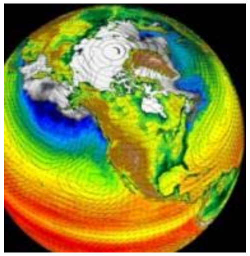
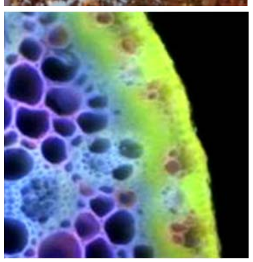
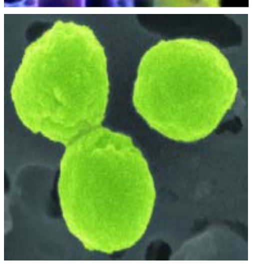


Integrated Modeling of Energy-Water-Land Systems Dynamics

Meeting of the NAS Board on Energy & Environmental Systems

April 3, 2013

Bob Vallario

Manager, IARP

Climate and Environmental Sciences Division

U.S. DEPARTMENT OF ENERGY

Office of Science

Office of Biological and Environmental Research

Why Water?

- Water underlies and influences many important climate processes and feedbacks – a leading cause of uncertainty in projecting future climate

Water vapor and cloud feedback

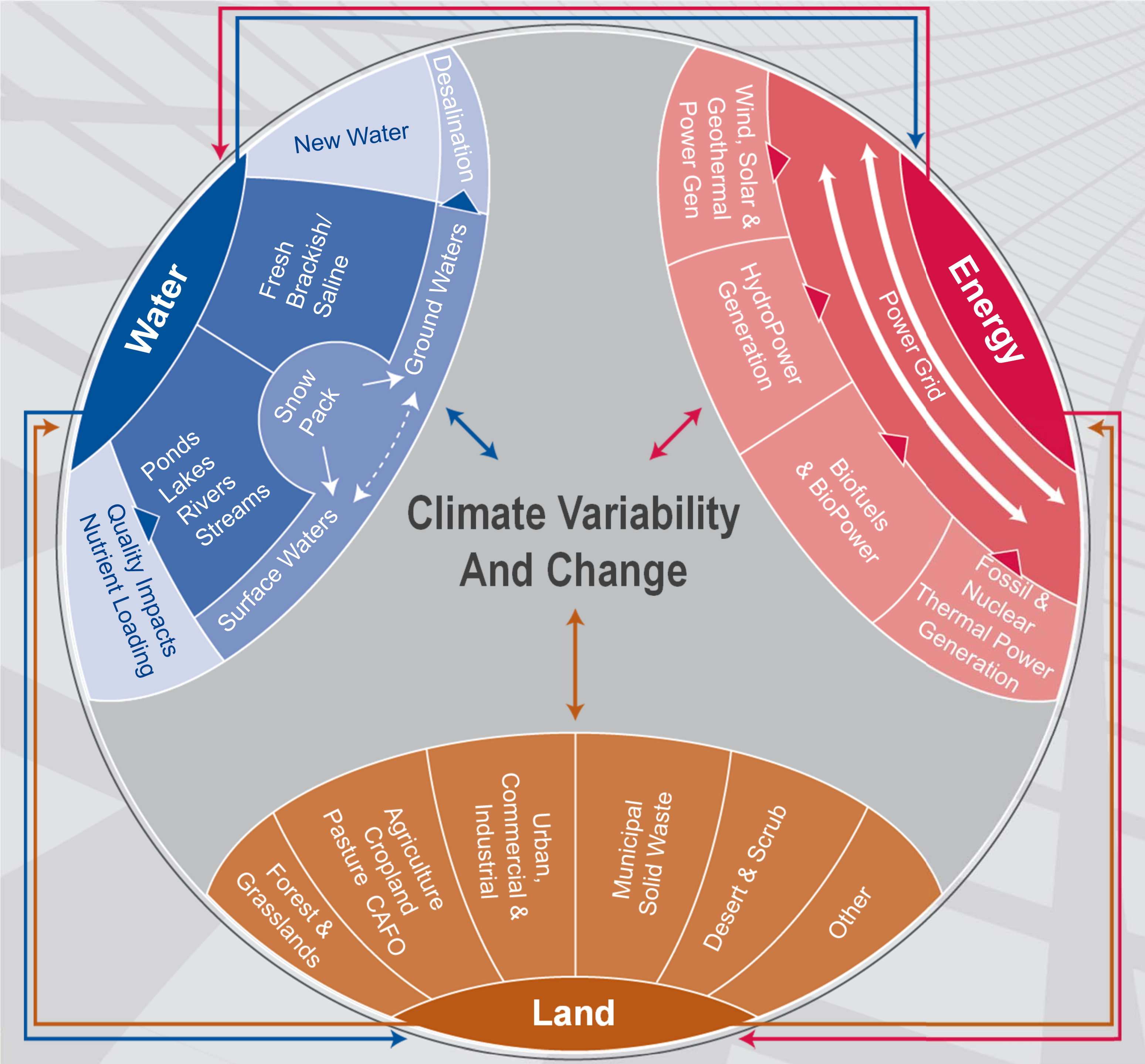
Snow-albedo feedback

Aerosol-cloud interactions

Carbon-water interactions

- Water is essential for energy systems, ecosystem services, and a wide range of life sustaining and other critical human activities

- Humans are reshaping regional water cycles



LAND FOR WATER

Water-Capture & Watershed
Ground Cover Vegetation
Hydro-Geology
Ecosystems

LAND FOR ENERGY

Infrastructure
dams/reservoirs
mines/wells
power plants
solar & wind farms
power lines
pipelines
railways
refineries
biomass feedstock & biofuels production
CCS
Energy Mineral Deposits

WATER FOR LAND

Forests & Ecosystems
Crop & Animal Agriculture
Mining/Energy Extraction
Industrial, Municipal, Commercial & Residential

WATER FOR ENERGY

Extraction
Cooling
Processing
Carbon Capture & Storage (CCS)

ENERGY FOR LAND

Development
Transportation
Economic Productivity
Resource Extraction & Conversion

