

# Assessing the Near-Term Risk of Climate Uncertainty: Interdependencies among the U.S. States

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# Introduction

- Background
- Our Conceptual Approach: Risk Based Impact Assessment
- Project Description
- Future Pathways and Partnerships (?)



# Background

## Group Technical Competencies

- Multi-domain System Analysis
- Spatio-temporal System Modeling
- Societal Impact and Effects
- Multi-scale Economics
- Earth Systems Impacts and Effects
- Applied Computer Science and Engineering
- Domain Expertise:
  - ⊕ Complex System Response, Evolution, Restoration, and Recovery
  - ⊕ Global/National/Regional Infrastructure Interdependencies
- Crisis Action Support and Analytics
- Agile Project and Portfolio Management Frameworks
- Quality Engineering



# Background Project Genesis

- **Secretary Chu requested a forecast of cost in the absence of climate policy**
  - ⊕ Use a “stakeholder-centric” risk methodology
  - ⊕ Make uncertainty a positive force for reframing policy debates
  - ⊕ Help Congress justify climate policy to constituency
  - ⊕ Have a metric for prioritizing science and technology research
- **The challenge was in producing and communicating an integrated methodology for risk assessment that includes climate science, uncertainty quantification, hydrology, infrastructure, human behavior, and macroeconomics**



# Background Assumptions

- Risk Assessment (risk management) is a tractable way to inform climate change policy and for making decisions under uncertainty
- The justification for implementing climate change policy in the present needs to hinge on the tangible near-term cost of inaction

***The uncertainty associated with climate change establishes the need to act protectively and proactively***

# What is Risk?

## ■ We Confront Risk Everyday

- ⊕ Walking to work
- ⊕ Playing sports
- ⊕ Having surgery
- ⊕ Going on a picnic

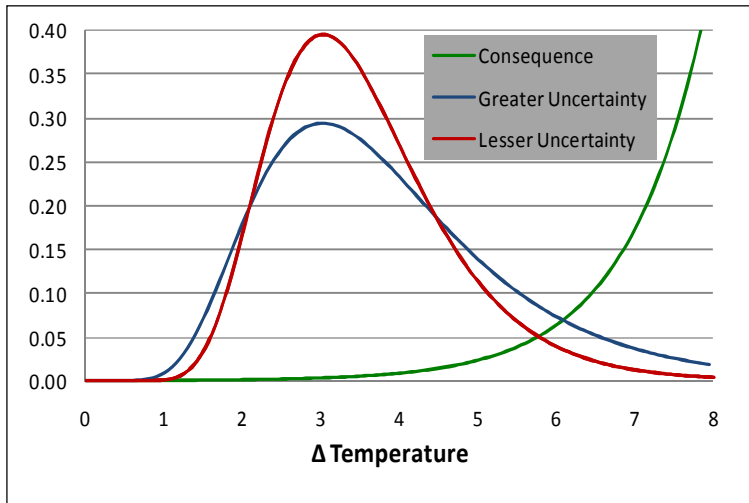
Depending on a persons risk tolerance, they may or may not choose to ignore the risk

## ■ Risk is a Function of:

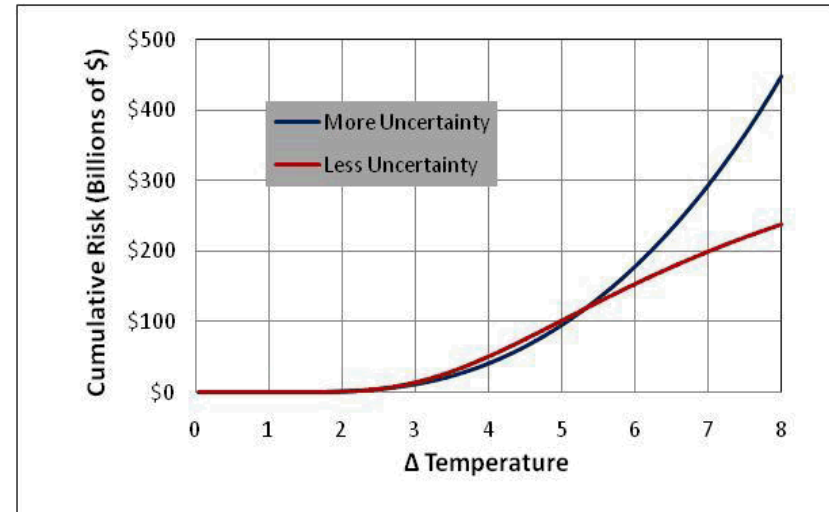
- ⊕ Probability
  - 1% chance versus 50% chance
- ⊕ Consequence
  - Death versus getting rained on



# The More The Uncertainty, The More The Risk



Probability Distributions with  
constant modes and  
consequence

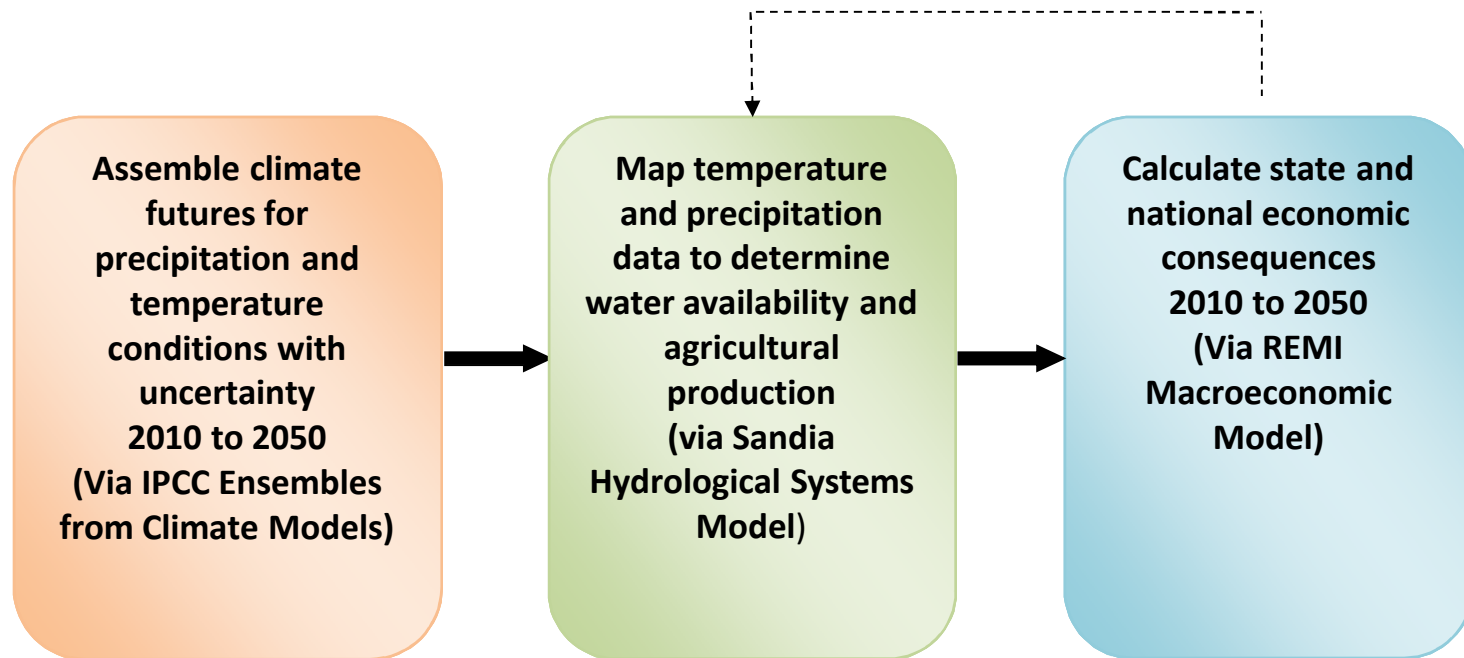


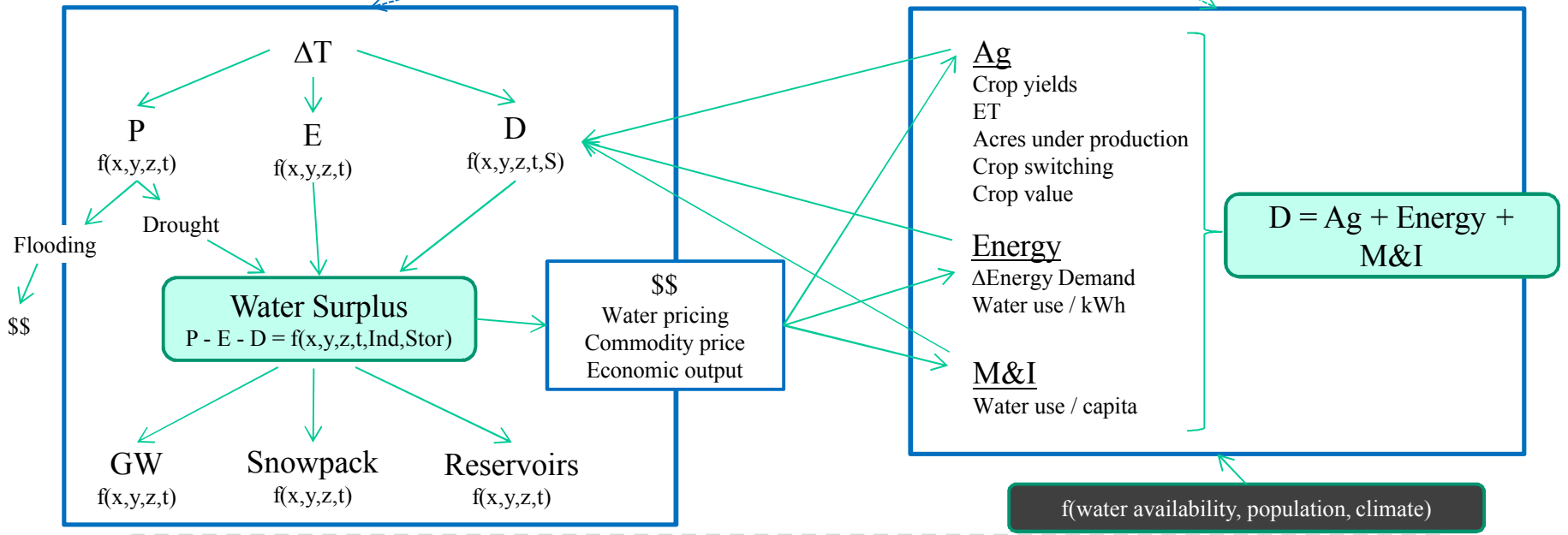
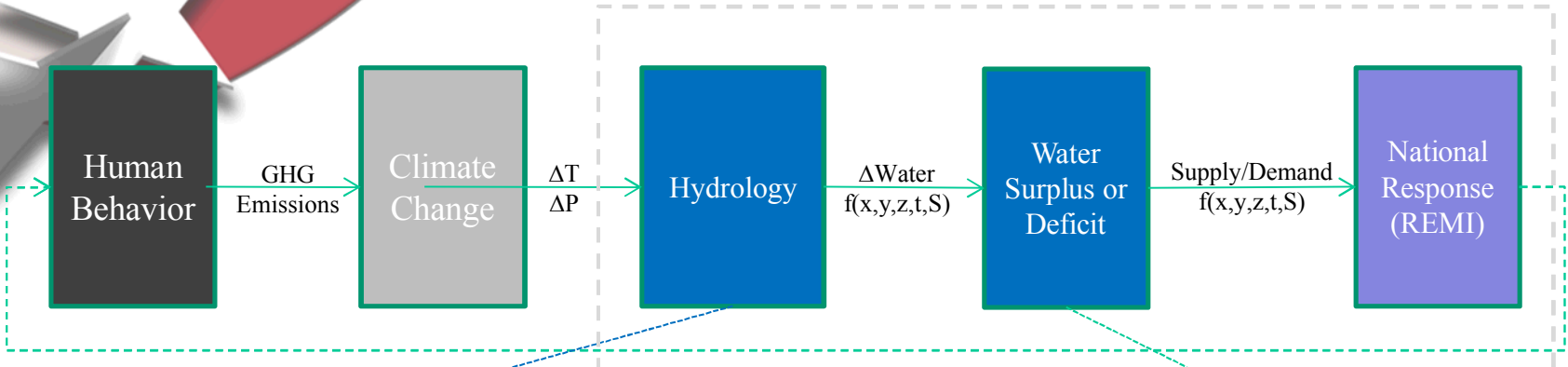
How uncertainty changes the  
CCDF tail of risk

