Exceptional service in the national interest

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Produced Water Availability, Applications, and Trends

ECOS Webinar - January 11, 2017

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Discussion Topics

- **Growing global fresh water supply challenges**
  - Regional economic and social impacts
- **Growing interest in use of new technologies and approaches to supplement fresh water resources with non-traditional waters**
  - Sea water, brackish water, produced water, extracted and frack water, storm water, municipal and industrial reclaimed water, even cow water
- **Consideration of produced water for beneficial reuse**
  - Availability
  - Regulatory, quality, and cost challenges
  - Emerging considerations, applications, and approaches

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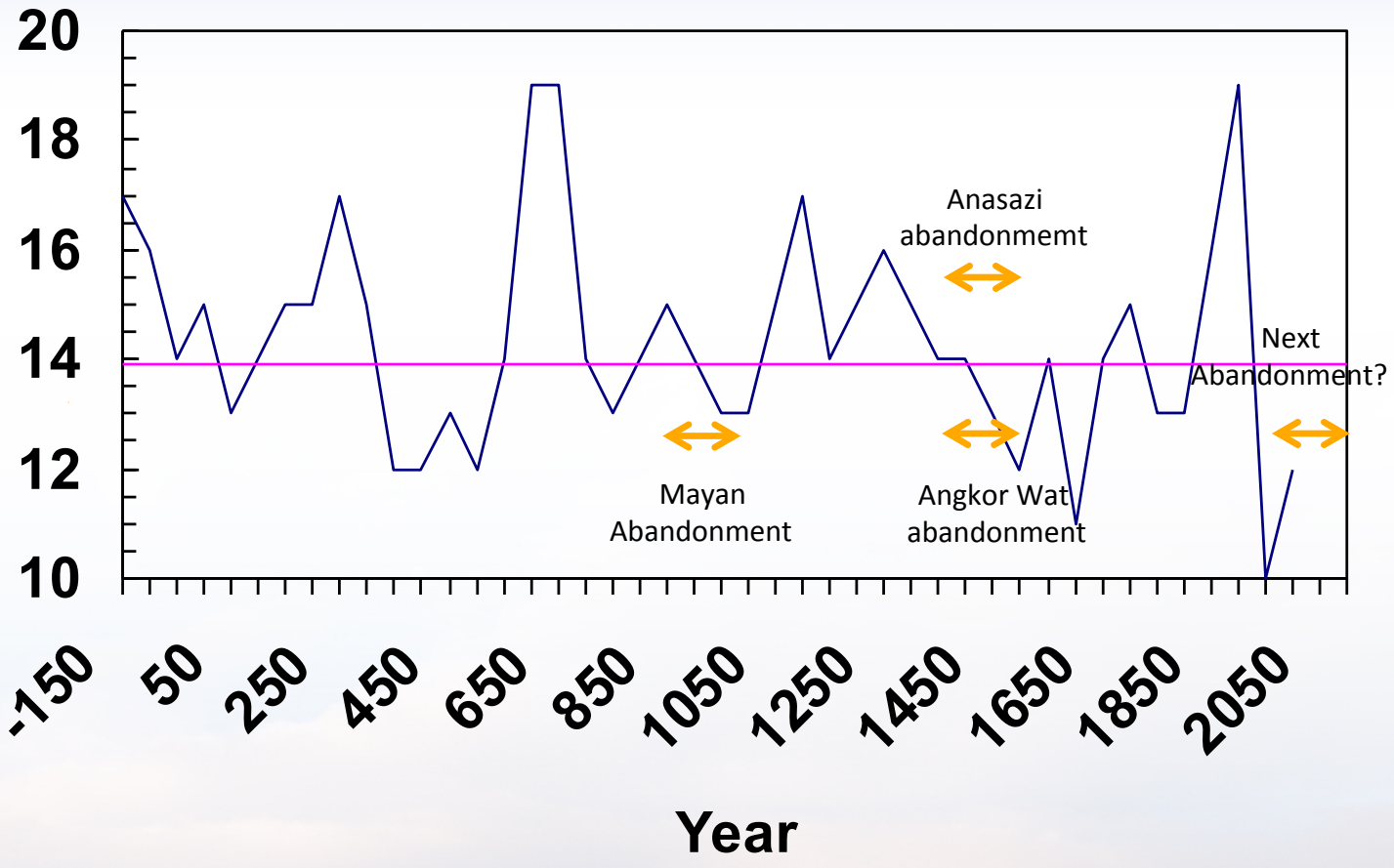
Southwest Climate History Based on Tree Ring Data



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

The southern U.S. and the mid-latitudes are in the 100th year of a 300 year arid cycle - not a drought cycle

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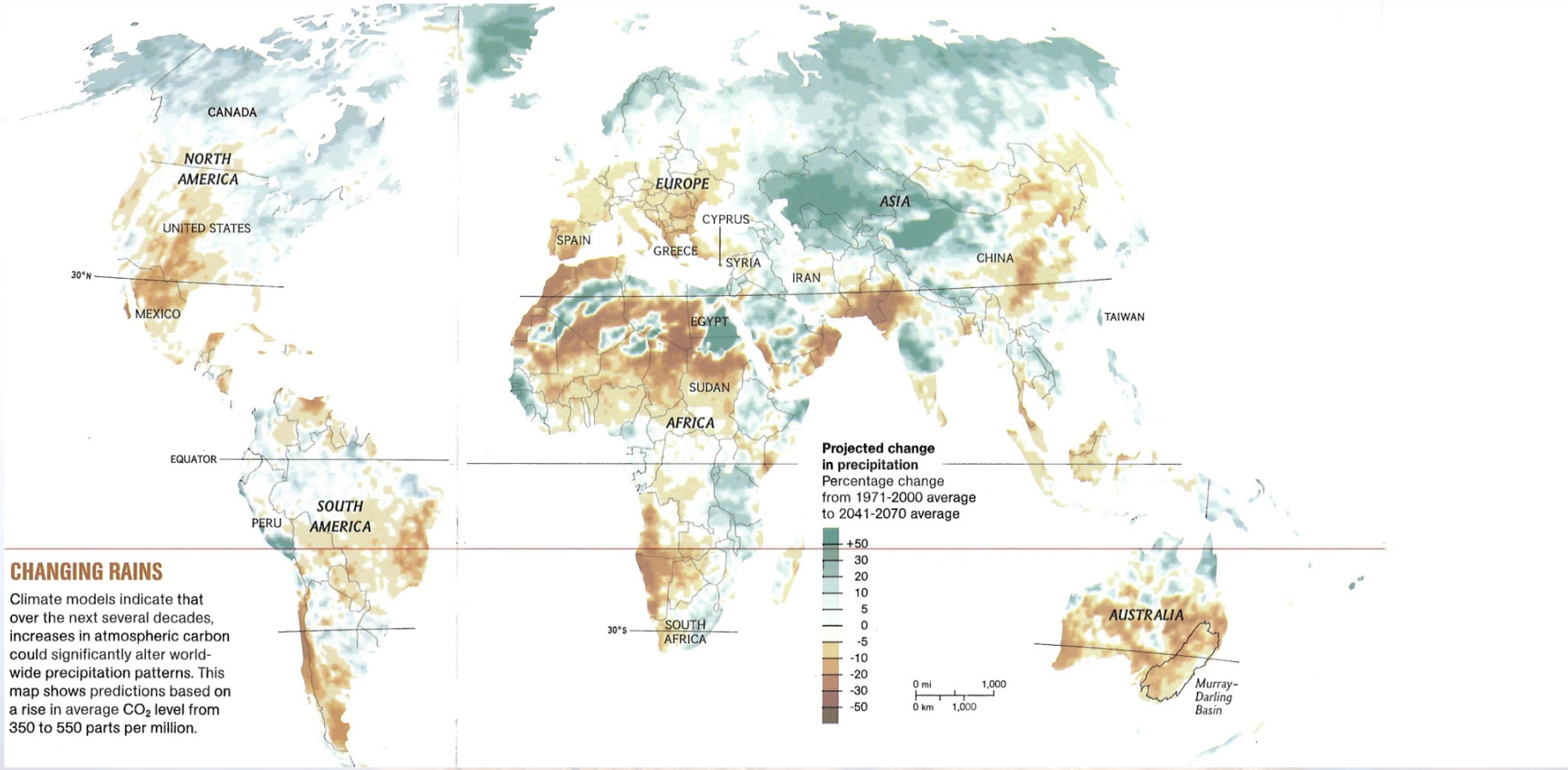
Climate Changes will Impact Temperatures, Precipitation, Evapotranspiration, and Runoff



