
  - ➢ 128 BGD - Agriculture
  - ➢ 152 BGD - Industry
  - ➢ 2.4 BGD - Oil and gas produced water
  - ➢ >27.4 BGD – Storm water
- Focus on treatment for beneficial reuse
- Leads selected for each area - GWPC and NMPWRC selected to lead produced water efforts



Oil and gas shale produced water management is an area of national impact and interest



BE BOLD. Shape the Future.

NEW MEXICO PRODUCED WATER RESEARCH CONSORTIUM

EPA definition of What is Produced Water?

- "Produced water is the fluid (often called brine) brought up from the hydrocarbon bearing strata during the extraction of oil and gas and includes, where present, formation water, injection water, and any chemicals added downhole or during drilling, production, or maintenance processes."
  - brine – water with a salinity greater than sea water (>35,000 ppm) total dissolved solids (TDS)
  - formation water – naturally occurring water in the geologic formation
  - injection water - water and chemical additives used in hydraulic fracturing to enhance production.
- Produced water = 4-10 times oil produced

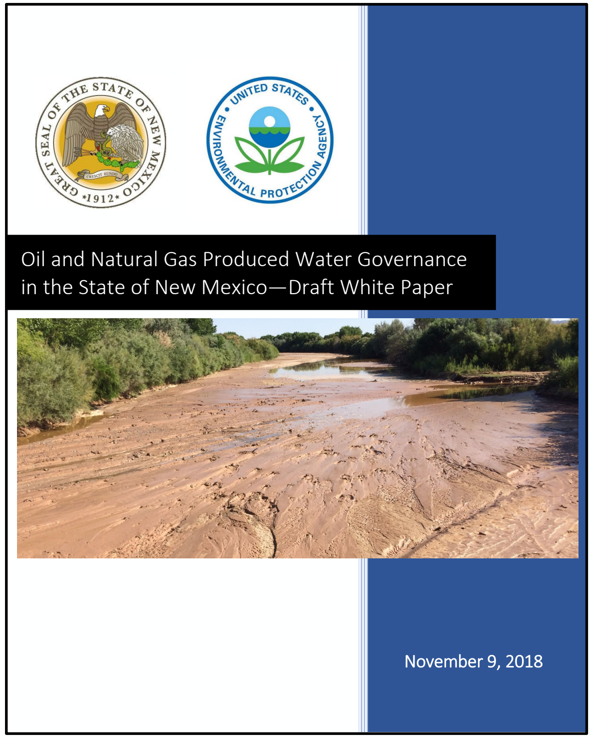
Summary of Input on Oil and Gas Extraction Wastewater Management Practices Under the Clean Water Act

EPA-821-S19-001

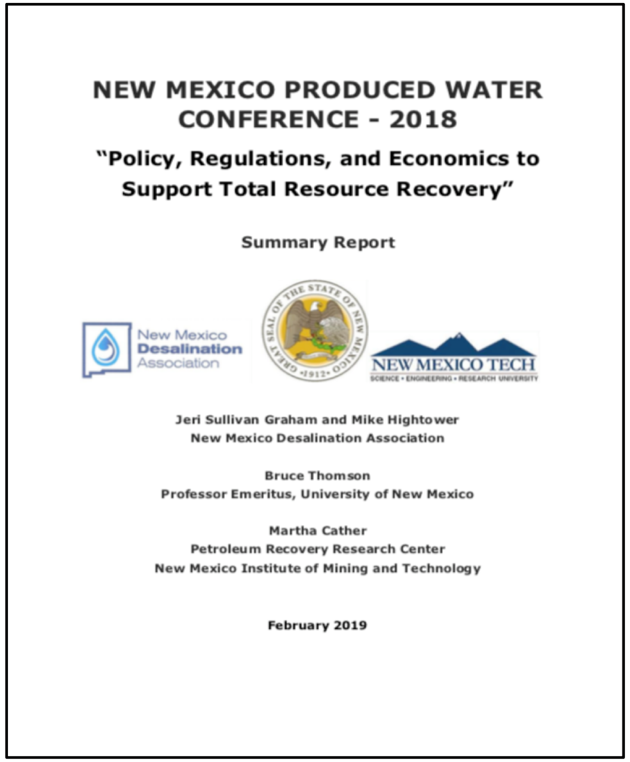
U.S. Environmental Protection Agency
Engineering and Analysis Division
Office of Water
1200 Pennsylvania Avenue, NW
Washington, D.C. 20460