$$Risk = \iint_{\tau, P} Consequence(t, p) \times dt \times dp$$

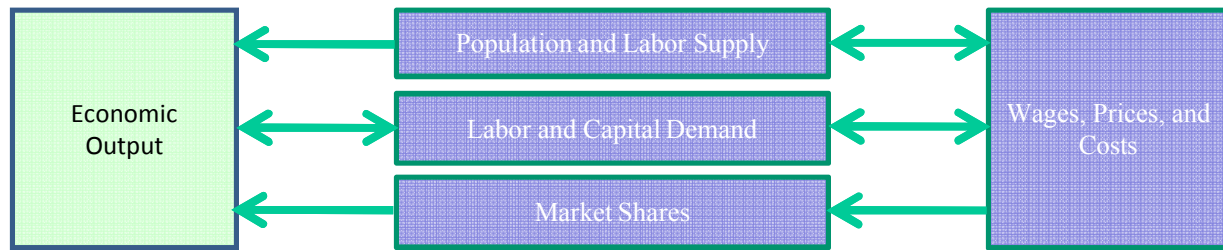
p = probability  
t = time

# Overview of the Analysis Process



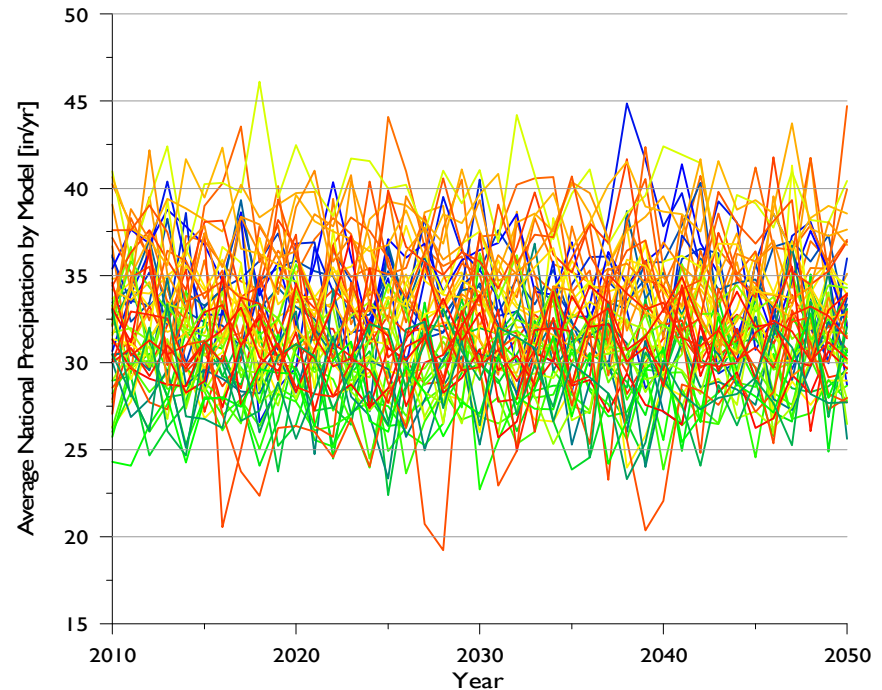


### REMI Economic Model



# Approach

- Examine the inter-model uncertainty for the IPCC AR4 suite of models w/ respect to precipitation for the CONUS
- Fit a probability model to the precipitation predictions and look at the full range of exceedance probabilities
- Simulate changes to agriculture, energy production, and mining from 2010 – 2050 as compared to the 2000-2009 baseline
- Simulate economic impacts using the REMI, Inc. model to examine changes in GDP, employment, and demographics



National average precipitation for the IPCC AR4 model ensemble.

# IPCC Models

No.	<u>Model Name</u>	<u>Country</u>	20C3M	SRESA1B	SRESB1
1	BCC-CM1	China	0	0	0
2	BCCR-BCM2.0	Norway	1	1	1
3	NCAR-CCSM3	USA	8	7	9
4	CCCMA-CGCM3.1(T47)	Canada	5	5	5
5	CGCM3.1(T63)	Canada	1	1	1
6	CNRM-CM3	France	1	1	1
7	CSIRO-Mk3.0	Australia	3	1	1
8	CSIRO-Mk3.5	Australia	3	1	1
9	ECHAM5/MPI-OM	Germany	4	4	3
10	ECHO-G	Germany/Korea	5	3	3
11	FGOALS-g1.0	China	3	2	3
12	GFDL-CM2.0	USA	3	1	1
13	GFDL-CM2.1	USA	3	1	1
14	GISS-AOM	USA	2	2	2
15	GISS-EH	USA	5	3	0
16	GISS-ER	USA	9	2	1
17	INGV-SXG	Italy	1	1	0
18	INM-CM3.0	Russia	1	1	1
19	IPSL-CM4	France	2	1	1
20	MIROC3.2(hires)	Japan	1	1	1
21	MIROC3.2(medres)	Japan	3	3	3
22	MRI-CGCM2.3.2	Japan	5	5	5
23	NCAR-PCM1	USA	4	4	4
24	UKMO-HadCM3	UK	2	1	1
25	UKMO-HadGEM1	UK	2	1	0
		<b>TOTAL</b>	<b>77</b>	<b>53</b>	<b>49</b>

# IPCC Experiments

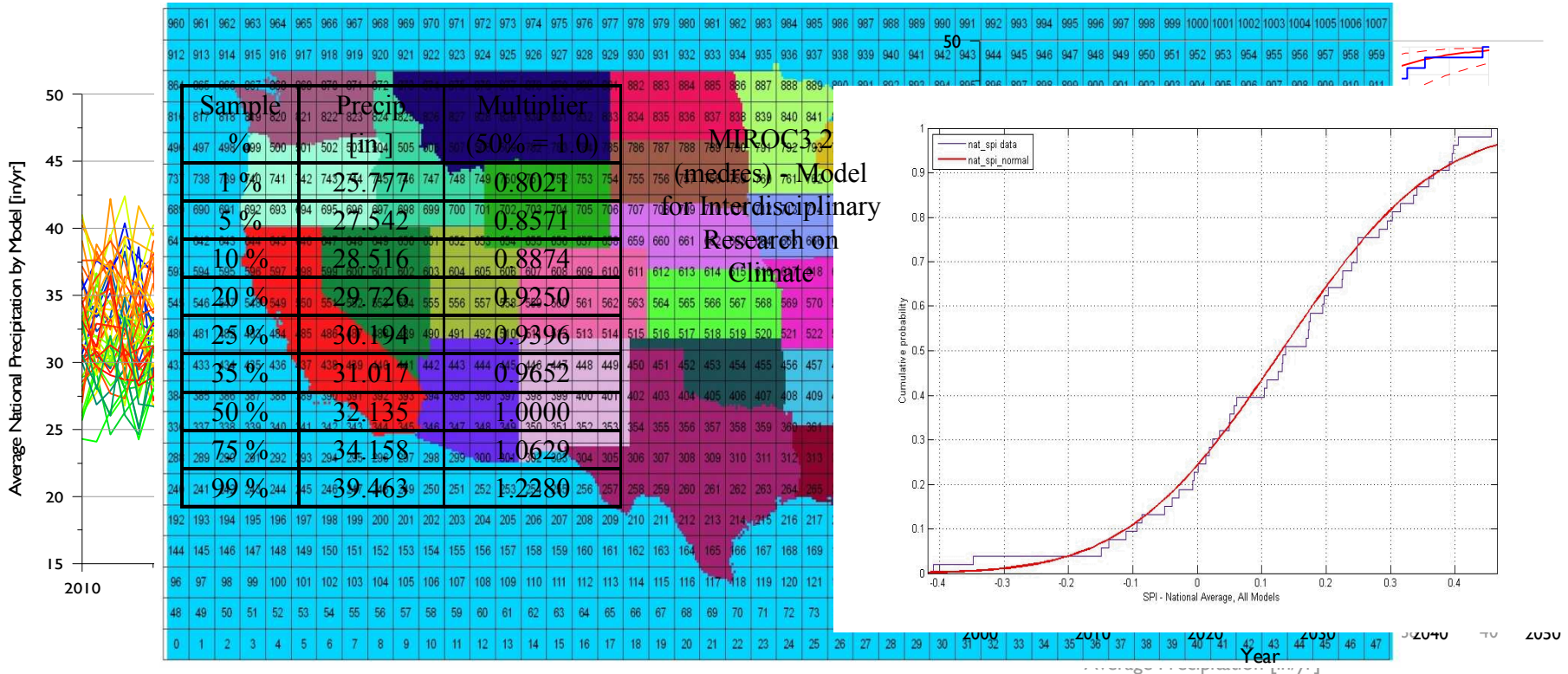
Exp. #	Name	Description	ID
1	Pre-industrial control	No anthropogenic or natural forcing. Simulations prior to ~1850.	PICNTRL
2	Present day control	No natural forcing and anthropogenic forcing is set to present day	PDCNTRL
3	Climate of the 20th century (20C3M)	Verification runs ~1850-present	20C3M
4	Committed climate change	Present - 2100, uses end of 20C3M as initial condition	COMMIT
5	SRES A2 experiment	Continuously increasing global population and economic growth, although more fragmented and slower than other scenarios. Present - 2100, uses end of 20C3M as initial condition	SRESA2
6	720 ppm stabilization experiment (SRES A1B)	Rapid economic growth, global population peaks in mid-century and declines after that. Rapid introduction for new technologies. Initialize w/ 20C3M and run to 2100. After 2100, hold concentrations steady and run to 2200	SRESA1B
7	550 ppm stabilization experiment (SRES B1)	Same as A1 conditions but future is based on clean and resource efficient technologies. Initialize w/ 20C3M and run to 2100. After 2100, hold concentrations steady and run to 2201	SRESB1
8	1%/yr CO2 increase experiment to doubling	Hold CO2 fixed after it has doubled. Run is initialized with either pre-industrial or 20C3M.	1PCTTO2X
9	1%/yr CO2 increase experiment to quadrupling	Hold CO2 fixed after it has quadrupled. Run is initialized with either pre-industrial or 20C3M.	1PCTTO4X

