SAND2016-0467PE

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Research Opportunities and Challenges at the Energy/Water Nexus

Sandia New Research Ideas Forum - January 2016

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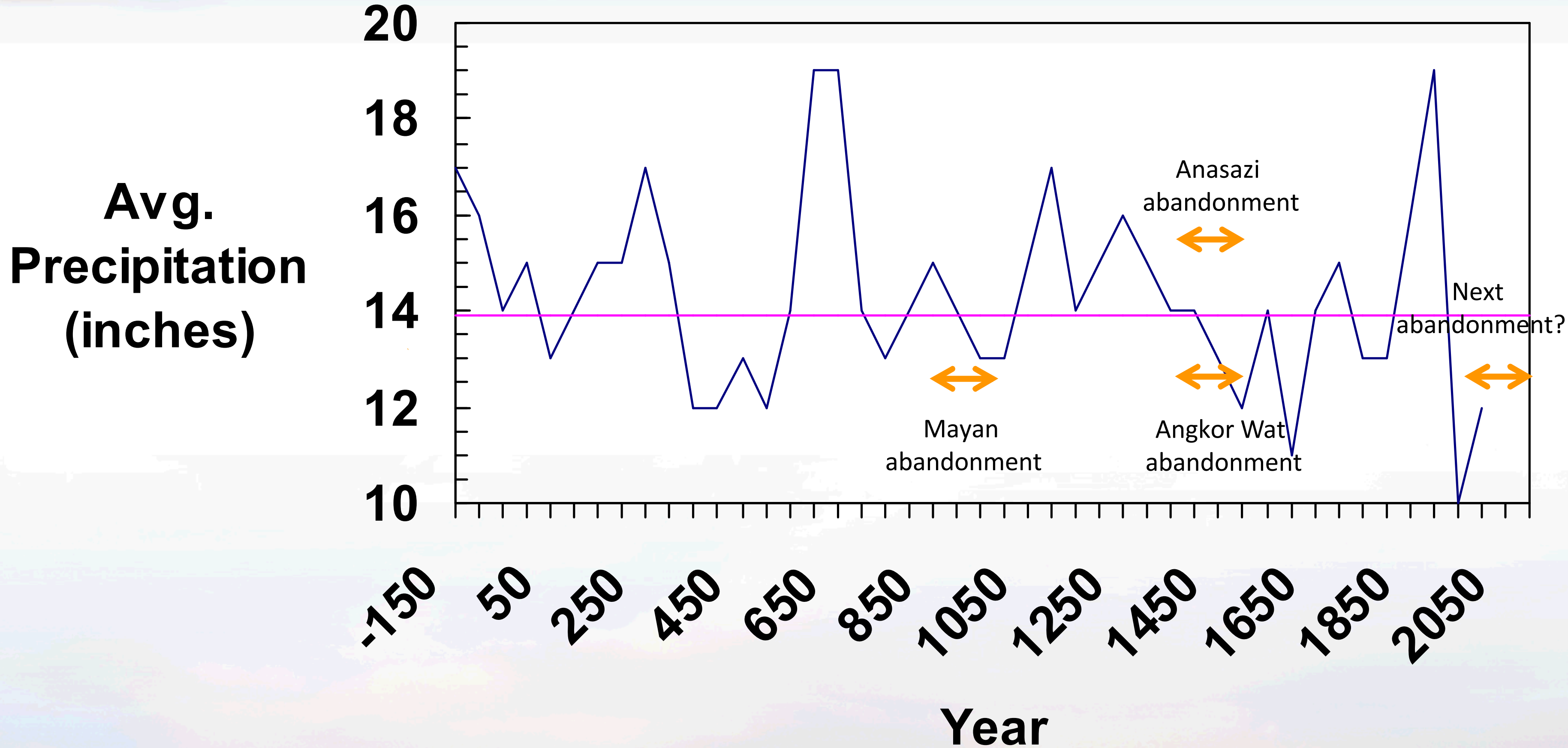
Southwest Climate History Based on Tree Ring Data



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

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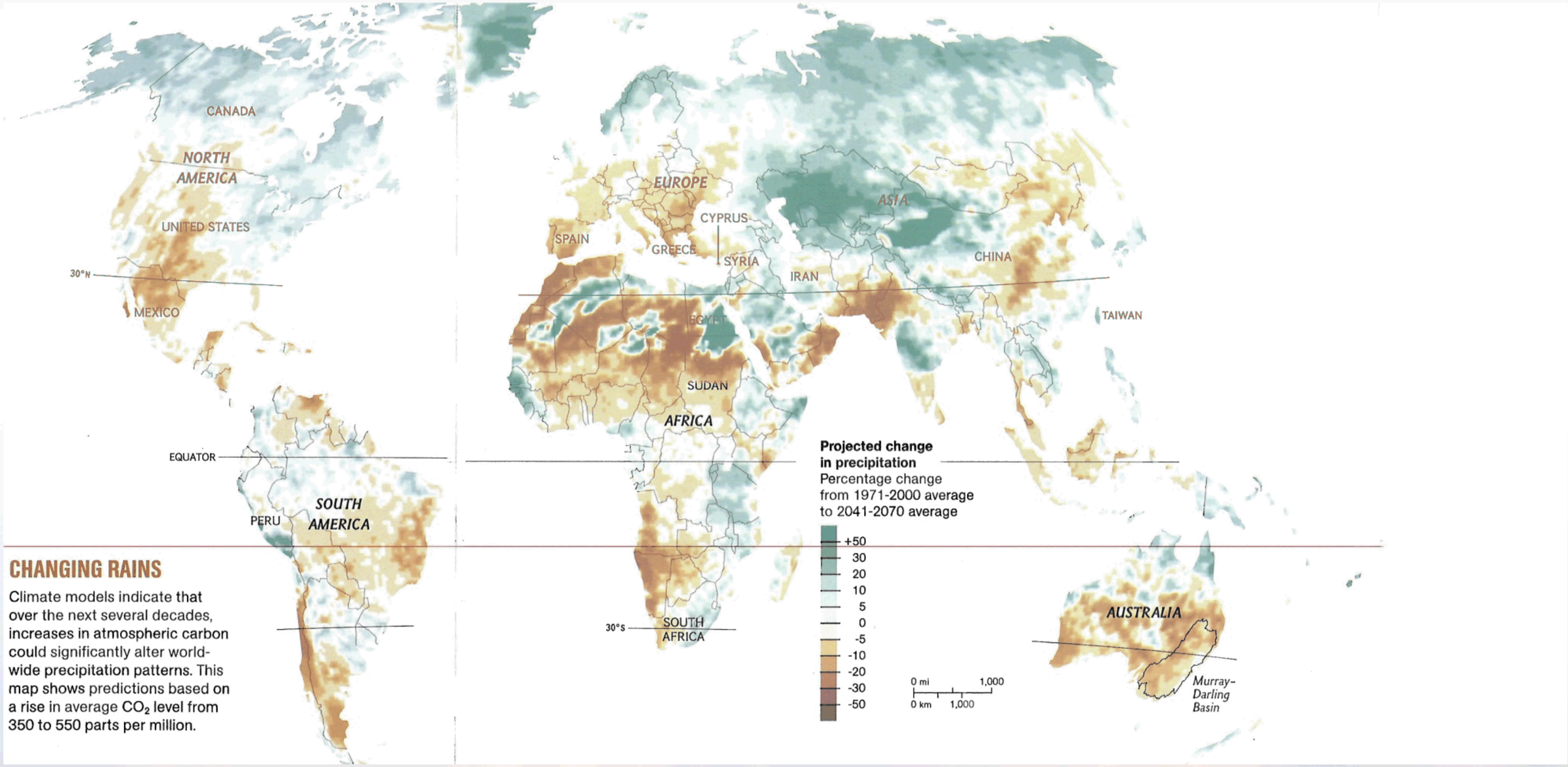
Climate Changes will Impact Temperatures, Precipitation, Evapotranspiration, and Runoff



Nat. Geo. April 2009 from IPCC

Mid-latitude population and grain belts will be strongly affected

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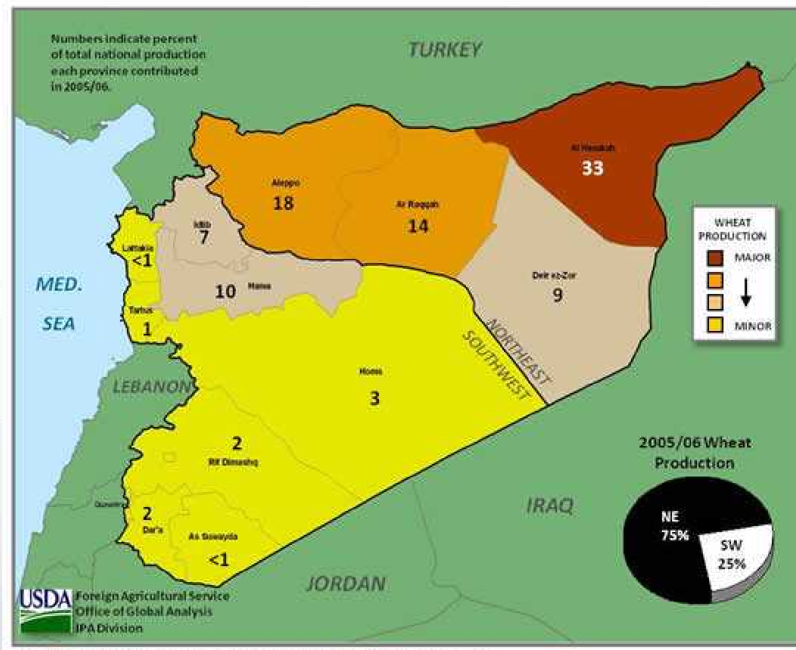
Syrian Drought Factoids from the World Watch Institute, November 29, 2012

- In 2008, wheat production dropped to 2.1 million metric tons, 56% below the 2003 peak
- Harvests have increased but remain a quarter below the 2003 level.
- The area primarily affected was the northeast, which accounts for 75 percent of total wheat production.
- Since the start of the drought, close to 75 percent of agriculture-dependent households in the northeast have suffered total crop failure.
- Prior to the drought, Syria's agriculture sector accounted for 40 percent of the country's workforce and 25 percent of GDP
- 2–3 million people have been pushed into extreme poverty by a combination of lack of crop income and the need to sell livestock at 60–70 percent below cost.
- Syria's livestock herd has been decimated from 21 million to an estimated 14–16 million.

