SAND2016-8377PE

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Sandia National Laboratories

# Regional Water Challenges And Oppertunties for Alternative Water

## August 2016

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**Sandia National Laboratories**
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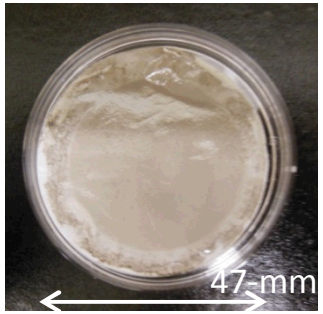
# Desalination

***A low-carbon, low-energy, low-cost desalination energy innovation hub*** will serve as a center of research focused on developing integrated technological system solutions and enabling technologies for de-energizing, de-carbonizing, and reducing the cost of desalination. While preliminary research is currently underway on these topics, the proposed effort will serve as a significant and necessary first-of-a-kind focused critical mass R&D effort on new technologies for cost-effective desalination. It will establish a central pillar in DOE and the nation's RD&D efforts in this critically important and highly multi-disciplinary field. This Hub will examine low-carbon, low-energy, low-cost desalination approaches that will support production of municipal drinking water, production of agricultural water supplies and treatment of nontraditional water sources, such as produced water from oil and gas extraction.

*2017 President's Budget Request*

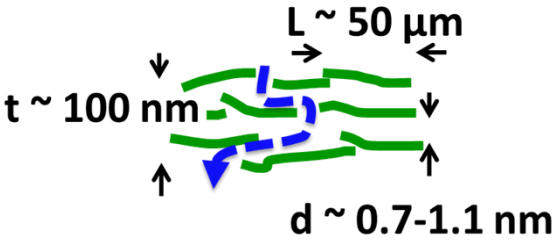
# Laminar GO desalination membranes are a potentially disruptive technology

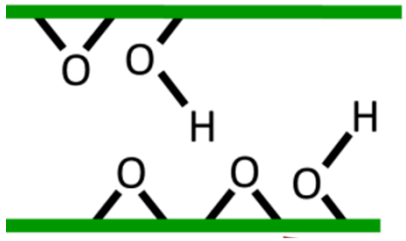
Intrinsic nanoscale properties of laminar GO drive water permeation and are optimum for desalination

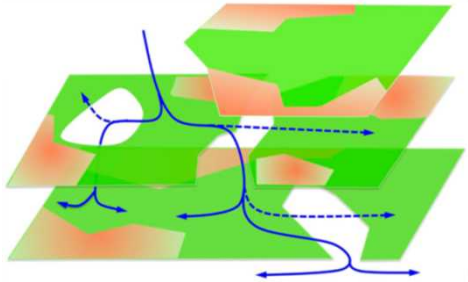


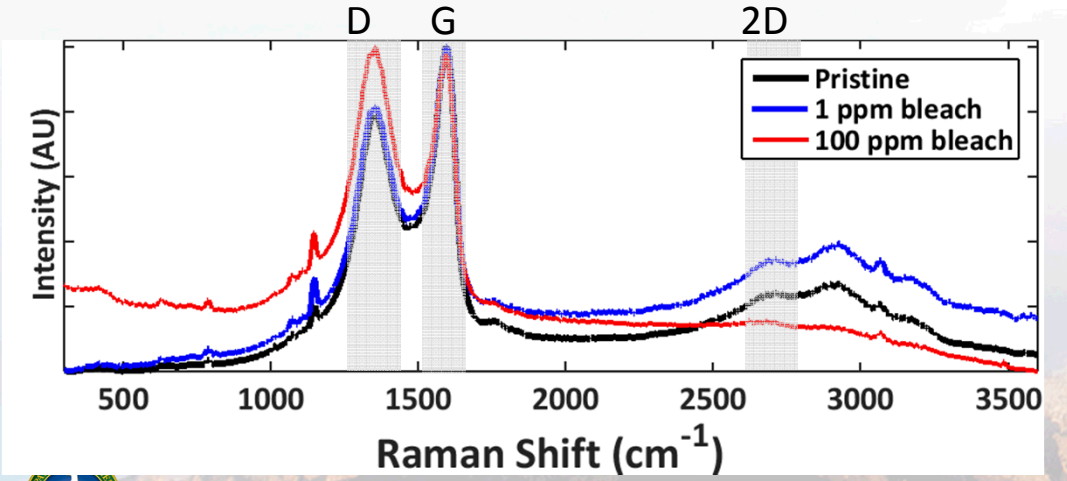

SNL GO/polyester membrane

Thin-slit permeation pathway defined by oxygen moiety “nanopillars”



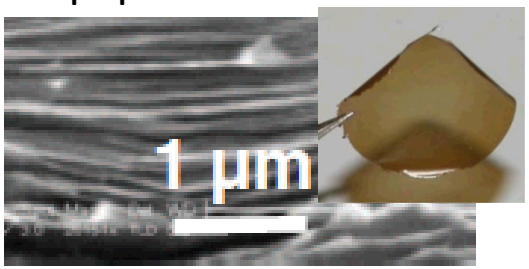



GO structure is robust to 1-ppm, **one month** free chlorine exposure.

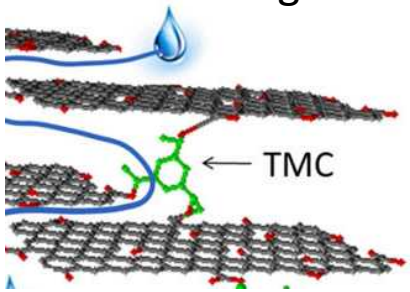
GO is chemically tolerant to many hydrocarbons (eg: toluene)

# Our covalent-binding chemistry is our competitive advantage

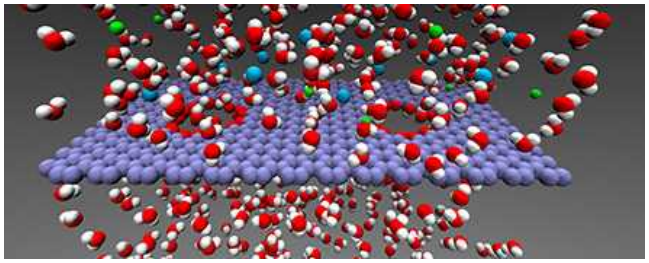
Geim *et al.*'s micron-thick GO paper membranes




Mi and Hu's intra-GO covalent bonding

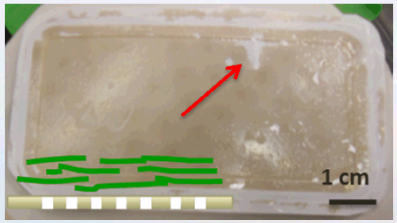



Lockheed Martin's Perforene, a nanoporous graphene



Preliminary tests show a paradigm-shattering 80 % reduction in energy intensity

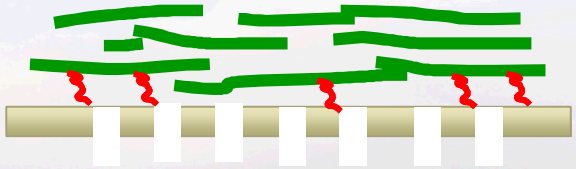
No binding chemistry




1.8 L $m^{-2}$ $h^{-1}$ $bar^{-1}$

Sulfate ion rejection: 15-20 %

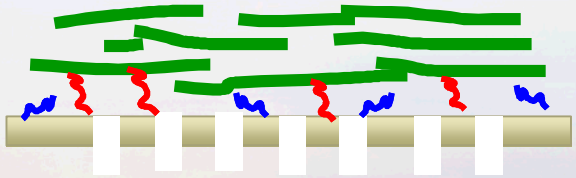
Isocyanate
Slightly hydrophilic



0.5 L $m^{-2}$ $h^{-1}$ $bar^{-1}$

Sulfate ion rejection: 80 %

Isocyanate:PEG



2.1 L $m^{-2}$ $h^{-1}$ $bar^{-1}$

Sulfate ion rejection: 90 %

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

Problem: Cheap clean water is critical globally, but current water desalination technology is costly.