- Standard IPCC simulation experiments as determined by the *Special Report on Emissions Scenarios* (SRES)
- Not all models submit results for every experiment
- Single models can submit several realizations of each experiment

# Precipitation to Uncertainty

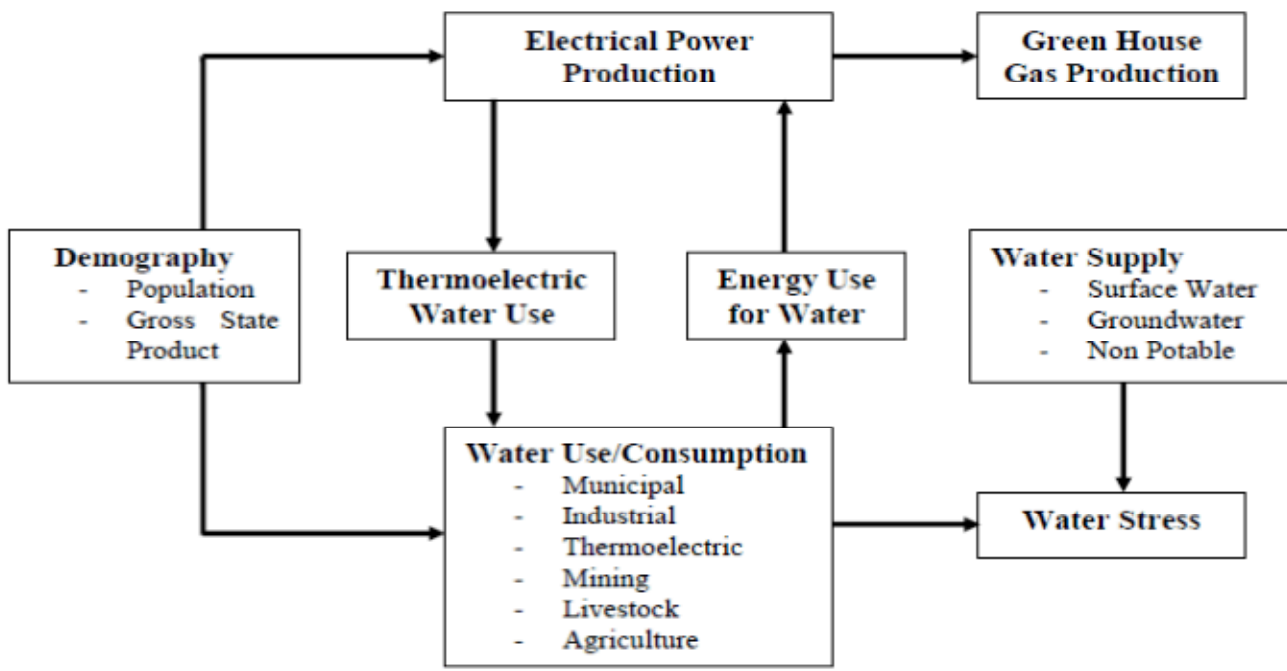
## ■ We Needed:

- ✦ A way to determine the timing of the precipitation
- ✦ A way to relate precipitation to water scarcity

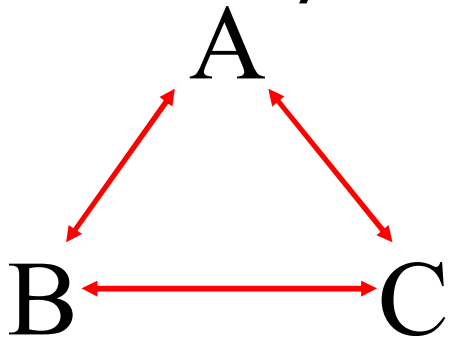


NCAR-CCSM3 model grid overlaid on the CONUS

# Energy-Water Model



## System Dynamics Architecture



After van den Belt

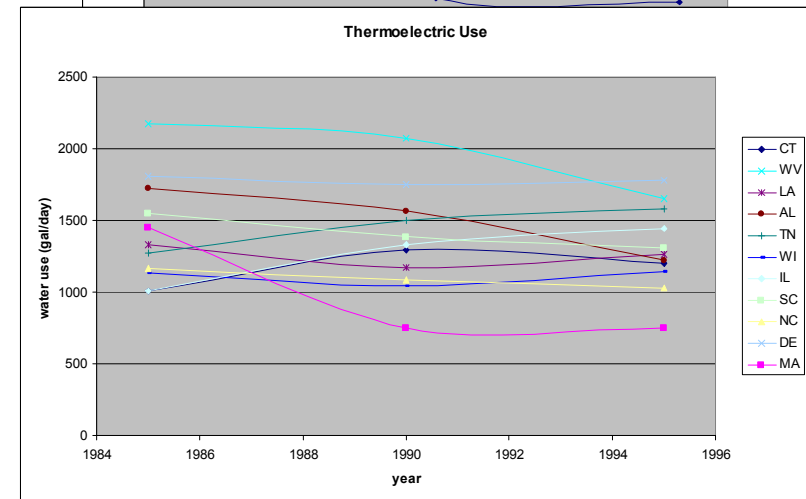
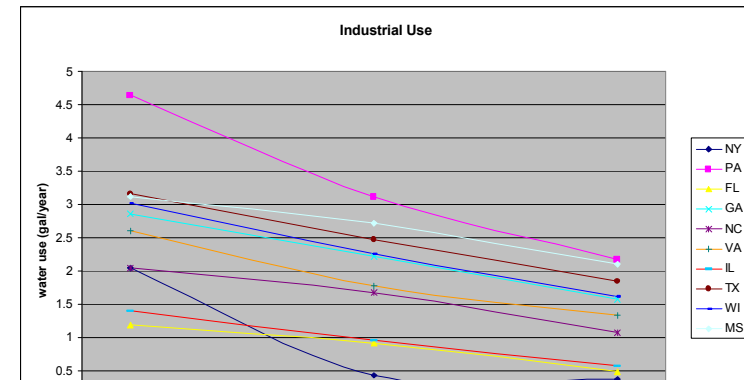
# Water Use Analysis

- Water use data taken from U.S. Geological Survey's "Water Use in the United States"
- Data were collected at five year intervals from 1985-1995
- Data are available at the national, state, county and watershed levels
- For purposes of analysis data are disaggregated by:
  - Sector (municipal, industrial, thermoelectric, mining, livestock, and agriculture)
  - Source (groundwater, surface water, other)
  - Use and consumption

The screenshot shows a web browser window displaying the USGS website. The address bar shows the URL: <http://water.usgs.gov/watuse/>. The page content includes a USGS logo, a navigation bar, and a main heading "Water Use in the United States". Below the heading is a graphic celebrating "50 years of water use" from 1958 to 2008. A "Reports" section lists several documents, including "Estimated Use of Water in the United States in 2005" (in progress), "Estimated Use of Water in the United States in 2000", "Estimated Use of Water in the United States in 1995", and "Estimated Use of Water in the United States in 1990". It also includes links for "Download 1990 or 1985 data for counties and watersheds" and "More on reports". Other sections include "Comparison of consumptive use and renewable water supply by water-resources region", "Introduction: The National Water-Use Information Program", "Selected bibliography of USGS water-use reports by State", and "Handbook for collecting water-use data". At the bottom, there are links for "Water Science for Schools" and "Water Questions & Answers". The footer contains accessibility information, FOIA, Privacy, Policies and Notices, and contact information for the U.S. Department of the Interior and U.S. Geological Survey.

# Water Use Analysis

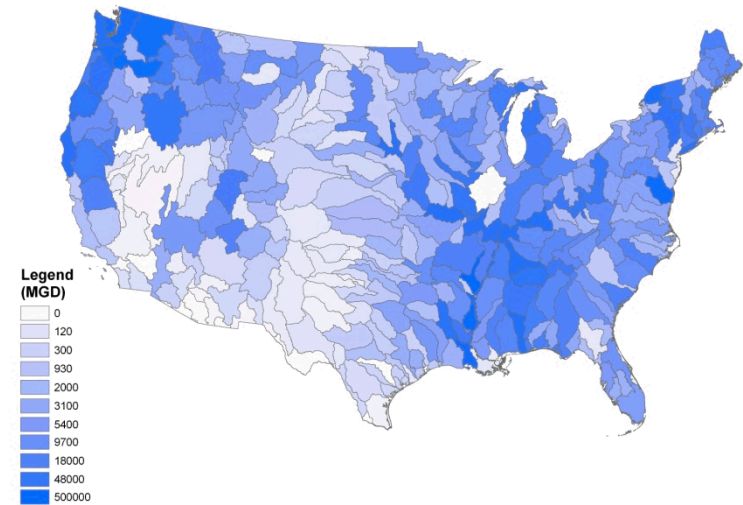
- Future water use projections based on historical trends
- Trends analyzed through simple linear regression over the available 10 years of data
- Trends explored in terms of:
  - Direct water use
  - Per capita use
  - Economic intensity
- Changes in population and GDP are driven by results from REMI



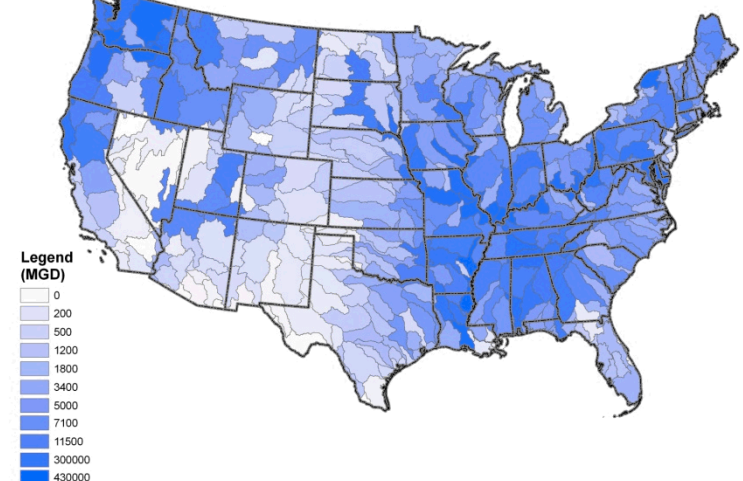
# Dynamic Supply Indicators

- Utilize historical stream gauging data from the USGS (cumulative distributions)
- Available surface water flow is estimated from mean stream flow
- Other exceedance flows are available
- Base flow is used as measure of sustainable groundwater recharge
- Future flows are reduced by upstream consumptive use