SYRIA: Governorate-Level Wheat Production



Data Source: Ministry of Agriculture & Agrarian Reform, Syria, 2005

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Water and Associated Economic Concerns within 15 Years

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

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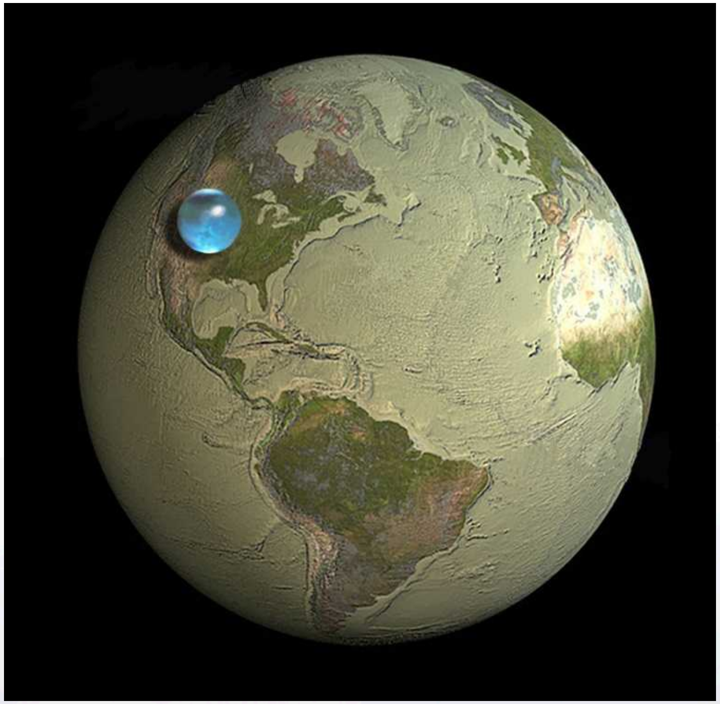
Energy Water Food Challenges

- **Energy sector accounts for 8% of world fresh water withdrawals**
  - 40% of withdrawals in developed countries
  - 55% of total withdrawals in the U.S., 65% in Canada
- **Ag sector accounts for 80% of world water consumption**
  - Similar in developed and developing countries
- **Energy use in water/waste water sector is expected to grow substantially**
  - Growth in water treatment of non-traditional sources, increased disinfection, increased water pumping and transportation, increased irrigation
  - Energy use could grow from 4% to 10% of total U.S. electricity demand by 2030
- **Energy/water/food national security concerns identified in joint work by Sandia, LANL, and NETL in 2002 -2004**



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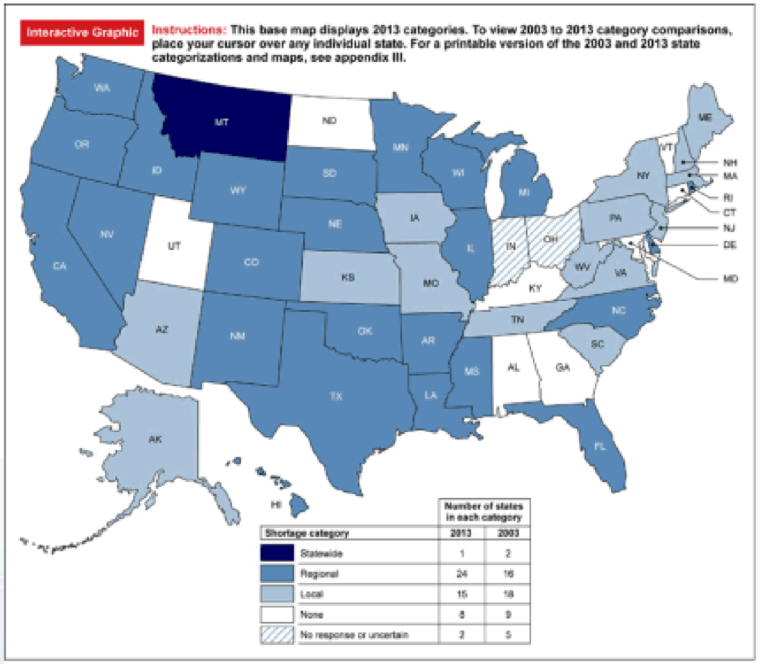
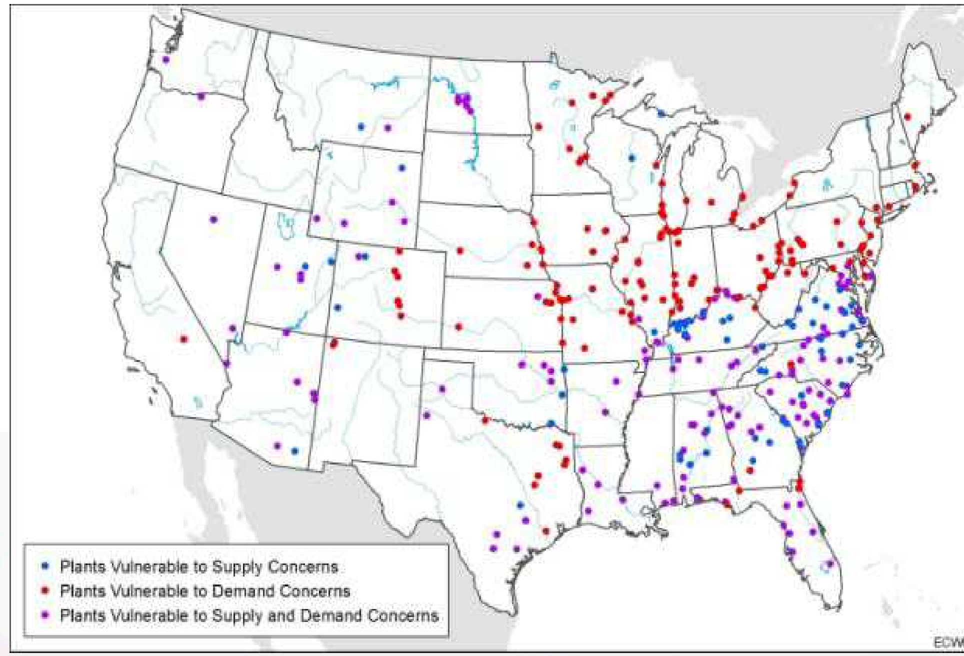
Water Stress Impacts on U.S. Electric Power



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



2013 State Water Stress

Coal Power Plants Vulnerable to Water Supply Stress and Water Competition

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Water Use and Consumption in 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	1050	50
Concentrating Solar	Closed-loop	750	740	10
Wind and Solar Photovoltaic	N/A	0	0	1-2

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Water Consumption for Transportation Fuels Alternatives

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 - Oil Refining	Water needed to extract and refine; Water produced from extraction	Produced water generated from extraction; Wastewater generated from processing;	7 – 20	~ 1.5
- NG extraction/Processing			2 – 3	~ 1.5
Biofuels - Grain Ethanol Processing	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	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)	~ 2 - 6 ‡§
			14 – 90 ‡§ (diesel)	~ 2 - 6 ‡§
Oil Shale - In situ retort	Water needed to Extract / Refine	Wastewater generated; In-situ impact uncertain; Surface leachate runoff	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 - Coal to Liquid (CTL)	Water needed for synthesis and/or steam reforming of natural gas (NG)	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

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The Energy Intensity of Water Supplies Varies Greatly

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 available*	
Groundwater	<250 kWh/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

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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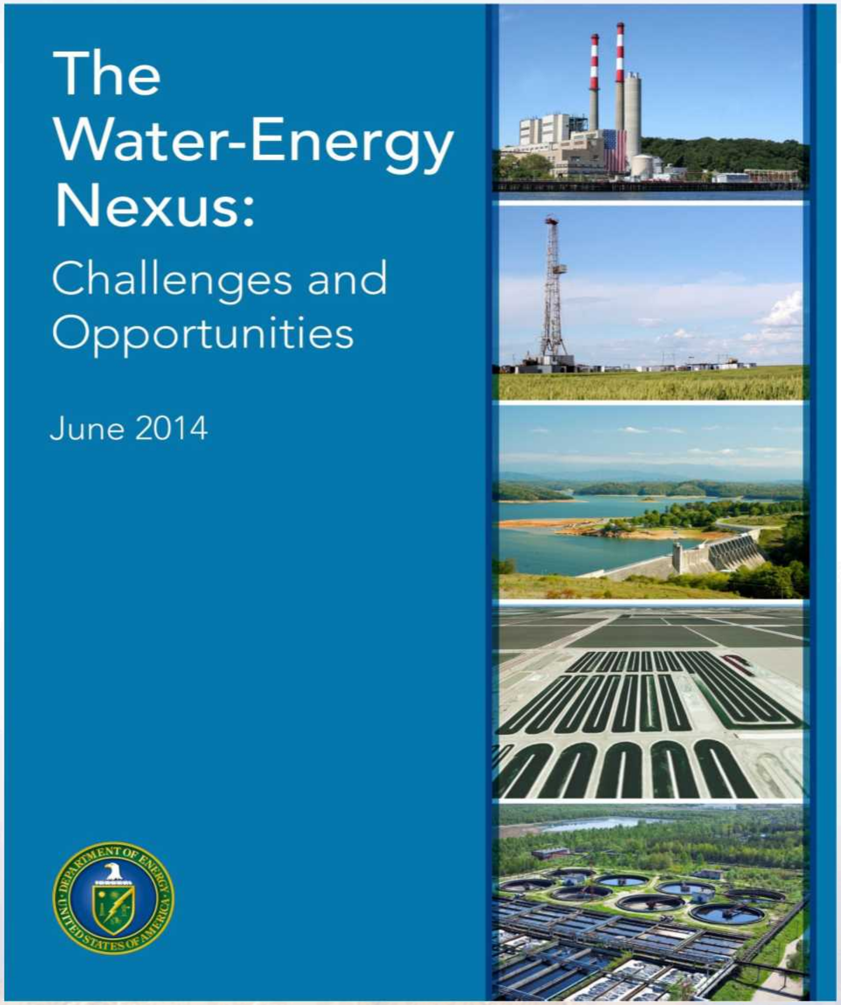
DOE Energy Water Program Plan

