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Water Challenges and Desalination Looking Back and Looking Forward a Decade

Multi-State Salinity Coalition
January 2016

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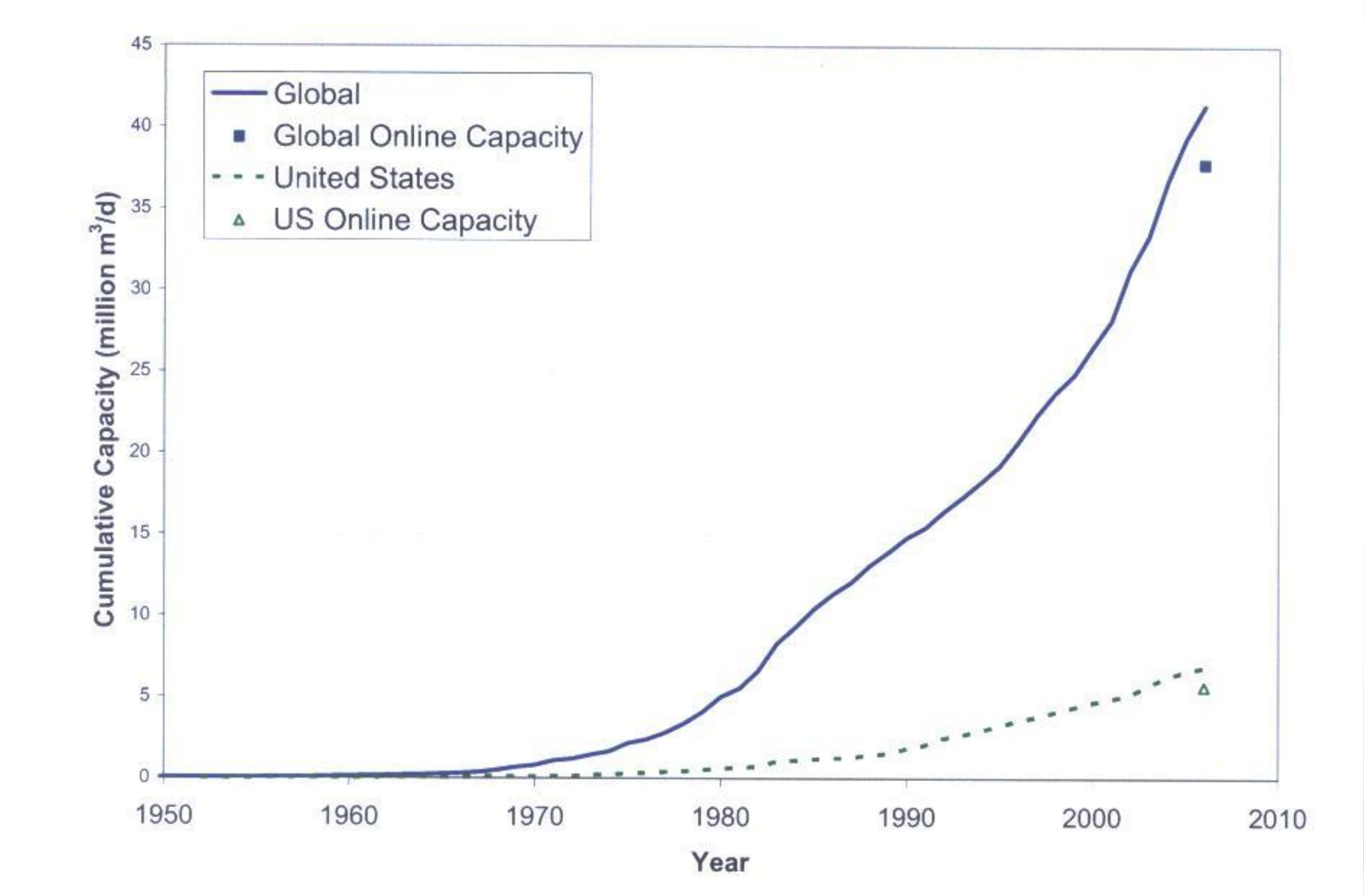
Desalination Capacity Growth Trends Circa 2005



(National Research Council, Desalination 2008)

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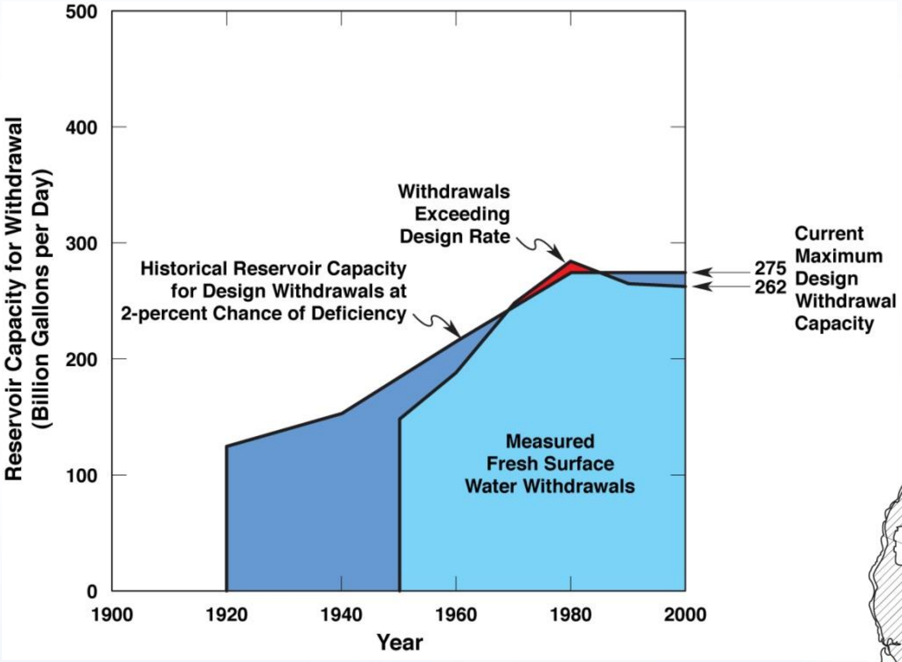
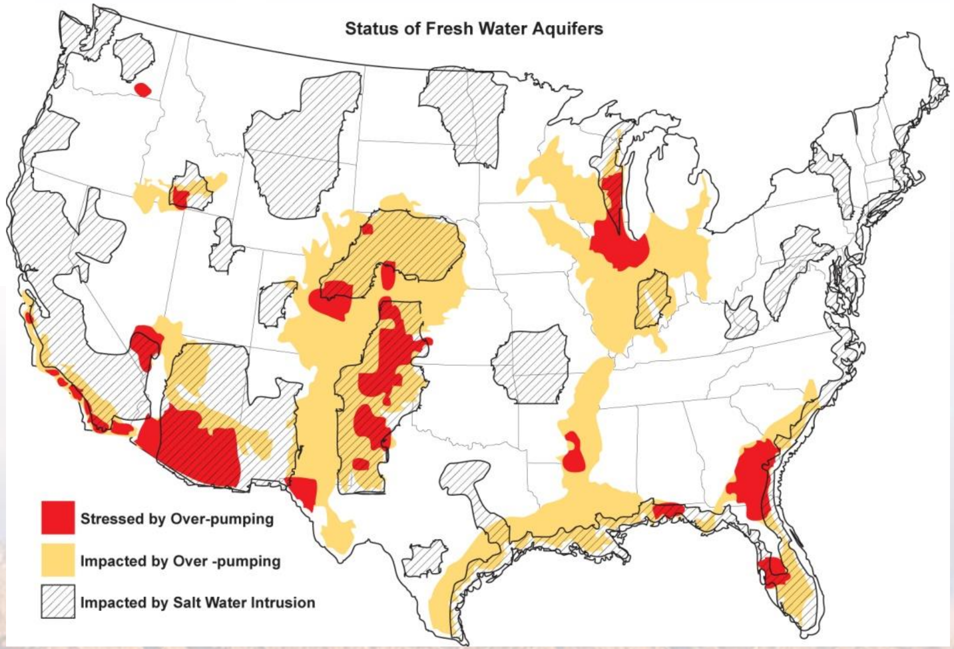
Growing Limitations on Fresh Surface and Ground Water Availability