Sustainable Groundwater Recharge

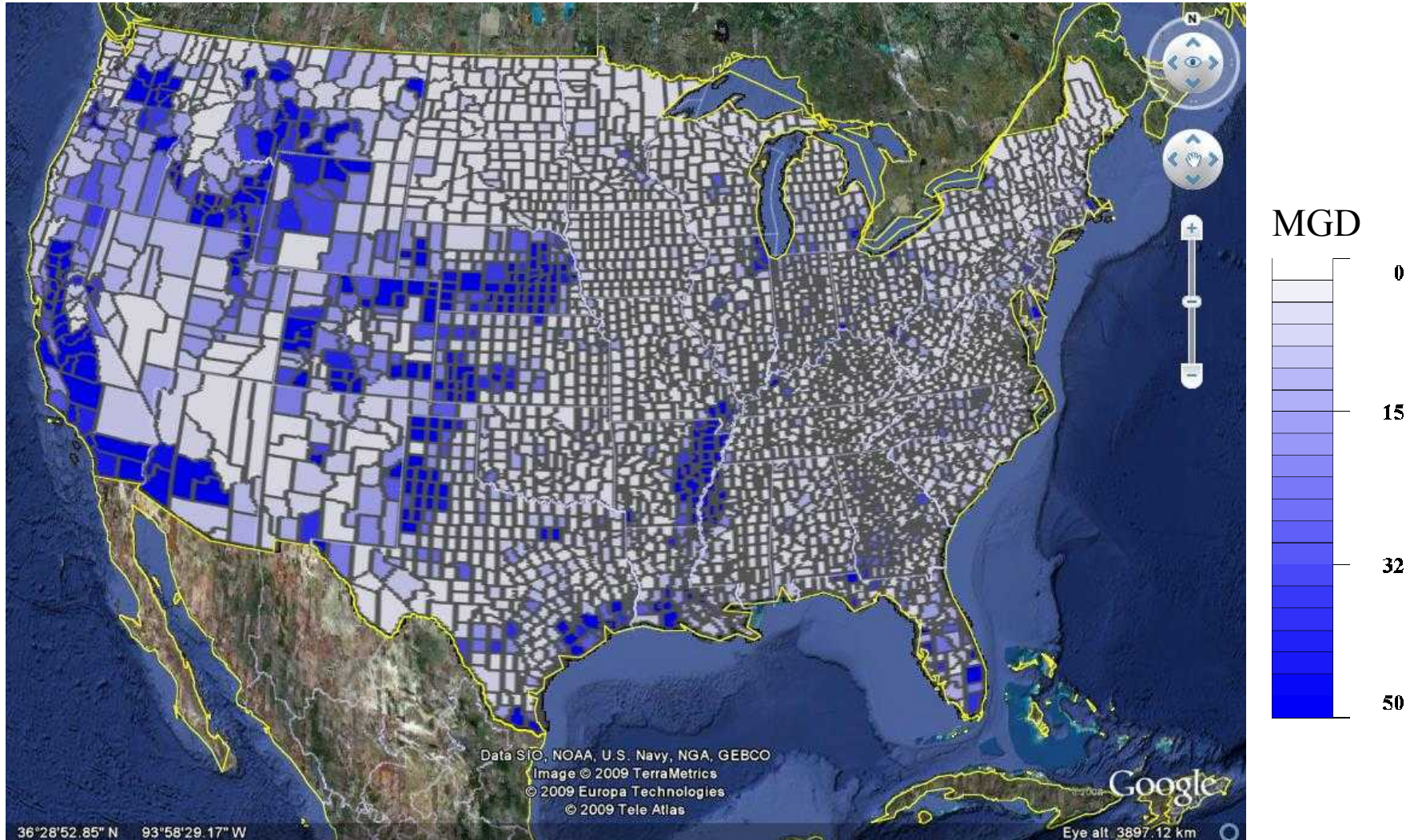


Annual Average Flow by Accounting Unit (MGD)



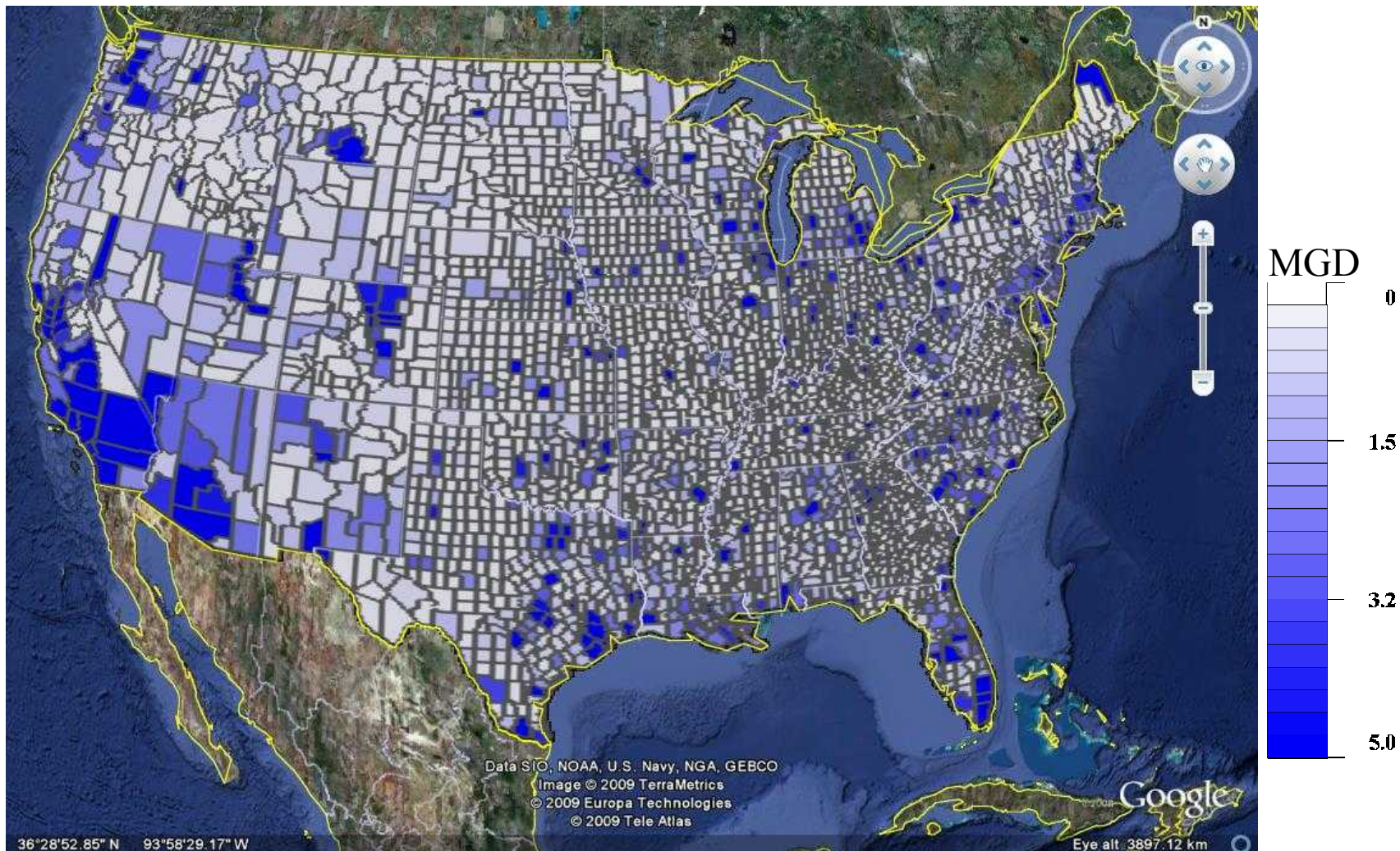
# Water Output

## Total Water Consumption in 2004



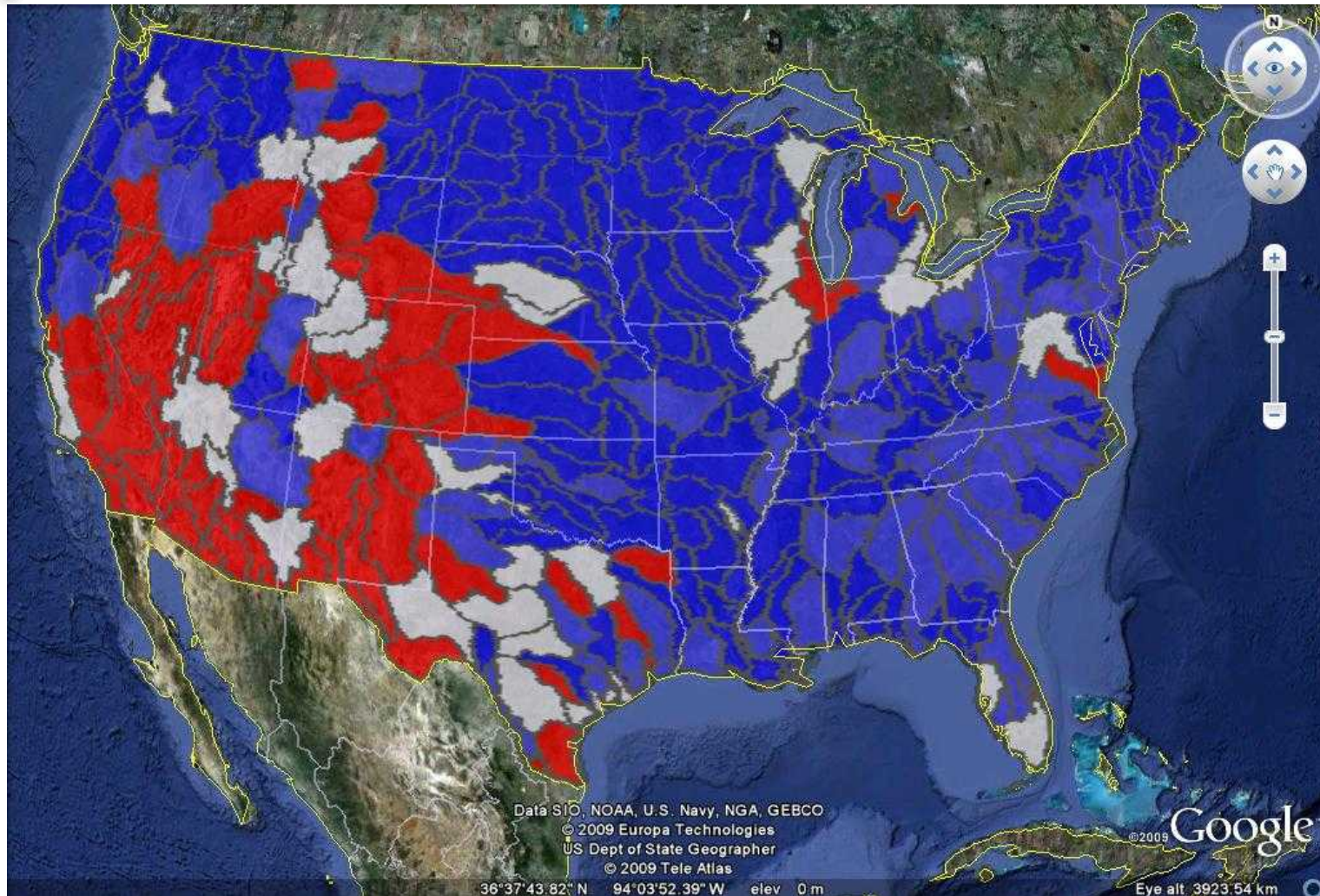
# Water Output: Base Case

*Projected Increase in Non-Thermoelectric Water Consumption 2004-2030*



# Water Output

Ratio of Mean Stream Flow to Surface Water Demand



# Water Stress Analysis

- Use supply/demand ratio to define point at which insufficient water is available to meet demand