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



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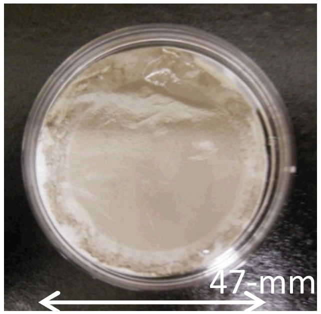
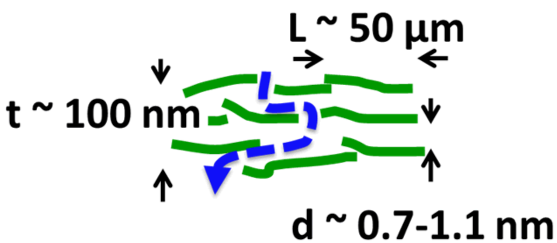
Laminar GO desalination membranes are a potentially disruptive technology

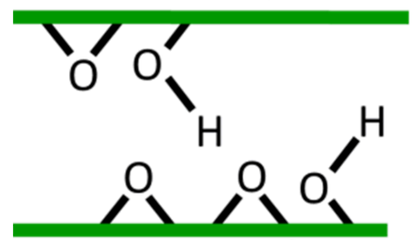
Intrinsic nanoscale properties of laminar GO drive water permeation and are optimum for desalination

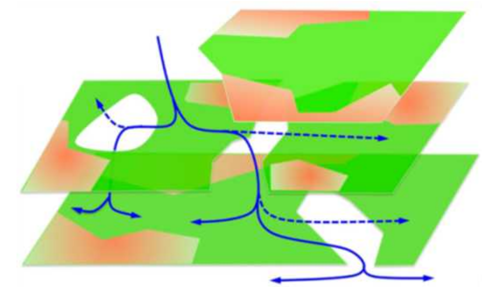


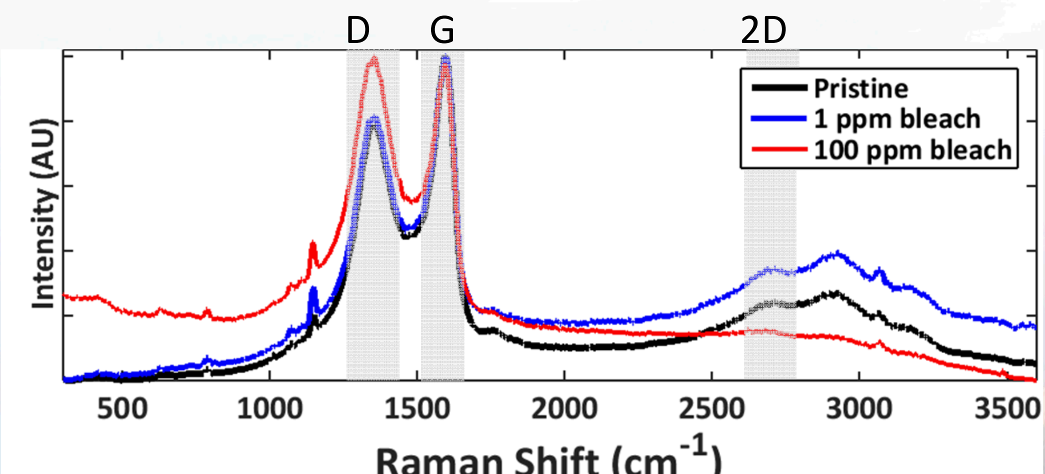
SNL GO/polyester membrane

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)

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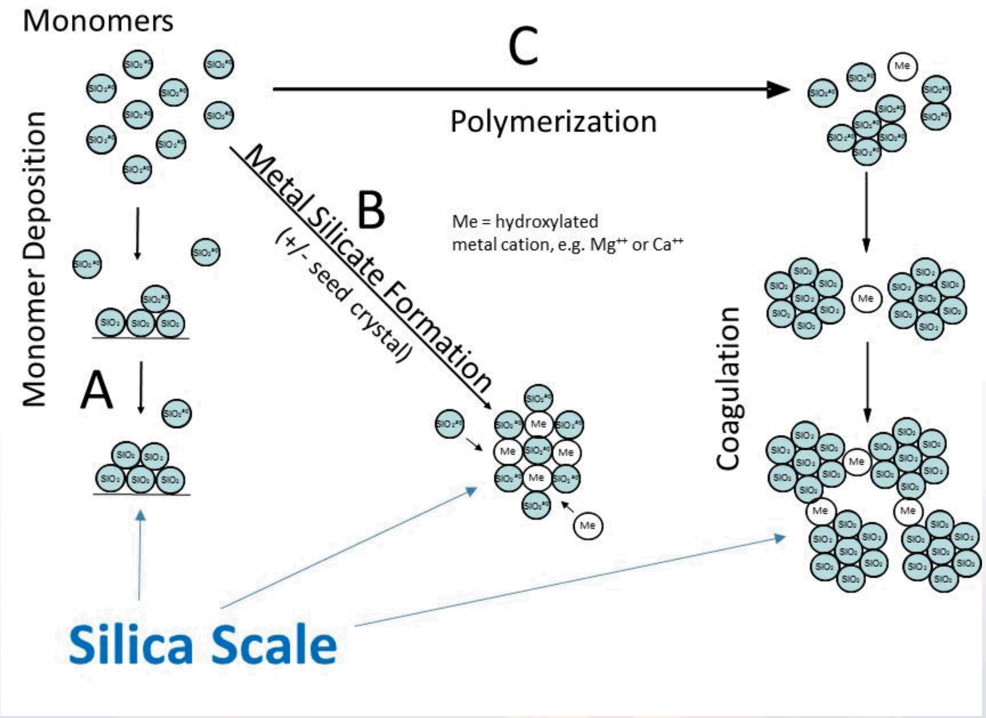
Silica Chemistry in the Energy-Water Nexus

Pat Brady, Tina Nenoff, and James Krumhansl

Dissolved silica often limits water recycling in energy extraction, energy production, and CO_2 capture. New methods are needed to prevent silica scale from forming in cooling towers and boilers.



Recent Projects:

- **Impaired Water Reuse in Power Plant Cooling** (Nenoff LDRD)
- **pH control/scale prevention in Power Plant Cooling** (Brady and Krumhansl, US Patent 9140145)
- **Advanced coagulation for Oil Sands Water Recycling** (Brady et al., WFO)
- **Carbon Mineralization for Climate Change** (Columbia/Sandia ARPA-E).

SiO_2^{aq} concentration in some problem waters:

LANL tap water, 88 ppm; Cooling tower, 123 ppm; El Paso desal conc. 148 ppm; SAGD, 239 ppm; Geothermal (Wairakei, Ohnuma), 520-560 ppm

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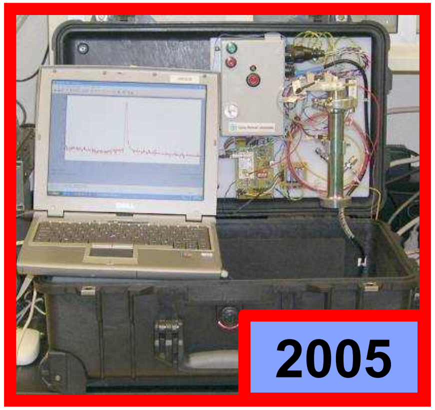
Detection of Disinfection Byproducts Using Nanoporous Carbon-Coated Surface Acoustic Wave Devices – Concept to Product

Water security & Health. Product enables rapid monitoring of hazardous chemicals in drinking water.

1997	Grand Challenge LDRD for CW detection begins
2001	Concept - leverage hardware for water monitoring
2002	LDRD begins
2005	LDRD prototype
2006	EPA demo, AWWA talk
2006	WFO begins: Parker Hannifin
2008	Licensing begins
2010	R&D 100 application
2011	Sales begin
2012	Patent granted
2015	2^{nd} generation sales begin (continuous monitor)

ppm detection → ppb detection



batch → continuous

1. M.P. Siegal, C.D. Mowry, K.B. Pfeifer, D.F.S. Gallis, *J Electrochem Soc*, vol. 162, pp. B114-B20, **2015**.
2. C.D. Mowry et al, SAND2005-6873.

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Waste Water for Power Generation via Energy Efficient Selective Silica Separations (16-0160); FY16-17, $800K

Tina M. Nenoff (1100), Patrick Brady (6910), Scott Paap (8112)

Project Purpose

- *Problem*
  - Thermoelectric power generation is the largest user of freshwater in the US (~500 B gal/day). Replacement of freshwater with produced waters is only possible if silica is removed (resistant to anti-scalant technology).
- *Goal*
  - Develop separations media to remove dissolved silica, resulting in produced water treatment with: lower energy penalty, ability to treat large volumes & sub into large range of energy production scenarios.