ENERGY FOR WATER

Pumping
Transport
Treatment
Conditioning

Overview

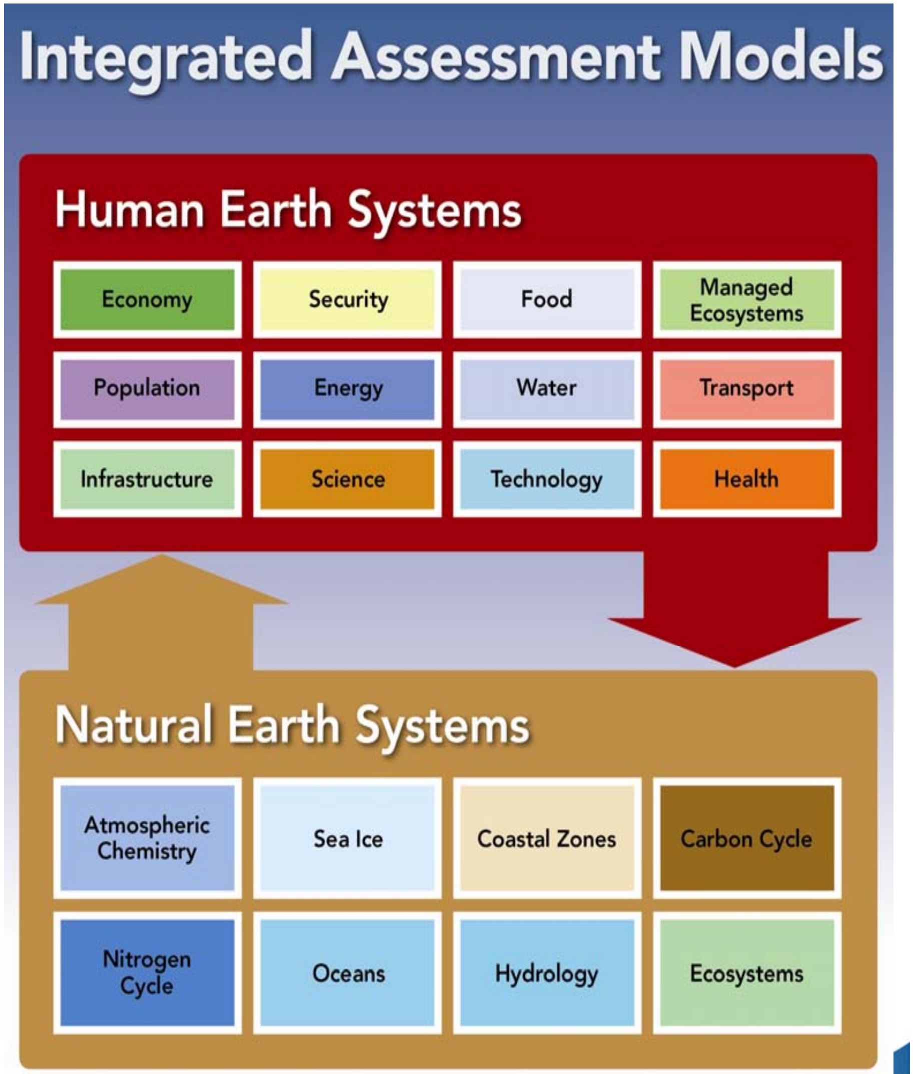
- **Basic science and translational research** converging on models and insights.
- **Understanding** of processes and systems dynamics
- Resulting **toolsets** advance our scientific understanding and are used by others for various applications.
- My focus today is more on **Integrated Assessment (IA) modeling and research**, one of the tools most often used (and also supported) by other components within DOE.
- The overwhelming majority of investments within our division are in global and regional **climate modeling and supporting process research**, including large field experiments and observational platforms.
- The combined **data systems are enormous**, e.g., LLNL manages the distributed data sets for the CMIP (think IPCC).

Areas of Focus for Today

- Incorporating water into Integrated Assessment Models (IAM's)
  - GCAM
  - IGSM
- Water and Multi-Scale Issues in Regional IAMs (RIAM)
- Energy-Water-Land Interactions and the National Climate Assessment
- Connected Infrastructure, Urban Systems, and Vulnerabilities
- Water in the Integrated Earth System Model (iESM)
- Improved modeling of the integrated water cycle (and recent community workshop)

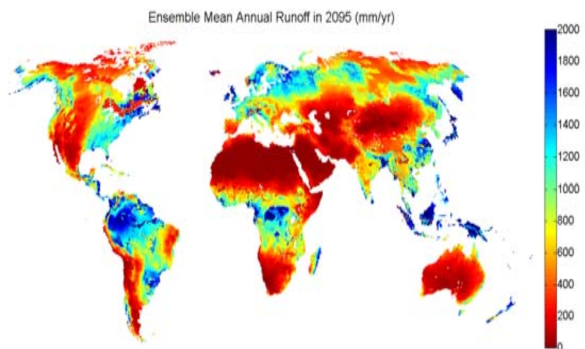
So What are Integrated Assessment Models?

- Understanding and modeling the complex interactions of human and natural systems
- Exploring developmental pathways, emissions, the role of energy innovations, and mitigation strategies
- Providing insights into climate change impacts, adaptations, and the effects of combined, multiple stressors with emphasis at the mitigation-adaptation interface
- Developing global, national, and regional perspectives within economic, risk and other policy-relevant frameworks