Ratio

Threshold

<3

LRAS\*

3-10

60% of LRAS

>10

40% of LRAS

\*LRAS Long Range Average Streamflow



# Water Shortage

- Water shortage, or that amount of water that goes undelivered, is simply the volume of water less than the threshold value.
- Water shortages are disproportionately distributed across sectors:
  - ⊕ 2/3 shortage borne by the agriculture, livestock and mining sectors
  - ⊕ 1/3 shortage borne by the municipal, industrial, and thermoelectric sectors

# Climate Change Impact on Crop Yield

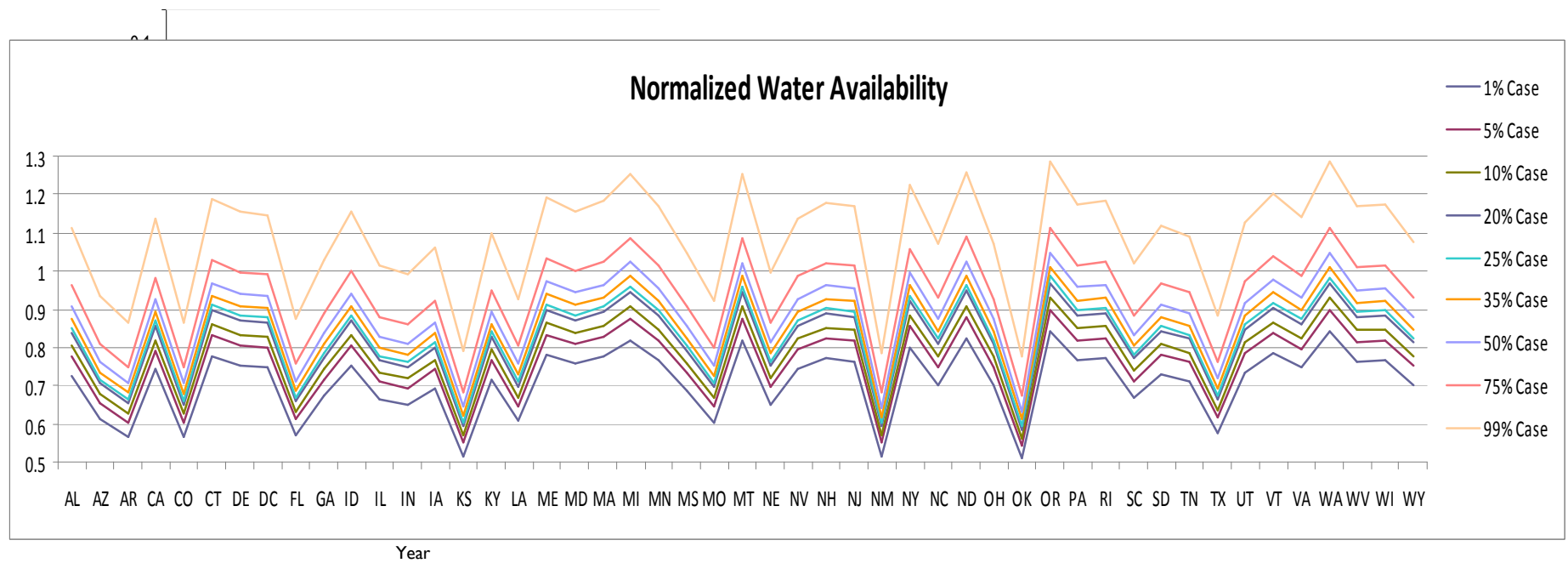
$$y = f(X, \beta) + h(X, \alpha)\varepsilon$$

McCarl et al. (2008)

- The model is empirically based on the historical impact of climate changes on crop yield distribution
- The model considers:
  - ⊕ Temperature - Rainfall Intensity Index
  - ⊕ Precipitation - PDSI
  - ⊕ Variance in inter-annual Temperature
- Rain-fed crops depend only on precipitation while irrigated crops depend both on precipitation and water deliveries.

# Precipitation Input

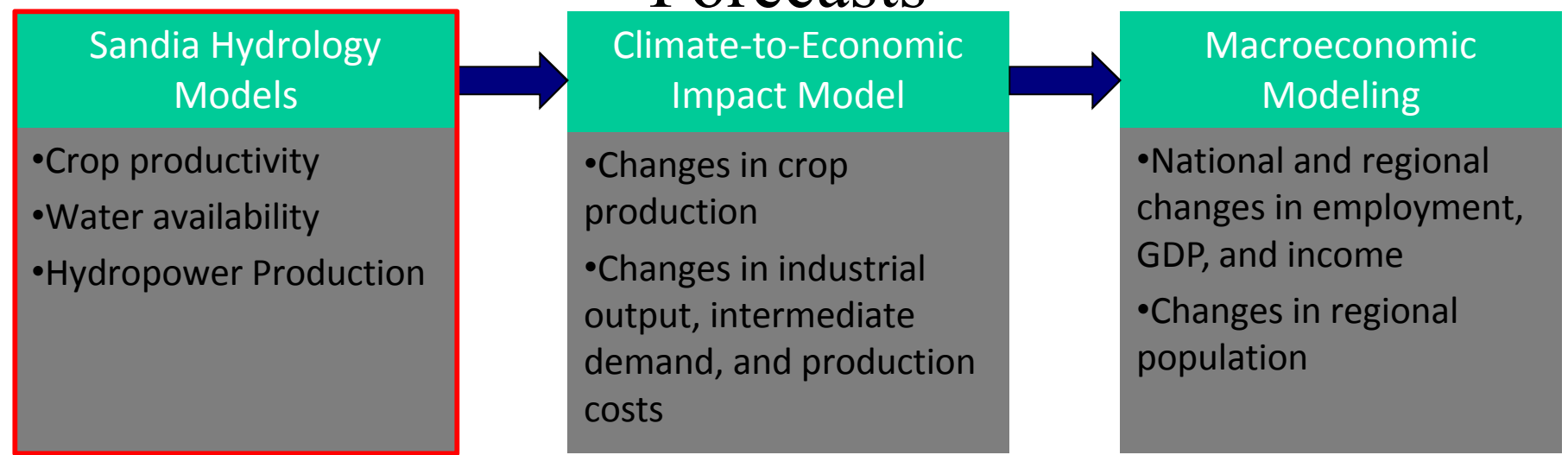
- The 2000-2009 average for the 50% Case was deemed the 'base-case'
- Variations are given as the deviation from this average



# Water availability and Climate Change (1% Exceedance Probability case)

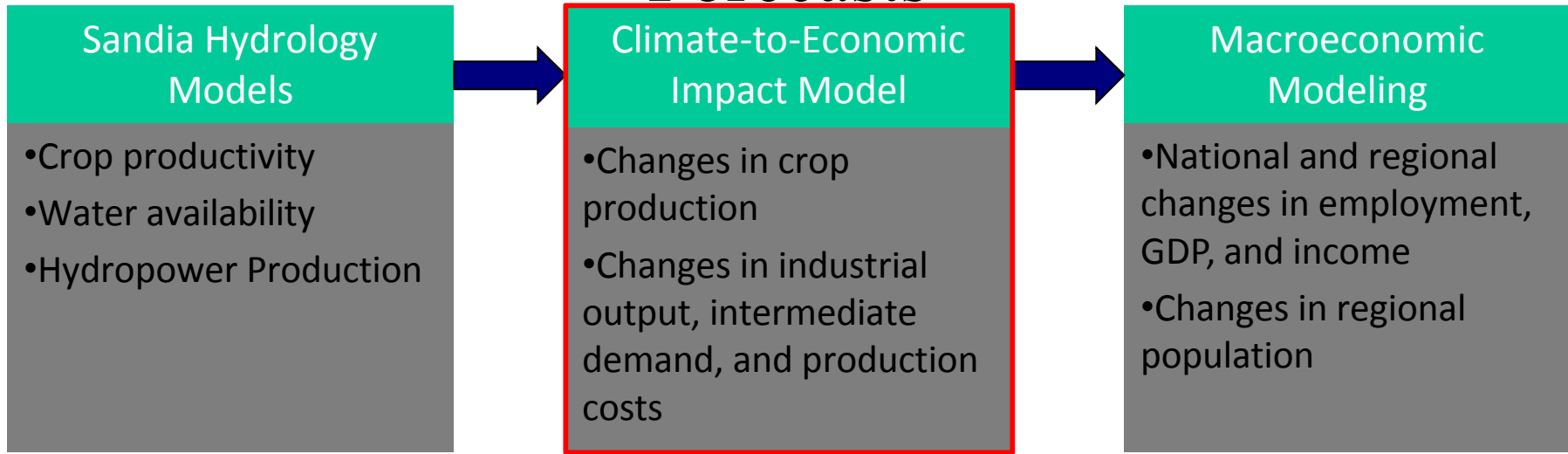
Year	AL	AZ	AR	CA	CO	CT	DE	DC	FL	GA	ID	IL	IN	IA	KS	KY	LA	MA	MD	ME	MI	MN	MS	MO	MT
2000	1.00	0.99	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2001	1.00	0.99	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2002	1.00	0.98	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2003	1.00	0.97	1.00	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2004	1.00	0.96	1.00	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2005	0.96	0.94	0.97	0.96	0.97	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2006	0.96	0.94	0.97	0.96	0.97	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2007	1.00	0.92	1.00	0.94	0.96	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2008	0.92	0.54	1.00	0.85	0.87	0.78	0.88	1.00	0.72	0.78	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2009	0.96	0.46	1.00	0.93	0.97	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2010	1.00	0.87	1.00	0.89	1.00	0.92	0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2011	1.00	0.87	1.00	0.84	0.81	0.72	0.86	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2012	1.00	0.87	1.00	0.84	0.74	0.72	0.81	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2013	0.83	0.74	1.00	0.81	0.86	0.82	0.86	1.00	0.76	0.72	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2014	0.99	0.48	1.00	1.00	0.97	0.96	0.79	1.00	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2015	1.00	0.86	1.00	0.74	1.00	0.77	0.82	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2016	0.92	0.48	1.00	0.88	0.91	0.81	0.81	0.89	0.76	0.76	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2017	0.59	0.67	1.00	0.36	0.92	0.66	0.61	0.69	0.59	0.49	0.84	0.85	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2018	0.64	0.74	1.00	0.37	0.93	0.41	0.26	0.38	0.48	0.48	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2019	0.77	0.56	1.00	0.68	0.59	0.62	0.65	0.62	0.73	0.69	0.69	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2020	1.00	0.92	1.00	0.80	0.77	0.58	0.62	1.00	0.48	0.56	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2021	0.60	0.73	1.00	0.81	0.82	0.78	0.76	1.00	0.24	0.22	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2022	0.32	0.78	1.00	0.57	0.62	0.63	0.71	1.00	0.28	0.27	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2023	0.50	0.72	0.99	0.67	0.68	0.73	0.79	1.00	0.73	0.53	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2024	0.75	0.69	1.00	0.62	0.87	0.81	0.99	1.00	0.67	0.69	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2025	0.62	0.78	1.00	0.41	0.83	0.86	0.95	0.93	1.00	0.82	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2026	0.60	0.48	1.00	0.41	0.86	0.79	0.67	0.69	0.71	0.51	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2027	1.00	0.34	1.00	0.47	0.84	0.86	1.00	1.00	0.99	0.76	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2028	0.88	0.47	1.00	0.63	0.74	0.63	0.68	0.91	1.00	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2029	0.83	0.87	1.00	0.67	0.80	0.78	0.82	0.98	1.00	0.83	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2030	0.41	0.28	1.00	0.33	0.87	0.83	0.85	0.88	0.91	0.89	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2031	0.54	0.66	1.00	0.57	0.80	0.76	0.81	0.99	1.00	0.84	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2032	0.45	0.46	1.00	0.47	0.63	0.67	0.65	0.72	0.69	0.69	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2033	0.75	0.49	1.00	0.62	0.94	0.73	0.68	0.89	0.89	0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2034	0.54	0.64	1.00	0.67	0.83	0.66	0.51	0.72	0.69	0.68	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2035	0.72	0.49	1.00	0.63	0.94	0.73	0.68	0.89	0.89	0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2036	0.54	0.64	1.00	0.67	0.83	0.66	0.51	0.72	0.69	0.68	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2037	0.75	0.49	1.00	0.63	0.94	0.73	0.68	0.89	0.89	0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2038	0.54	0.64	1.00	0.67	0.83	0.66	0.51	0.72	0.69	0.68	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2039	0.72	0.49	1.00	0.63	0.94	0.73	0.68	0.89	0.89	0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2040	0.54	0.64	1.00	0.67	0.83	0.66	0.51	0.72	0.69	0.68	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2041	0.72	0.49	1.00	0.63	0.94	0.73	0.68	0.89	0.89	0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2042	0.54	0.64	1.00	0.67	0.83	0.66	0.51	0.72	0.69	0.68	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2043	0.72	0.49	1.00	0.63	0.94	0.73	0.68	0.89	0.89	0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2044	0.54	0.64	1.00	0.67	0.83	0.66	0.51	0.72	0.69	0.68	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2045	0.72	0.49	1.00	0.63	0.94	0.73	0.68	0.89	0.89	0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2046	0.54	0.64	1.00	0.67	0.83	0.66	0.51	0.72	0.69	0.68	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2047	0.72	0.49	1.00	0.63	0.94	0.73	0.68	0.89	0.89	0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2048	0.54	0.64	1.00	0.67	0.83	0.66	0.51	0.72	0.69	0.68	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2049	0.72	0.49	1.00	0.63	0.94	0.73	0.68	0.89	0.89	0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2050	0.40	0.52	0.92	0.74	0.68	0.50	0.50	0.78	0.45	0.57	0.58														