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

- Little increase in surface water storage capacity since 1980
- Concerns over climate impacts on surface water supplies

- Many major ground water aquifers seeing reductions in water quality and yield



(Shannon 2007)

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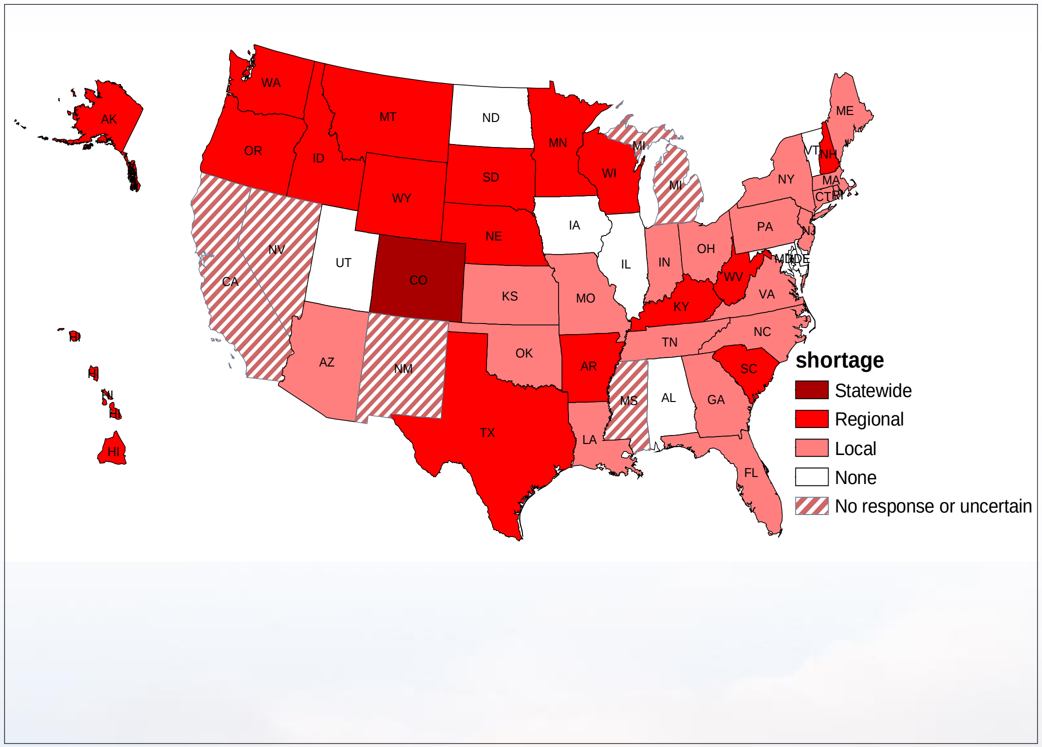
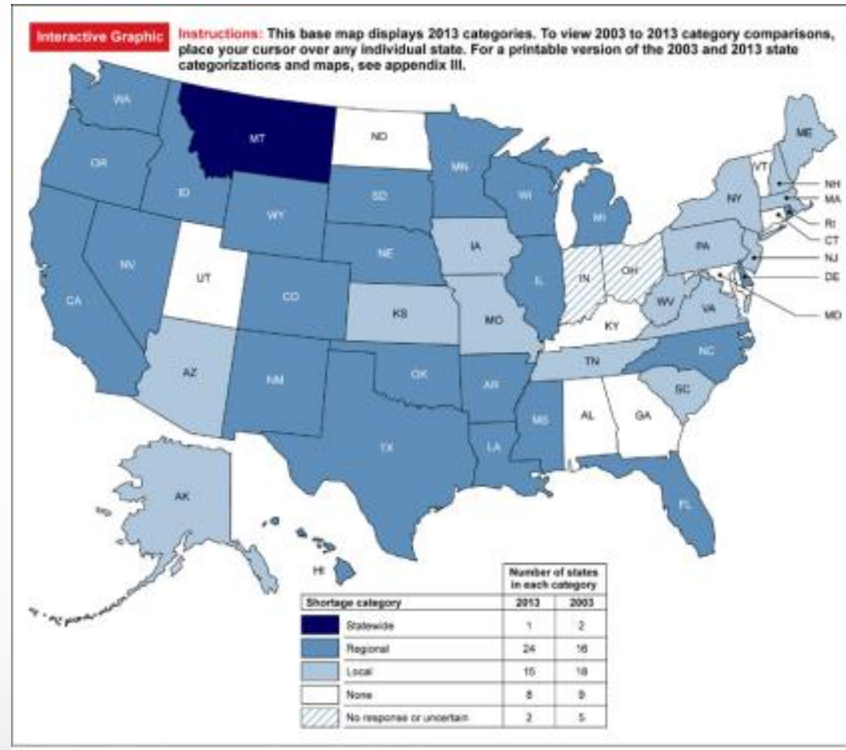
Expected State Water Shortages Increasing