Nat. Geo. April 2009 from IPCC

Mid-latitude population and grain belts will be strongly affected

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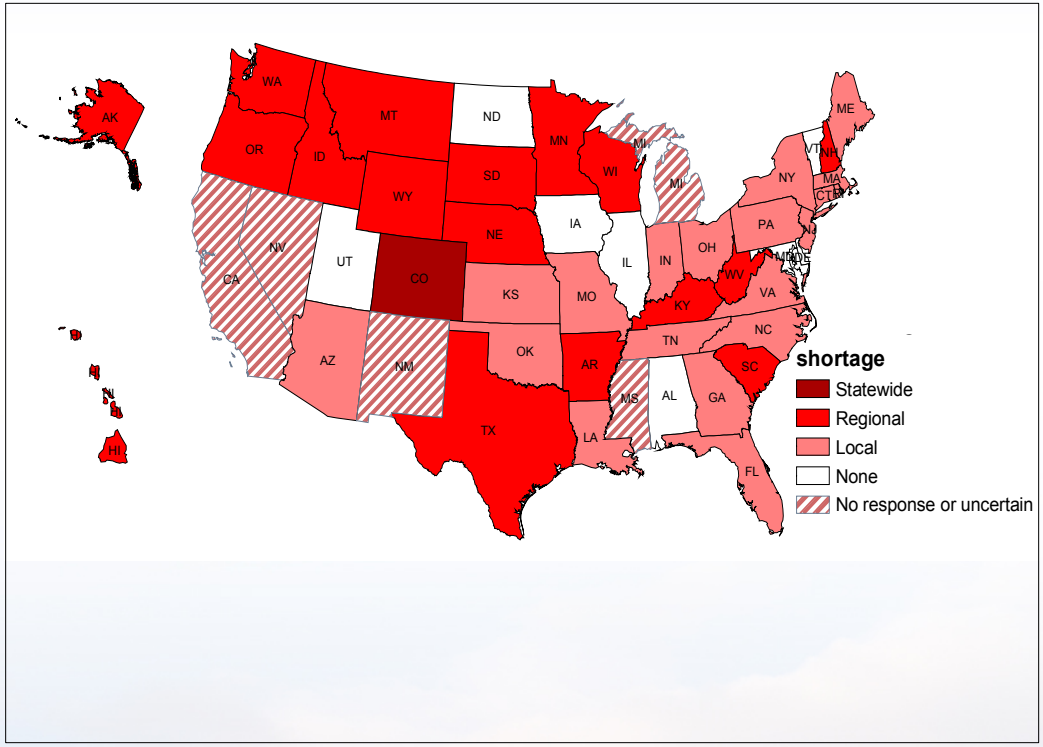
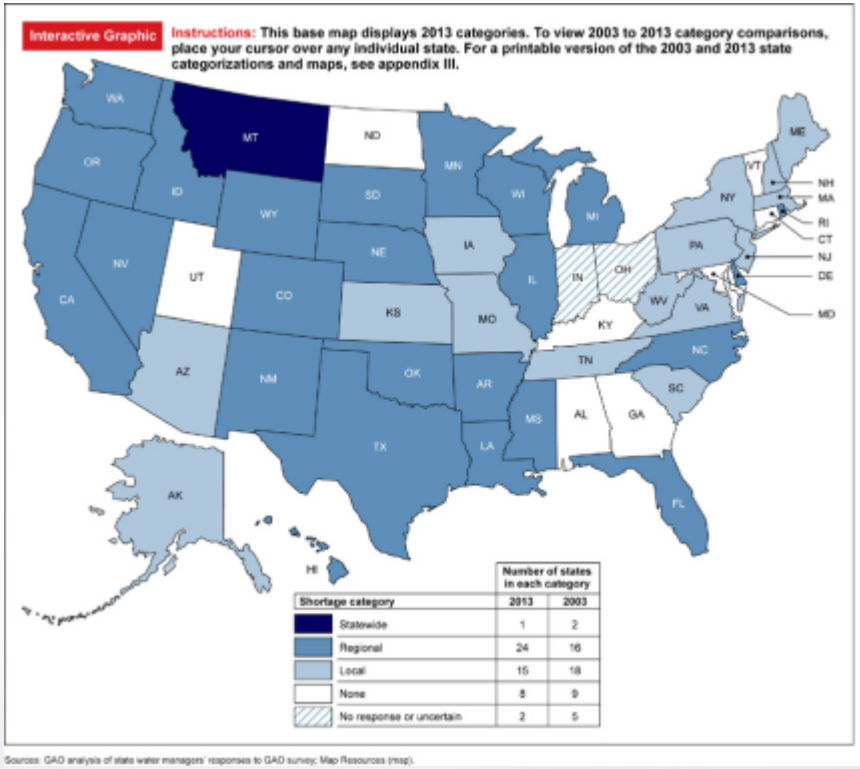
Expected State Water Shortages Increasing



GAO 2003



GAO 2013

Water stress is increasing nationally

The Energy Intensity of Water Supplies Can Vary Greatly Across a State

Sacramento River Energy Intensity per Acre-Foot of Water

Type of Water	Energy Intensity (= 1-250 kWh/AF, = 251-500 kWh/AF)	Percent of Regional Water Supply*
Colorado (Project)	*This type of water not available*	0%
Federal (Project)	<250 kWh/AF	12%
State (Project)	<250 kWh/AF	12%
Local (Project)	<250 kWh/AF	15%
Local Imports	*This type of water*	38%
Groundwater	<250 kWh/AF	19%

* Hetch Hetchy is a net energy provider

San Francisco Energy Intensity per Acre-Foot of Water

Type of Water	Energy Intensity (= 1-250 kWh/AF, = 251-500 kWh/AF)	Percent of Regional Water Supply*
Colorado (Project)	*This type of water not available*	0%
Federal (Project)		12%
State (Project)		12%
Local (Project)	<250 kWh/AF	15%

South Coast Energy Intensity per Acre-Foot of Water

Type of Water	Energy Intensity (= 1-250 kWh/AF, = 251-500 kWh/AF)	Percent of Regional Water Supply*
Colorado (Project)		21%
Federal (Project)	<250 kWh/AF	<1%
State (Project)		27%
Local (Project)	<250 kWh/AF	4%
Local Imports	0*	5%
Groundwater		33%