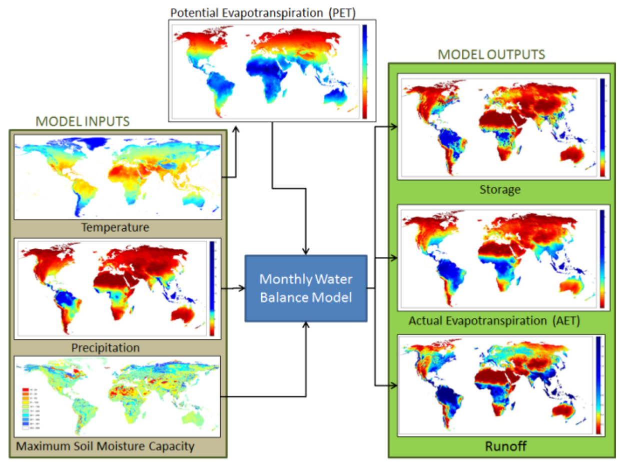


Water Supply & Demand in PNNL's GCAM

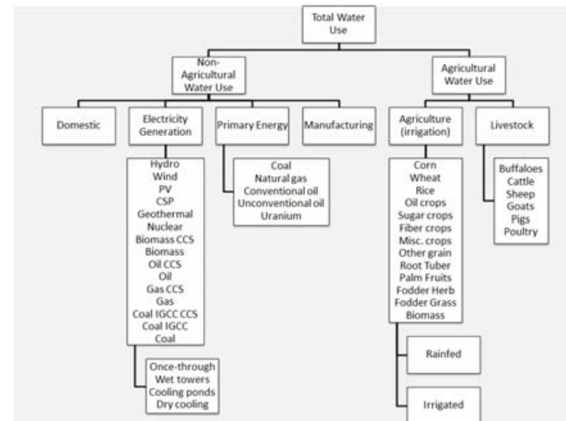
Supply Representation



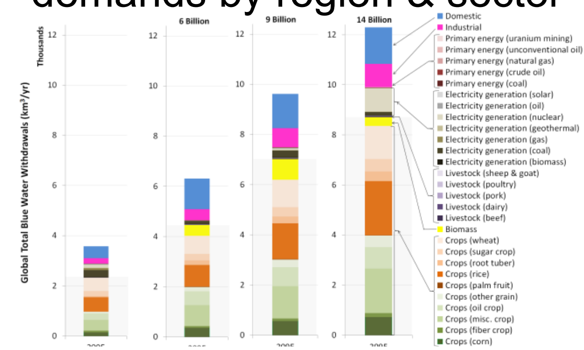
Water Availability

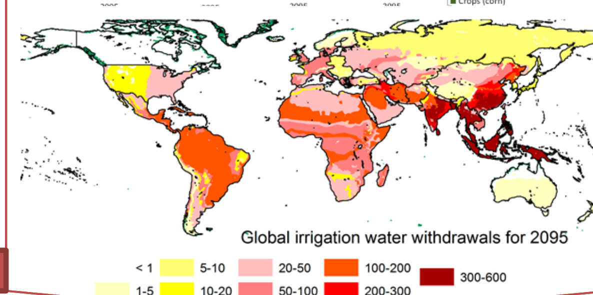


Demand Representation

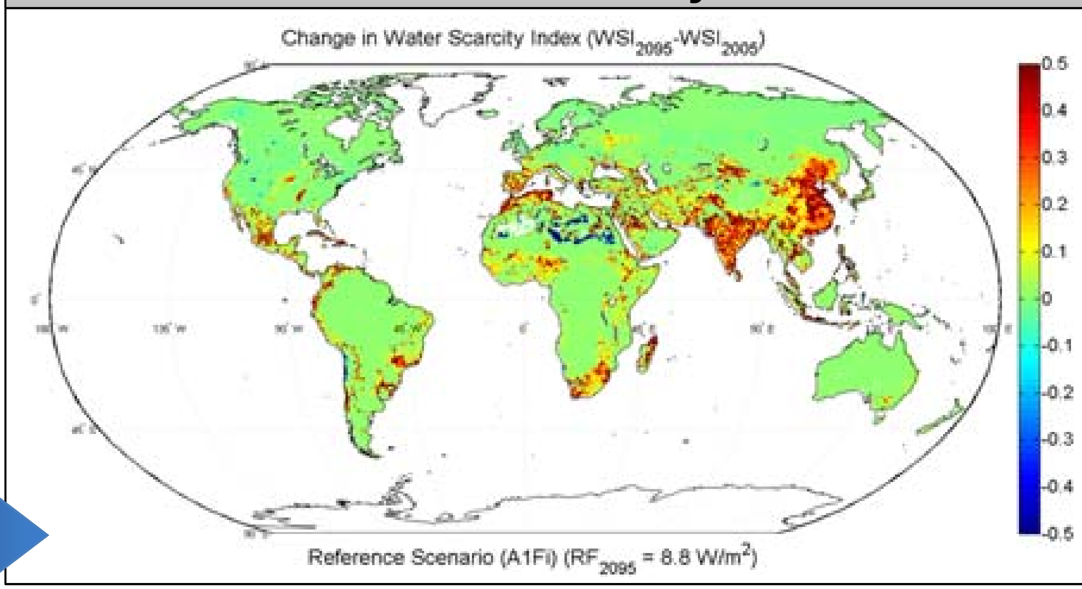


Technology-detailed water demands by region & sector

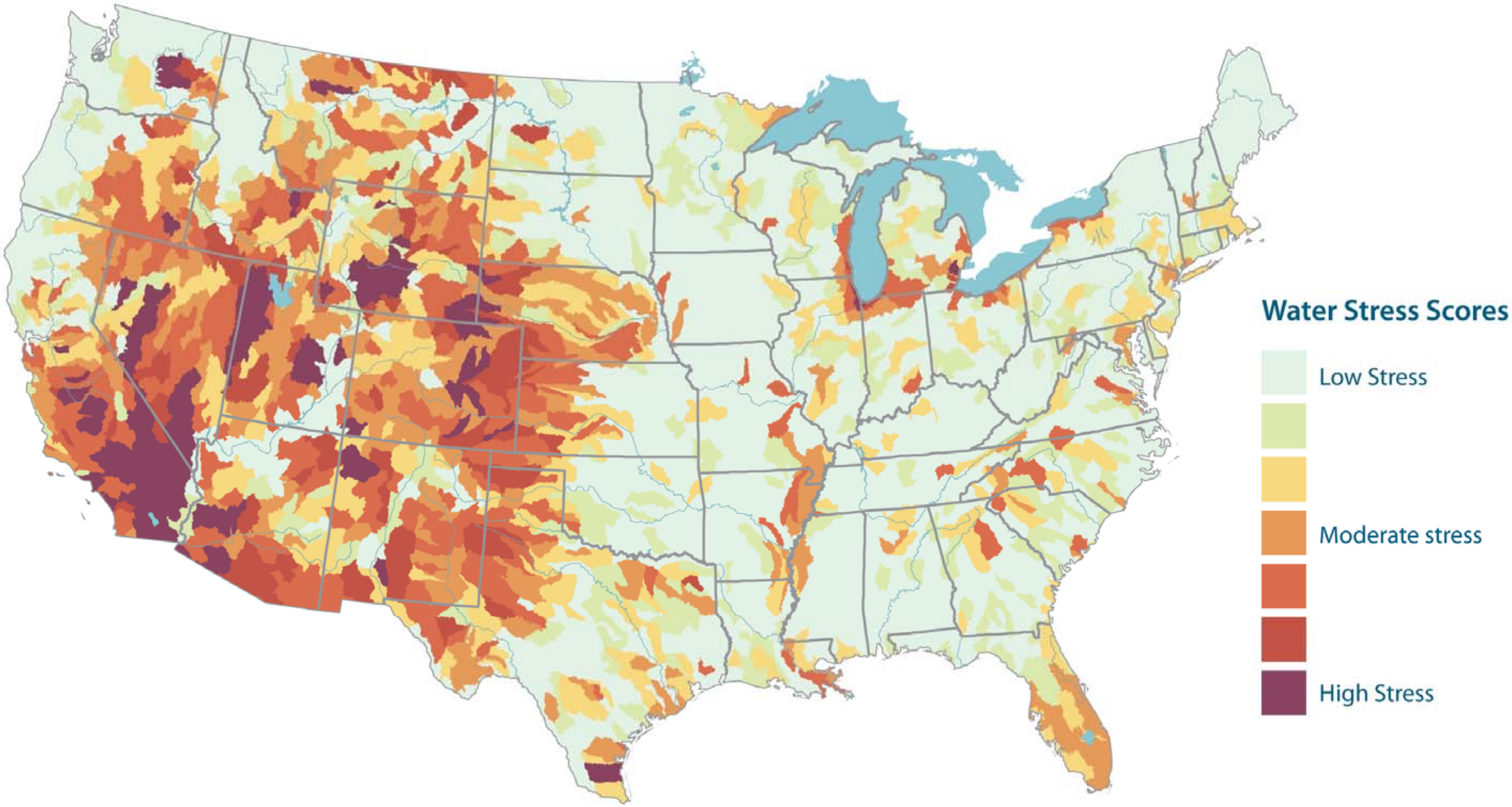




Water Scarcity



National Climate Assessment Study on Climate Change and Energy-Water-Land Interactions
WATER FOR ENERGY: ALREADY STRESSED?