Final May 2020

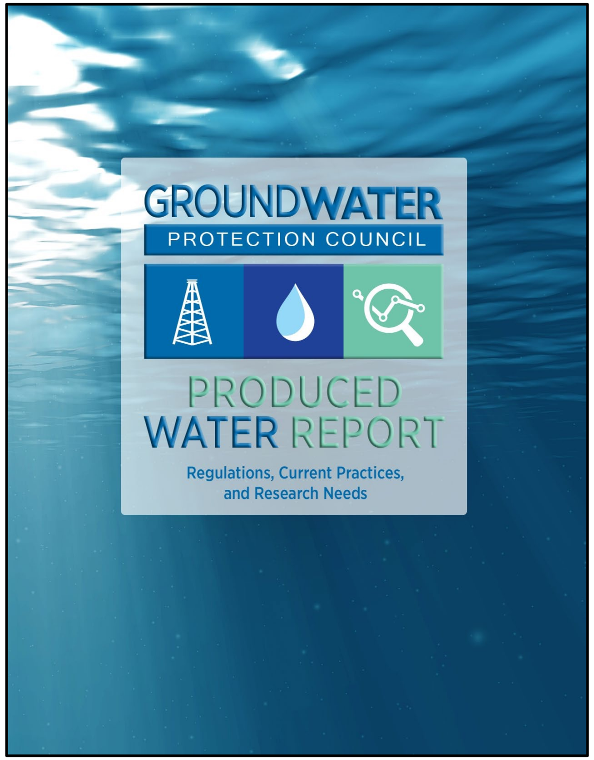
Recent New Mexico Efforts on Produced Water Treatment and Reuse



NMED, OSE, EPA 2017-18



NMED, OSE, EMNRD
2017-19



EMNRD 2016-19

NM 2019 Produced Water Act, HB 546

- Through the Act, statutory and regulatory authority for the reuse of produced water was modified:
  - Reuse inside oil and gas sector remains under the Oil Conservation Division (OCD) of the NM EMNRD,
  - **Reuse outside the oil and gas sector, was designated to the NM Environment Department (NMED).**
- The Act encourages produced water reuse outside oil and gas to:
  - enhance fresh water sustainability,
  - reduce or eliminate fresh water use in the oil and gas sector,
  - support new economic development opportunities,
  - maintain public and environmental health and safety.

This regulatory transition is an emerging trend in the oil and gas sector – OK, TX, CA

New Mexico Environment Department Needs

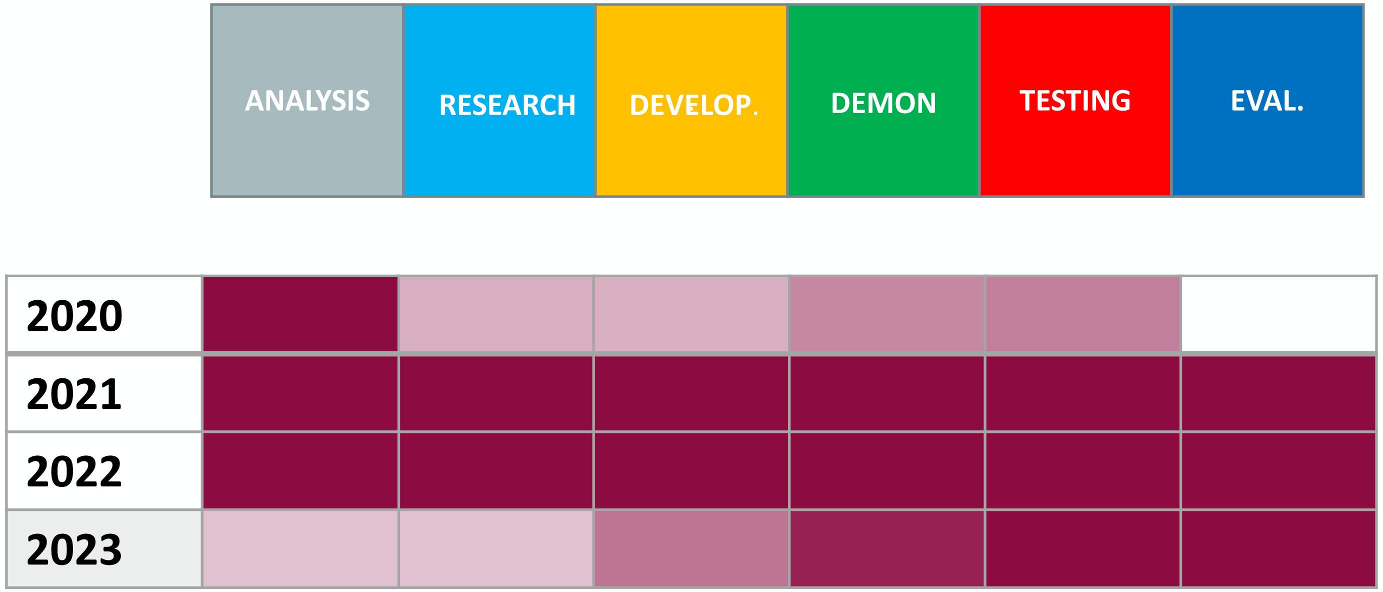
Investing in Science and Innovation

- MOU with New Mexico State University launched the **New Mexico Produced Water Research Consortium** to fill science and technology gaps for off-field reuse of treated produced water (details available at https://nmpwrc.nmsu.edu/).
- Examples of NMED's research questions:
  - What contaminants are in the produced water generated in NM?
  - How can the produced water be treated to be safe?
  - What changes are needed to our state water quality standards to protect water resources and human health?
- NMED will look to results of Consortium efforts to inform future science-based regulations for treatment and reuse of produced water while protecting our most precious natural resource, fresh water.