* Los Angeles Aqueduct is a net energy provider

Source: California Water Plan Update 2013

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Energy Requirements of Various Water Resource Options

Water Supply Options	Energy Demand (kWhr/kgal)
Fresh Water Importation (100-300 miles)	10-18
Seawater Desalination w/Reverse Osmosis	12-20
Brackish Groundwater Desalination	
Reverse Osmosis Treatment	7-9
Pumping and concentrate management	1-3
Total	8-12
Aquifer Storage and Recovery	
Pre-treatment (as needed)	3-4
Post-treatment (as needed)	3-4
Pumping	2-3
Total	5-11

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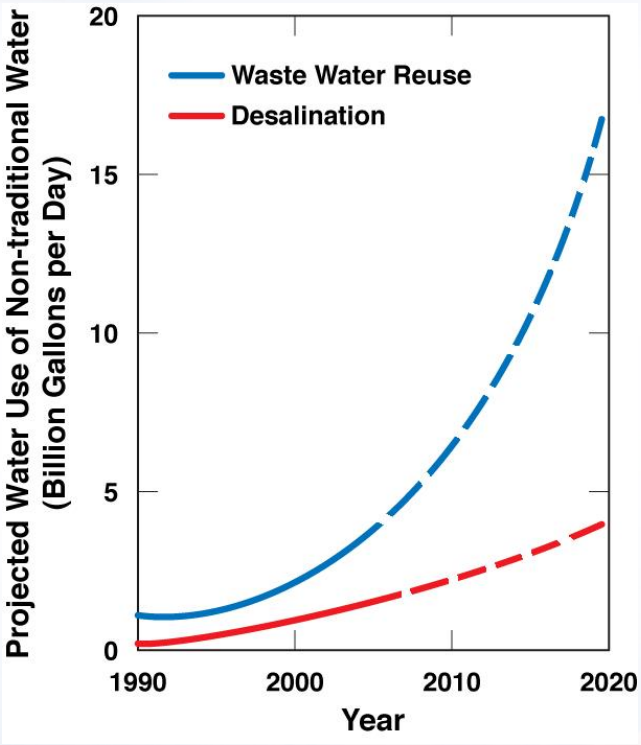
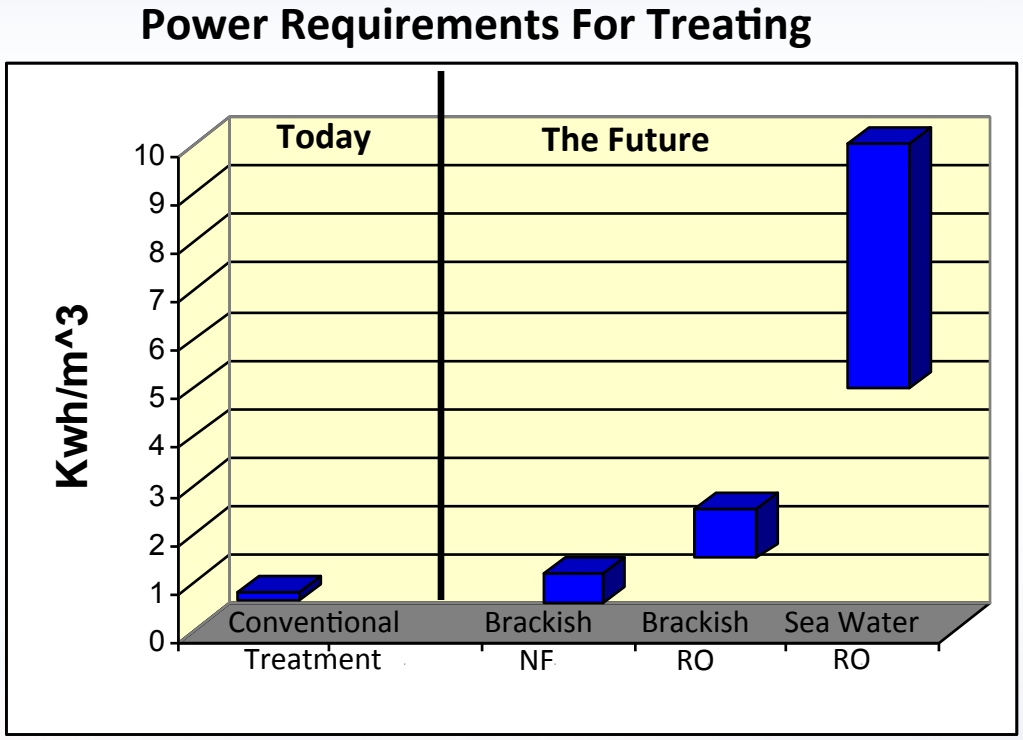
Growing Use of Non-traditional Water Resources



(From EPA 2004, Water Reuse 2007, Mickley 2003)



(Einfeld 2007)

U.S. Trends in Desalination and Use for Nontraditional Water Resources

- **Over 300 desalination plants currently in the U.S.**
- **Desalination growing at 10% per year, waste water reuse at 15% per year**
- **By 2050, 40% of Texas drinking water supply will be from nontraditional water resources per TWDB**
- **Fresh water supply vs demand in many regions is decreasing due to population growth, economic growth, and climate impacts**
  - Number of nontraditional water supplies - seawater desalination and brackish water desalination- are increasingly cost competitive
  - Other nontraditional waters that can use desalination approaches – produced water, coal bed methane, municipal and industrial reuse, etc. – could become much more cost effective

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Produced Water References

United States Government Accountability Office

GAO

Report to the Ranking Member, Committee on Science, Space, and Technology, House of Representatives

January 2012

ENERGY-WATER NEXUS

Information on the Quantity, Quality, and Management of Water Produced during Oil and Gas Production

G A O

Accountability * Integrity * Reliability

GAO-12-156

Prepared for the Ground Water Protection Council

GROUNDWATER PROTECTION COUNCIL

John Veil, Veil Environmental, LLC

ve Veil Environmental, LLC

April 2015

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Produced Water Is from Oil and Gas Production but Quality Overlaps Many Other Waters

Fresh Water - 500 ppm TDS
Brackish Water – 1,000-10,000 ppm TDS
Sea Water – 35,000 ppm TDS

Produced Water – 5,000 – 200,000 ppm TDS
- 25% < 30,000 ppm TDS
- 25% > 30,000 ppm TDS < 60,000 ppm TDS
- 50% > 60,000 ppm TDS
- Includes oils, organic acids, naturally occurring radioactive materials (NORM), boron, beryllium, lithium, hydrogen sulfide, etc.