GAO 2003



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

GAO 2013

Water stress is increasing nationally

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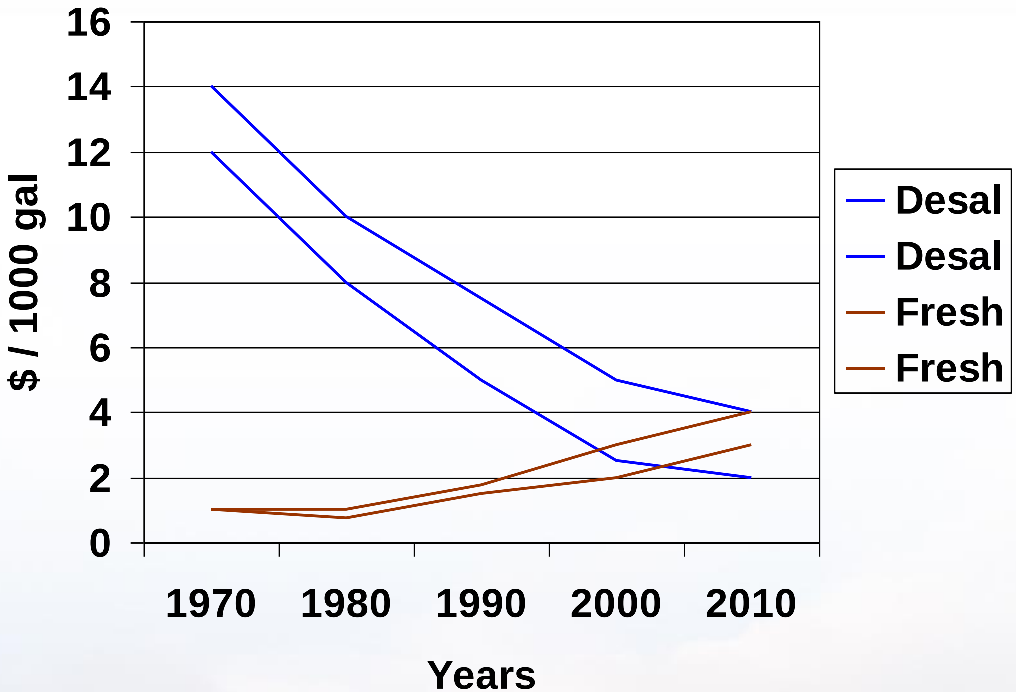
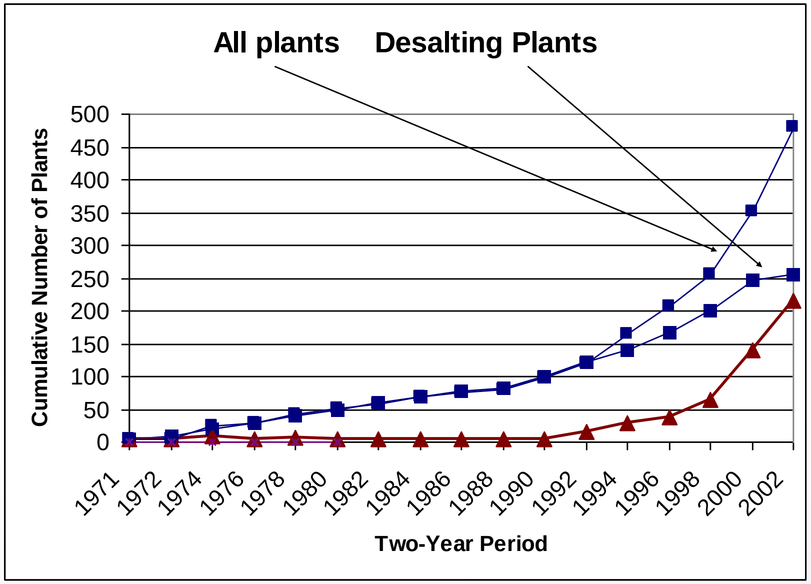
Desalination vs. Fresh Water Costs and Growth in U.S. Desalination Plants





Brackish water desalination and waste water reuse increasingly cost competitive with other water solutions

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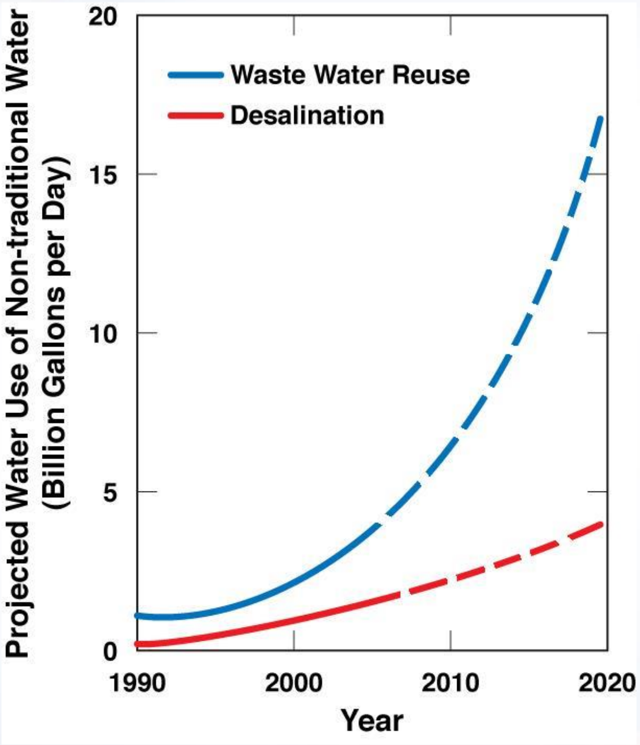
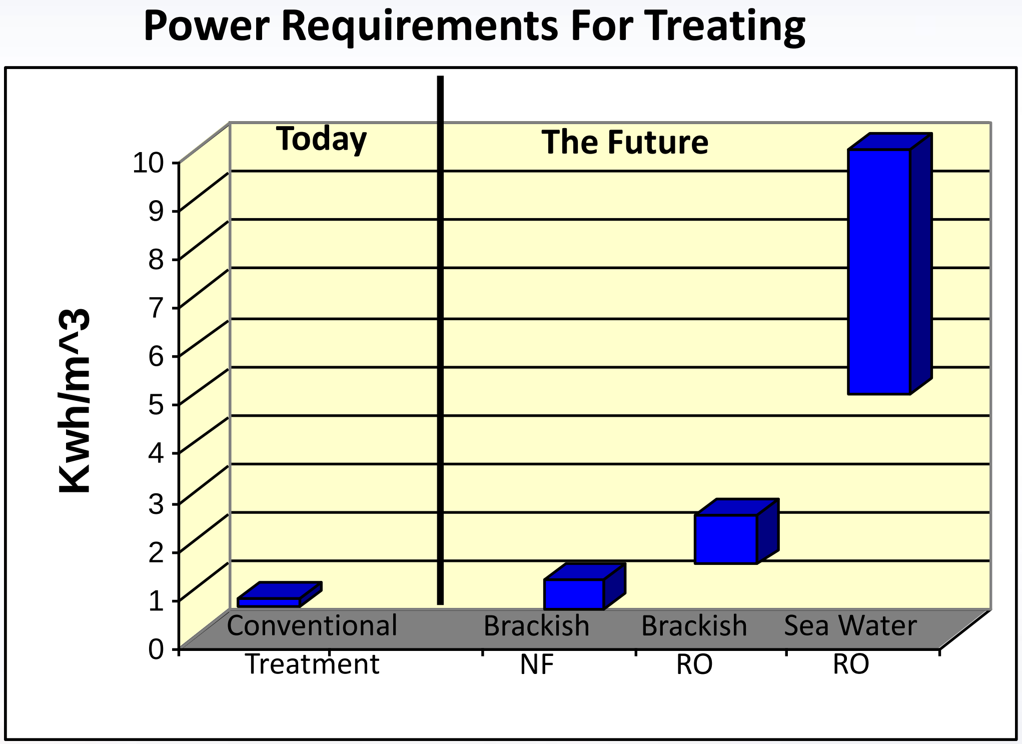
Growing Use of Non-traditional Water Resources