R&D Goals & Milestones

- Downselect candidate silica materials 12/15/15
- Synthesize Complexants & Seeding/Crystal 5/15/16
- Synthesize Ion Ex. & Flocculants 8/15/16
- Silica Selectivity single comp batch tests 6/15/16
- Silica Selectivity complex stream tests 8/15/17
- Technoeconomic Analysis-Build models 8/30/16
- Technoeconomic Analysis-produced H_2O output 6/30/17
- SAND report(s) 09/30/16-17

R&D Approach

- Integrating synthesis/characterization, testing & techno-economic analysis to develop highly selective, easily scalable silica getter materials from produced waters.
- Best candidate materials optimized thru iterative ion ex./surface complexation analysis and modification, then tested for Silica uptake in synthetic and produced waters
- Technoeconomic analysis will establish cost effectiveness and be used to select tested produced water compositions;
  - Allowing for mapping of reclaimed water to potential markets

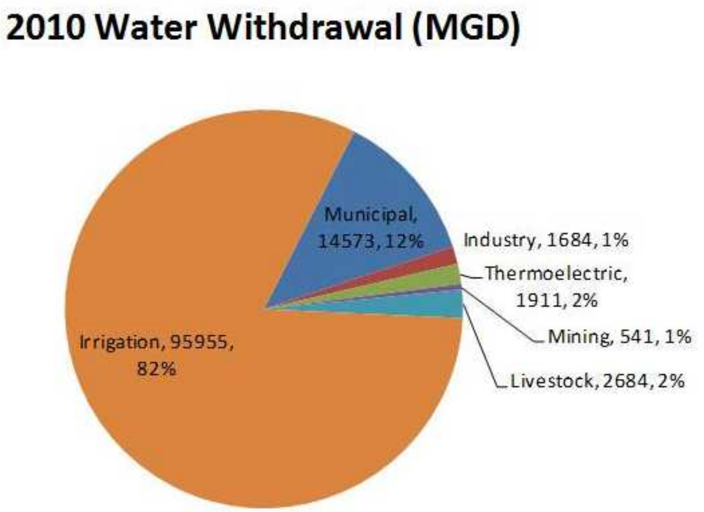
Significance of Results

- Downselection of most promising silica getter materials.
- Estimated operating costs and complexity of incorporation of silica getters into industrial systems thru licensing and/or CRADAs
- Support EC's interest in *Secure and Sustainable Energy Future (SSEF)* and its mission area in *Climate and Environmental Challenges*, by providing materials and process improvements to industry that

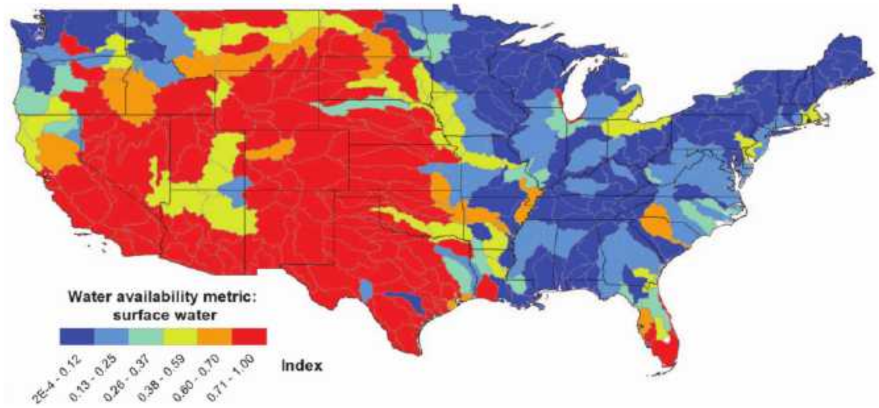
  "Reduce fresh water needed for all stages of energy production and to treat 'produced waters'."

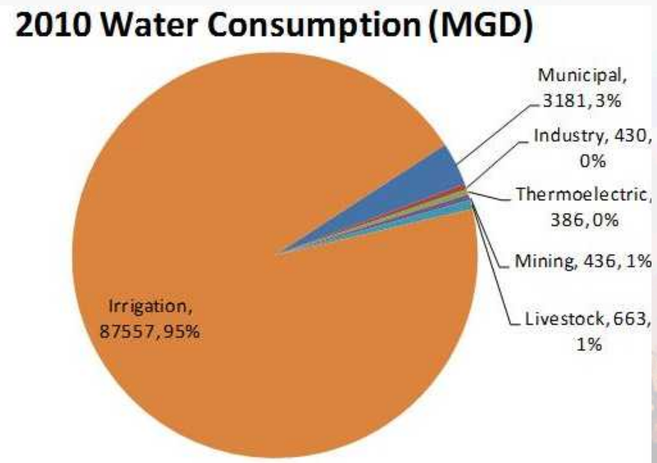
The Challenge

Water for a Growing Electric Sector

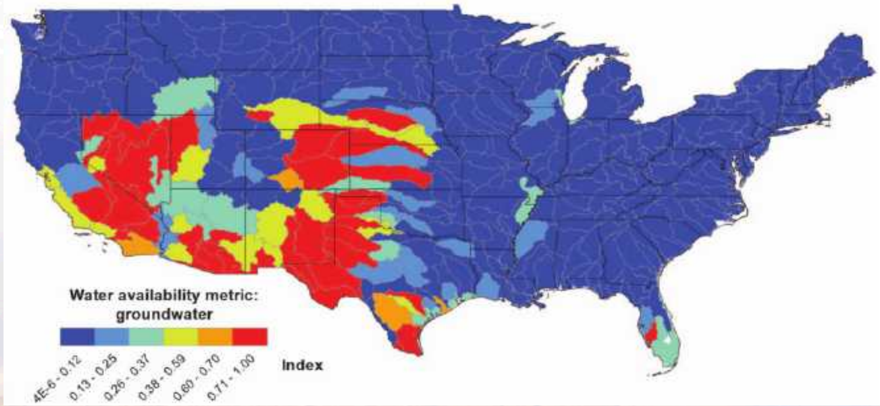


Surface Water Availability





Groundwater Availability



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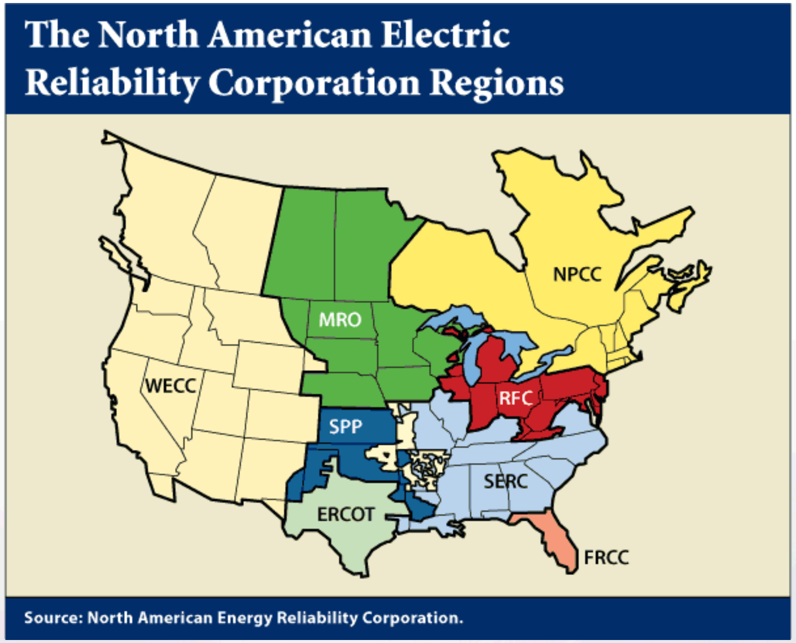
Objective

- **Integrate water related concerns into long-range transmission expansion planning (20 yrs.) of WECC:**
  - Siting of new power plants
  - New transmission capacity

WECC



WESTERN GOVERNORS' ASSOCIATION
Serving the Governors of 19 States and 3 US-Flag Pacific Islands

WSWC
Western States Water Council

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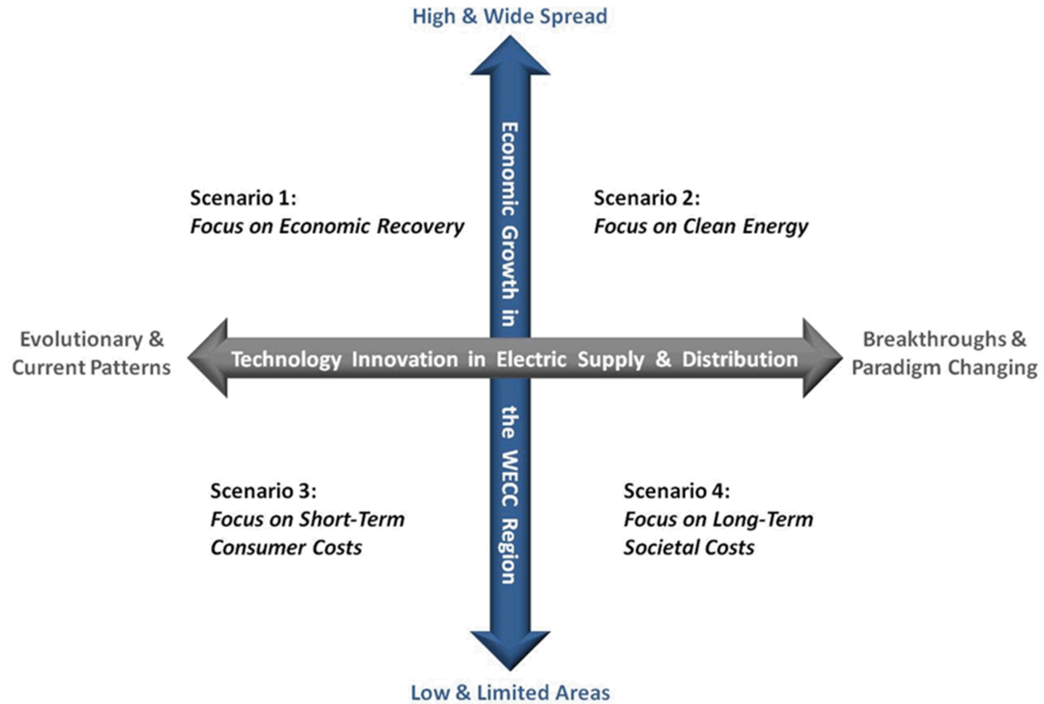
Methods: Scenario Development

- *Reference Case:* adopted trajectory of recent WECC planning information.
- *Scenario One:* favored continued trends in growing use of natural gas and renewables.
- *Scenario Two:* distinct shift toward renewables, energy efficiency and significant carbon tax.
- *Scenario Three:* reliance on traditional technologies while simply meeting current state renewable portfolio standards.
- *Scenario Four:* similar technology development and policies as in scenario two except limited by sluggish economic growth.