Western U.S. Produced Water Holding Pond

Frack Water
- Fresh to 250,000 ppm TDS
- Flow back water – 10,000 to - 200,000 ppm TDS

Extracted Water
- Deep saline waters for carbon storage > 200,000 ppm TDS

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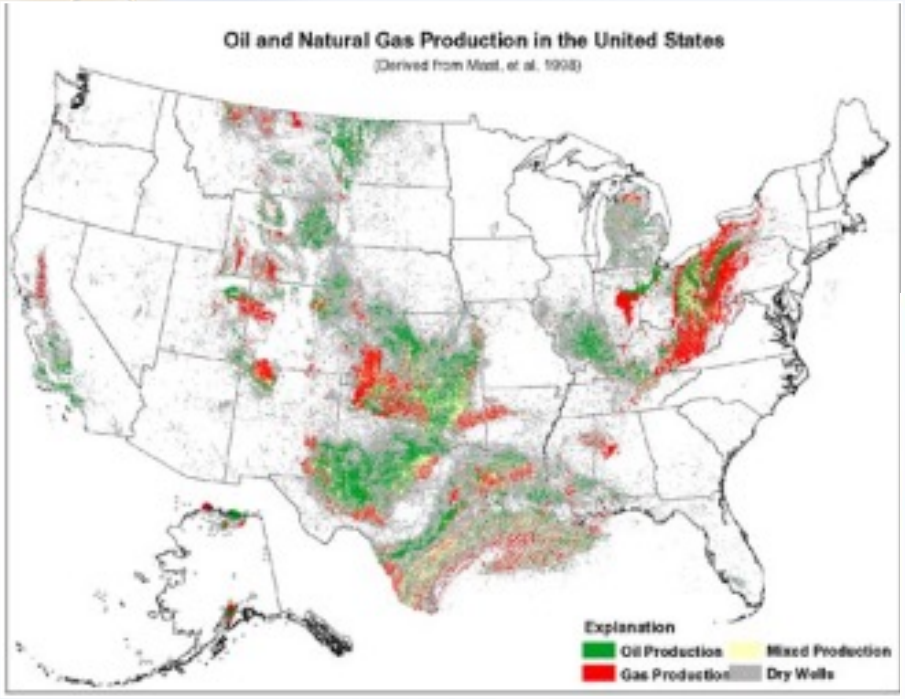
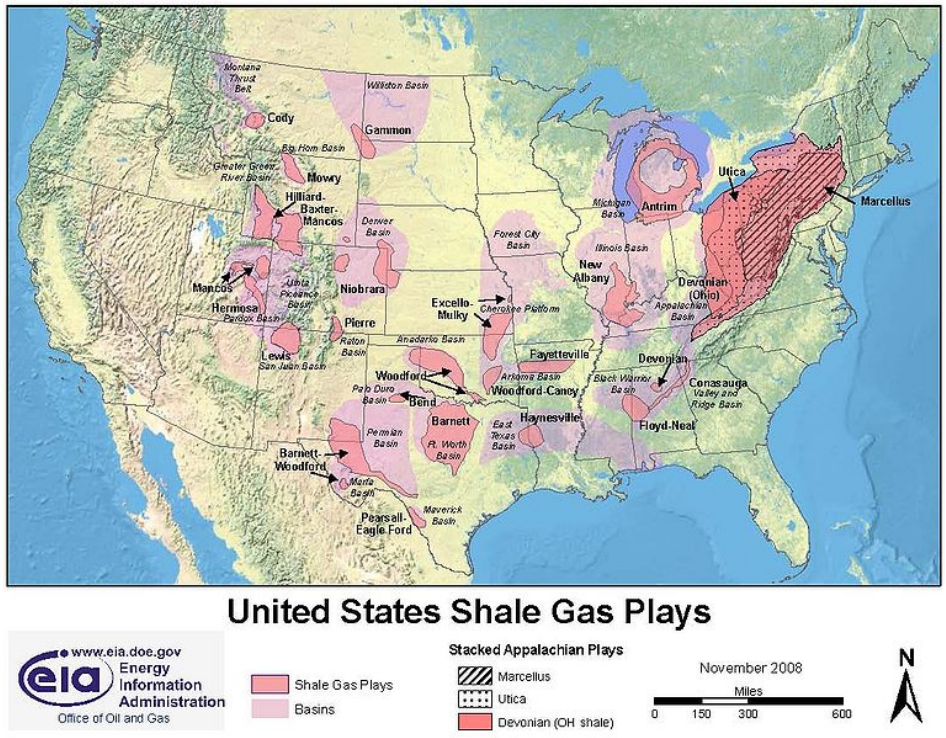
Oil and Gas Produced and Frack Water Development Areas



Oil and Gas Produced Water



Examples of Produced Water Production Ration by State and Region

Ratio of Water to Oil Production

- Not all states provided separate water from oil production and water from gas production
- The weighted average water-to-oil (WOR) for 21 states is 9.2 bbl water/bbl oil.
  - Two of the key water producing states (Texas and Oklahoma) were unable to distinguish the water generated from oil wells vs. water coming from gas wells. Both of those states have large numbers of older wells from mature fields that typically have very high WORs (much higher than the weighted average). It is very likely that if the wells from those states were averaged in, the national weighted average WOR would be higher than 10 bbl/bbl.

State	Crude Oil (bbl/year)	Water from Oil (bbl/year)	WOR
Alabama	11,310,000	37,858,000	3.3
Alaska	192,368,000	768,133,000	4.0
Arizona	51,900	66,700	1.3
Arkansas	6,567,600	174,614,000	26.6
California	197,749,000	3,071,362,000	15.5
Illinois	8,908,000	105,268,000	11.8
Indiana	2,350,000	48,931,000	20.8
Kansas	43,743,000	971,009,000	22.2
Michigan	7,400,000	25,000,000	3.4
Mississippi	24,146,000	228,069,000	9.4
Missouri	175,000	2,103,000	12.0
Montana	26,495,000	179,085,000	6.8
Nebraska	2,514,000	57,873,000	23.0
Nevada	368,000	5,865,000	15.9
New Mexico	85,341,000	674,902,000	7.9
New York	360,000	208,000	0.6
North Dakota	243,272,000	284,426,000	1.2
Ohio	5,063,000	4,860,000	1.0
South Dakota	1,754,000	5,296,000	3.0
Virginia	9,700	54,400	5.6
Wyoming	45,382,000	1,646,601,000	36.3
Total Volume	905,327,200	8,291,584,100	
Weighted Average WOR			9.2

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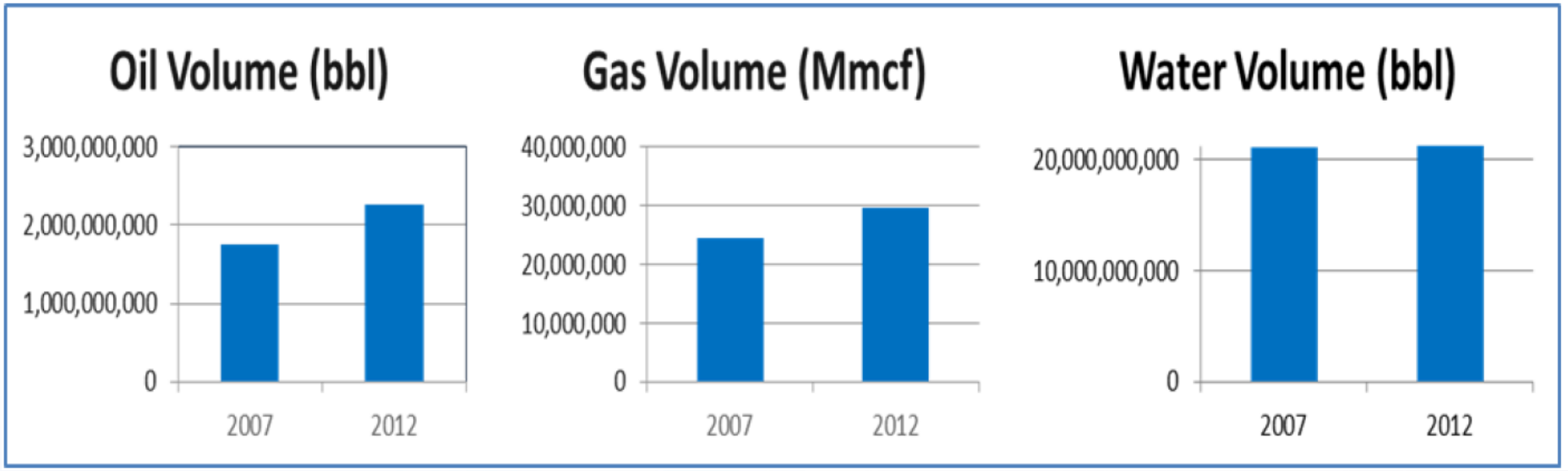
U.S. Produced Water Volume Trend