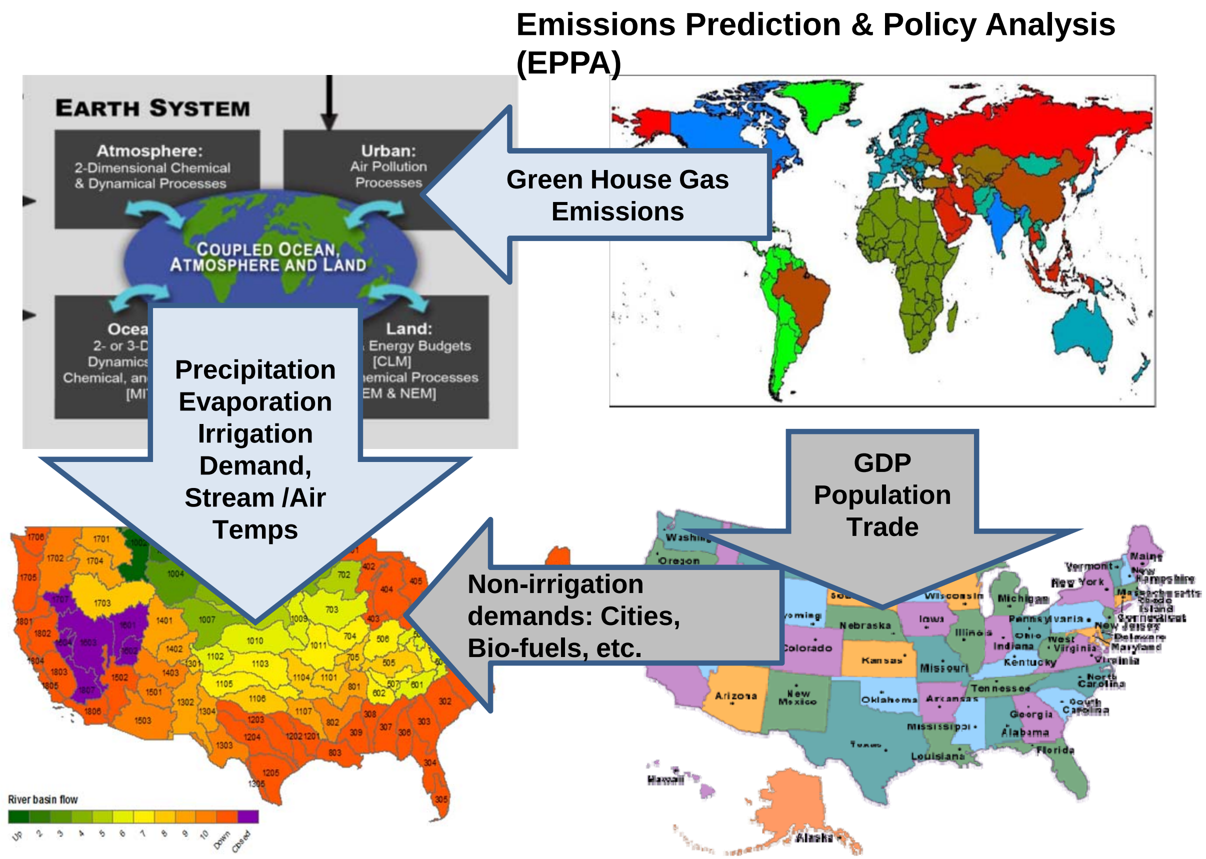
Water Supply & Demand in MIT's IGSM

Objective

Link the natural water cycle in an AOGCM with a river-routing and water resource allocation model to evaluate areas of water stress, potential adaptation, and economic impacts.

Approach

Utilize the existing EPPA component of the MIT IGSM to drive climate, incorporate the NCAR Community Atmospheric Model (CAM), and add a river-routing and water allocation model. The approach uses variable scaling of global regions/countries, U.S. states and hydrological units. Here we show a version resolved for the U.S. A global water allocation model has also been developed.



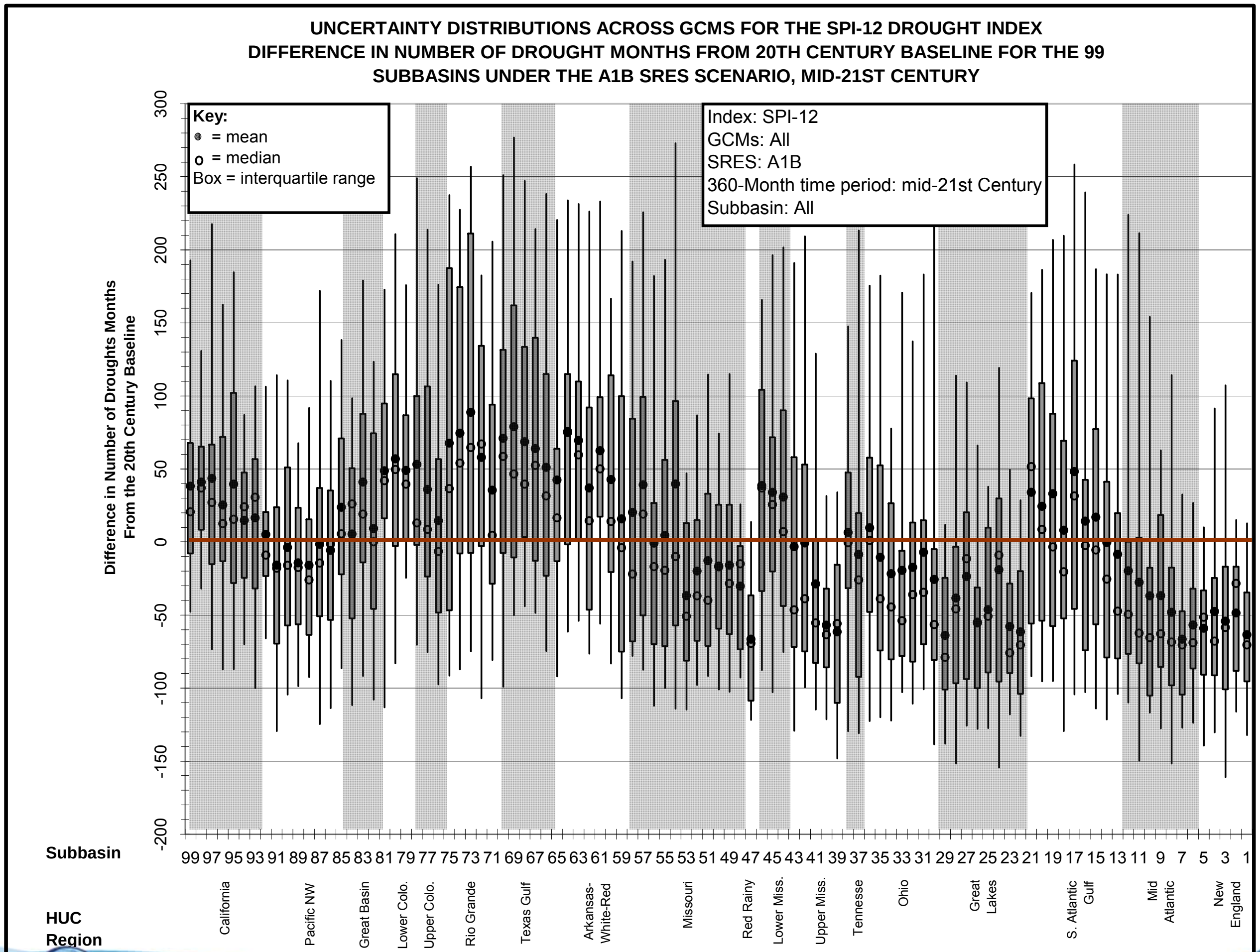
Impact

By identifying river basins potentially subject to water stress the system can help water planners identify adaptation measures to limit economic costs. The system can explore linkages among water for irrigation, energy, industrial, residential and environmental uses.

Modeling of Potential Drought Risks

Objective: Assess changes in the number of drought months in the U.S. at a 99 river basin resolution, reflecting the range of climate projections in the IPCC-AR4 scenario archives.