Source: WECC 2013

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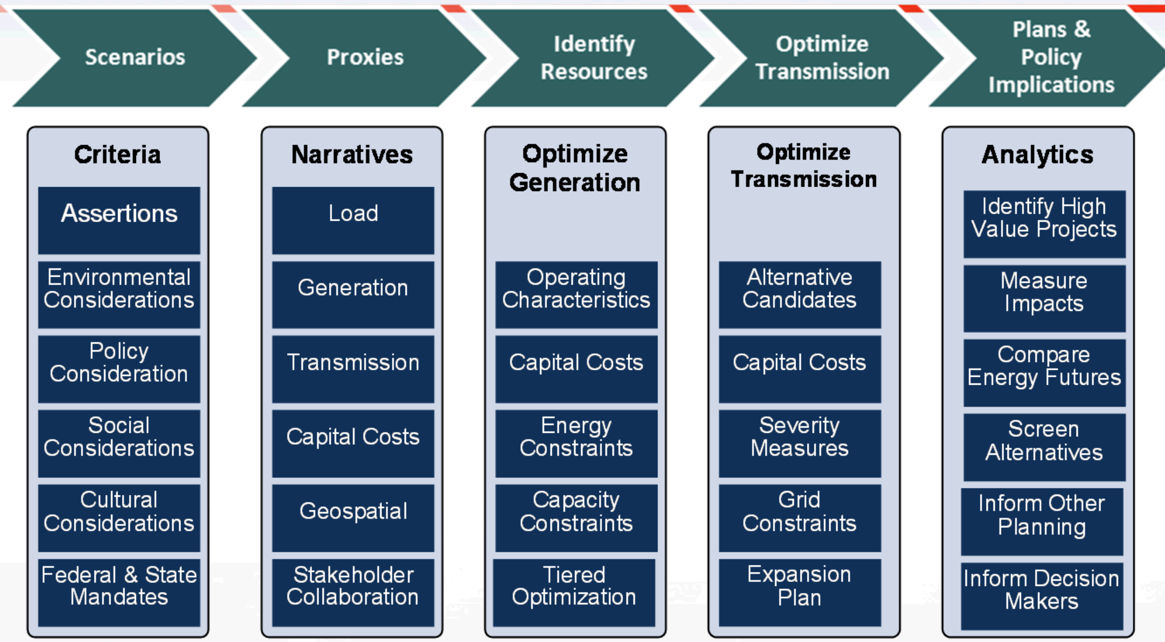
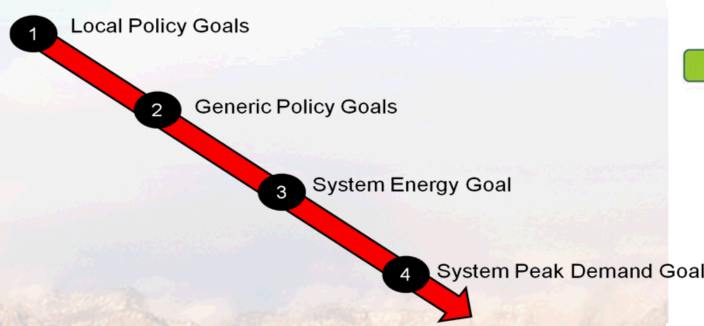
Methods: Capital Cost Expansion Tool

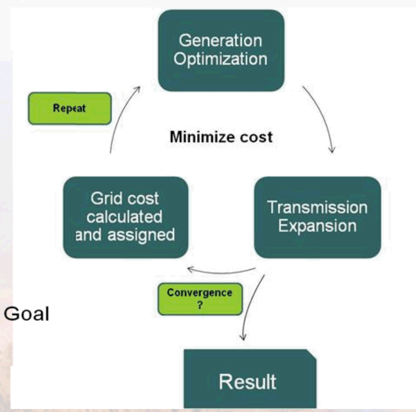
Source: WECC 2013

- **Co-optimize generation and transmission additions.**
- **Least cost solution subject to goal related constraints:**
  - Energy,
  - Policy,
  - Environmental, and
  - Societal conditions.
- **Water is one of many considerations.**





Generation Selection Structuring of Goals



Optimization Iteration

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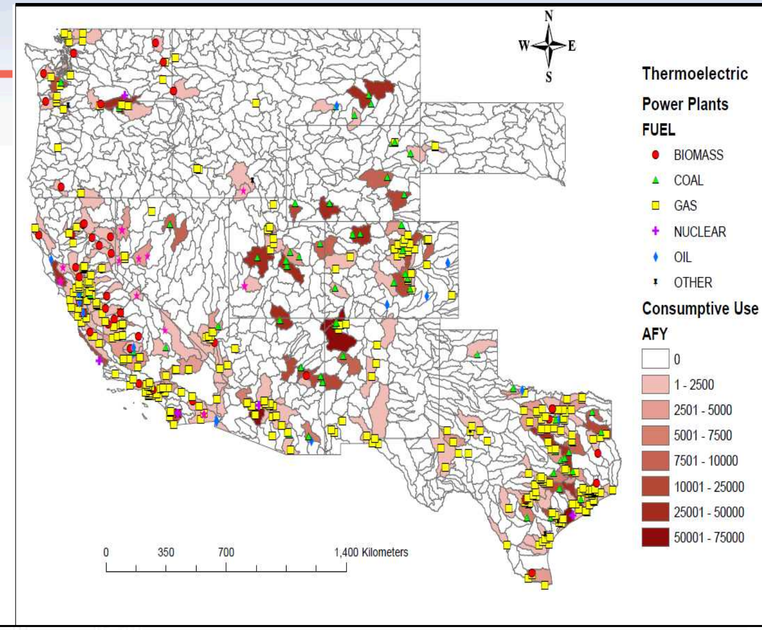
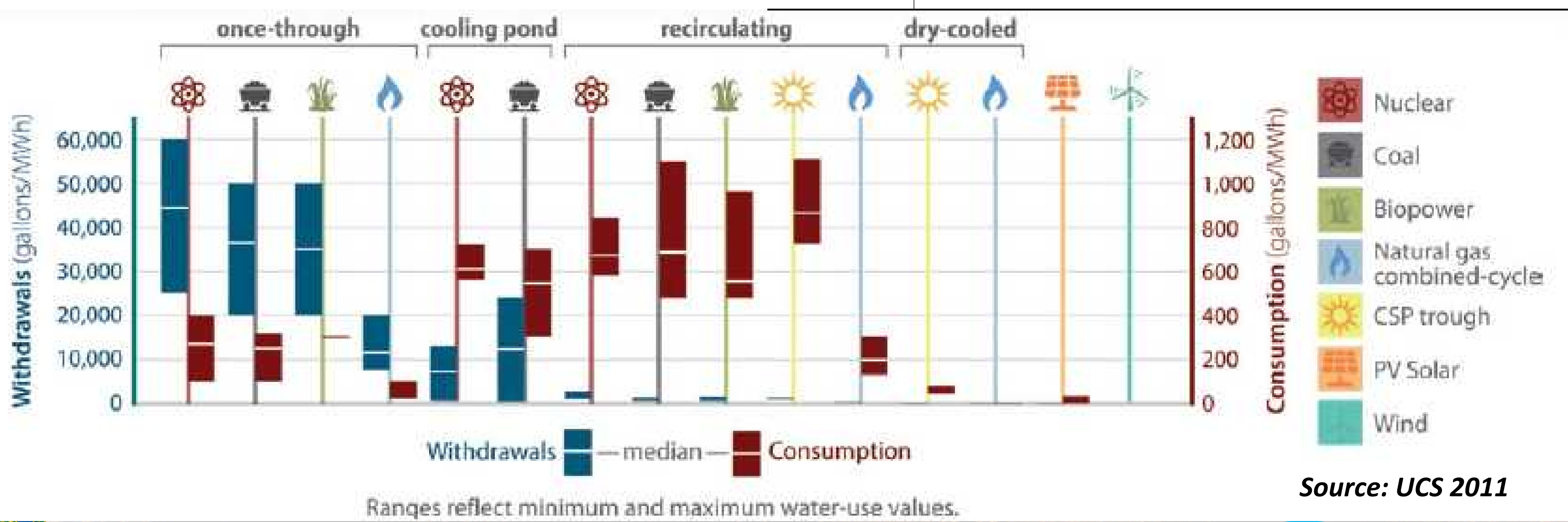
Methods: Water for Thermoelectric Power

- Water withdrawal and consumption at existing power plants
- Water intensity of future thermoelectric power plants

Water Consumption for Existing Power Plants





Source: UCS 2011

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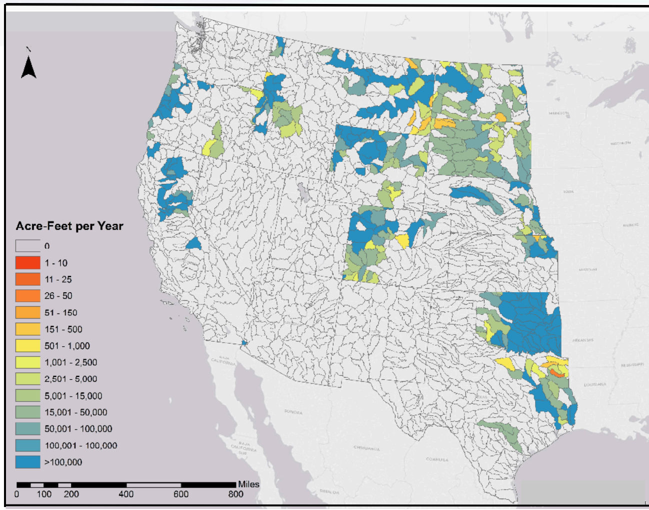
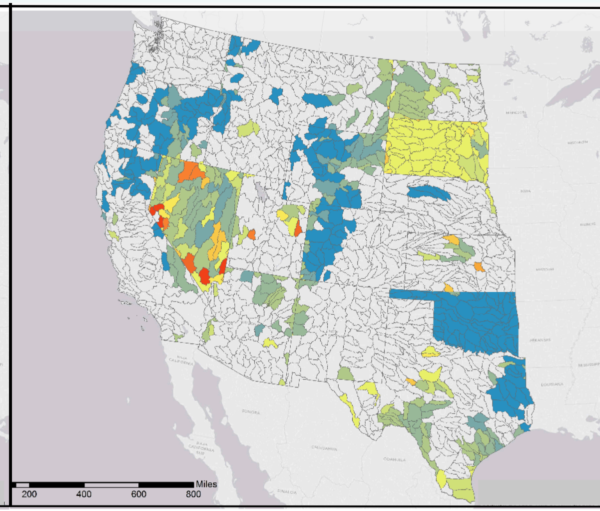
Methods: Water Supply Availability