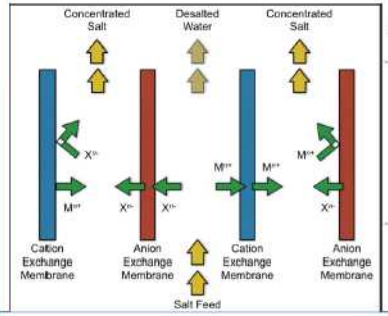
- Energy – water - food interdependence
- Clean water essential to coal-fired electricity, biofuels, agriculture
- 2.4 billion gallons/day water produced in extraction (oil, gas, mining), but limited reuse due to desal. cost
- Unprecedented drought risk in US & worldwide (*Science*, Feb. '15), causes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

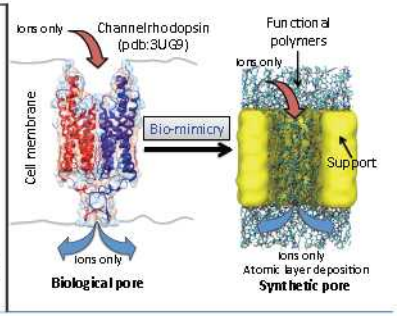
Innovative Solution: Develop advanced, low-cost electro-dialysis (ED) membranes inspired by newly discovered cellular proto-types to clean salty waters cheaply.

- 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
- Risk→Mitigation: 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

Team Expertise & Capabilities:

- 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




Why Sandia/Broad Impact:

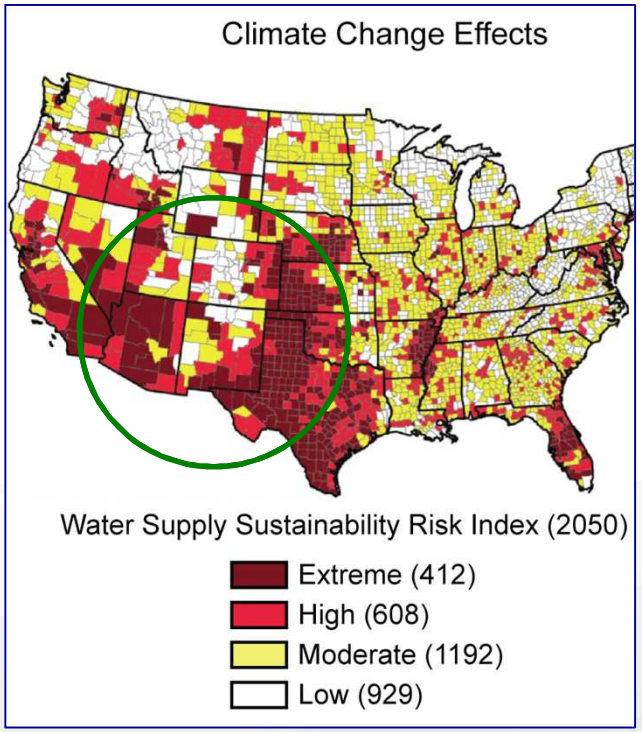
- Team's expertise & recent successes in quantifying ion-matrix interactions & fabricating ultra-thin peptide-lined membranes (*PNAS*, '13; *JACS*, '14)
- Leverages SNL investments in Part 1: synergistic, but distinct water-selective RO membranes, currently in transition by industry (R&D 100 Award, 2011)
- 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

# Test Beds

***Regional-Scale Data, Modeling, and Analysis Test Beds***, new in FY 2017, will design and begin deployment of three regional-scale data, modeling, and analysis test beds. Major objectives of the test beds are to accelerate development and synthesis of integrated toolsets in diverse, contextualized environments; test the predictive limits and identify gaps of current and evolving capabilities on priority topics at the Nexus; identify and capitalize on unique topical and place-based DMA resources; and, ultimately, explore complex systems dynamics and the interaction of stressors at sub-regional and trans-regional scales.

*2017 President's Budget Request*

- **An excellent test-bed for nationally important water-energy <u>challenges:</u>**
  - Climate impacts on the water-energy nexus
  - Disruptive events: fire, floods, infrastructure failure
  - Fully allocated water rights
  - Growing population
  - Rapid and extensive energy development
  - Abundant brackish and produced water supplies
  - Need for novel cooling and other next-generation technologies
  - Large potential for renewable energy insertion and integration at the water-energy nexus

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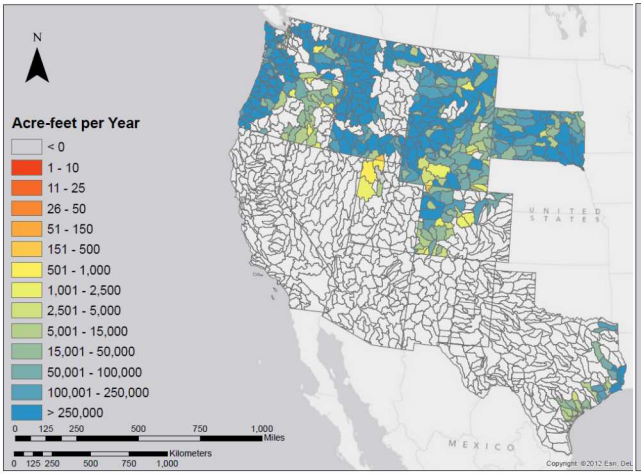
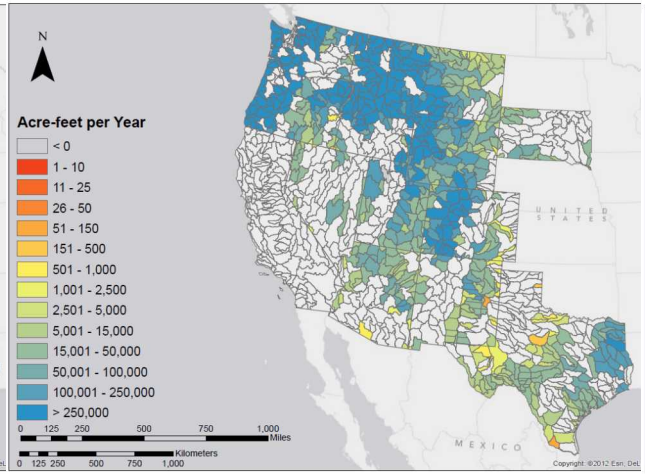
# Western Water Availability