Approach: Use the Standardized Precipitation Index (SPI-12) based on Warren et al,[1] and utilize IPCC scenarios to construct an estimate of changes in drought months for all climate scenarios and each Hydrologic Unit of Code (HUC) region.[2]

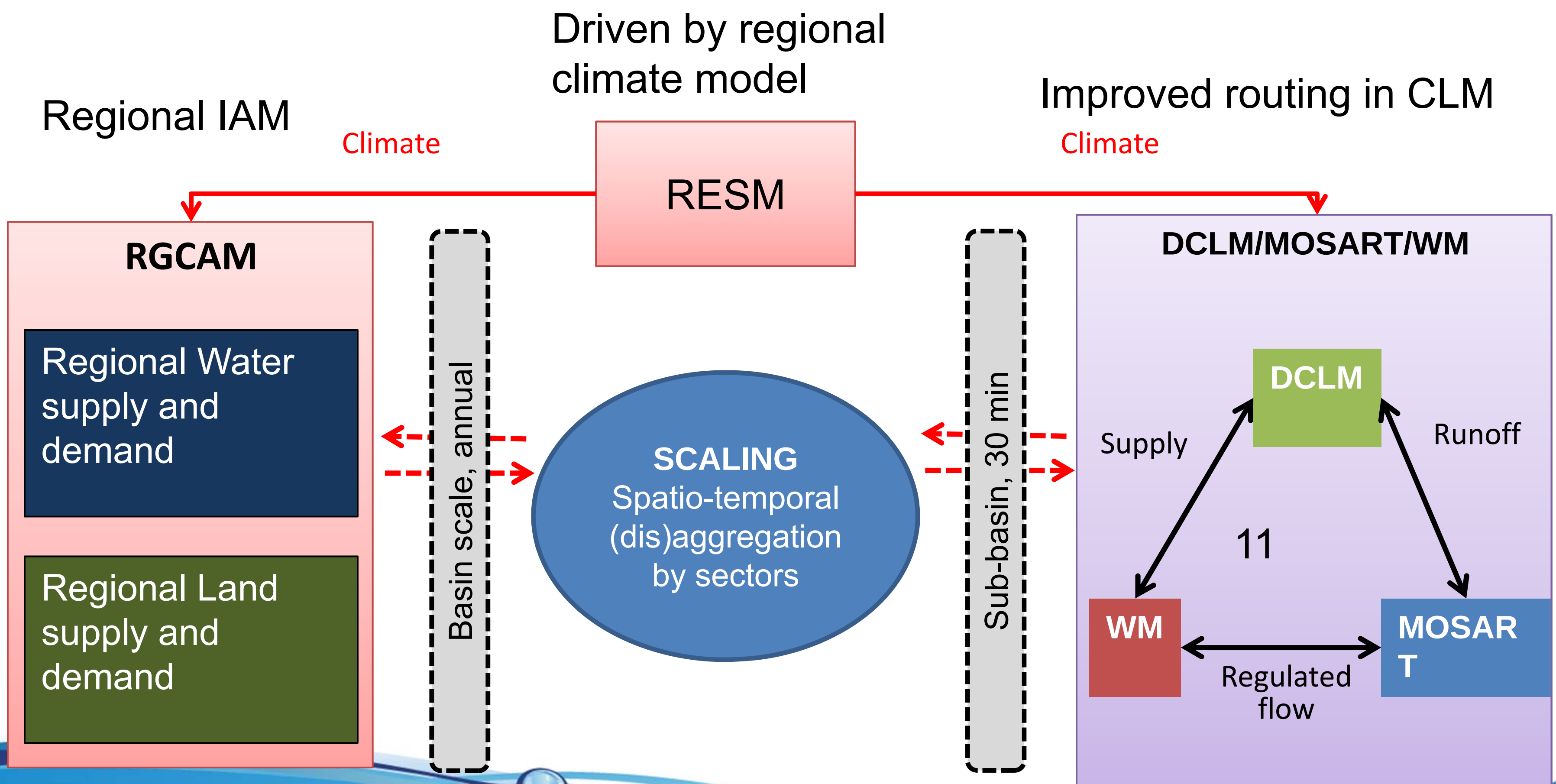


Impact: Results show a potential increase in drought months in nearly every one of the 99 U.S. river basins. HUC regions 99-1 plotted left to right (west to east) show likely increases in drought months (mean or median >0) especially in the western and southern U.S. and a greater likelihood of reduced drought months in much of the north and east.

[1]Warren et al (2009) Future European drought regimes under mitigated and un-mitigated climate change IOP Conf. Ser. Earth Environ. Sci. 6 292012

[2]Strzepek et al (2010) Characterizing Changes in Drought Risk for the United States from Climate Change. Environmental Research Letters 5(044012) 1-9, 2010

Interaction of Water and Energy at Regional Scales: Research in Progress (Gulf Coast Modeling Test-Bed)



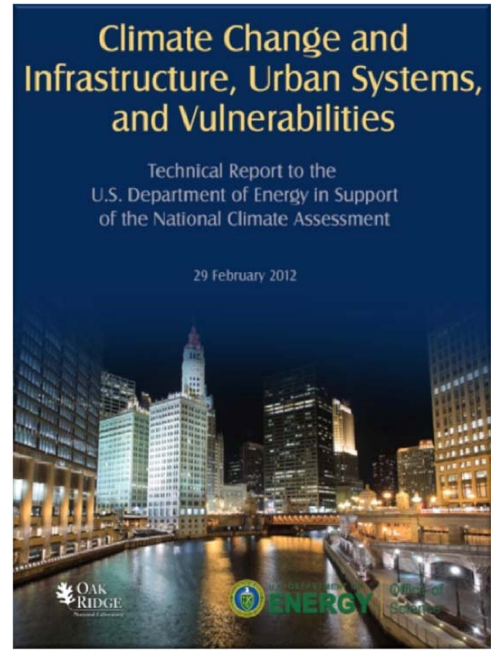
Connected Infrastructure and Urban System Modeling: Significant Energy-Water Dependencies

Objective

- Improve the understanding of inter-dependencies among built infrastructures, especially in urban systems, as an issue for integrated analyses of climate change implications for the energy sector and energy-water sector interactions

Approach

- Adapting Critical Infrastructure Protection (CIP) models, developed by DHS for National Infrastructure Simulation and Analysis Centers (NISAC) at Los Alamos and Sandia National Laboratories, into the Integrated Assessment Research Program (IARP) family of models
- Took first steps toward integrating CIP and IAM perspectives in preparing a report for the National Climate Assessment (NCA).
- Commissioned an analysis by CIP of interactions between the energy and water sectors (SNL)



The report prepared for NCA by DOE on infrastructure and urban systems implications.

Impact

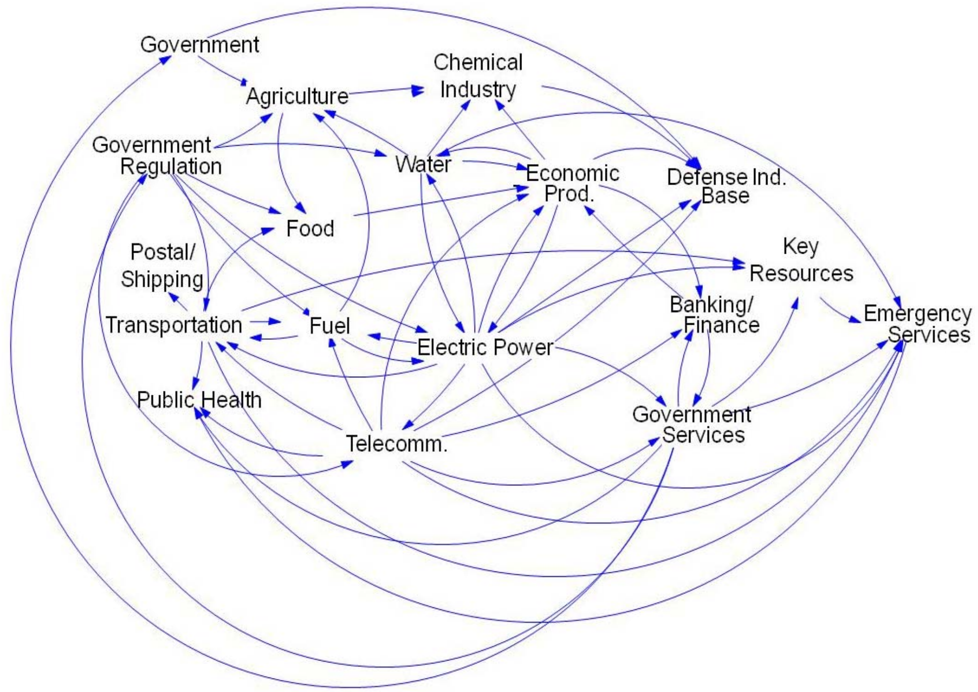
- Important implications and insights as stand alone IAV models. Exploring IAM-CIP interoperability.