# Modeling Economic Impacts from Hydrology Forecasts



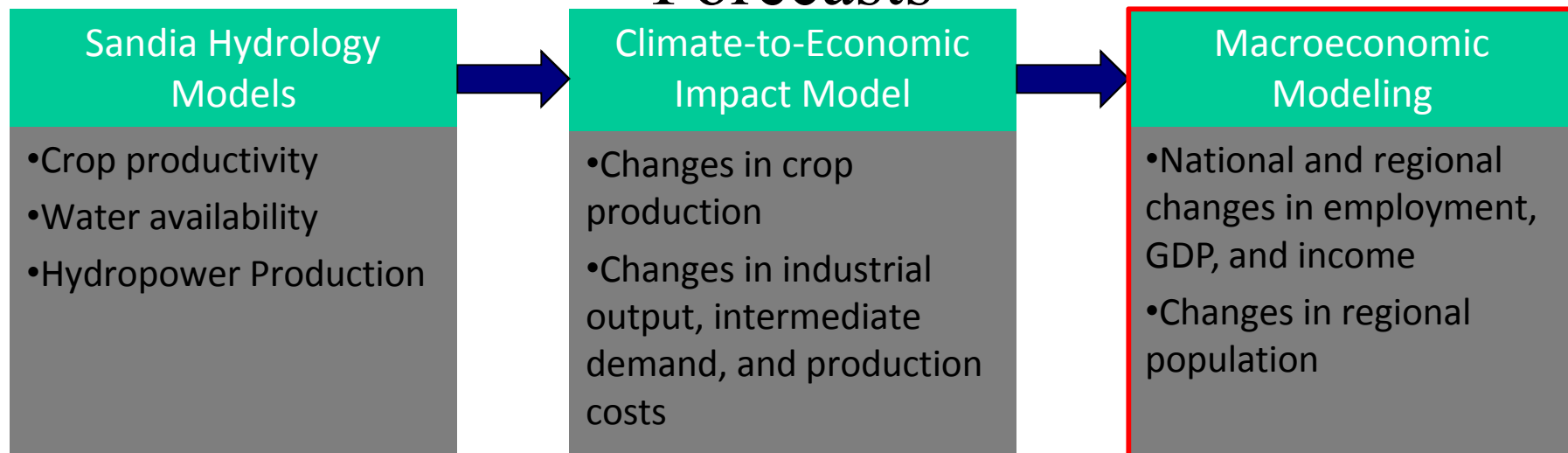
■ Uncertainties are reflected in the outputs of the hydrology models, which are used as inputs in economic modeling

# Modeling Economic Impacts from Hydrology Forecasts



- The Climate-to-Economic Impact Model is a type of “pre-modeling” by making economic sense of hydrology models
  - ⊕ Forecasting direct economic impacts

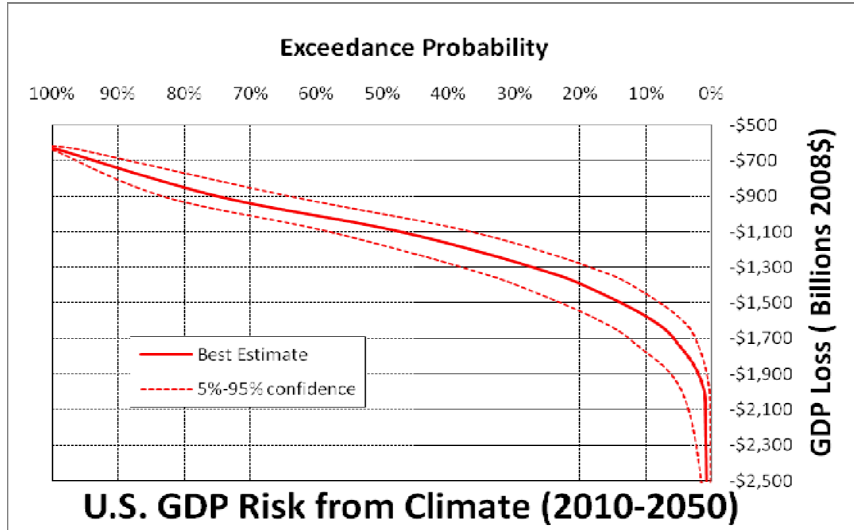
# Modeling Economic Impacts from Hydrology Forecasts



■ Regional Economic Models, Inc. (REMI) model used to model broad economic/demographic effects.

- ⊕ REMI is a dynamic, 51-region model that creates annual forecasts to 2050.

# Climate Change Risk Assessment: National Summary Results

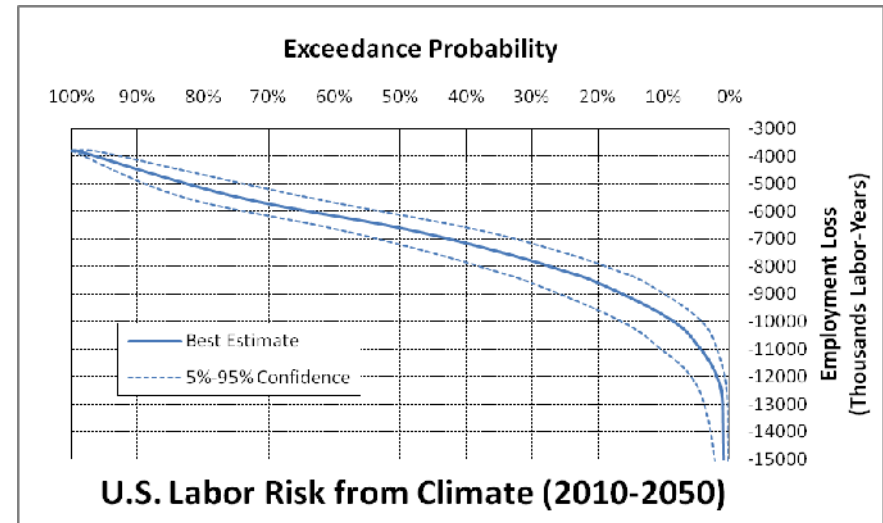
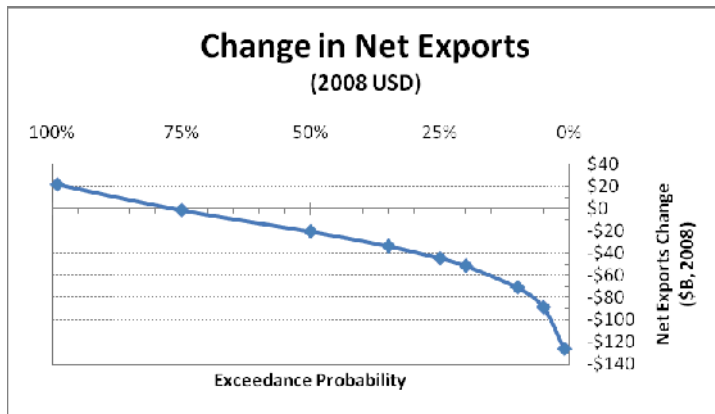