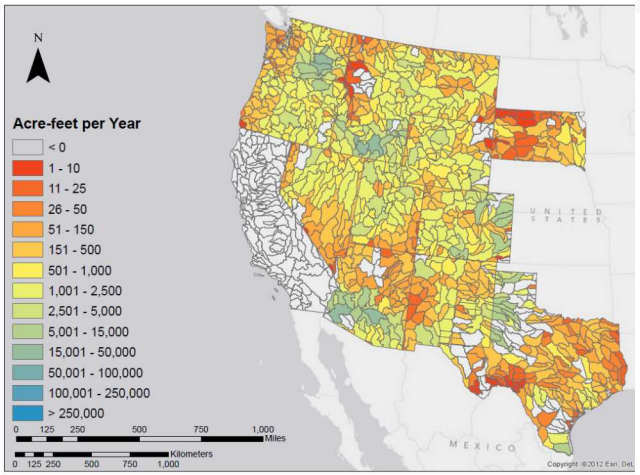
Unappropriated Surface Water Metric



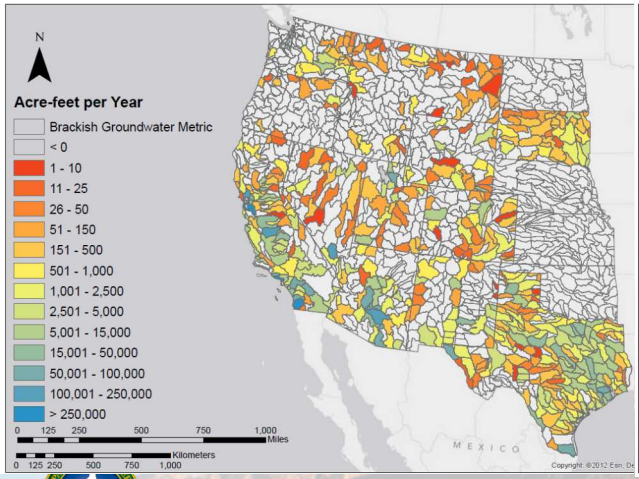

Potable Groundwater Metric



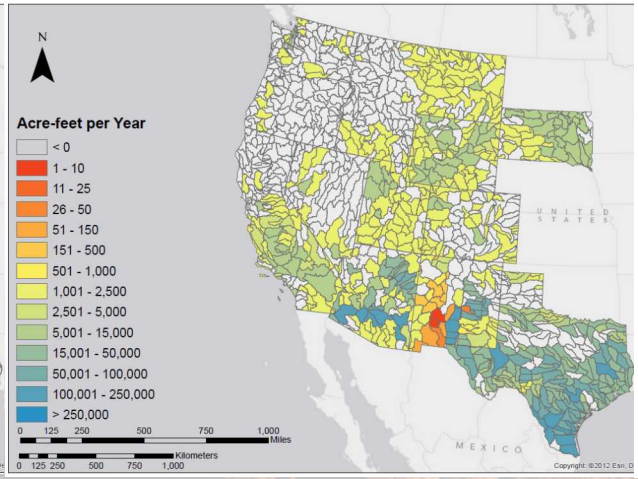

Appropriated Surface Water Metric



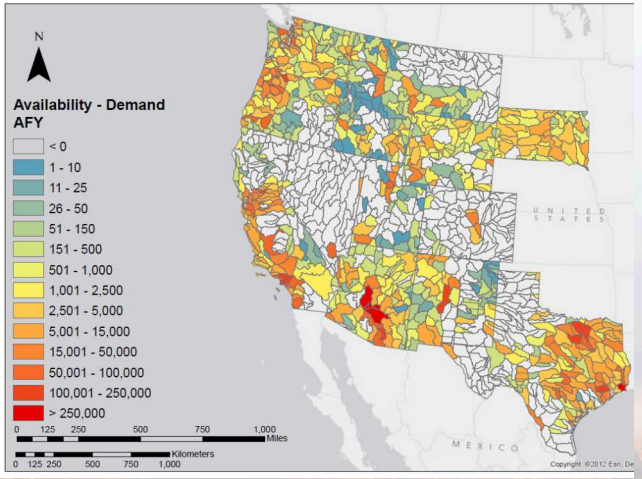

Wastewater Metric




Brackish Groundwater Metric




Change in Demand, Present - 2030

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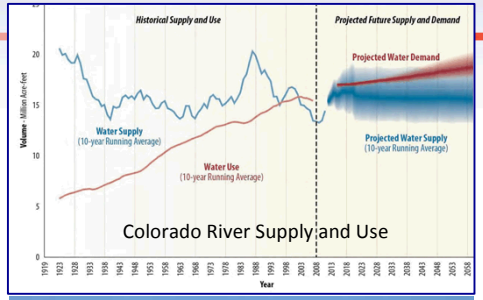
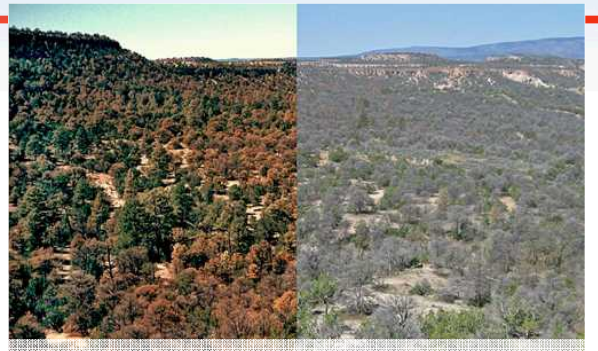
# Climate and Water-Energy Systems Analysis

- **Test Bed Focus**
  - Regional climate change and disruptive events
    - Critical watersheds account for majority of water supply for energy
    - Coupled impacts of drought, fire, vegetation succession, and snow-rain shift on water quantity, quality, and timing
  - Interface between natural and engineered systems
  - Impacts, Adaptation and Vulnerability (IAV) assessments for watersheds and surface and groundwater supply and utilization
  - Uncertainty quantification and decision support



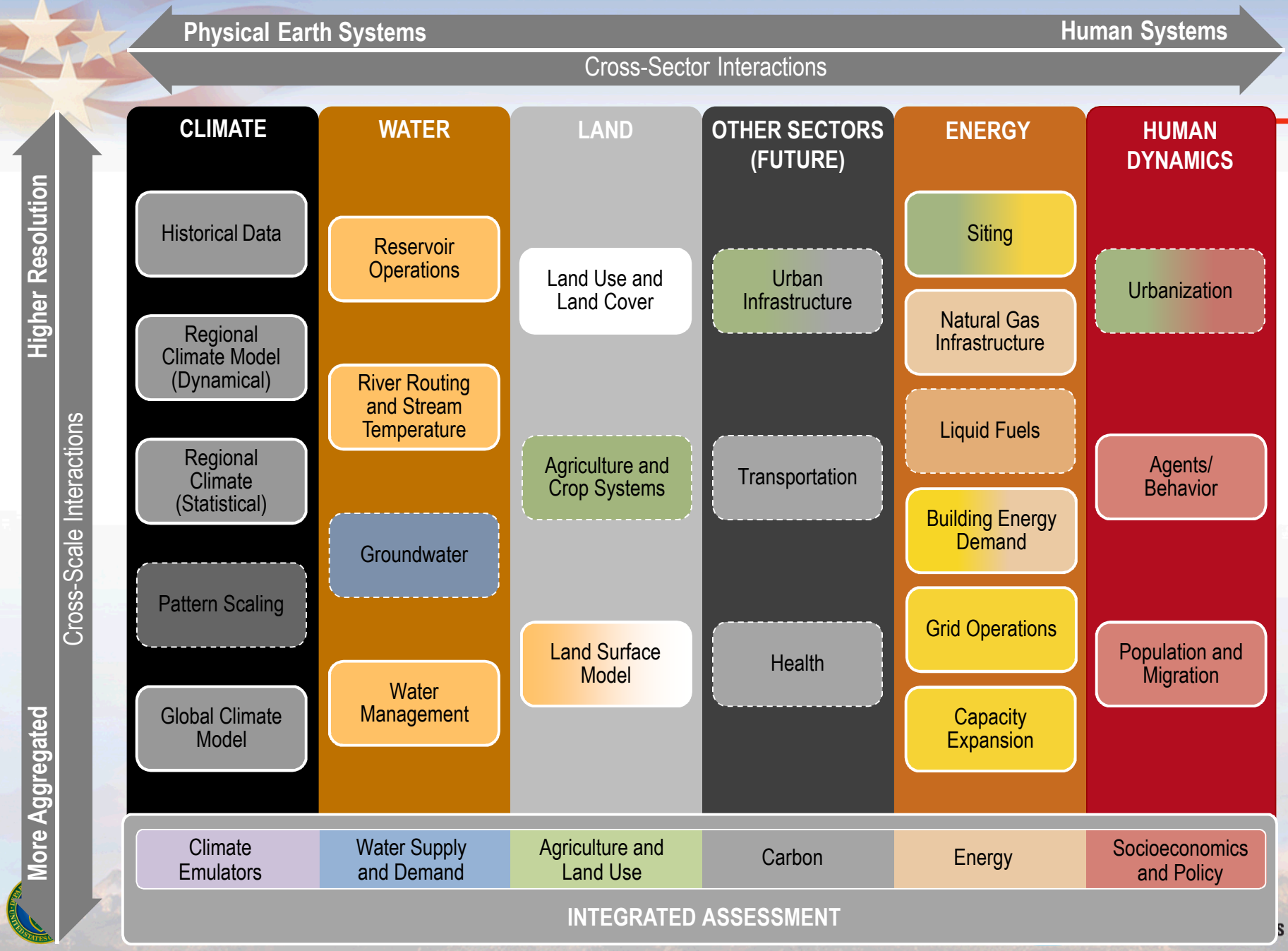
Colorado River Supply and Use


Energy: Long-term shortages


Catastrophic drought, plant mortality


Increased frequency and intensity fires


Energy: short-term disruptions


Physical Earth Systems
Human Systems
Cross-Sector Interactions
Higher Resolution
More Aggregated
Cross-Scale Interactions
CLIMATE
WATER
LAND
OTHER SECTORS (FUTURE)
ENERGY
HUMAN DYNAMICS
Historical Data
Regional Climate Model (Dynamical)
Regional Climate (Statistical)
Pattern Scaling
Global Climate Model
Reservoir Operations
River Routing and Stream Temperature
Groundwater
Water Management
Land Use and Land Cover
Agriculture and Crop Systems
Land Surface Model
Urban Infrastructure
Transportation
Health
Siting
Natural Gas Infrastructure
Liquid Fuels
Building Energy Demand
Grid Operations
Capacity Expansion
Urbanization
Agents/ Behavior
Population and Migration
Climate Emulators
Water Supply and Demand
Agriculture and Land Use
Carbon
Energy
Socioeconomics and Policy
INTEGRATED ASSESSMENT