NM PWR Consortium Organization

Modeled after DOE Innovative Treatment Remediation Demonstration Program and EPA Environmental Technology Verification (ETV) Program

Consortium Project Efforts

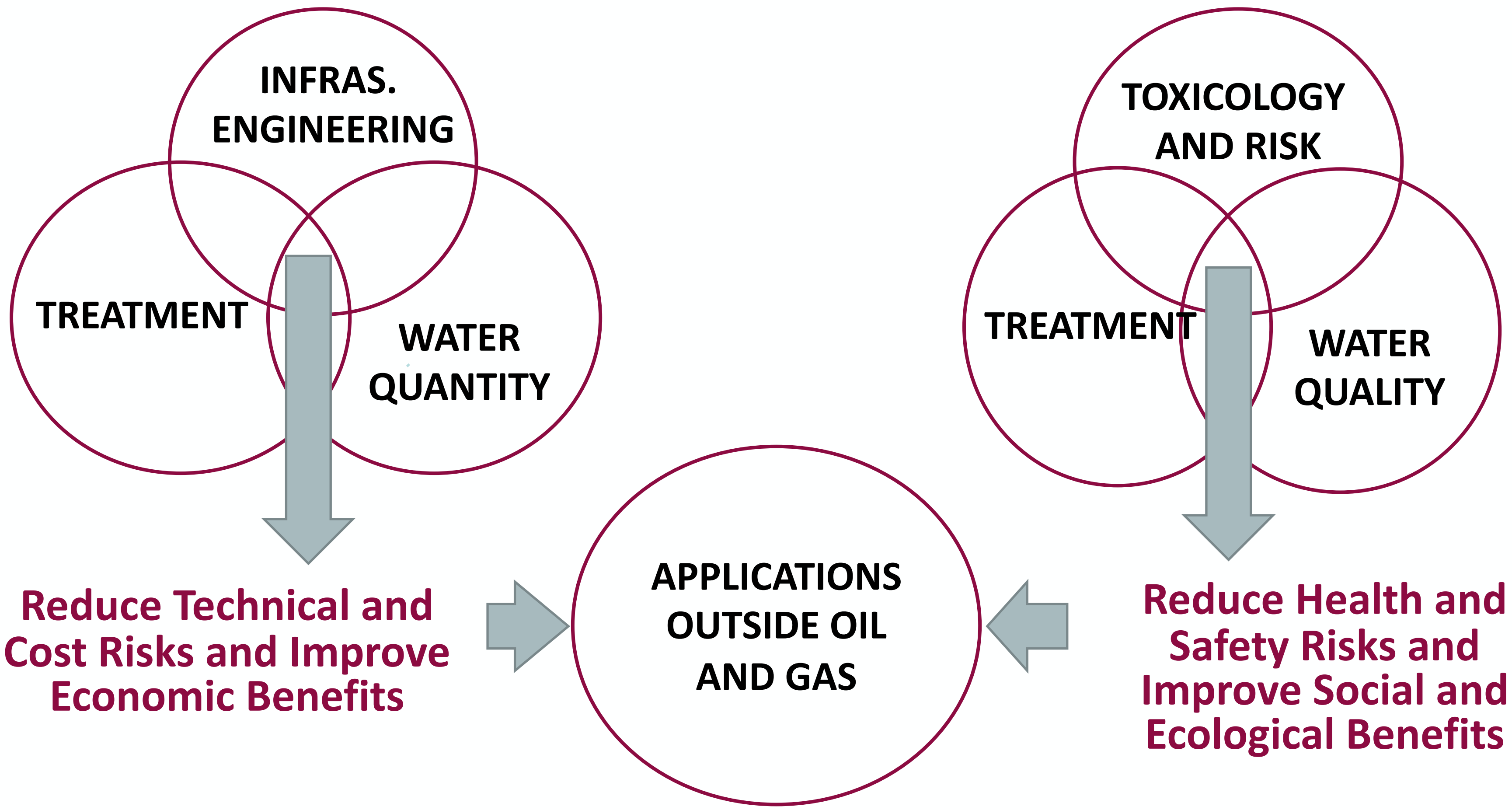


More extensive research, demonstration and testing efforts are shaded

Government Agency Regulatory Coordination

- Most produced water reuse options and efforts will require interaction with multiple natural resource agencies and regulatory environments
  - One example - a treatment facility at an OCD regulated facility on state land, that wants to move treated produced water across BLM land, to supply water for the State Engineer to meet Compact Delivery requirements to Texas on the Pecos River, in an area with critical aquatic habitat.
  - A second example – a pumped hydro storage facility with two 10,000,000 barrel storage reservoirs for treated produced water, one on state land and one on BLM land coordinated by two different EMNRD groups
- GAB coordination and direction is needed to make sure that testing and evaluation and application options consider agency regulation and policy coordination/cooperation