Oil production now at about 9 million bbls/day or 3.2 B bbls per year
Natural gas production now at 75 Bcf/day or 28 M (mmcf/day)

~9-10 barrels of water produced for every barrel of oil produced
60-80 % of the produced water is reinjected for disposal/oil reservoir management (EOR)

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Produced Water Potentially Available for Regional Reuse

State Rank in Produced Water Generated	Produced Water Production MGD	Available Water @30% Reuse MGD
Texas	860	258
California	353	106
Oklahoma	264	79
Wyoming	250	75
Kansas	122	37
Louisiana	115	35
New Mexico	88	26
Alaska	71	21
Colorado	37	11

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Alternative Uses for Produced Water to Support Water Resource Sustainability

- **Reuse in oil and gas production**
  - Hydraulic fracturing up to 250,000 TDS
  - Steamflooding (California) 5,000 TDS
- **Irrigation (after treatment or dilution)**
  - Rangeland rehabilitation up to 12,000 TDS
  - Non-food crops - low boron and 3,000 TDS
  - Algal biofuel production up to 20,000 TDS
  - Support wetlands up to 20,000 TDS
- **Injection/hydraulic control and dust/ice control**
  - Reduce subsidence and salt water intrusion
- **Use for industrial applications**
  - Hybrid cooling towers up to 10,000 TDS
  - Pumped hydro – high TDS
  - Solution mining, wash water

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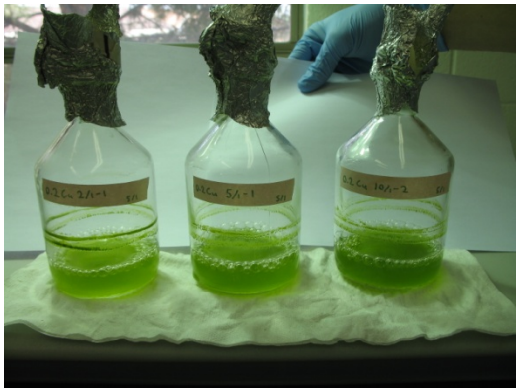
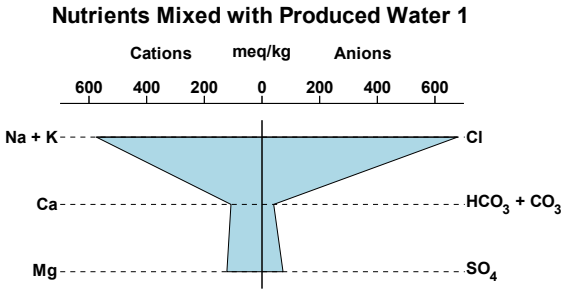
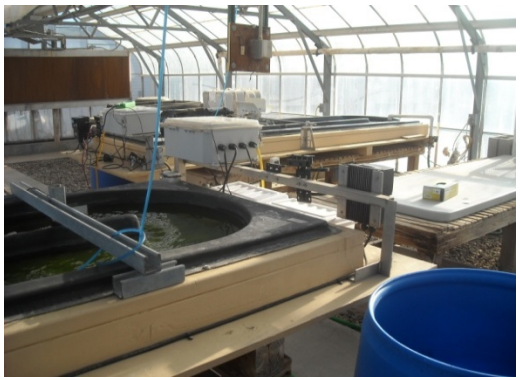
Growing algae in Produced Water



Lab Scale-LANL

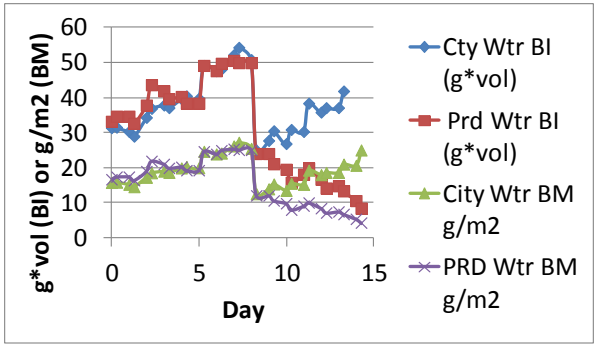
N. Salina 1776; *Scenedesmus+Tetracystis*
Salinity 10,000-30,000 mg/L
Testing various salinity ranges (10,000-30,000 mg/L); Cu:Zn ratios; HCO_3^- concentrations (200-1,000 mg/L)
Modeling used to optimize media recipes





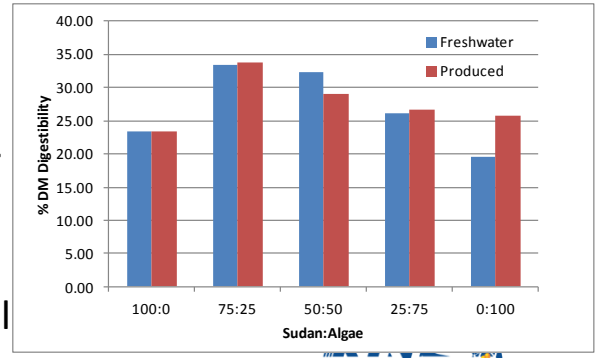
Pilot Scale-Texas Agrilife Pecos

N. Salina 1776;
salinity 19,000-28,000 mg/L
OD=0.6-0.8; AFDW=0.35 g/L;
BI=8-50 g/L
Exhibited low tolerance to higher salinity range



Field Scale-Eldorado Biofuels

Scenedesmus+Tetracystis (Jalgae™);
Salinity 11,000-13,000 mg/L
Growing consistently in treated PW
Low concentration commercial fertilizer sources of N, P, K
HCO_3^- concentrations ~700-900 mg/L
Diluent fresh water from local stock well
Quality is similar to FW samples



Rangeland Improvement

- **Watered with ~4000, ~5000 and ~12,000 TDS produced water**
  - Limited irrigation, focus to establish (jump start) grasses
  - The Sodium Absorption Ratio (SAR) and Electrical Conductivity (EC) of the soil rose only slightly and remained under critical limits for forage production for most grasses planted
- **Chief Intermediate Wheatgrass, Hy-Crest Crested Wheatgrass, and San Louis Slender Wheatgrass had best overall rating for stand establishment**
- **Land Management Guidance, ~1500 TDS water**