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



(Einfeld 2007)

Desalination growth - 10%/year,
Waste water reuse - 15%/year

U.S. Desalination Research Efforts - 2005

- Desalting Handbook for Planners - 2003
- Desalination Technology Roadmaps –
  - 2002, 2005, 2007 – new technologies
- NRC National Desalination Perspective, 2008
  - Recommended $20M/yr U.S. research budget, etc.
- Wide-area, and wide-spread droughts
  - Multi-year droughts in West, Texas, SE, NE, and NW
- USGS not monitoring desalination
  - Desalination use data difficult to verify and to identify and estimate trends
- BOR upgrade of Yuma Desalination Plant
- BOR desalination research budget of $1-2M/yr
- BOR Construction of Brackish Groundwater National Desalination Research Facility

Desalination Plant Trends - 2005

- Large seawater RO desalination plants being constructed and planned*
  - Tampa Bay -25 MGD
  - Perth – 35 MGD
  - Australia* – 5 additional plants of 30- 80 MGD
  - Ashkelon – 90 MGD
  - Israel* – 4 additional plants of 100 MGD
  - Carlsbad – 50 MGD
  - California* - 4 additional plants of 30-50MGD
- Large inland brackish desalination plants were being considered
  - El Paso – 30 MGD
  - Phoenix, Tucson, Las Vegas* – 50 MGD