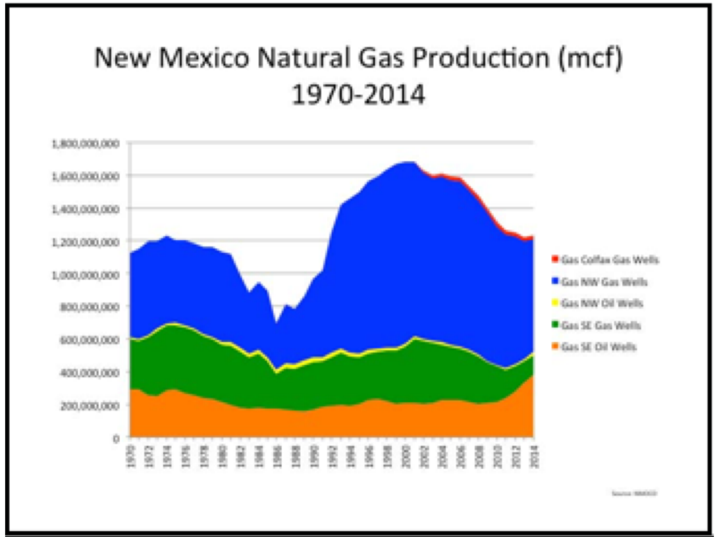
Technical Organizational and Operational Structure

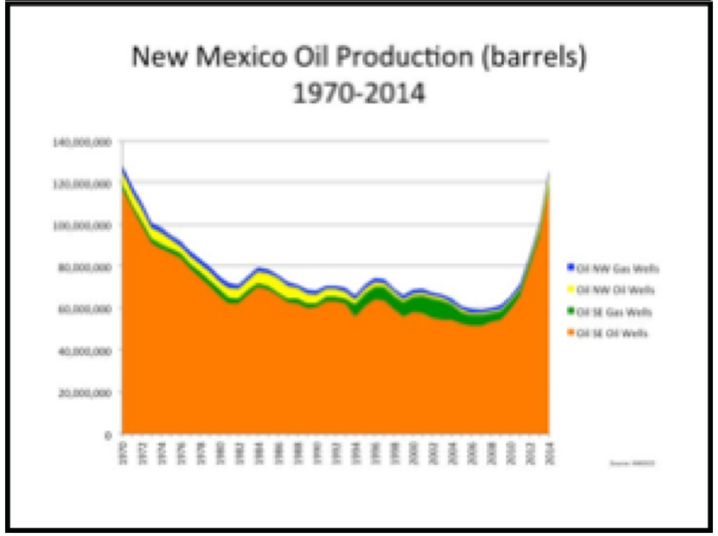


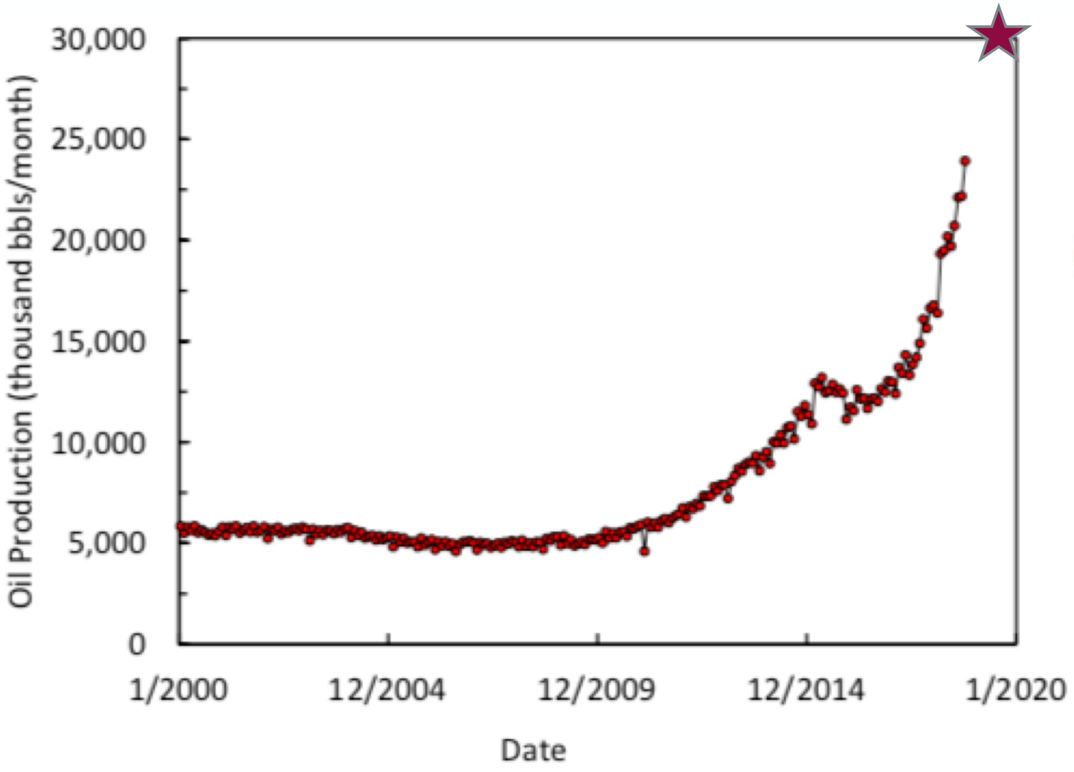
NM Produced Water Research Consortium Focus