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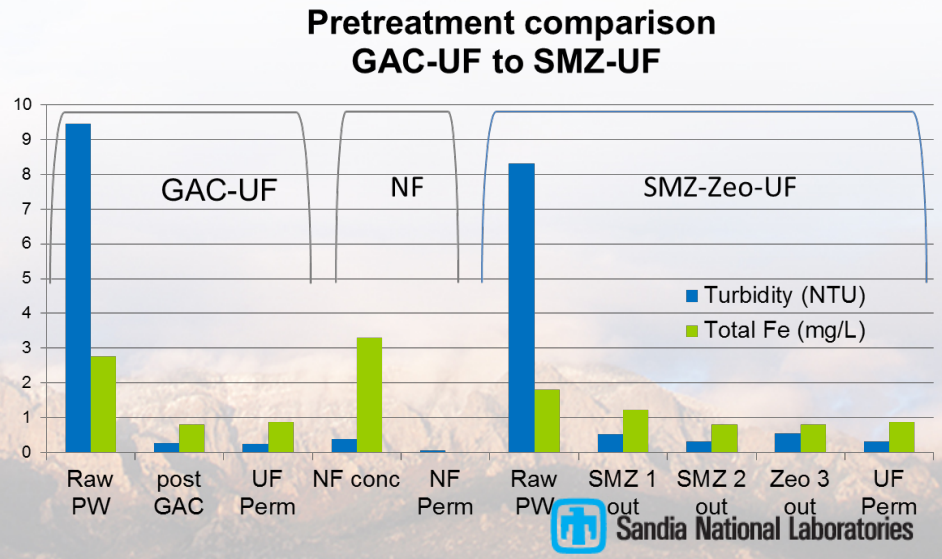
Produced Water Treatment for use in Rangeland Rehabilitation, Bloomfield NM

- Coal bed methane produced water was treated with multiple steps for organic, coal fine, and salt removal
- Water was discharged to comparative rangeland plots to evaluate most appropriate quality for vegetation rehabilitation
- Collaborative effort between Conoco Phillips, small businesses, LANL, Sandia, Bureau of Land Management, and State of NM

Coal fines accumulating in the modified zeolite filtration medium.



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Brackish/Produced Water Research Facilities

NRS Inc. salt recovery from El Paso desalination plant, recovers 66% of concentrate as fresh water (2 MGD) and chemicals

Unilever (Voltea) capacitive desalination testing with Bureau of Reclamation, of produced water from Artesia, New Mexico (8000 ppm TDS)

Additional produced water treatment facilities at Texas A&M and new facilities proposed in Texas with disposal wells

30 MGD El Paso Desal Plant
Largest Inland Desal Plant in the World

Brackish Groundwater National Desalination Research Facility, Alamogordo NM

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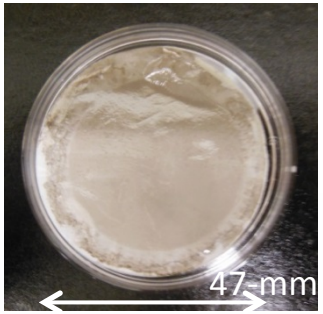
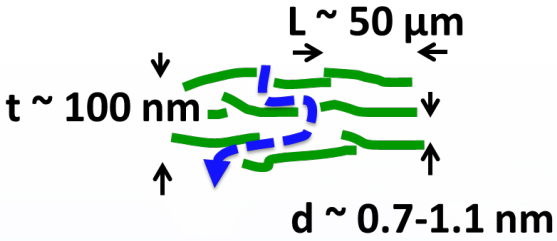
Laminar GO membranes are Potentially Disruptive for Produced Water Treatment

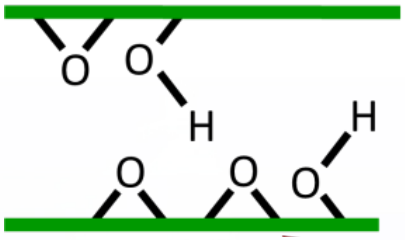
Intrinsic nanoscale properties of laminar graphene oxide (GO) drive water permeation and are optimum for desalination

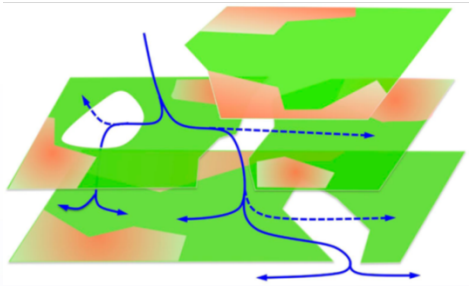


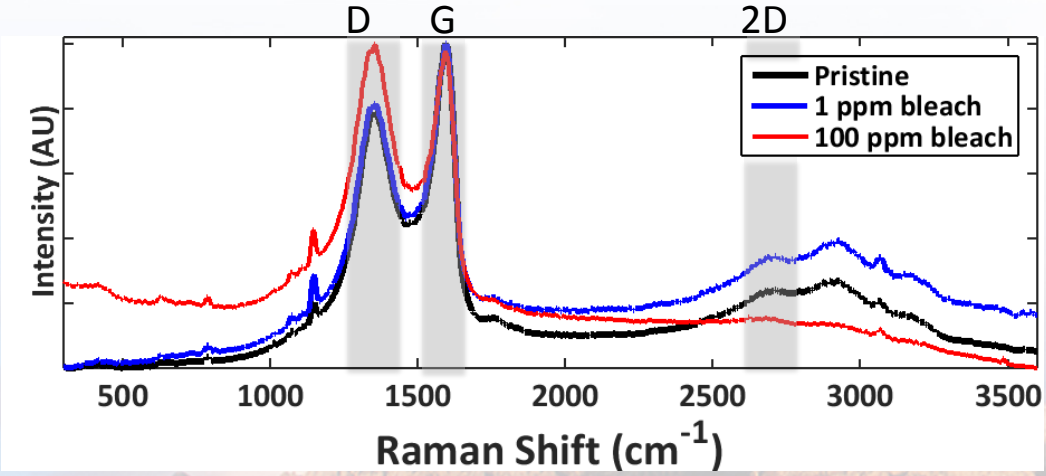
SNL GO/polyester membrane

Thin-slit permeation pathway defined by oxygen moiety "nanopillars"