**Change in National GDP (Billions of 2008\$)**

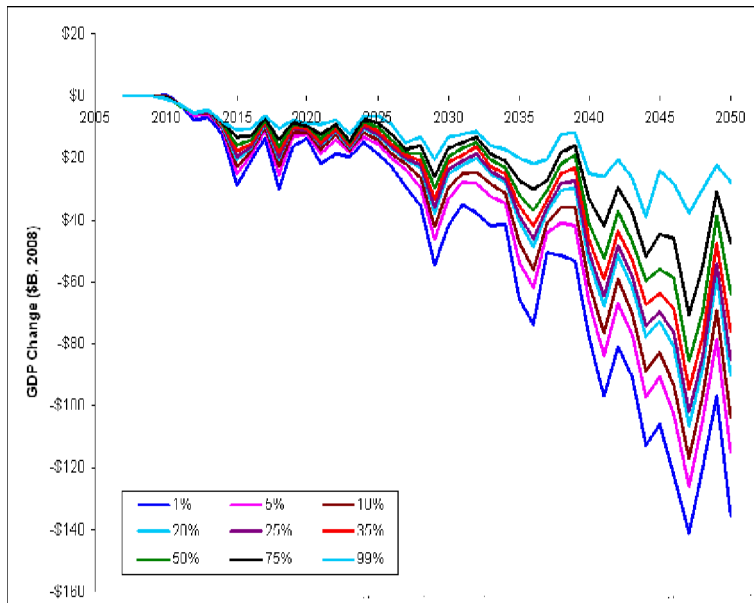
Discount rate	Exceedance Probability									Summary Risk
	99%	75%	50%	35%	25%	20%	10%	5%	1%	
0.0%	-\$638.5	-\$899.4	-\$1,076.8	-\$1,214.5	-\$1,324.6	-\$1,390.8	-\$1,573.9	-\$1,735.4	-\$2,058.5	-\$1,204.8
1.5%	-\$432.0	-\$595.9	-\$707.4	-\$795.0	-\$865.1	-\$907.2	-\$1,024.6	-\$1,129.3	-\$1,340.2	-\$790.3
3.0%	-\$301.9	-\$407.4	-\$479.4	-\$536.6	-\$582.4	-\$610.0	-\$687.2	-\$756.8	-\$898.2	-\$534.5

**Change in Employment (Thousands)**

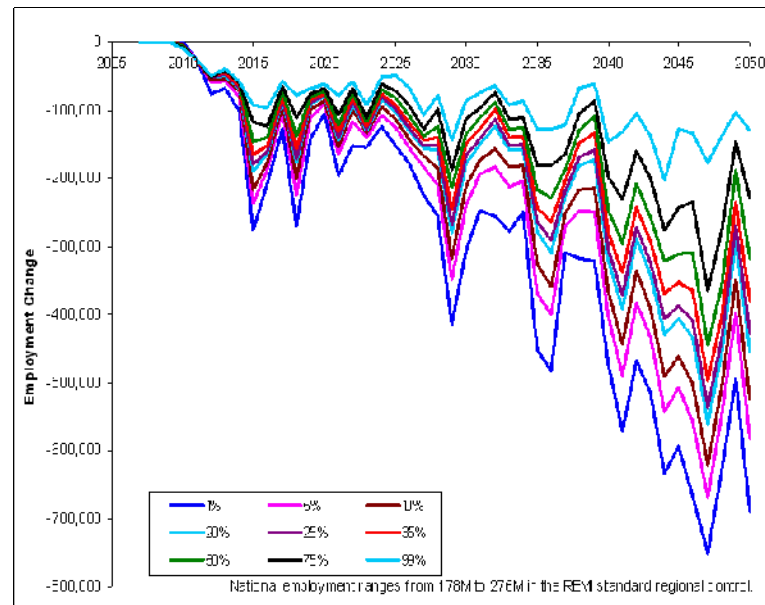
Exceedance Probability	Summary Risk									
	99%	75%	50%	35%	25%	20%	10%	5%	1%	
99%	-3,815	-5,463	-6,601	-7,468	-8,166	-8,587	-9,764	-10,819	-12,961	-6,863



# Volatility and Exceedance Probability

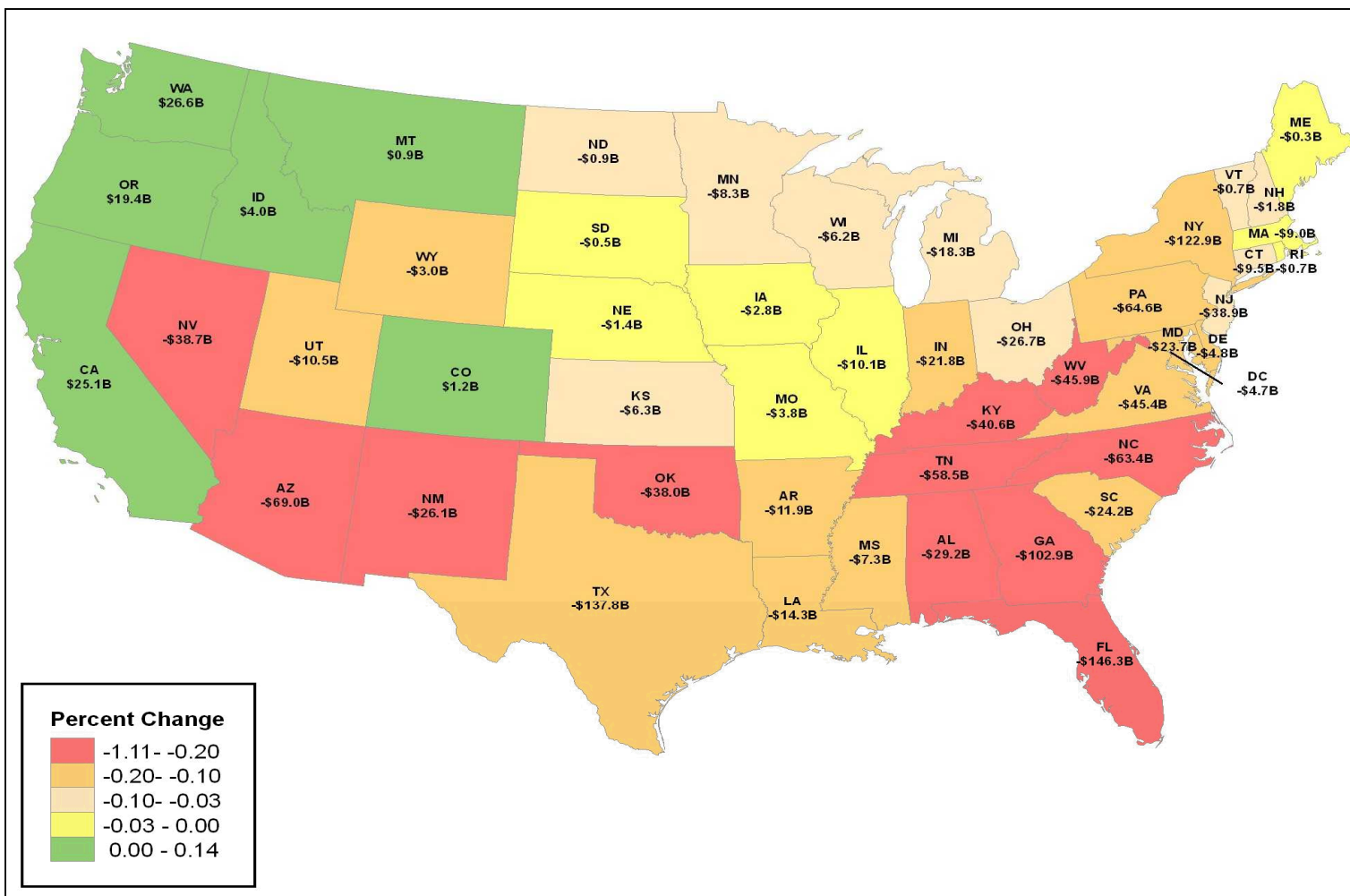


Annual U.S. GDP impacts.