ORNL, 2012. Climate Change and Infrastructure, Urban Systems, and Vulnerabilities, Technical Report to DOE in support of the National Climate Assessment, 20 February 2012.

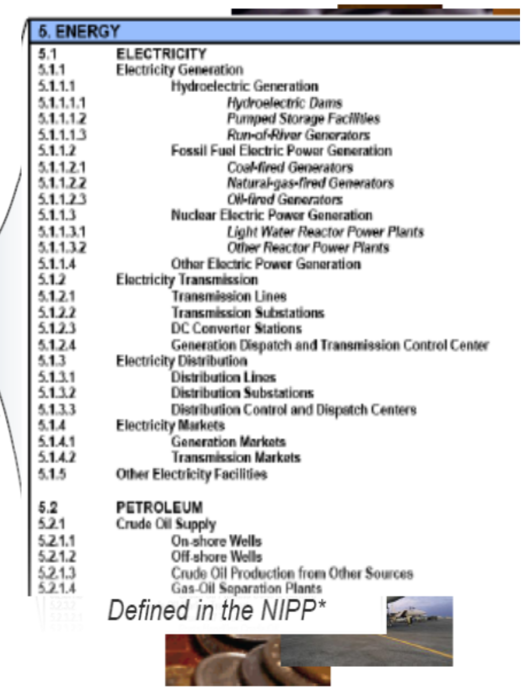
Wilbanks, T., and others, forthcoming. "Integrated Perspectives on Sustainable Infrastructures for Cities and Military Installations," in I. Linkov, ed., Sustainable Cities and Military Installations. New York: Springer.

Infrastructure and services complexity and feedbacks

Illustration of infrastructure interdependencies



- Agriculture & Food
- Banking & Finance
- Chemical
- Commercial Facilities
- Dams
- Defense Industrial Base
- Emergency Services
- Energy
- Government Facilities
- Manufacturing
- Nuclear Reactors, Materials & Waste
- Information Technology
- National Monuments & Icons
- Postal & Shipping
- Public Health & Healthcare
- Telecommunications
- Transportation
- Water



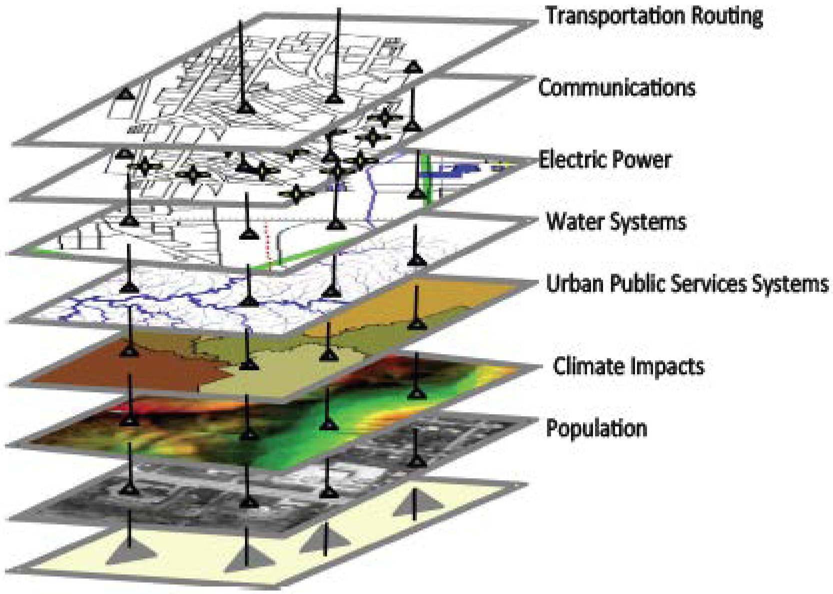
5. ENERGY	
5.1	ELECTRICITY
5.1.1	Electricity Generation
5.1.1.1	Hydroelectric Generation
5.1.1.1.1	*Hydroelectric Dams*
5.1.1.1.2	*Pumped Storage Facilities*
5.1.1.1.3	*Run-of-River Generators*
5.1.1.2	Fossil Fuel Electric Power Generation
5.1.1.2.1	*Coal-fired Generators*
5.1.1.2.2	*Natural-gas-fired Generators*
5.1.1.2.3	*Oil-fired Generators*
5.1.1.3	Nuclear Electric Power Generation
5.1.1.3.1	*Light Water Reactor Power Plants*
5.1.1.3.2	*Other Reactor Power Plants*
5.1.1.4	Other Electric Power Generation
5.1.2	Electricity Transmission
5.1.2.1	Transmission Lines
5.1.2.2	Transmission Substations
5.1.2.3	DC Converter Stations
5.1.2.4	Generation Dispatch and Transmission Control Center
5.1.3	Electricity Distribution
5.1.3.1	Distribution Lines
5.1.3.2	Distribution Substations
5.1.3.3	Distribution Control and Dispatch Centers
5.1.4	Electricity Markets
5.1.4.1	Generation Markets
5.1.4.2	Transmission Markets
5.1.5	Other Electricity Facilities
5.2	PETROLEUM
5.2.1	Crude Oil Supply
5.2.1.1	On-shore Wells
5.2.1.2	Off-shore Wells
5.2.1.3	Crude Oil Production from Other Sources
5.2.1.4	Gas-Oil Separation Plants

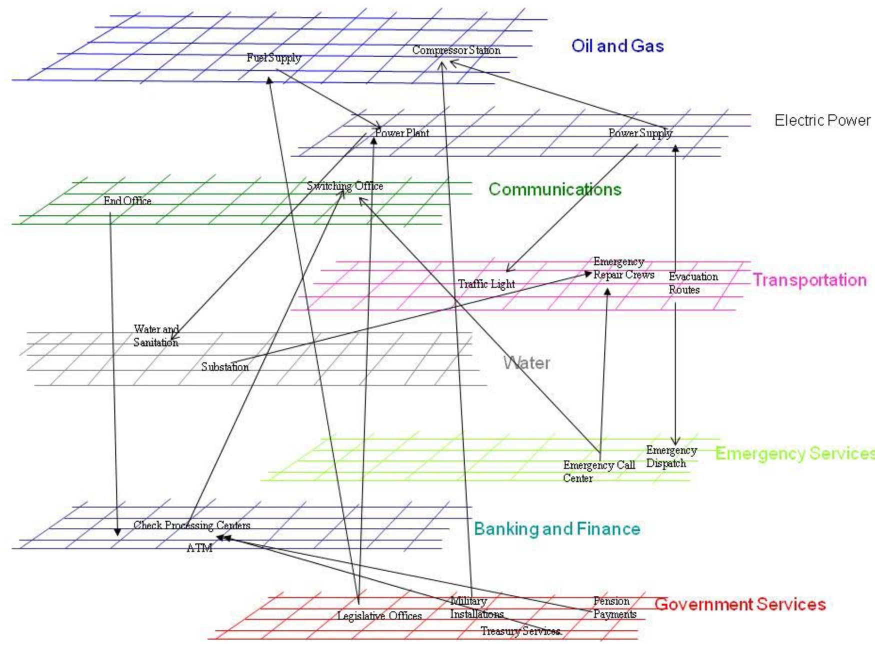
*Defined in the NIPP**

*National Infrastructure Protection Plan

A complex system-of-systems problem with significant detail in the energy and connected systems