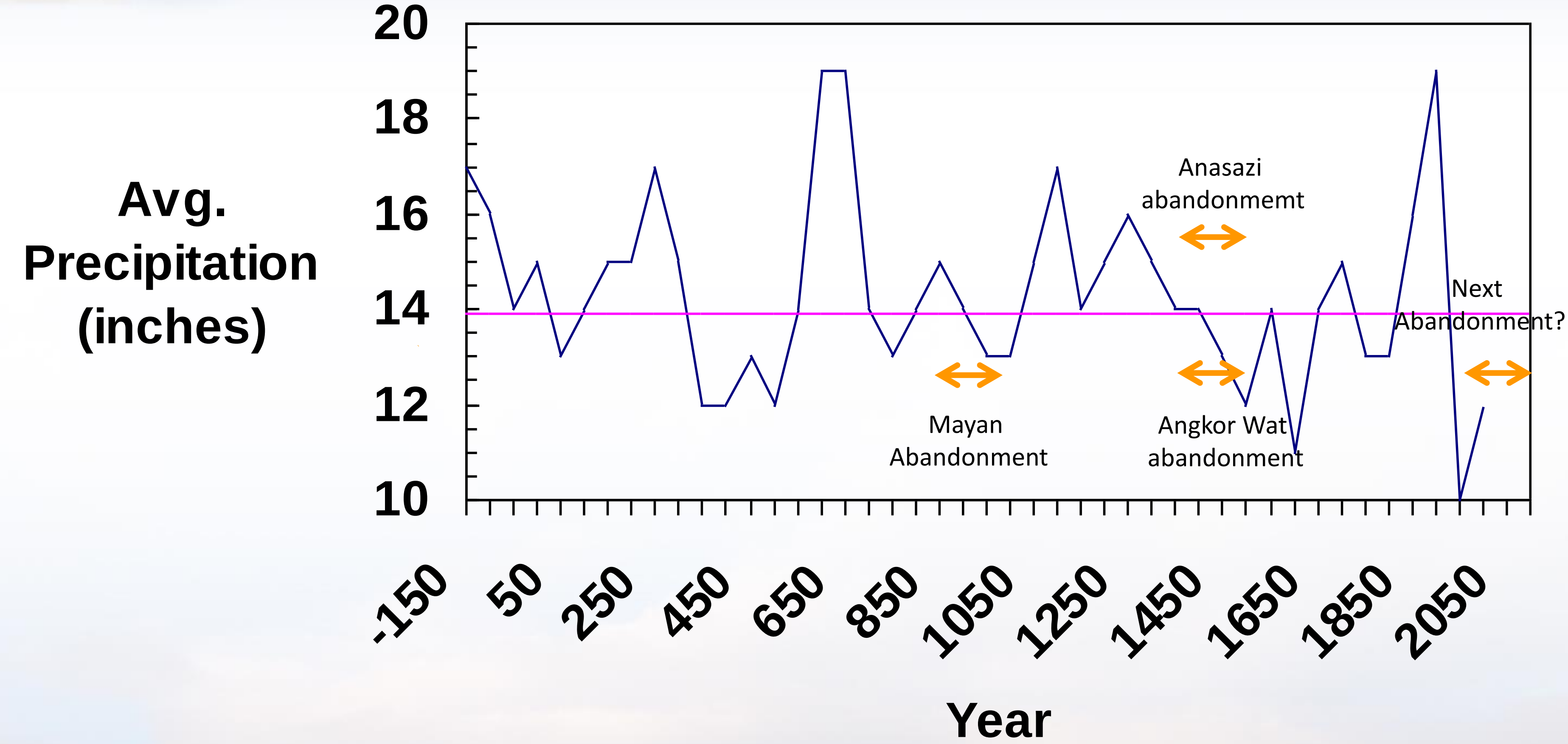
Ashkelon

Perth

Tampa

El Paso

U.S. Water 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

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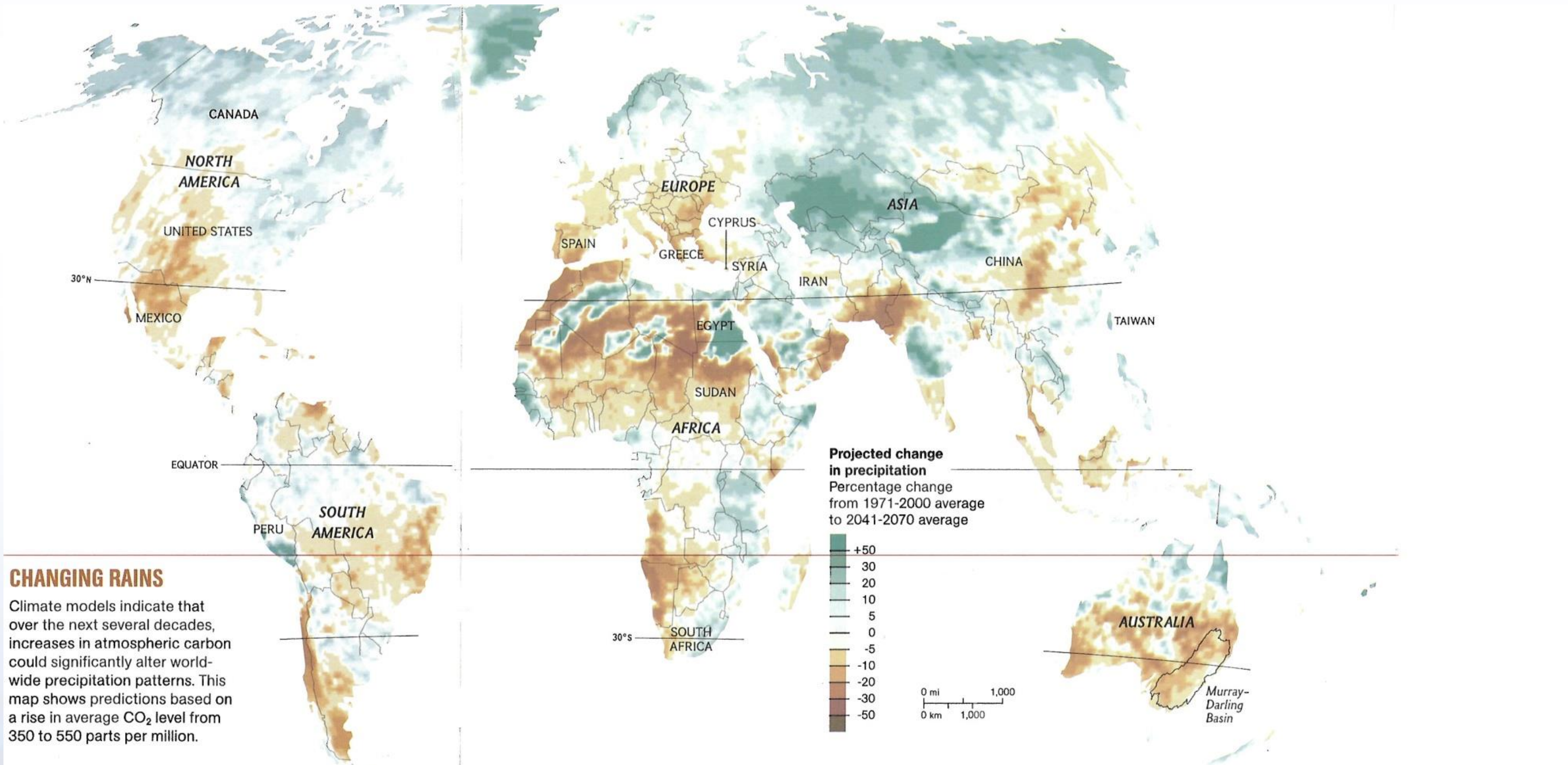
Climate Changes will Impact Temperatures, Precipitation, Evapotranspiration, and Runoff