# Watershed Analysis

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

U.S. Department of the Interior Bureau of Reclamation
aps
NREL National Renewable Energy Laboratory
PNM
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Pacific Northwest National Laboratory
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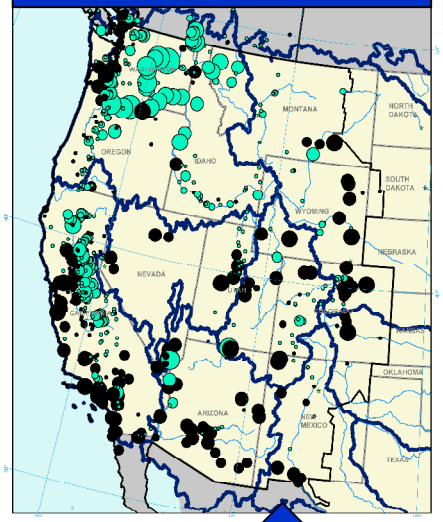
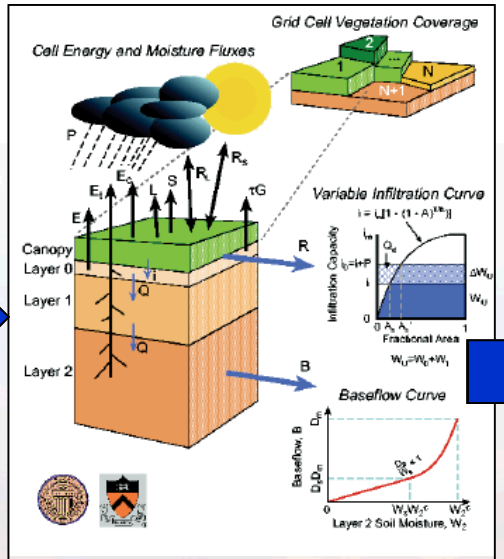
Western Grid

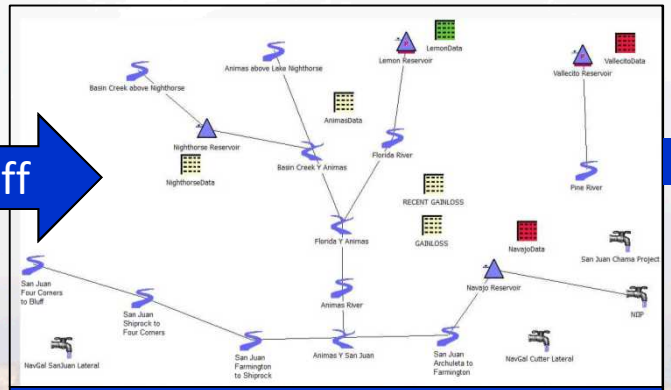


Climate




Natural System

Runoff



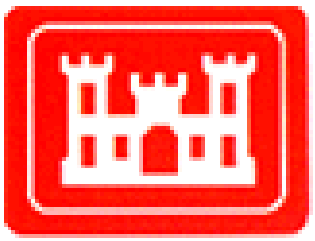
Engineered System

**Deliveries**

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

# MRG Operations Planning

- **Develop a decision support tool that is consistent with and complimentary to the Upper Rio Grande Water Operations Model (URWOM).**
  - The primary purpose of the tool is to provide a platform for rapid scenario screening, and
  - Educate and engage the public and decision makers in water operations decision-making and planning.



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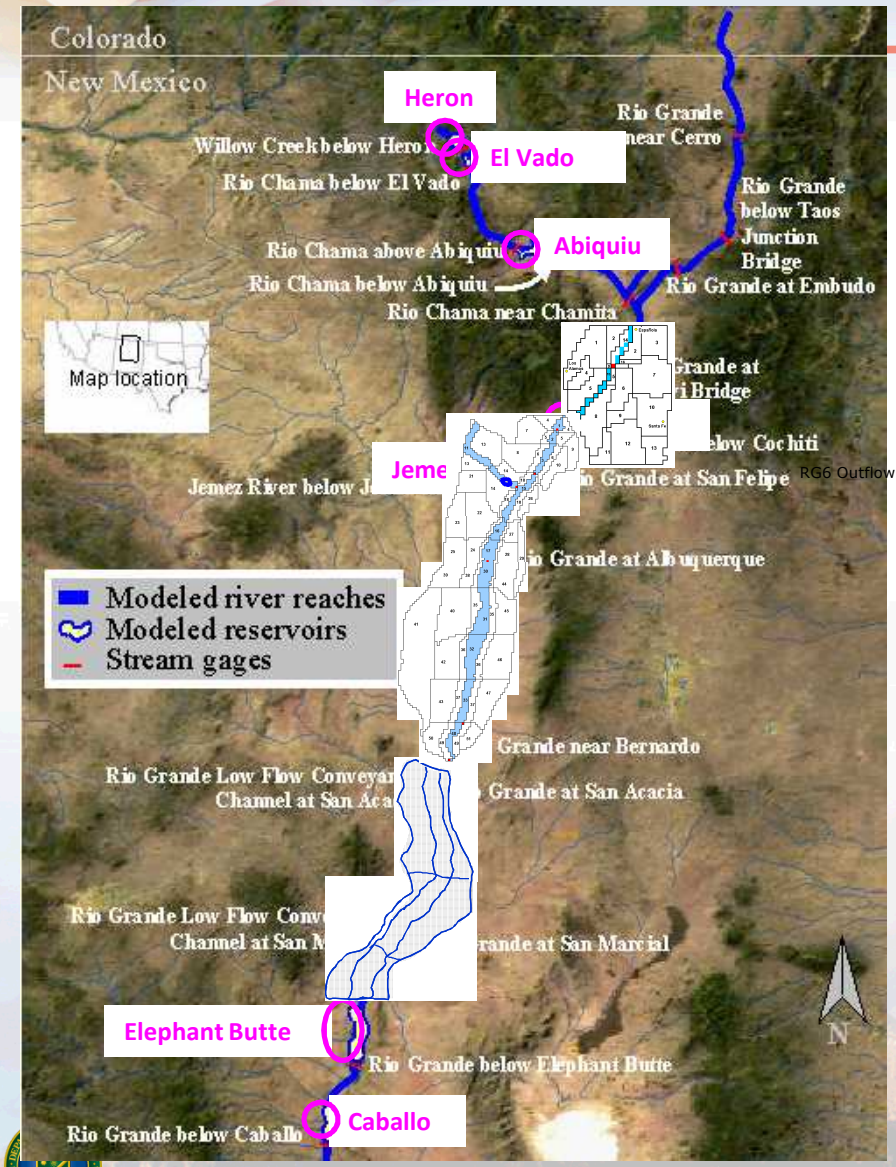
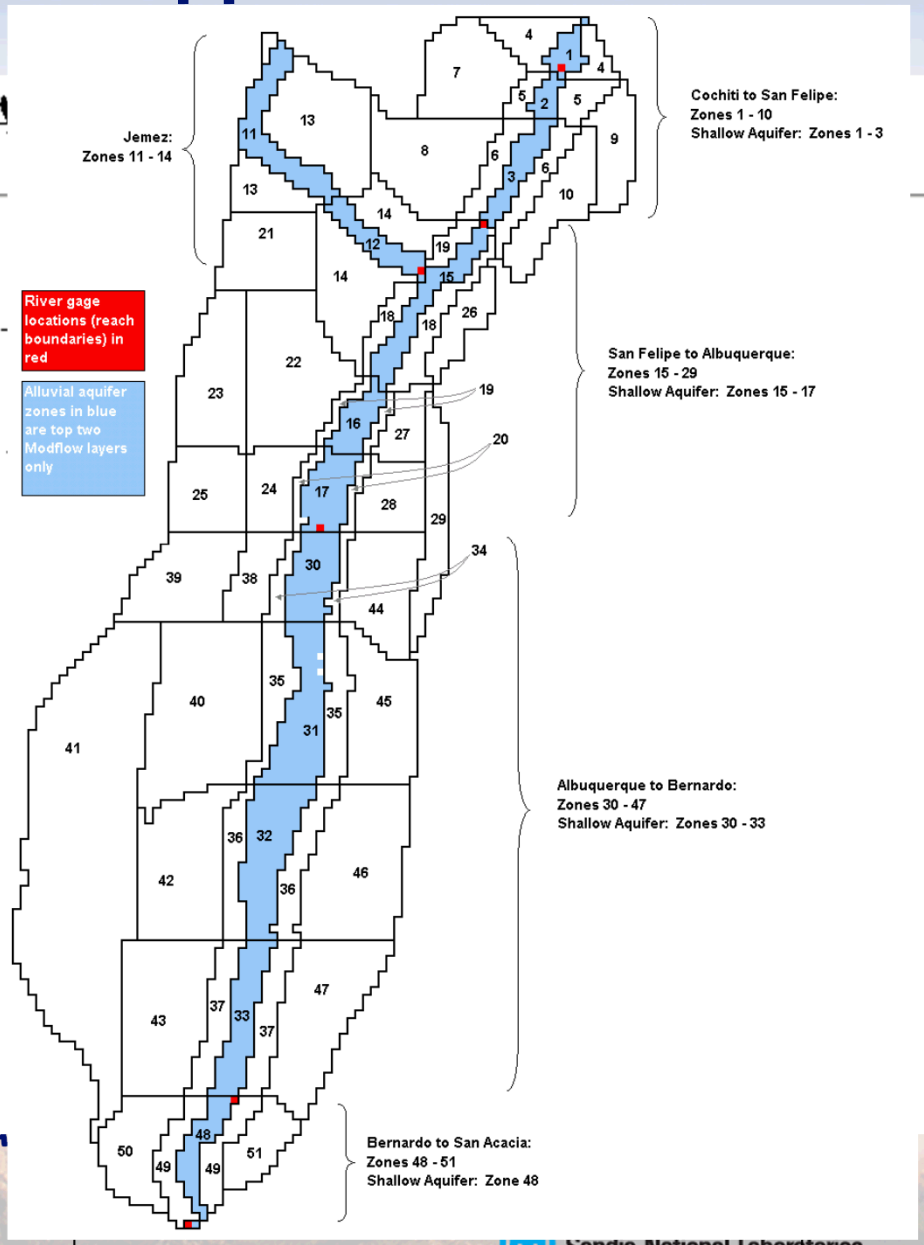
# Operations Model for the Upper Rio Grande