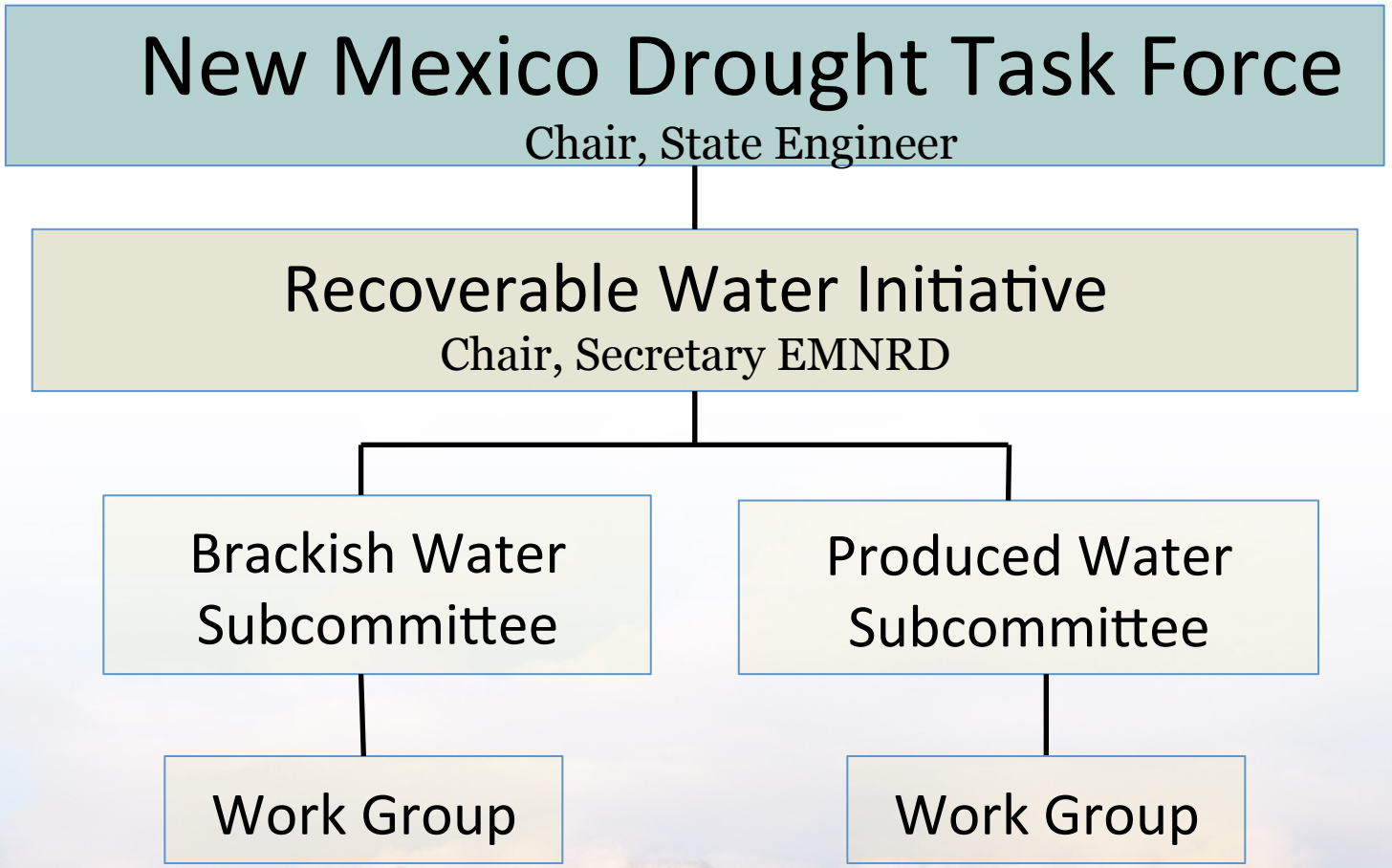




GO structure is robust to 1-5ppm, **one month** free chlorine exposure.

GO is chemically tolerant to many hydrocarbons (eg: toluene)

Example of Recoverable Water Initiatives



Example of New Integrated Brackish Water and Produced Water Rules in New Mexico

- **Less than 1,000 mg/L TDS**

or

- **Above 2,500 feet below ground surface**

Then normal water permit applications and jurisdiction apply. Water rights are assigned for beneficial use.

- **Greater than 1,000 mg/L TDS**

and

- **More that 2,500 feet below ground surface**

Then a permit is required, but no beneficial use assignment is needed.

Additionally, no impairment of fresh water may occur by extraction of the BW.

Therefore most produced waters are not a water of the state, and can be sold if they meet environmental water quality requirements.

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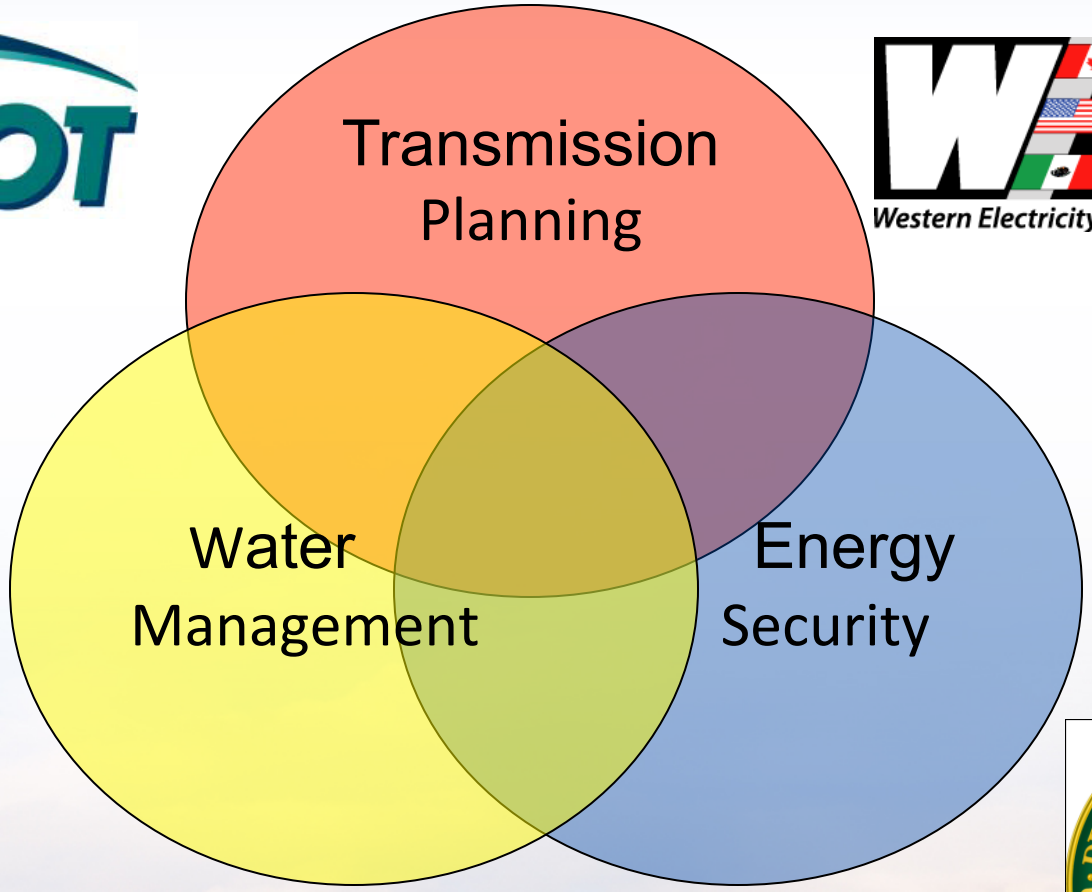
U.S. Water Atlas Mapping Efforts Include Produced Water Availability

ERCOT



WECC
Western Electricity Coordinating Council

Western Governors' Association
Serving the Governors of 19 States and 3 US-Flag Pacific Islands

WSWC
Western States Water Council

Department of Energy, United States of America

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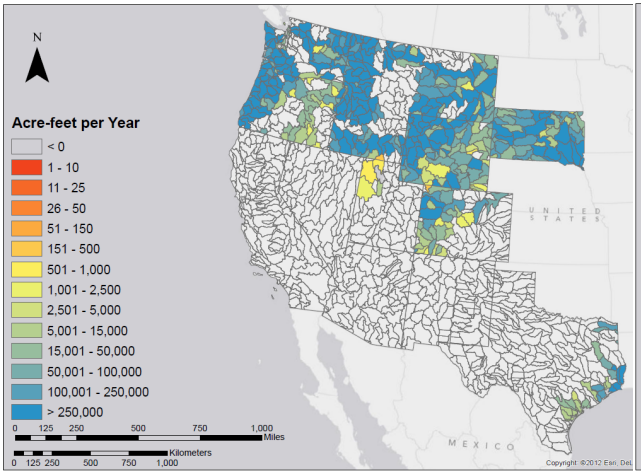
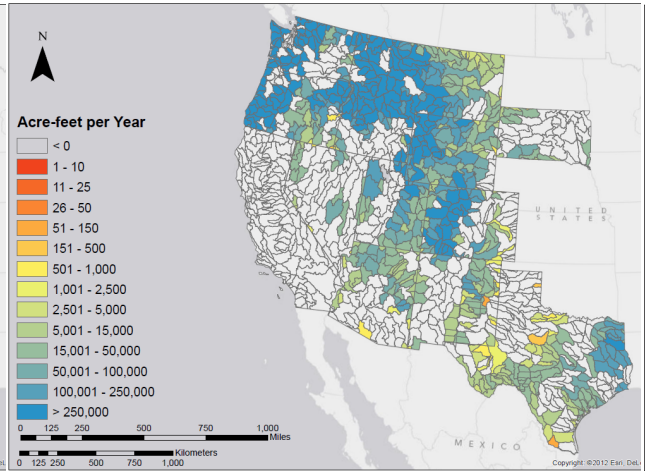
Currently Information on Western Water Availability – Adding Eastern Water Availability