Nat. Geo. April 2009 from IPCC

Mid-latitude population and grain belts will be strongly affected

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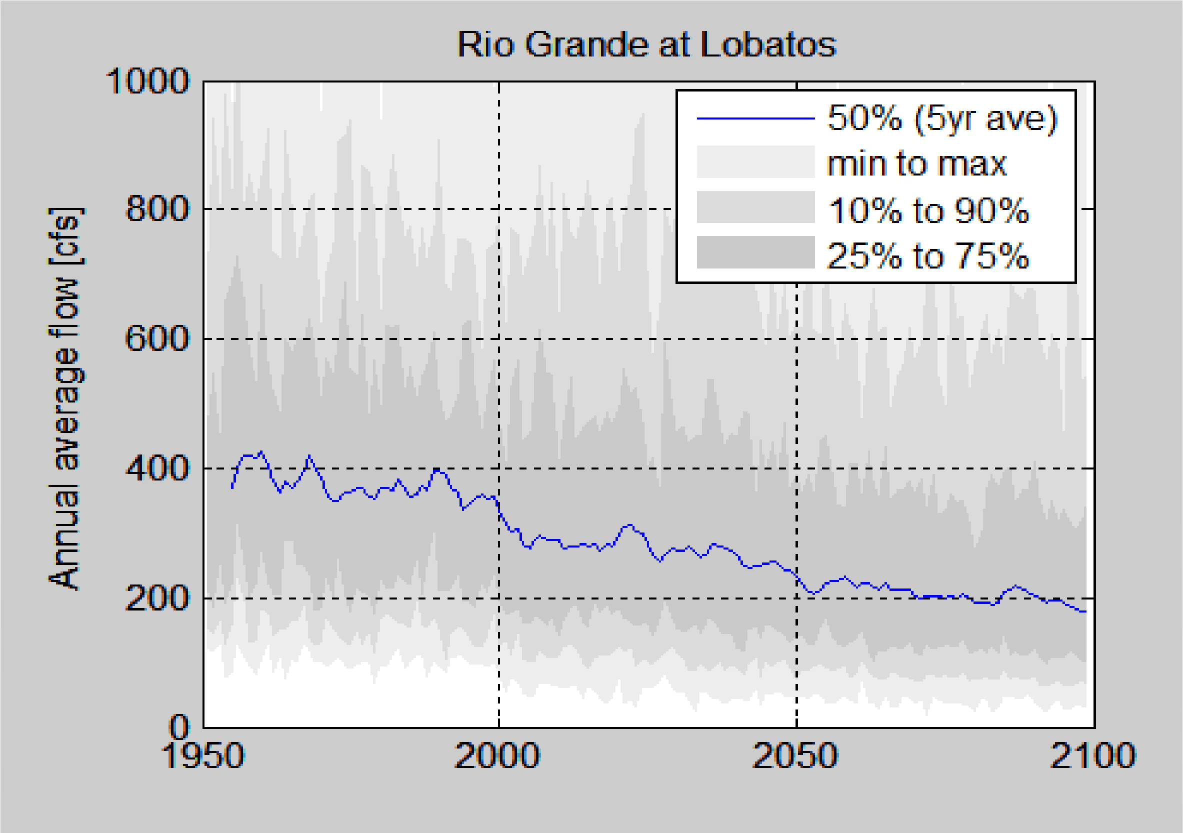
Projected Rio Grande Flows through 2100



"Results are not predictions, but rather a starting point for dialogue and increased awareness of potential impacts of climate change."

Roach et al.

Global Desalination Trends - 2015

- Global desal plant increase
  - 13,000 to 17,000 plants since ~2005
  - From 60 M m^3/day to 80 Mm^3/day
- Israel has added 4 new large plants
  - Capacity to 600 Mgal/day
- Australia built 7 large plants
  - 2 operating in Perth – 100 Mgal/day
  - 5 mothballed
- Increased desalination research facilities
  - Including National Center of Excellence in Desalination in Perth

Perth Binningup Plant 60MGD 2013

National Center of Excellence in Desalination – Murdoch University Perth Australia 2010

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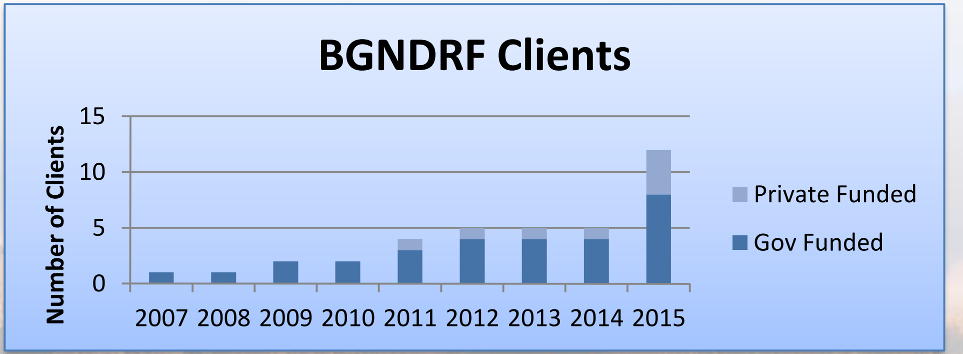
U.S. Desalination Trends - 2015

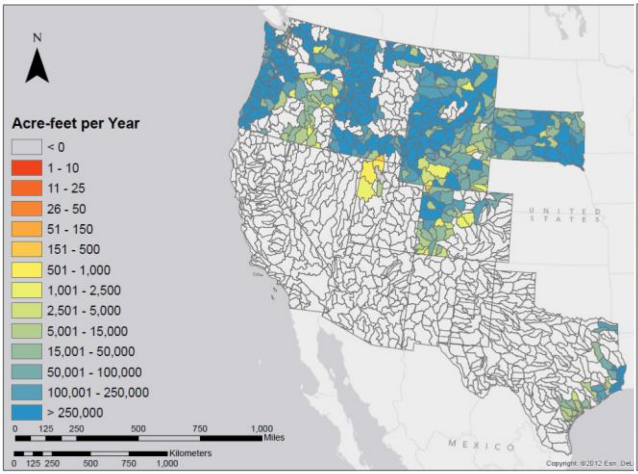
- Carlsbad seawater desalination plant opens after 10 years of permitting
- Improved understanding of available traditional and non-traditional water resources in the west
- By 2050, 40% of Texas drinking water supply will be from nontraditional water resources
- New federal desal research being proposed
  - DOE Energy for Water efforts
  - White House Water Summit
- Expanding research on brackish desalination and waste water reuse