Leveraging a substantial modeling investment based on a layered approach to systems/services connections



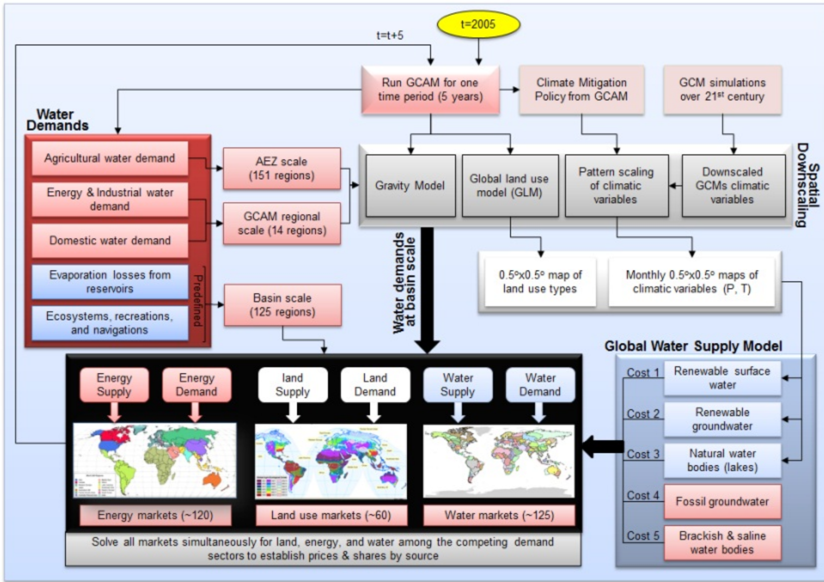


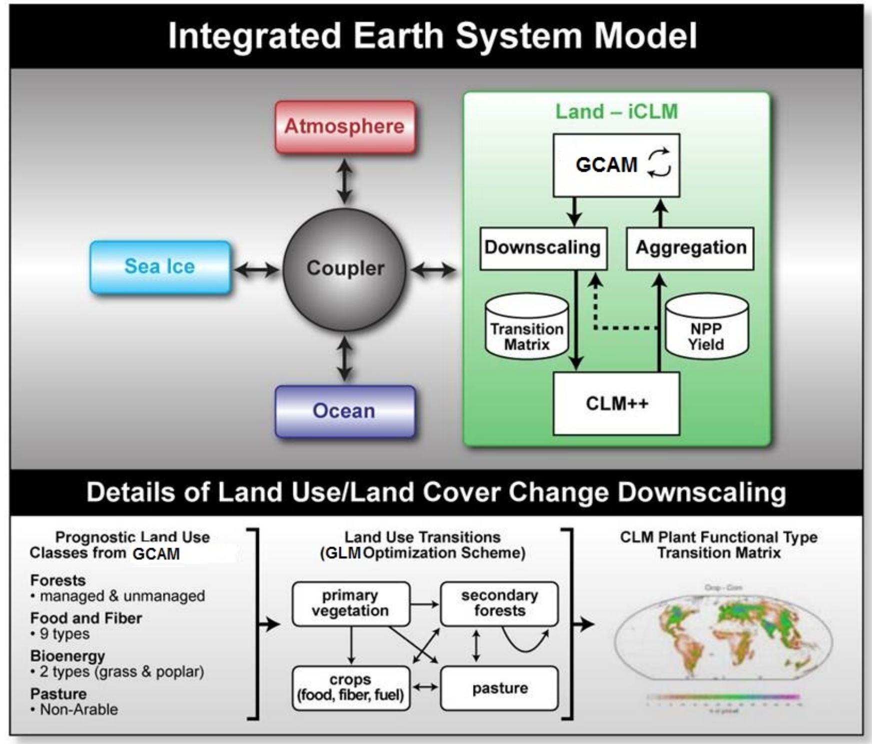
An interdependent system of systems approach

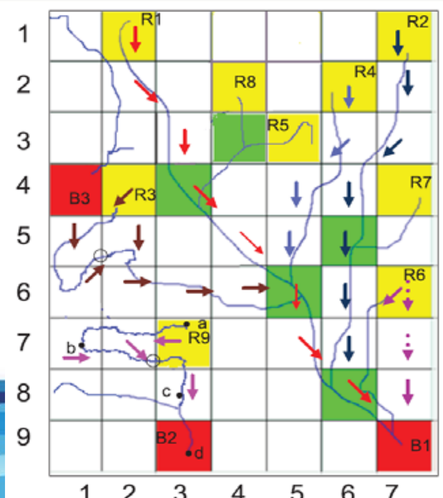
Infrastructure systems can be modeled as interconnected infrastructure layers.

A First, Fully Coupled Integrated Earth System Model: Incorporates water demand and supply within GCAM and improved routing within CLM