- Fill science and technology gaps to accelerate innovative technology cost and performance testing to:
  - address fit-for-purpose treatment for various applications - industrial, road construction, agriculture, rangeland, municipal, aquifer storage, surface supplies.
- Make sure treatment requirements are protective of public, environmental, ecological, and watershed health and safety.
- This is requires a system-level, multi-parameter optimization consideration:
  - Cost-effective, sustainable, reliable, resilient and flexible to address multiple use applications, and safe for public, environmental and ecological health and safety
  - Needs to be quantitatively justified, and a better approach relative to other potential waste water resources (produced water vs toilet water)

Quantify Produced Water Available for Reuse







Average 4-5 bbls of produced water/ barrel of oil
~4 million bbls produced water/day (3 ABQ's)

Aqua Zia Produced Water Data Portal

- Near-term
  - Update the NM Petroleum Recovery Research Center (PRRC) GoTech produced water data base with water quantity and quality data from 2016-2020
  - Establish data QA/QC, API, and Tiered Data query framework
- Midterm
  - Integrate GoTech data into GWPC Aqua Star produced water data management and analysis system with GWPC financial support
  - Provides a direct Interface with updated Well Finder and Frac Focus to improve data accuracy and timeliness
  - Meets the needs of a national produced water reuse platform:
    - 2-D and 3-D plotting, mapping, contours, time series analysis, charts, etc.
    - Applicable for state agencies, the public, as well as engineering/economic evaluations
    - Web-based and enables integration of metadata
    - Meets Findable, Accessible, Interoperable, Reusable, and Reliable data requirements

Frac Focus
Chemical Disclosure Registry

Quantitative Treatment Data at Scale

- **Produced Water Treatment Pilot Demonstration Planning, Testing, and Evaluation**
  - Provides a step-by-step process and information required to conduct research and development or pilot test demonstrations with the Consortium
  - Is based on several federal agency – EPA, DOE, and DoD –managed innovative treatment and remediation technology demonstration, testing, and evaluation programs
  - Includes approach to accurately collect operational cost and performance data with Consortium oversight

Planning

- Experiment Design
- Sampling and Analysis Plan
- Set Performance Goals
- Process Flow
- SOP
- Site and Water Selection
- Cost and Schedule
- Data Management Plan
- Waste and Environmental Risk Plan
- 3rd Party Oversight
- Laboratory Data Completion

Demonstration

- Responsibilities & Communication
- Process Operation
- Sample and Data Collection
- Sample and Data Analysis QA/QC
- 3rd party Oversight
- Energy, process mass balance
- Photo-documentation
- Cost collection of manpower, chemiclas, energy, sampling, etc.
- Schedule & O&M Performance
- Emergency Responce Plan

Evaluation

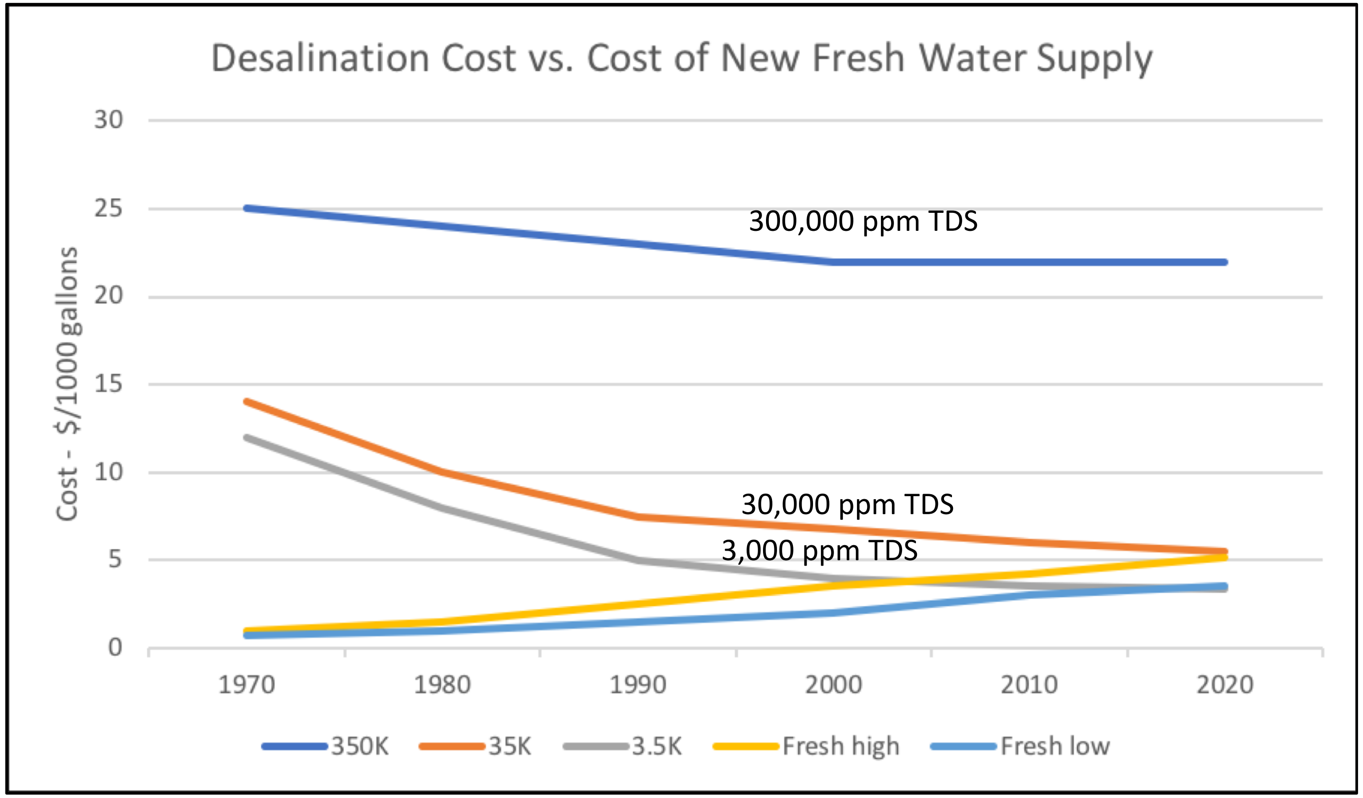
- Data results and assessment summary
- Operational performance data and summary
- Environmental Risk Summary
- Report Findings
- 3rd Party Cost and Perforamnce Evaluation Report