Carlsbad Desal Plant started 2005 completed 2015

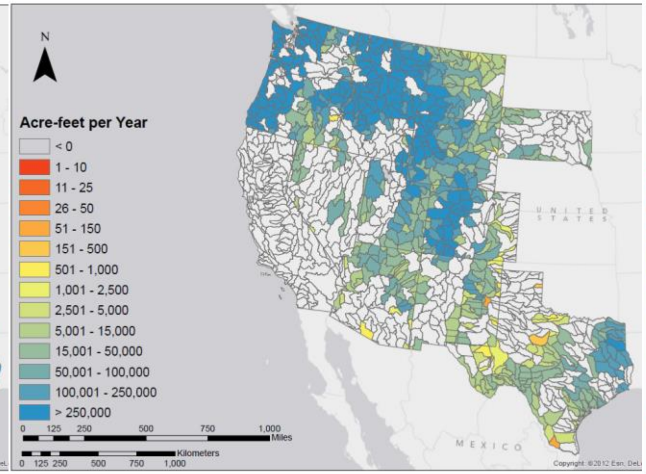


Western Water Availability Assessment

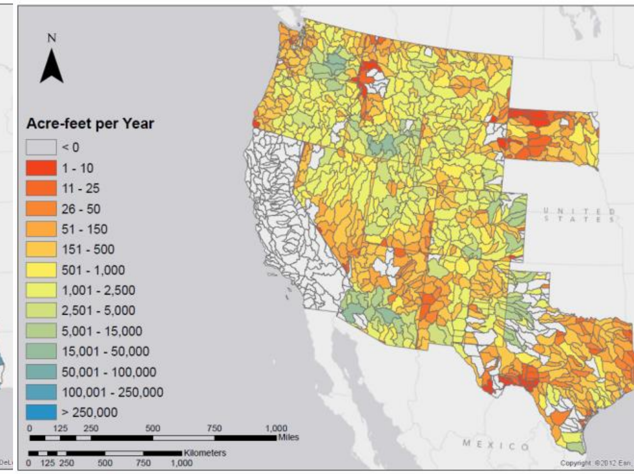
Unappropriated Surface Water Metric



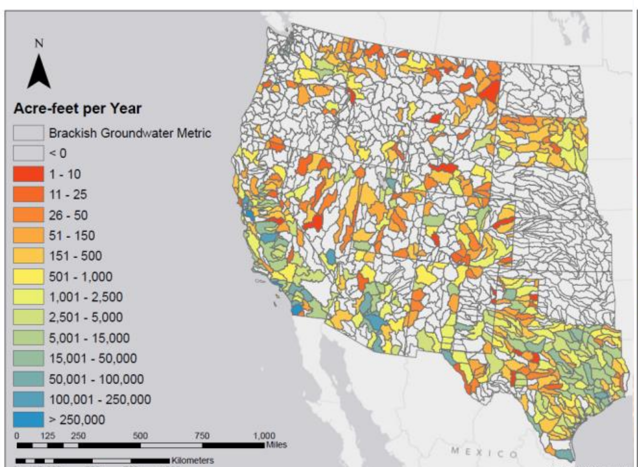
Potable Groundwater Metric



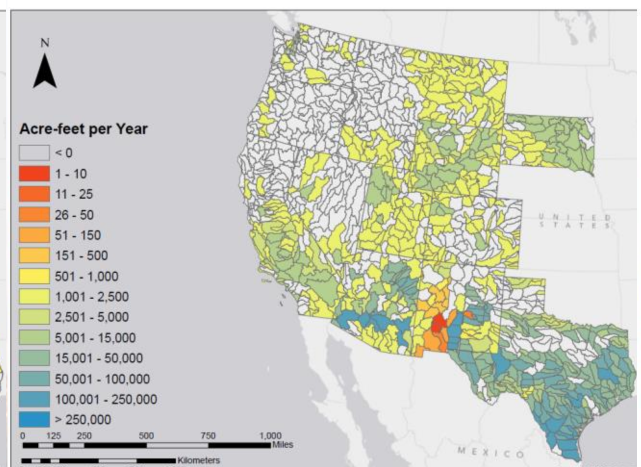
Appropriated Surface Water Metric



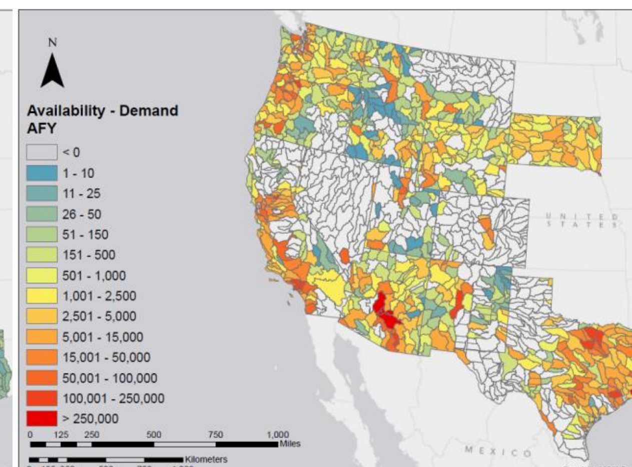
Wastewater Metric



Brackish Groundwater Metric



Change in Demand, Present - 2030



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The Energy Intensity of Water Supplies varies greatly across California

Source: California Water Plan Update 2013

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	28%
State (Project)	<250 kWh/AF	<1%
Local (Project)	<250 kWh/AF	30%
Local Imports	*This type of water not availa*	
	h/AF	

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

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%
Local Imports	*<250 kWh/AF	38%
Groundwater		19%

* Hetch Hetchy is a net energy provider

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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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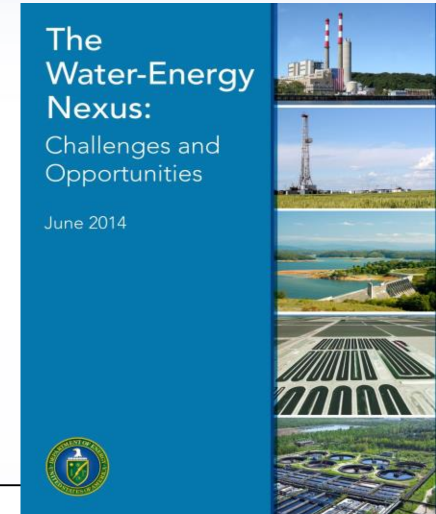
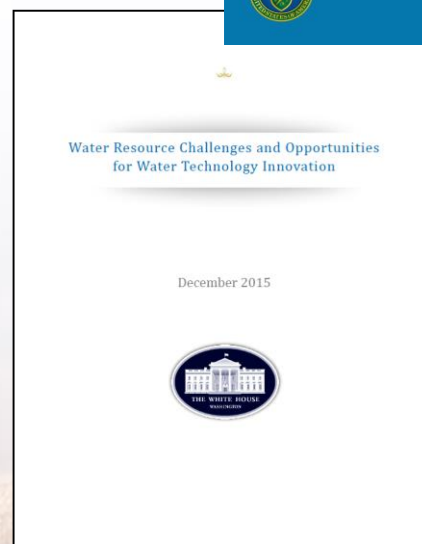
Recent Energy Water Program Plans

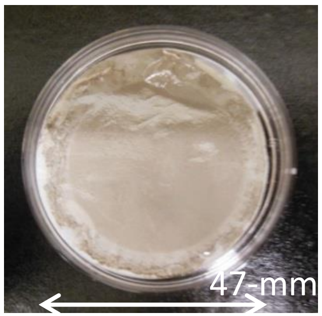
- ***Technology RDD&D***
  - *Thermoelectric Cooling Improvements*
  - *Waste Heat Recovery in Energy Systems*
  - *Process Water Use Efficiency and Quality*
  - *Traditional and Non-traditional Hydropower Improvements*
  - *Alternatives to Fresh Water Use in Energy Production Using Advanced Materials 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***