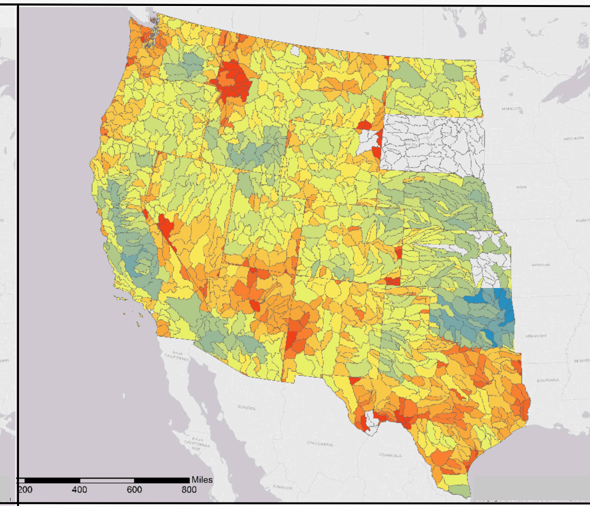
Unappropriated Surface Water



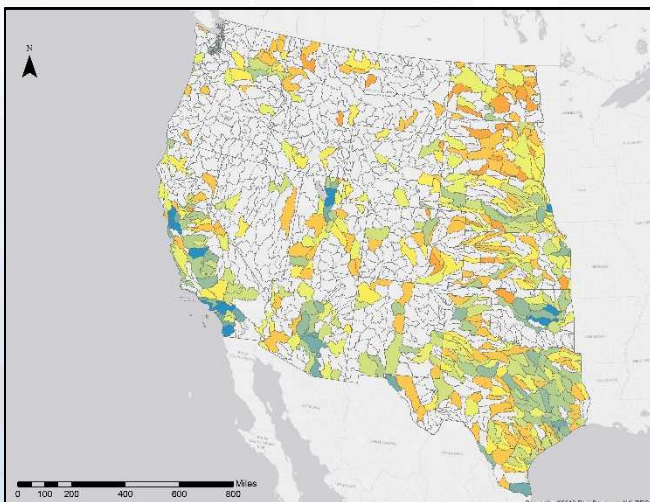
Unappropriated Groundwater



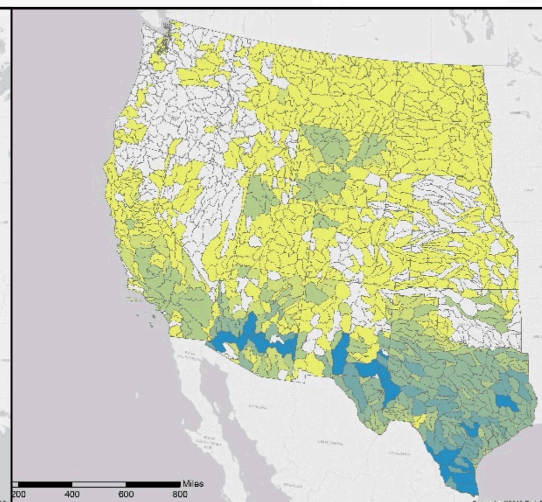
Appropriated Water



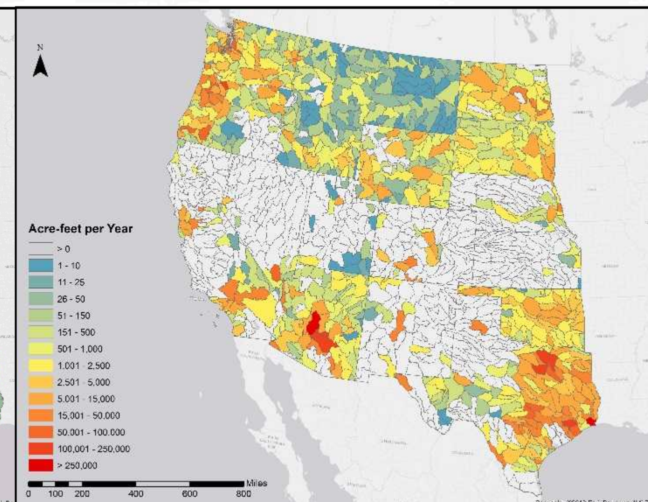
Municipal Wastewater



Brackish Groundwater



Consumptive Demand 2010-2030



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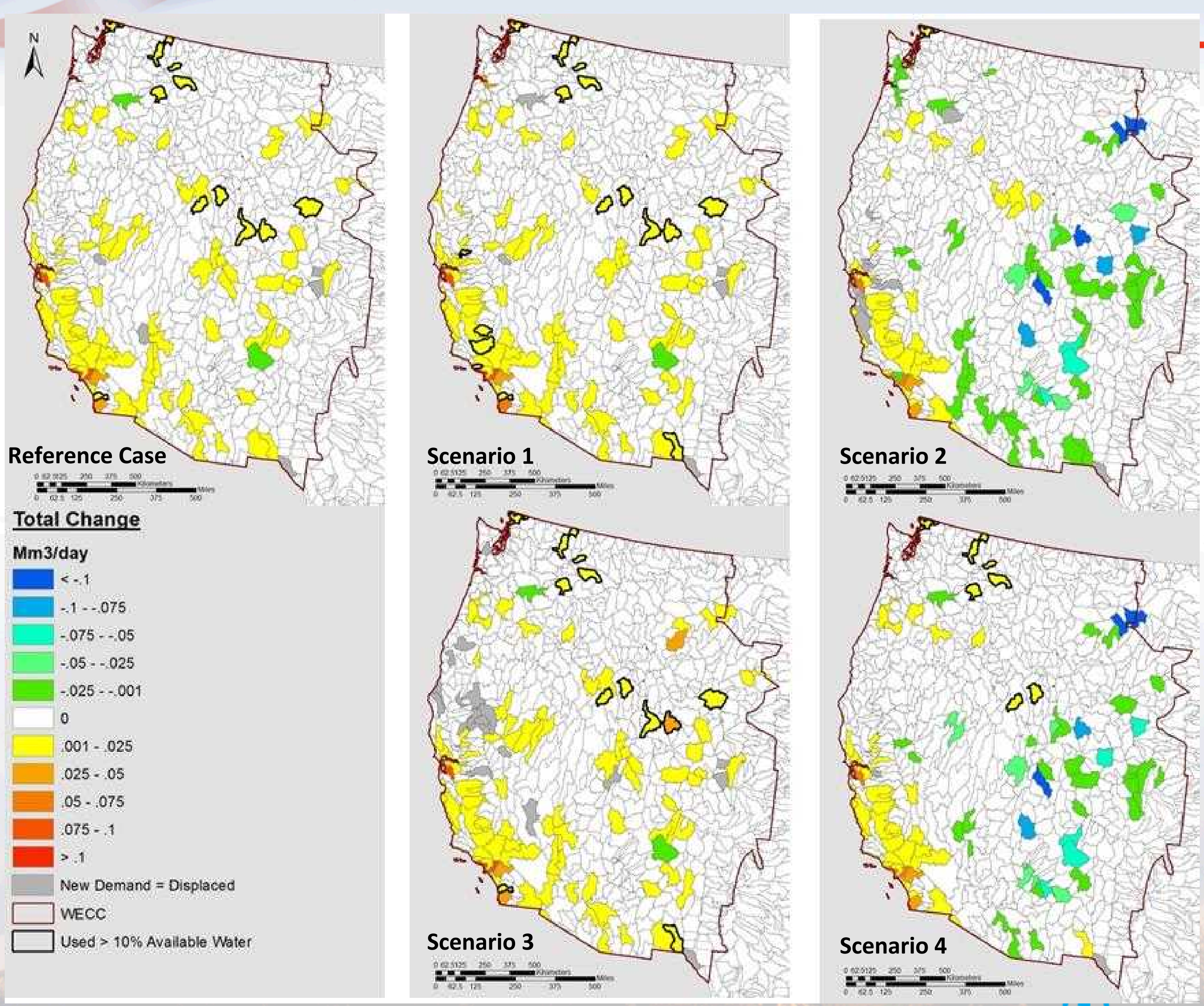
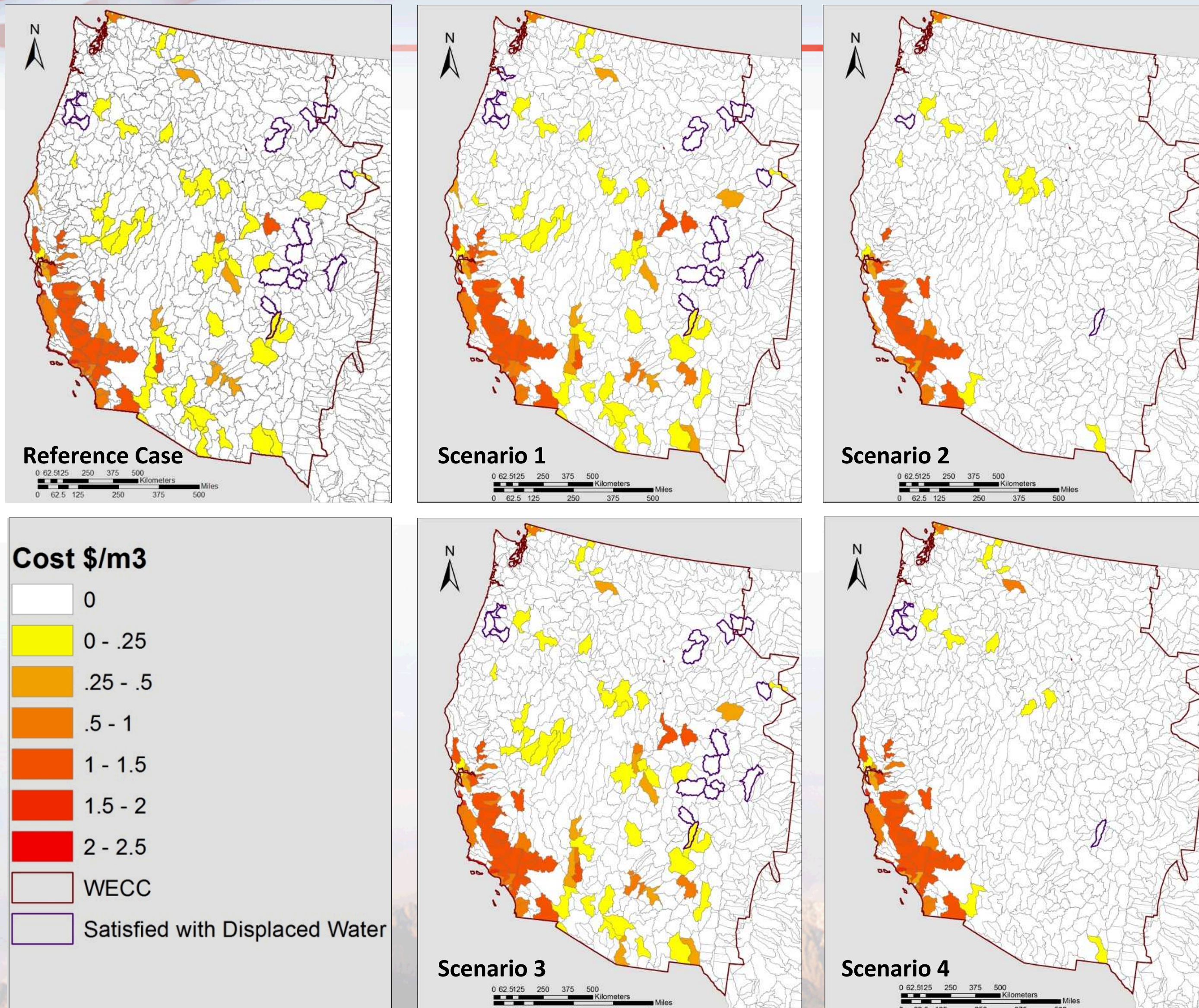
Results: Watershed Supply Analysis