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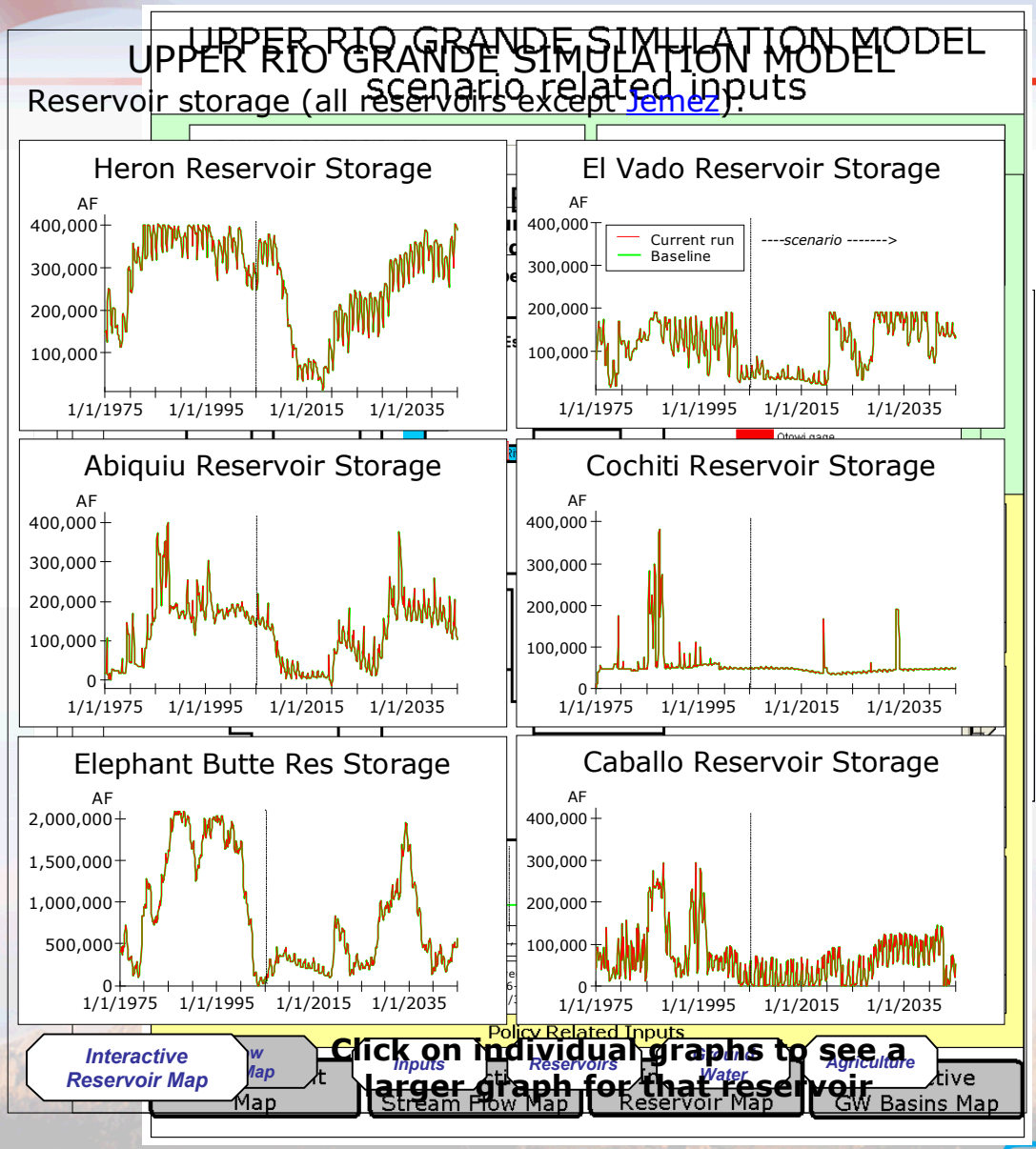
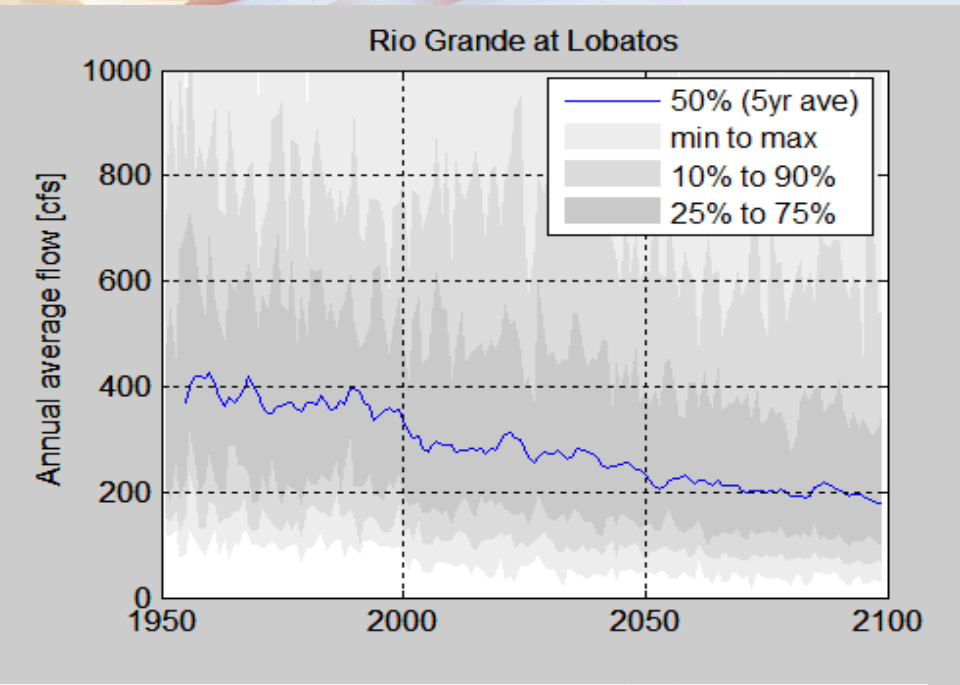