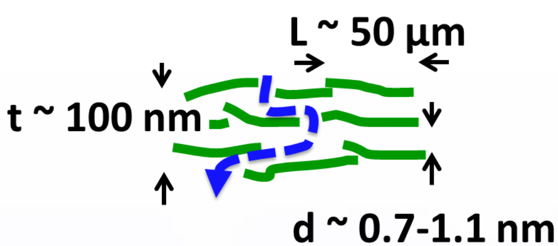
Laminar GO desalination membranes are a potentially disruptive technology

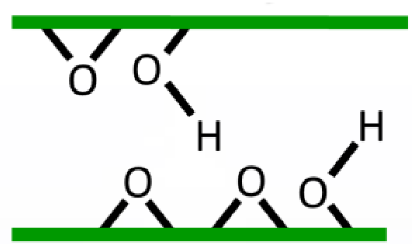
Intrinsic nanoscale properties of laminar GO drive water permeation and are optimum for desalination

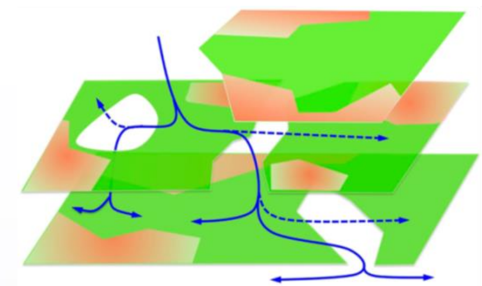


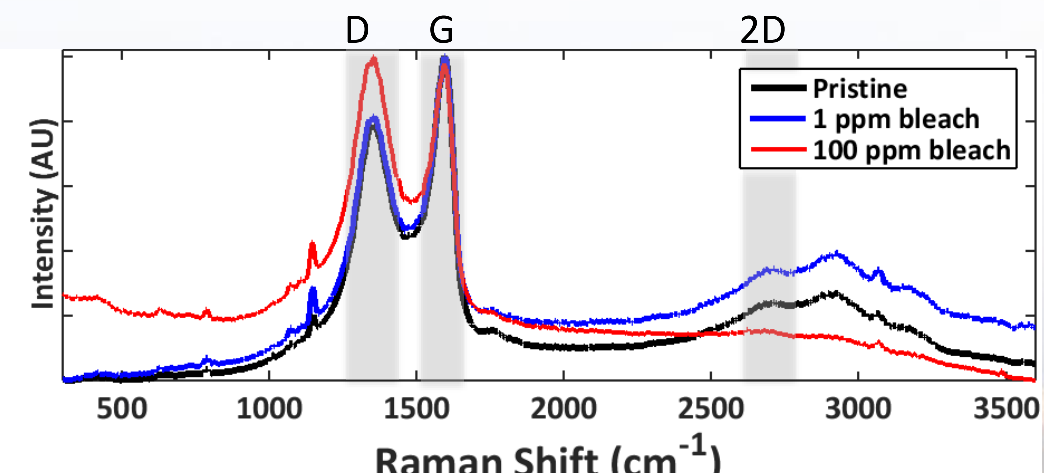
SNL GO/polyester membrane

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









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

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

Détente in the Water-Energy Nexus via Bio-inspired Ion-Selective Membranes

<u>Problem</u>: Cheap clean water is critical globally, but current water desalination technology is costly.

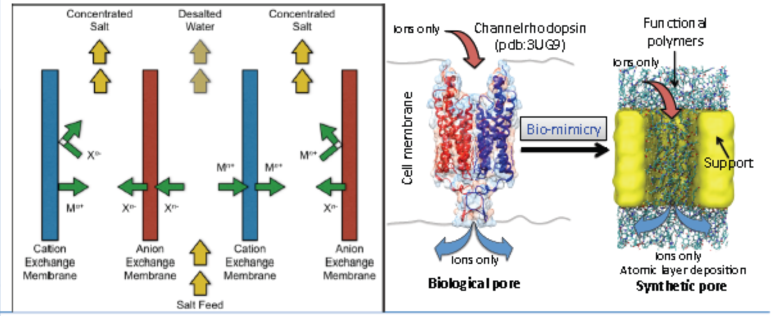
- Energy – water - food interdependence
- Clean water essential to coal-fired electricity, biofuels, agriculture
- 2.4 billion gallons/day water produced in extraction (oil, gas, mining), but limited reuse due to desal. cost
- Unprecedented drought risk in US & worldwide (*Science*, Feb. '15), causes crises (food/energy/health) & international tension
- Reverse osmosis and distillation are costly due to high pressures (P), temperatures (T), membrane fouling

<u>Innovative Solution</u>: Develop advanced, low-cost electro-dialysis (ED) membranes inspired by newly discovered cellular proto-types to clean salty waters cheaply.

- Salty waters abundant: brackish, oil/gas, mining
- Costly to remove multiple ions: Na^+, Ca^{2+}, Cl^-, HCO_3^-
- ED promising due to fouling resistance & low P /T, but membranes require higher multi-ion permeability to lower cost
- Use biomembrane pores (ChR, CFTR) with ~10x higher, multi-ion transport for inspiration:
    - Apply high-resolution theory, experiment, fabrication
    - Identify key structural components for optimal binding & transport of multiple ions
    - Translate biodesigns to robust, synthetic membranes
- <u>Risk→Mitigation</u>: protein stability → ChR stable already in one matrix; polymer stability → polypeptide/polymer already deposited in thin films; commercially viable → test in small-scale electrodialysis plants at UT

<u>Team Expertise & Capabilities</u>:

- Rempe (PI) – structure vs function of ion-pore interactions via quantum & molecular simulations
- Bachand & Hibbs –protein & polymer synthesis
- UNM/UT – fabrication & `father' of ED membranes



<u>Why Sandia/Broad Impact</u>:

- Team's expertise & recent successes in quantifying ion-matrix interactions & fabricating ultra-thin peptide-lined membranes (*PNAS*, '13; *JACS*, '14)
- Leverages SNL investments in Part 1: synergistic, but distinct water-selective RO membranes, currently in transition by industry (R&D 100 Award, 2011)
- Timely: newly discovered ion-selective protein prototype (ChR); produce high-performing resilient membrane & understand catalytic control of bio/abiotic systems (Research Challenges)
- Potential for licensing (Bettergy, Danfoss)
- Success positions team to win funding in DOE's crosscut Water/Energy Nexus focus on water treatment technology; WETT; EPA; DOI Reclamation; Navy