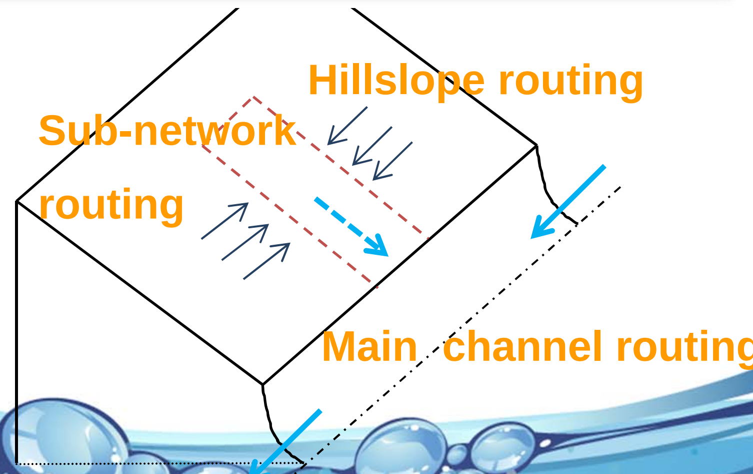
SOLVING WATER MARKETS IN GCAM





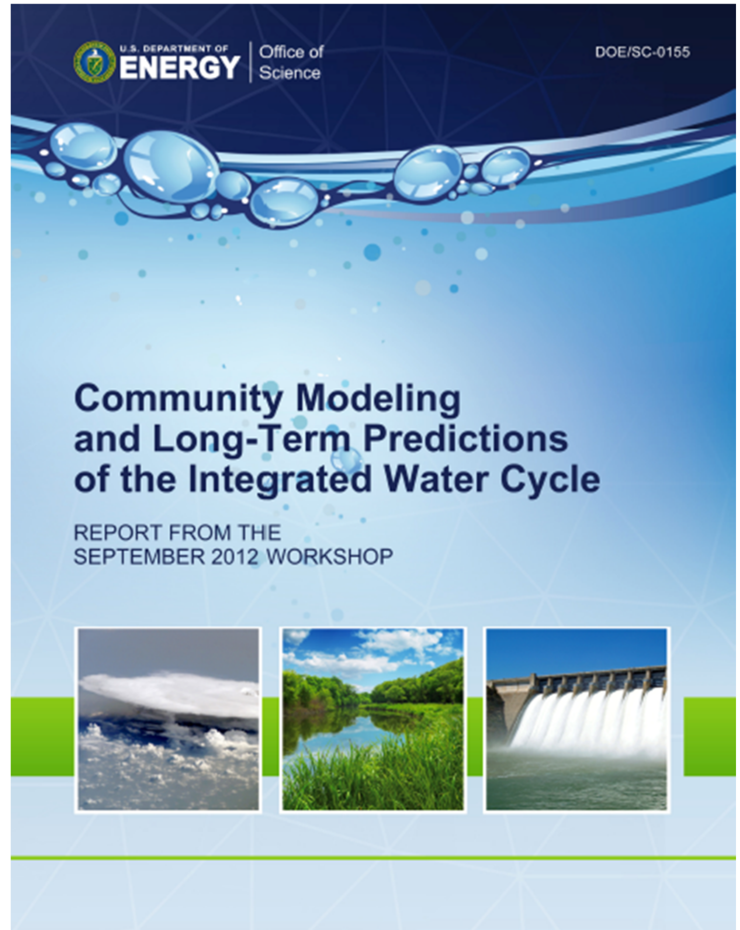


This hierarchical dominant river tracing method preserves the baseline high resolution hydrography (flow direction, flow length, upstream drainage area) at any coarse resolution

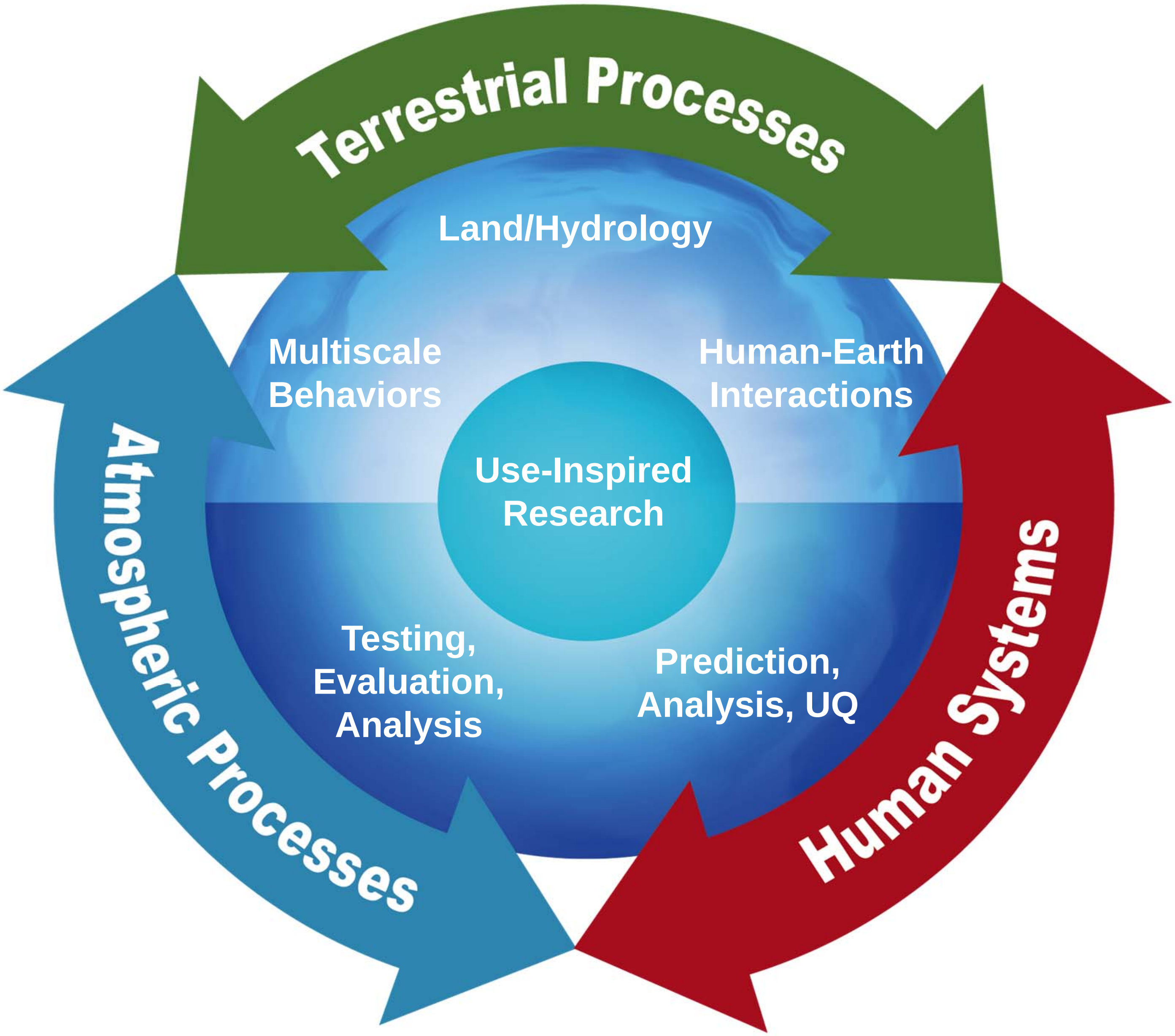


Workshop on Regional-Scale Modeling of the Integrated – Water Cycle

- Goal: Identify challenges of next generation human-earth system models for improving long-term predictions of the **regional-scale integrated water cycle**
- Co-chairs:
  - L. Ruby Leung, PNNL
  - Bill Collins, LBNL
  - Jay Famiglietti, UC Irvine
- ~ 80 invited participants including representatives from 8 agencies
- Culminated with an interagency panel discussion



Workshop Focus: Six Major Elements



Workshop Outcomes

DOE and Research Community

Workshop Topics

- Multi-scale behaviors of the water cycle
- Human-earth system interactions and impacts on the water cycle
- Challenges for land surface/ hydrologic modeling
- Model testing, analysis, and evaluation and data needs
- Prediction and uncertainty quantification of water cycle statistics and extremes
- Use-inspired water cycle research to meet the most pressing energy and environmental challenges

Science Grand Challenges

1. Modeling the multi-scale atmospheric and terrestrial processes and their interactions
2. Modeling the integrated human-earth system and its links with water resources
3. Advancing prediction and uncertainty quantification for decision support and mission-oriented objectives

Crosscutting Needs

- Hypothesis driven modeling experiments and predictability studies
- Multi-scale, multi-system needs for science and decision support
- Model development needs
- Data/observation needs
- Model intercomparison, testing, and evaluation
- Computational requirements
- Software infrastructure
- Data management and visualization
- Strategies for interactions with the users

Integrative Modeling Experiments

1. Implications of land cover and land use change for regional climate, water resources, and energy pathways in the U.S.
2. Multi-model hierarchies that address a wide range of user needs for predicting the integrated regional water cycles
3. Sustainability of water and energy resources in eastern versus western North America under climatic and societal change

Leads to Scientific Understanding and Advances Predictive Modeling

Thank You!