Produced Water Treatment Research Studies

- Phase 1 - Publish RFP for treatment research using developed **Research Selection and Management Plan**
  - NMSU WRRI process, with technical review team
- Phase 2 – Select projects, approve test plans, establish independent oversight teams, 4-10 projects in 2021
- Monitor progress and prepare cost and performance reports
- Establish lessons learned for 2022

Decreasing Treatment/Increasing Fresh Water Costs

(EWRI Hightower 2018)



2000 Permian Basin Avg. Produced Water Disposal costs $2/1000 gal

2020 Permian Basin Avg. Produced Water Disposal costs $20-50/1000 gal

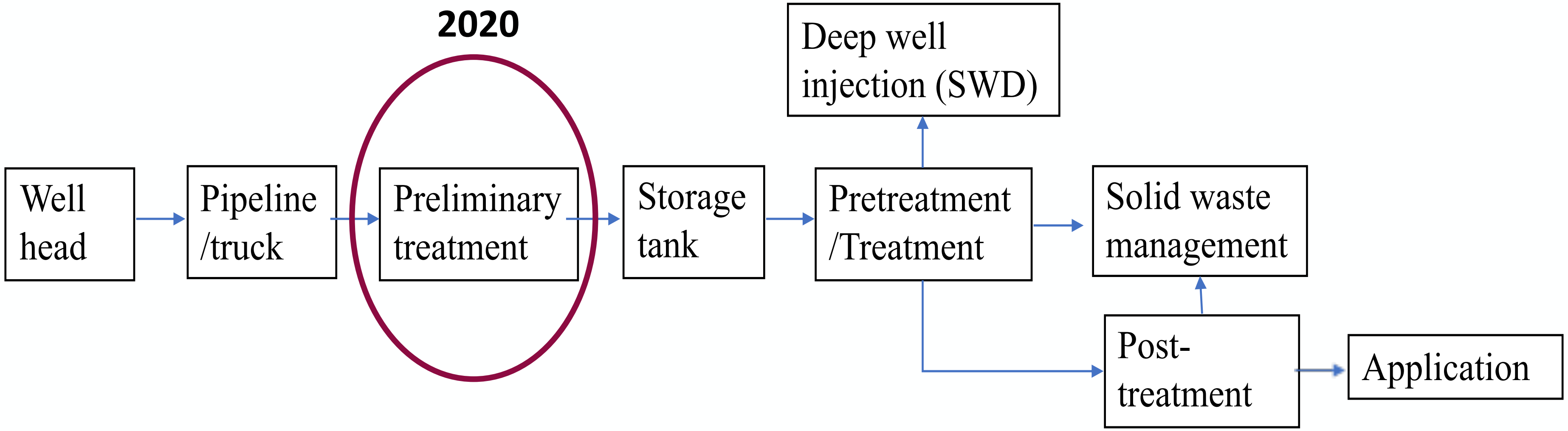
Example System Cost Analysis of Treatment of Produced Water

Water Cost Element	Produced Water Disposal - $/bbl		Produced Water Treatment - $/bbl	
	2020	2025	2020	2025
Fresh water for drilling	1.00	1.25	-	-
Produced water transportation	0.25	0.30	0.25	0.35
Pre- treatment	0.05	0.20	0.20	0.30
Treatment	-	-	1.50	2.30
PW Disposal	0.75	1.75	-	-
Residuals Disposal	-	-	0.25	0.60
Water sale value	-	-	(0.00-0.20)	(0.00-0.25)
Total Cost	2.05	3.50	2.00- 2.20	3.30-3.55

Clean Brine Standard Changes the Landscape on Produced Water Reuse

Pre-treatment | **Treatment** | **Post-treatment** | **Disposal**

PWS Clean Brine Standard 2020



Improve reuse options to reduce fresh/brackish water use in drilling and fracking

Water recovery for wholesale and fit-for-purpose uses

Mineral and resource recovery

Waste and seismicity reduction

Clean Brine Standard - Benefits to Produced Water Reuse

- Preliminary treatment standards will drive compatibility of different produced waters
  - Enables the ability to mix or share produced water without chemical or biological fouling or sludge formation, reduce air emissions and organic residuals, etc.
- Establishes a general baseline water quality to reduce pre-treatment and treatment variability
- Increases treatment economies of scale to 10-15 MGD plants, utilizing common industry and midstream produced water infrastructure capabilities
- Often good access to high volume waste disposal capacity
- Support basic (wholesale) quality indices for reuse inside or outside oil and gas sector