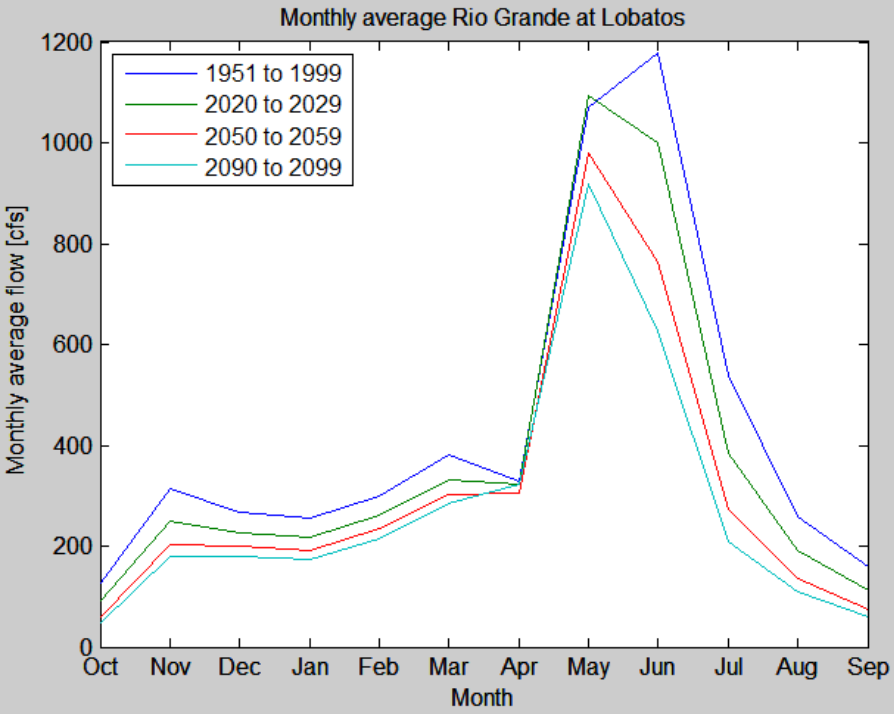
# Impact on Rio Grande Flows



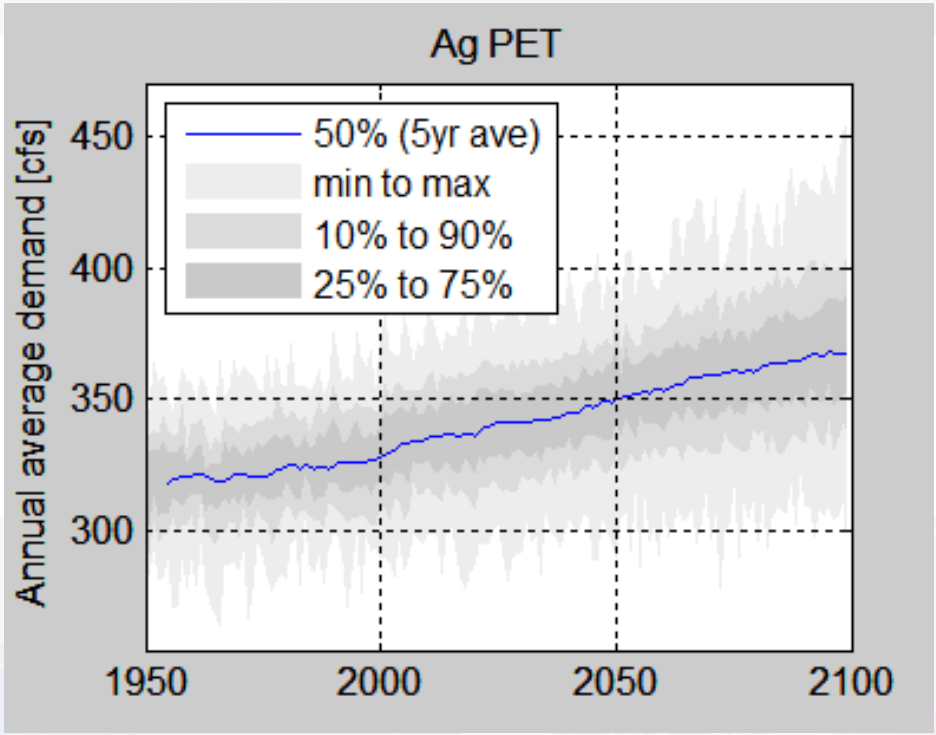


*"Results are not predictions, but rather a starting point for dialogue and increased awareness of potential impacts of climate change."*