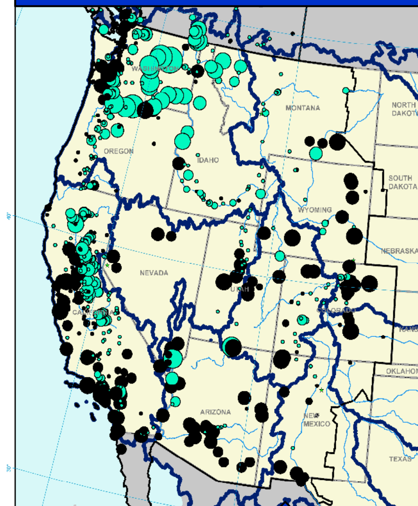
Results: Watershed Cost Analysis



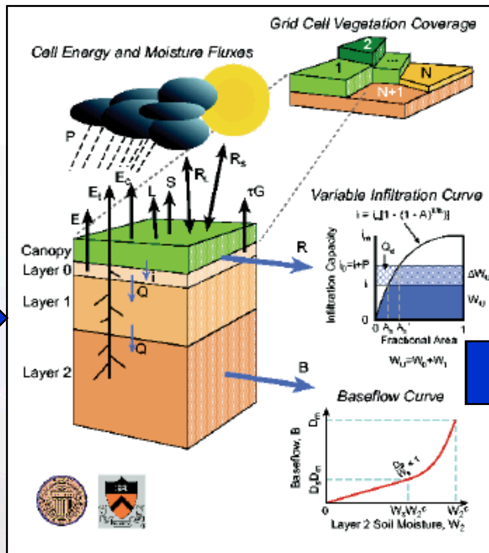
Climate Vulnerability

- Framework that links natural and engineered systems to evaluate climate vulnerabilities:
  - Multiple interdependent systems,
  - Multiple interacting scales, and
  - Multiple stakeholders.