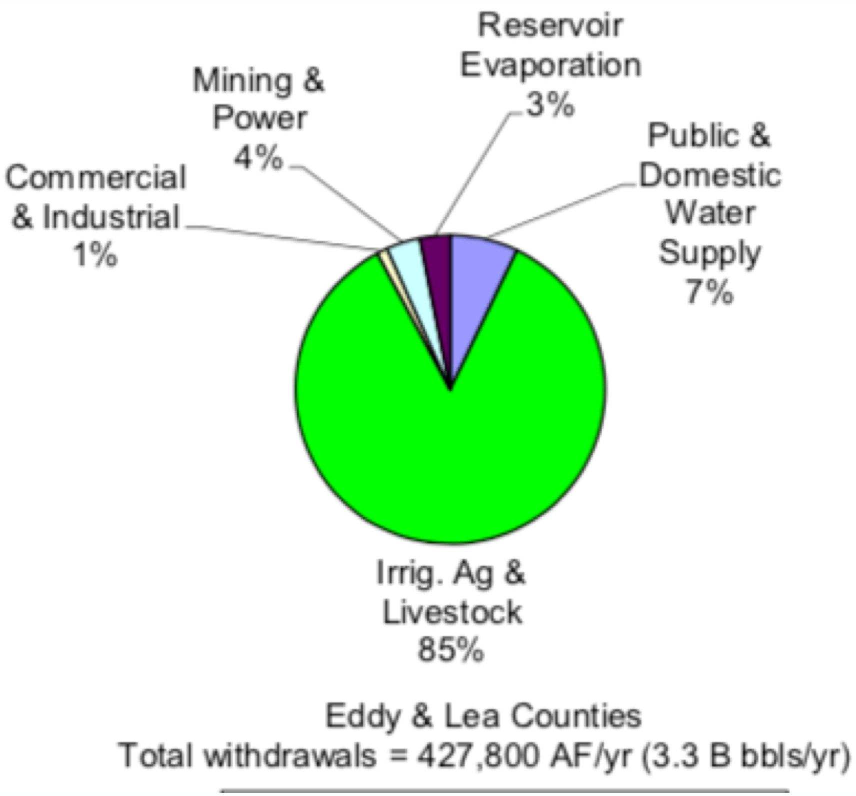
Potential Wholesale Produced Water Quality Metric

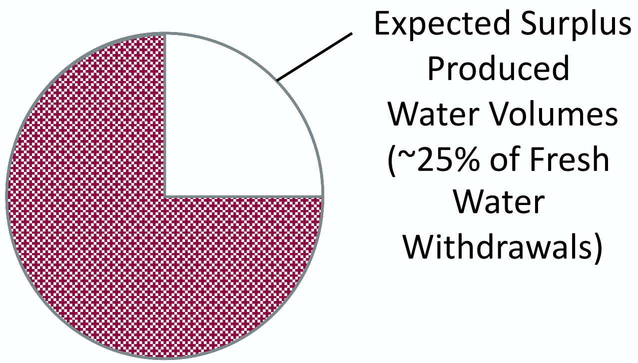
Application	Common Water Quality Requirements (ppm) TDS
Drinking	500-600
Cooling Water	1,000-2,000
Process Water	500-1,000
Pumped Hydro	3,000-10,000
Rangeland Restoration	4,000 – 10,000
Surface Flow	600-2000
Mineral Recovery	>100K (no discharge)
Road Constr.	Up to 100,000
Average Wholesale Index	3000-4000

Water Quality Requirements for Various Reuse Applications

Produced Water Quality (ppm) TDS	Application	Common Water Quality Requirements (ppm) TDS	Typical Treatment Process
Conventional 10K to 50K 50%<35K 50%>35K	Drinking	500-600	Chemical/membrane/thermal
	Aquifer Storage & Recovery	300-5,000	Chemical/membrane/thermal
	Agriculture and livestock	Class 1 <700, <60% Na, B<0.5 Class 2 2000, 60-75% Na, B<2.0 Class 3 >2000, 75% Na, B~2	Chemical/membrane/thermal
	Rangeland	4,000 – 10,000	Chemical/membrane/thermal
Unconventional 60K to 300K 25%<100K	Surface Flow	600-2000	Chemical/membrane/thermal
	Mineral Recovery	>100K (no discharge)	Chemical/thermal
	Road Constr.	Up to 100,000	Chemical/membrane/thermal

Economic Impact Of Produced Water Reuse





Surplus expected to be ~1 B bbls/yr (2-3 M bbls/day)

Annual Fresh Water Withdrawal

Projected Produced Water Surplus

Socioeconomic Benefits of Produced Water Reuse – Too Qualitative

Element	Value
Oil production value	$6-8 B
Gas production value	$5-7 B
General Fund direct revenues	$2 B
General Fund	$1B
Capital Outlay	$.4-.5 B
Taxes to local government	$.5 B
Percent of Budget from Oil and Gas Revenues	30%