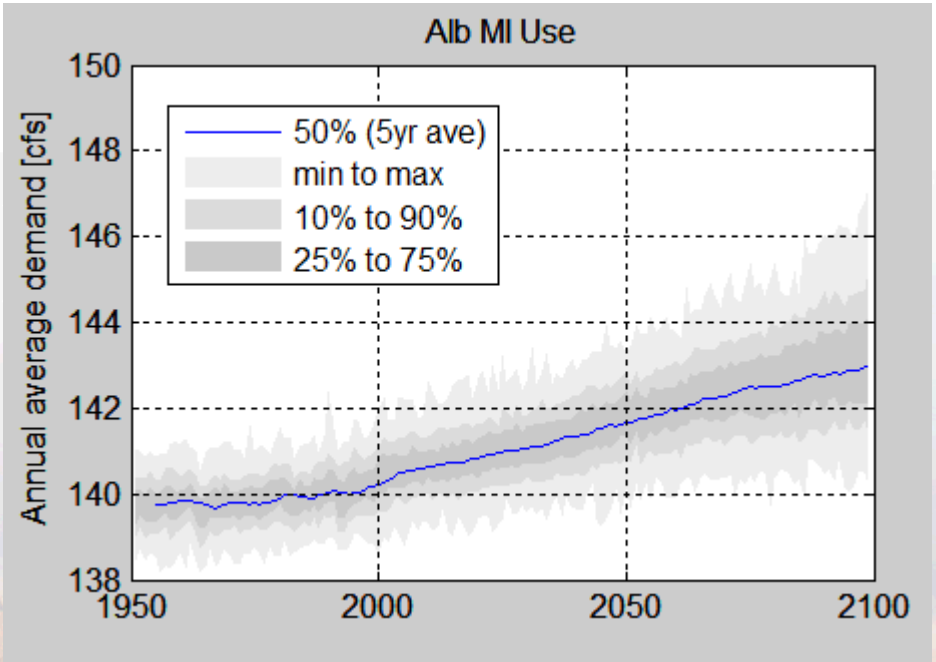
Roach et. al., 2013



# Impacts on Water Demand




Roach et. al., 2013

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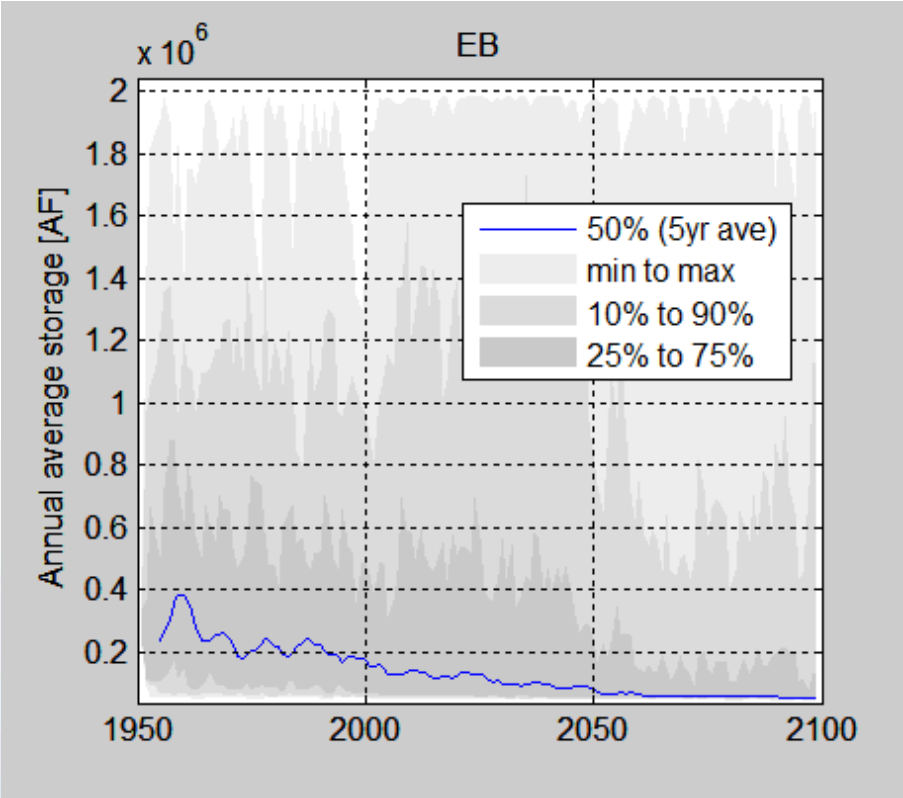
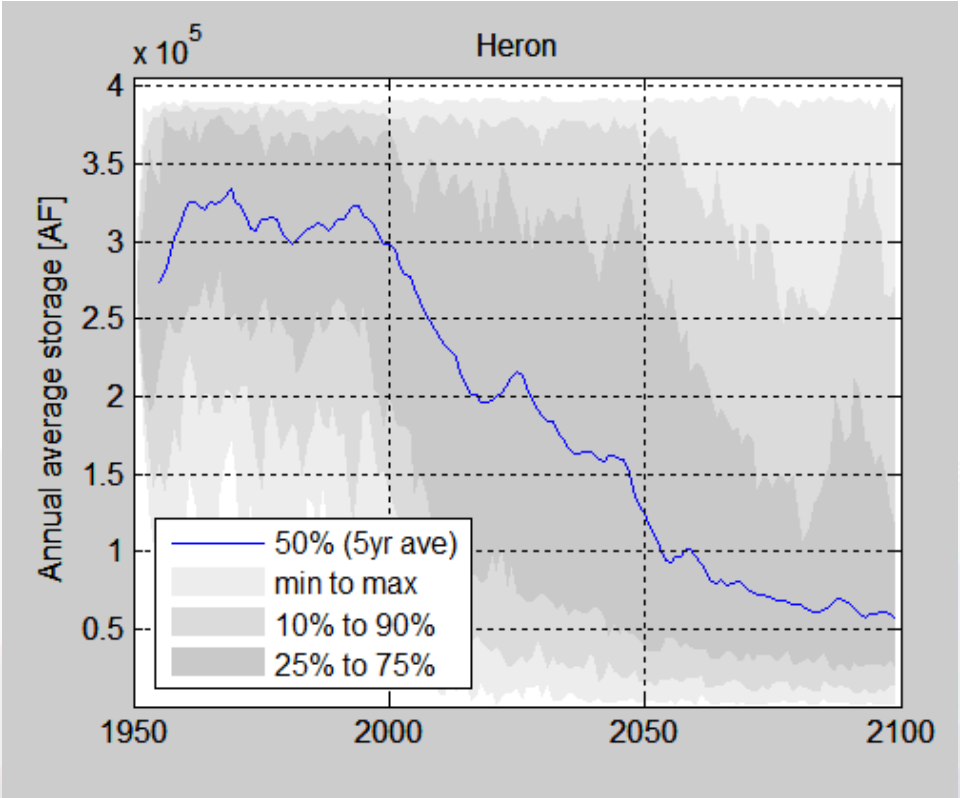
# Impacts to Reservoirs




Roach et. al., 2013

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# Water Leasing Market Experiments

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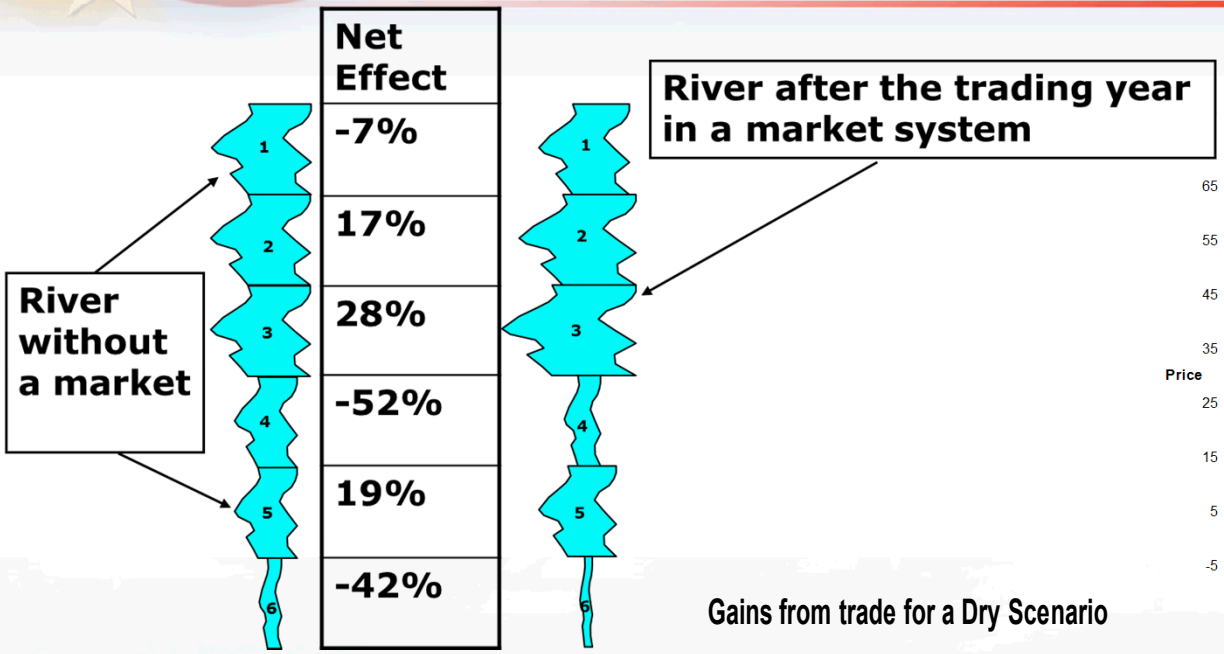
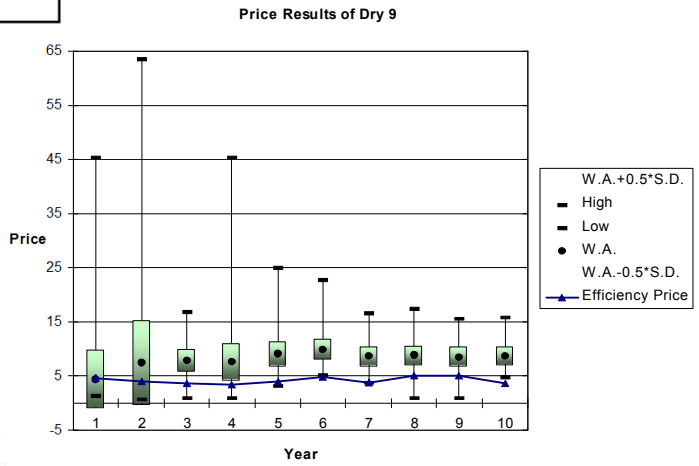
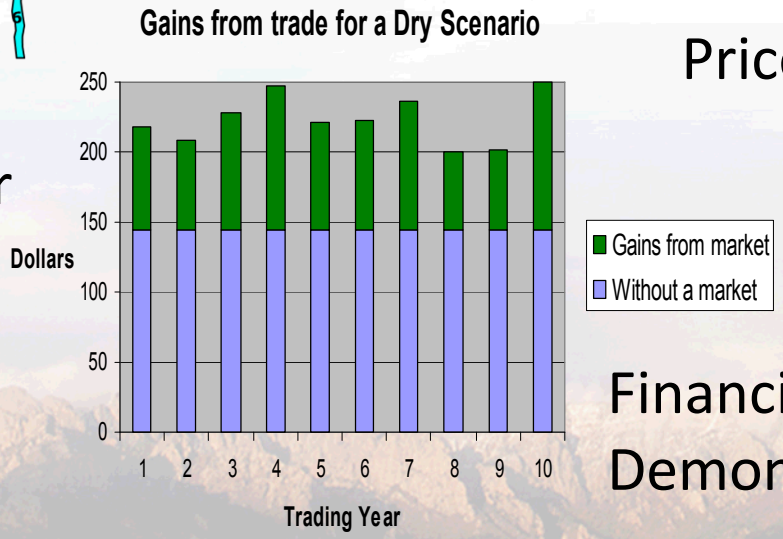