Western Grid

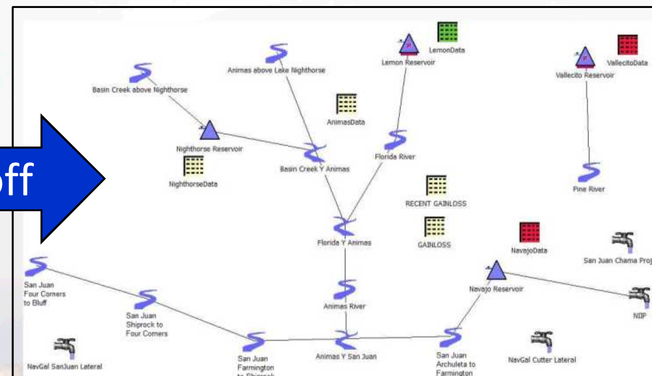


Climate



Natural System

Runoff

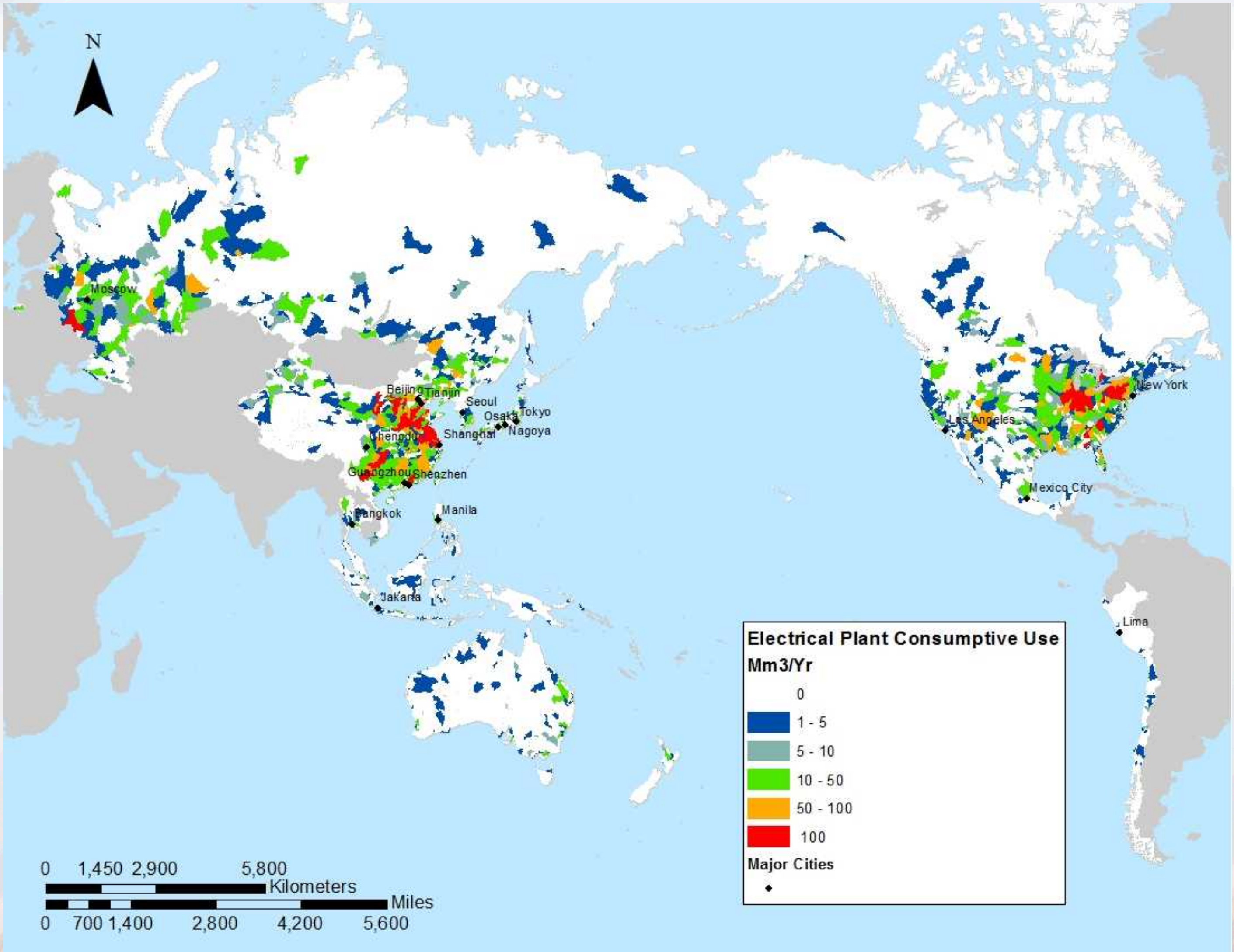


Engineered System

Deliveries

- Electric Power
- Irrigation
- Instream Flows
- Compact Native American

Water for Thermoelectric Power



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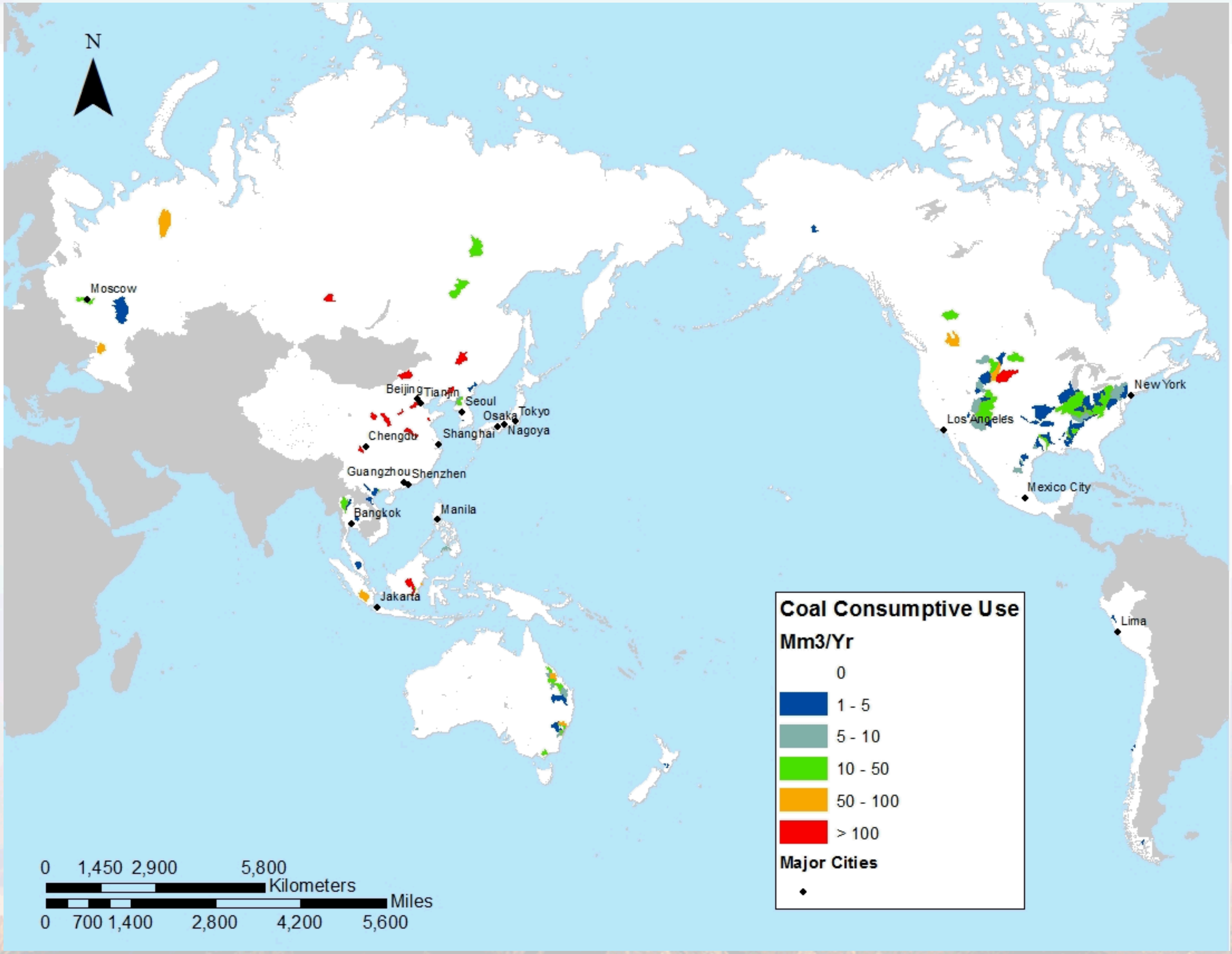
Water for Coal Extraction



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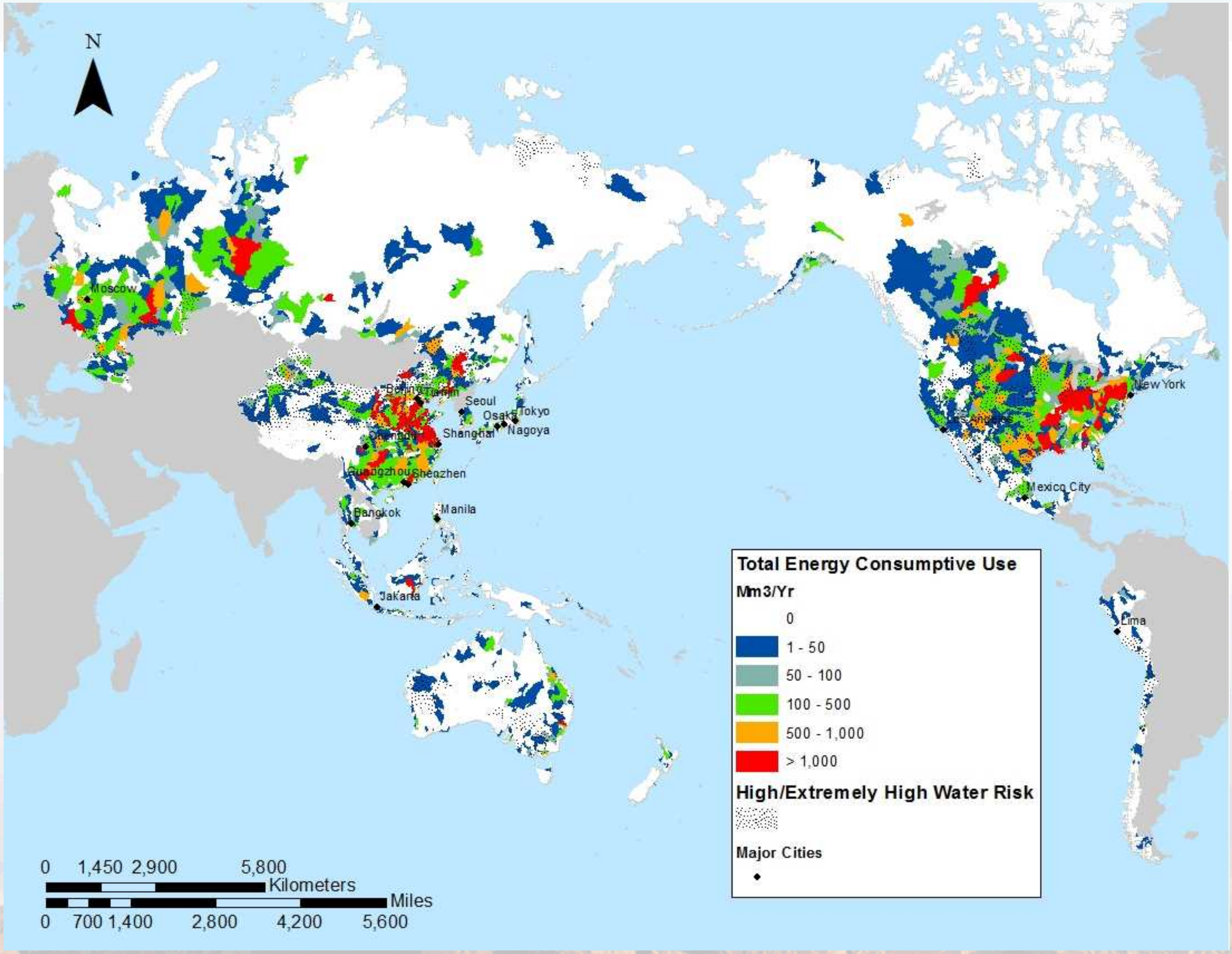
Water for Energy with Water Stress



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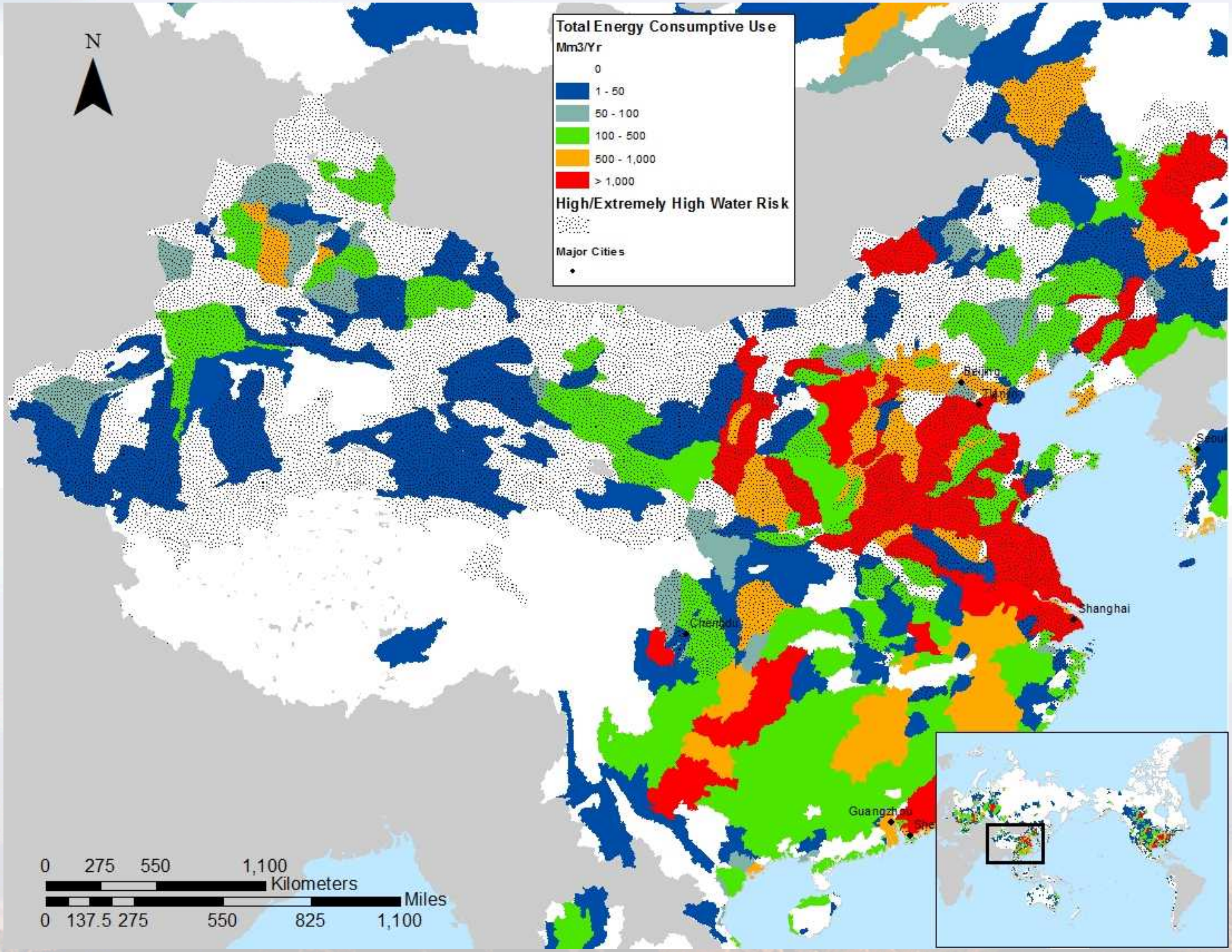
Water for Energy: Detail China



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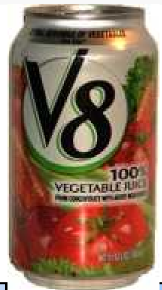
An edible salinity scale



V8 juice
1800 ppm Na^+

Low sodium
38,000 ppm Na^+

brackish | **sea water**

1000—10000 ppm | **35,000 ppm**

Regular
61,000 ppm Na^+

sea water | desal concentrate

10,000 ppm | **35,000 ppm** | **60,000 ppm** | **100,000 ppm**

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