(NM LFC Finance Facts, 2018)

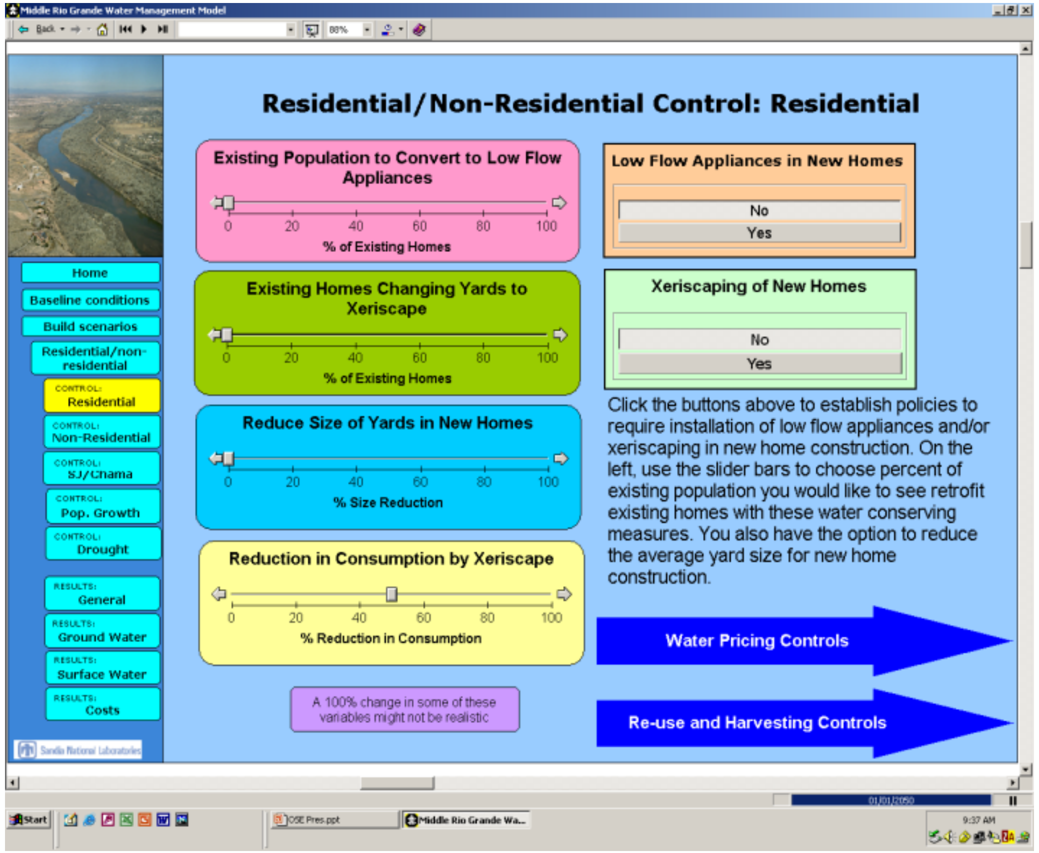
Supporting state economic growth and societal benefits

Cost/Benefit	Range of Values
Price of Oil (WTI)	$55.00
Price of Recycled Water per barrel	$0.50 - $7.00
Marginal Cost of Production & Taxes	$20 - $25
Marginal Cost of Water Disposal per barrel	$0.50 - $2.25
Marginal Cost of Transportation	$0.00 - $9.00
Marginal Cost of Recycling	$1.00 - $16.00
Marginal Private Value of Recycled Water	$0.25 - $1.75
Marginal Social Value of Recycled Water	$0.48 - $51.24

(Chermak & Patrick, 2018)

Quantitative Approach for Socio-economic, environmental Ecological Cost-Benefit Analysis of Produced Water Reuse

- Most important analysis attributes identified include:
  - Economic, social, environmental, ecological, sustainability, and health risk metrics
  - Allow broad stakeholder involvement
  - Provides quantitative rather than qualitative answers
- Considered several cost-benefit analysis and decision support approaches
  - Triple Bottom Line
  - Environmental, Social, Governance (ESG)
  - Holistic resource management
  - Choosing by Advantage (CBA)
- System dynamics is most flexible, most quantitative, and most amenable to stakeholder participation for multi-parameter performance optimization and relative-risk mitigation



Summary Data on Oil and Gas Operation Impacts on Public and Environmental Health and Safety

< 0.25 miles from oil and gas operations

- Highest level of acute public health impacts and concerns
- Highest occurrence of environmental impacts - noise, air, land. and water pollution and contamination

0.25 - 0.50 miles from oil and gas operations

- Significanlty reduced public health impacts
- Significantly reduced environmental impacts or damage from operations or accidents

> 0.50 miles from oil and gas operations

- Little observed acute or chronic public health and safety or environmental impacts
- Especially in open, flat, and non-wooded operational areas

- Highest impacts in populated areas, especially in wooded, rolling terrain
- Highest impacts to permanent residents on small private land parcels in closely aggregated operations
- NM DOH has no record of fracking damaging a personal water supply

Physicians for Social Responsibility-Colorado Symposium - Health Effects of Oil and Gas Development, December 4, 2020.

Part 2: Questions and Answers

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