Impacts on Distribution of River Flows




Prices Trend to Theory




Financial Gains Demonstrated

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# Acequias vs. Climate Change and Urban Growth

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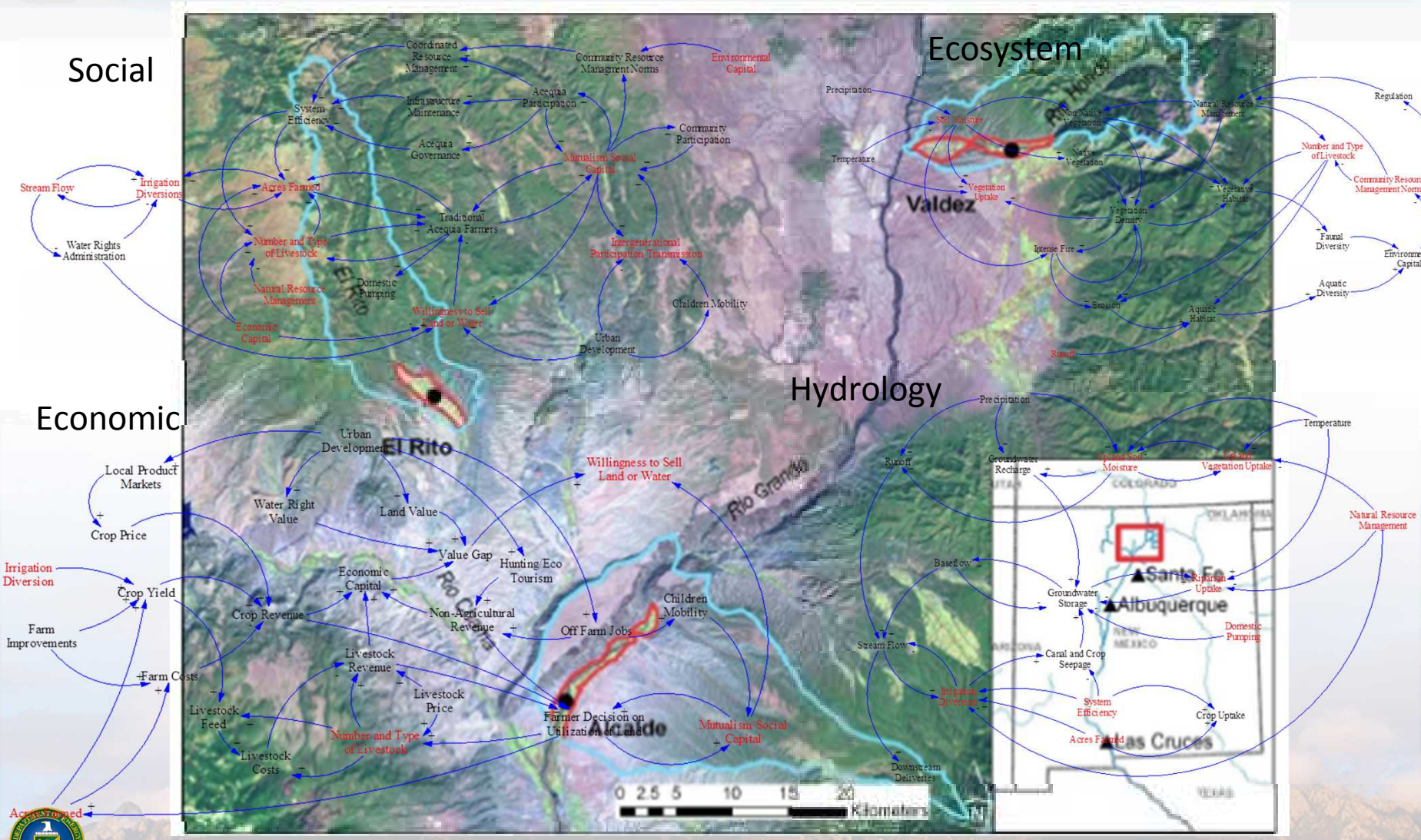
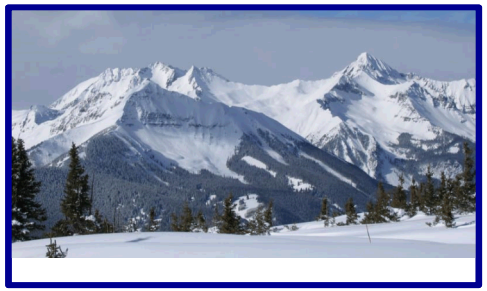
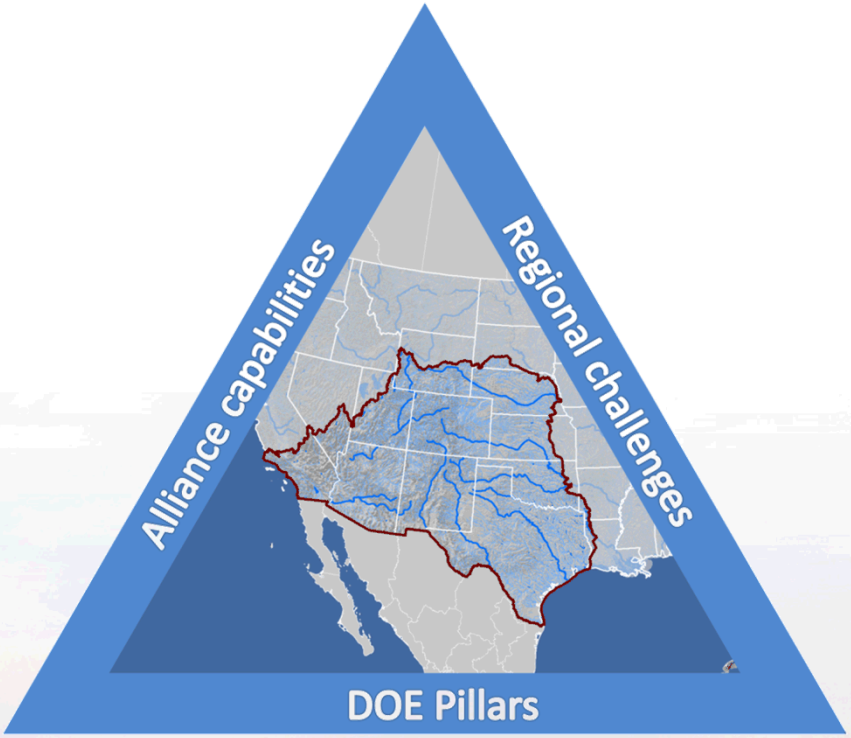


# Southwest & Southern Rocky Mountain Water-Energy Nexus Alliance






**October 2014**

**Concept Plan and Progress**

# Strategy Kickoff Meeting – June 24, 2014


- **Los Alamos National Laboratory**
- **Sandia National Laboratories**
- New Mexico State Engineer
- New Mexico Secretary of Energy, Minerals and Natural Resources
- US Bureau of Reclamation
- US Bureau of Land Management
- Public Service Co. of New Mexico
- New Mexico Oil and Gas Association
- NM US Senators' Staff (all)
- NM US Representatives' Staff (all)
- Nature Conservancy
- New Mexico Water Resources Research Institute

- University of New Mexico
- New Mexico Tech University
- New Mexico State University
- New Mexico EPSCOR
- University of Texas, El Paso
- University of Nevada Las Vegas
- University of Arizona
- Texas A&M University
- Southwest Water Technology Cluster
- Regrets from:
  - **National Renewable Energy Laboratory**
  - **Colorado School of Mines**
  - **University of Texas, Austin**

**Unilateral support of participants for an integrated, multi agency, regional, research and development program to address unique energy and water issues in the Southwest and Southern Rocky Mountains**

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