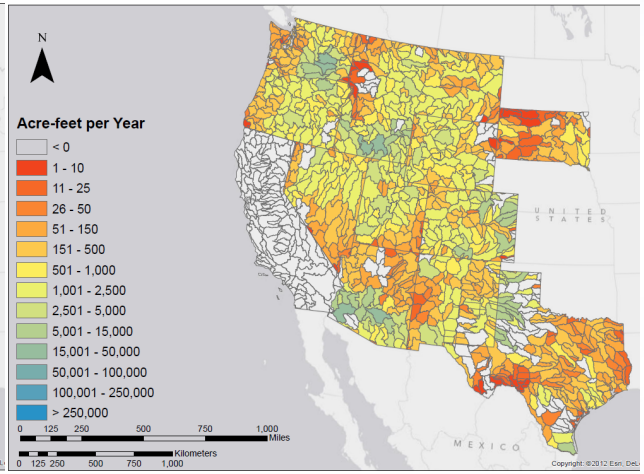
Unappropriated Surface Water Metric



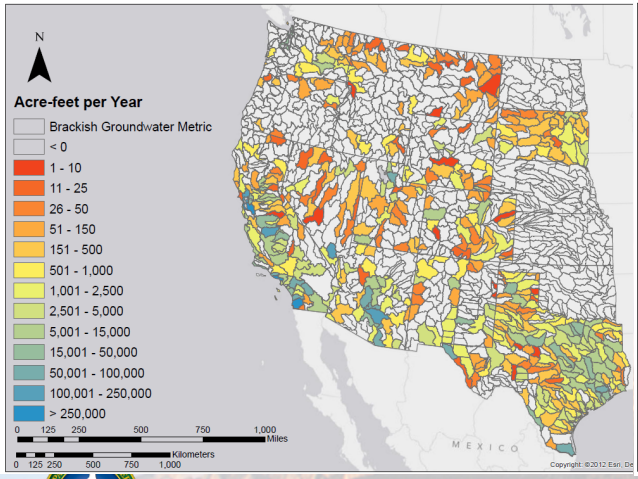
Potable Groundwater Metric



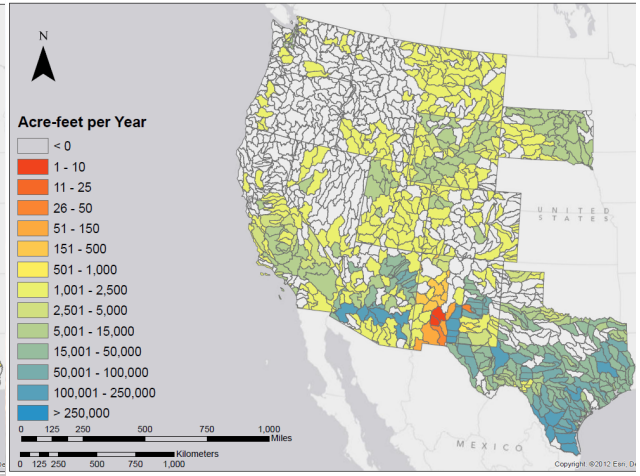
Appropriated Surface Water Metric



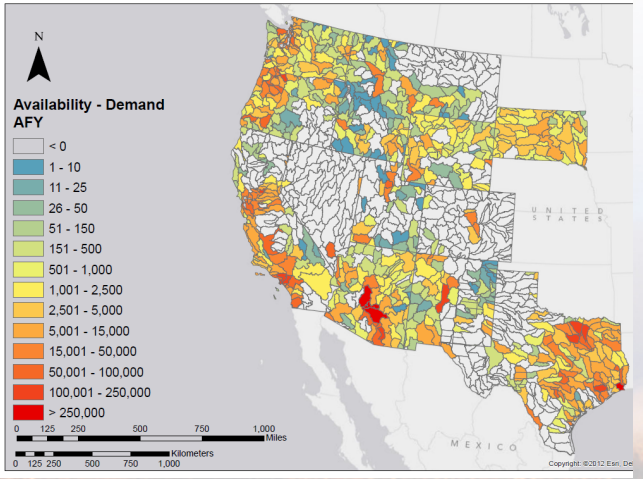
Wastewater Metric



Brackish Groundwater Metric



Change in Demand, Present - 2030



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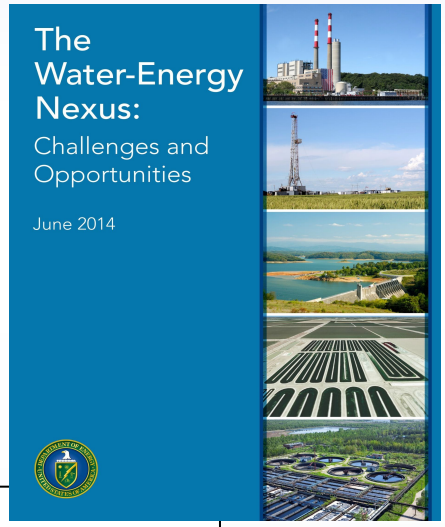
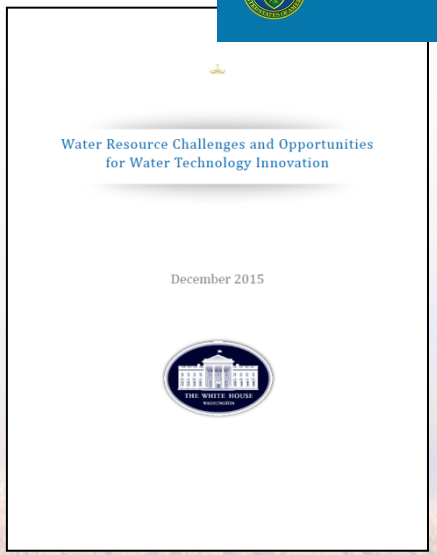
DOE Energy Water Research Includes Produced Water Treatment and Management

- ***Technology RDD&D***
  - ***Thermoelectric Cooling Improvements***
  - ***Waste Heat Recovery in Energy Systems***
  - ***Process Water Use Efficiency and Quality***
  - ***Traditional and Non-traditional Hydropower Improvements***
  - ***Alternatives to Fresh Water Use in Energy Production Using Advanced Materials and Processes***
  - ***Desalination Improvements***
  - ***Net-Zero Municipal Wastewater Treatment***
  - ***Sensors***
  - ***Deployment***
- ***Analysis and Modeling***
  - ***Integrated Analytical Platforms***
  - ***Decision Support Tools***
- ***Policy Framework***
- ***Stakeholder Engagement***
- ***International Diplomacy***





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