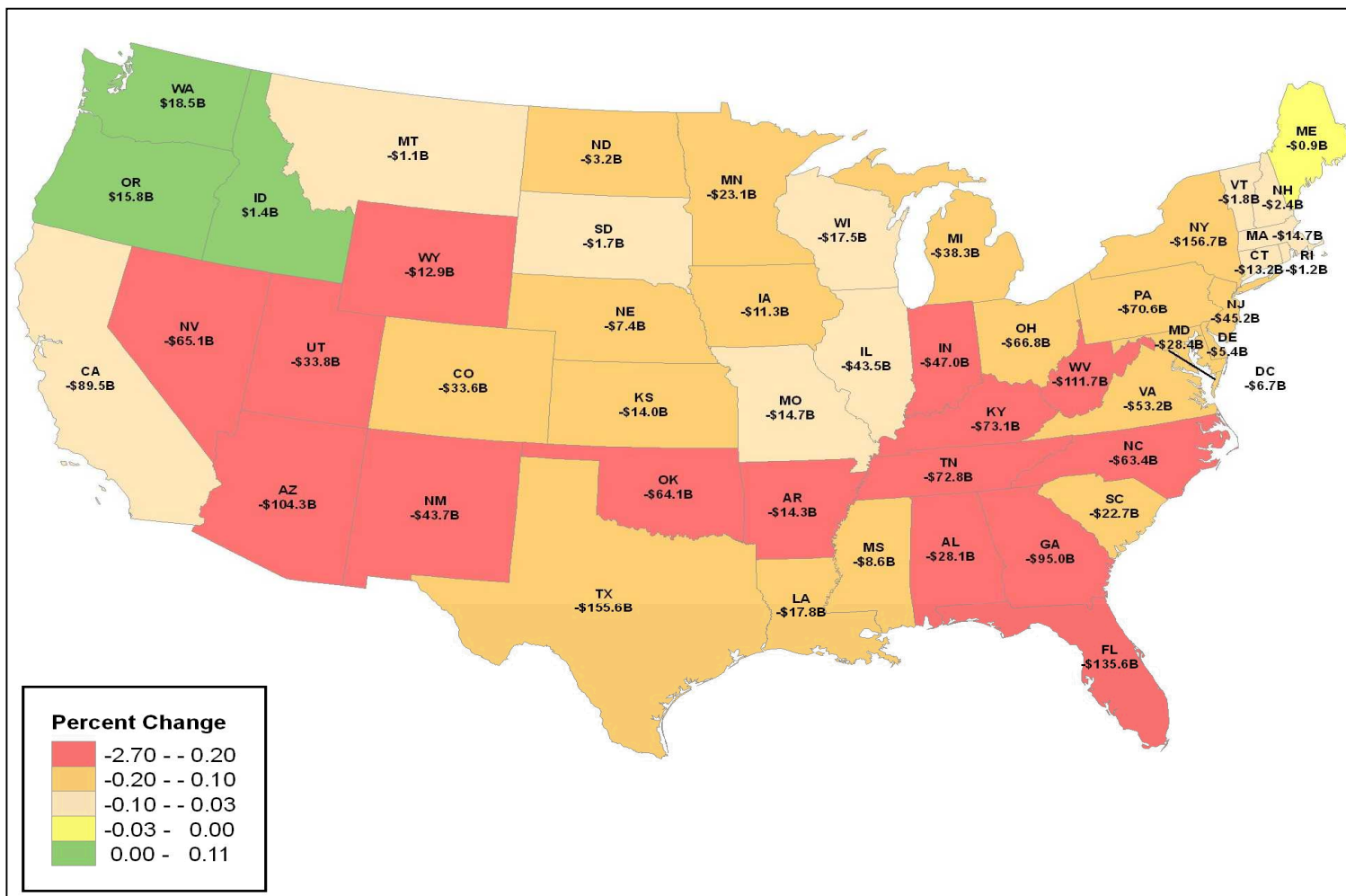


Annual U.S. employment impacts

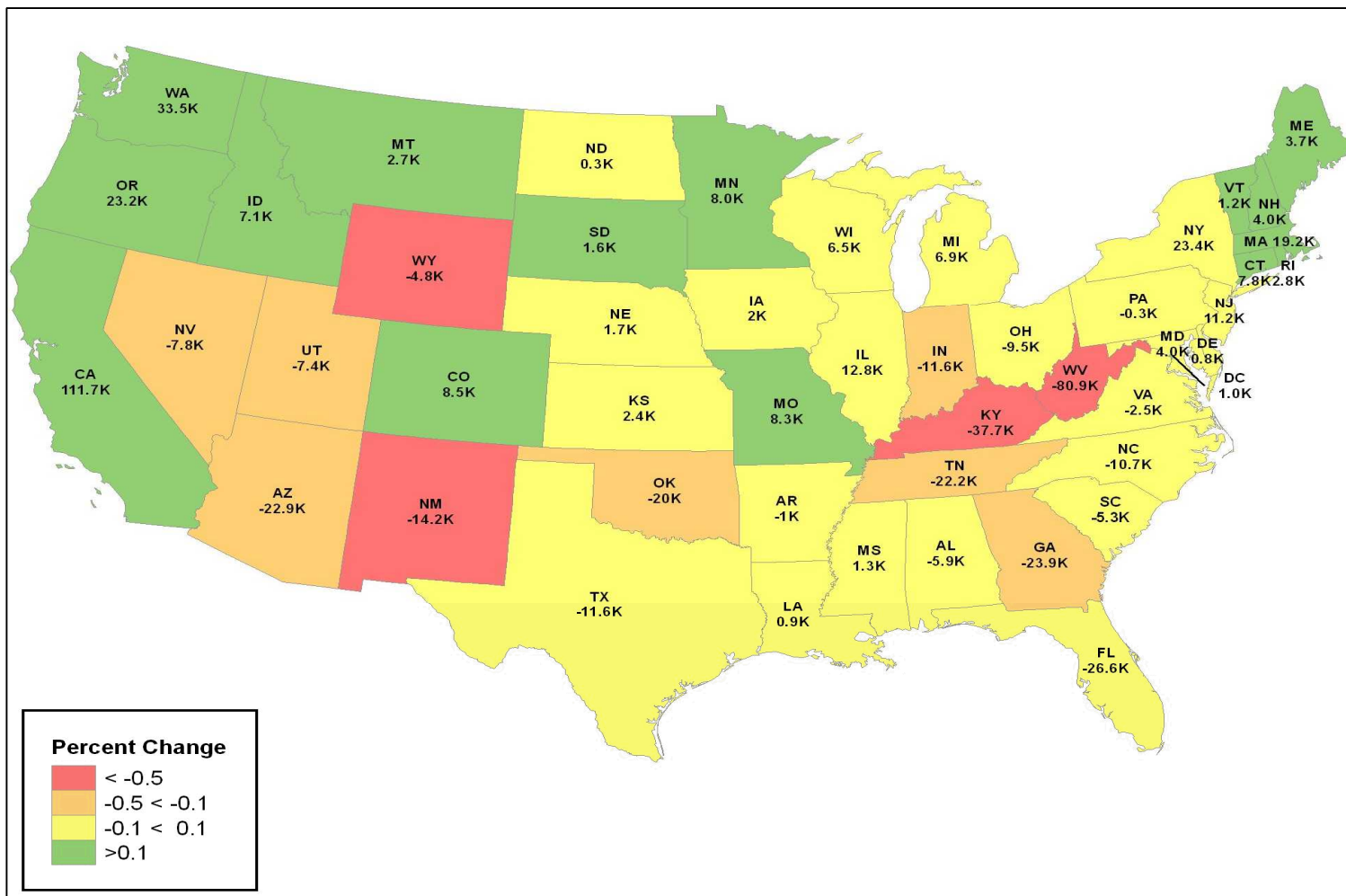
# GDP risk by State



# GDP Impact (1% Exceedance Probability)



# Population Impact (1% Exceedance Probability)



# The Public Message of Risk

## Summary of Climate Impacts (2010-2050)

Region	Change in GDP (Billions of 2008\$)			Change in Empl. (Thous. Labor- Years)	Change in Pop. (Thous. People)
	Discount Rates				
	0.0%	1.5%	3.0%		
<b>United States</b>	<b>-\$1,204.8</b>	<b>-\$790.3</b>	<b>-\$534.5</b>	<b>-6,862.7</b>	<b>0.0</b>
Alabama	-\$29.2	-\$18.9	-\$12.6	-246.1	-10.8
Arizona	-\$69.0	-\$45.8	-\$31.2	-481.2	-14.8
Arkansas	-\$11.9	-\$7.6	-\$5.0	-96.8	-2.4
California	\$25.1	\$16.6	\$11.5	152.0	115.7
Colorado	\$1.2	\$0.4	\$0.0	22.8	15.3
Connecticut	-\$9.5	-\$6.3	-\$4.3	-36.4	4.7
Delaware	-\$4.8	-\$3.1	-\$2.1	-30.3	0.0
D.C.	-\$4.7	-\$3.1	-\$2.1	-15.5	0.5
Florida	-\$146.3	-\$97.5	-\$66.9	-1,242.4	-55.5
Georgia	-\$102.9	-\$67.7	-\$45.9	-752.6	-40.0
Idaho	\$4.0	\$2.5	\$1.6	33.3	6.9
Illinois	-\$10.1	-\$5.1	-\$2.5	-36.7	15.7
Indiana	-\$21.8	-\$12.9	-\$7.8	-130.1	-4.0
Iowa	-\$2.8	-\$1.4	-\$0.6	-10.3	3.1
Kansas	-\$6.3	-\$4.1	-\$2.7	-43.5	2.3
Kentucky	-\$40.6	-\$24.9	-\$15.6	-289.6	-21.6
Louisiana	-\$14.3	-\$9.4	-\$6.3	-119.4	-0.9
Maine	-\$0.3	-\$0.2	-\$0.2	-4.4	2.5
Maryland	-\$23.7	-\$15.6	-\$10.5	-163.0	0.1
Massachusetts	-\$9.0	-\$5.9	-\$4.1	-37.8	12.9
Michigan	-\$18.3	-\$11.2	-\$7.1	-107.7	7.1
Minnesota	-\$8.3	-\$4.9	-\$2.9	-36.8	7.6
Mississippi	-\$7.3	-\$4.7	-\$3.1	-63.0	-0.8
Missouri	-\$3.8	-\$2.2	-\$1.3	-22.7	8.3

Region	Change in GDP (Billions of 2008\$)			Change in Empl. (Thous. Labor- Years)	Change in Pop. (Thous. People)
	Discount Rates				
	0.0%	1.5%	3.0%		
Montana	\$0.9	\$0.6	\$0.4	12.8	2.9
Nebraska	-\$1.4	-\$0.8	-\$0.4	-4.4	2.5
Nevada	-\$38.7	-\$26.2	-\$18.1	-220.6	-2.8
New Hampshire	-\$1.8	-\$1.2	-\$0.8	-12.1	2.6
New Jersey	-\$38.9	-\$25.8	-\$17.6	-205.9	3.6
New Mexico	-\$26.1	-\$17.9	-\$12.7	-217.6	-8.3
New York	-\$122.9	-\$80.5	-\$54.4	-560.4	7.2
North Carolina	-\$63.4	-\$41.6	-\$28.1	-492.4	-19.8
North Dakota	-\$0.9	-\$0.5	-\$0.3	-5.4	0.8
Ohio	-\$26.7	-\$16.1	-\$10.0	-167.7	1.7
Oklahoma	-\$38.0	-\$25.2	-\$17.2	-312.0	-15.3
Oregon	\$19.4	\$12.5	\$8.3	152.7	20.5
Pennsylvania	-\$64.6	-\$42.4	-\$28.7	-459.1	-7.7
Rhode Island	-\$0.7	-\$0.5	-\$0.3	-3.2	1.8
South Carolina	-\$24.2	-\$15.9	-\$10.7	-235.4	-10.2
South Dakota	-\$0.5	-\$0.3	-\$0.2	-2.1	1.3
Tennessee	-\$58.5	-\$37.3	-\$24.4	-440.0	-23.0
Texas	-\$137.8	-\$91.0	-\$61.9	-1,045.9	-28.5
Utah	-\$10.5	-\$6.9	-\$4.6	-72.2	2.2
Vermont	-\$0.7	-\$0.4	-\$0.3	-5.5	1.0
Virginia	-\$45.4	-\$29.7	-\$20.1	-314.2	-5.9
Washington	\$26.6	\$17.0	\$11.2	190.7	29.5
West Virginia	-\$45.9	-\$27.7	-\$17.0	-306.4	-34.5
Wisconsin	-\$6.2	-\$3.7	-\$2.2	-38.8	6.6
Wyoming	-\$3.0	-\$1.9	-\$1.3	-19.2	-0.5

# The Corporate Message of Risk

Forestry and logging; Fishing, hunting	-\$0.6	Water transportation	\$0.0
Agriculture, forestry support activities; Other	-\$0.3	Truck transportation, couriers	-\$19.9
Oil and gas extraction	-\$9.4	Transit and ground passenger transportation	-\$0.6
Mining (except oil and gas)	-\$86.3	Pipeline transportation	-\$0.2
Support activities for mining	-\$7.3	Tourist transportation; support activities	-\$0.8
Utilities	\$13.6	Warehousing and storage	-\$2.1
Construction	-\$30.8	Publishing industries, except Internet	-\$12.4
Wood product manufacturing	-\$1.1	Motion picture and sound recording industries	-\$4.5
Nonmetallic mineral product manufacturing	-\$3.3	Internet publishing, information services	-\$10.8
Primary metal manufacturing	-\$2.4	Broadcasting, Telecommunications	-\$28.1
Fabricated metal product manufacturing	-\$3.7	Monetary authorities, funds, trusts, financials	-\$34.1
Machinery manufacturing	-\$4.2	Securities, commodity contracts, investments	-\$39.9
Computer and electronic product mfg.	-\$10.3	Insurance carriers and related activities	-\$6.4
Electrical equipment and appliance mfg.	\$1.4	Real estate	-\$38.2
Motor vehicles, bodies & trailers, parts mfg.	-\$8.8	Rental and leasing services	-\$8.4
Other transportation equipment manufacturing	-\$1.6	Professional and technical services	-\$41.4
Furniture and related product manufacturing	-\$3.6	Management of companies and enterprises	-\$13.9
Miscellaneous manufacturing	\$1.4	Administrative and support services	-\$21.2
Food manufacturing	-\$82.3	Waste management and remediation services	-\$0.5
Beverage and tobacco product manufacturing	-\$29.4	Educational services	-\$2.2
Textile mills	\$0.0	Ambulatory health care services	-\$66.8
Textile product mills	-\$1.0	Hospitals	-\$5.5
Apparel manufacturing	\$0.8	Nursing and residential care facilities	-\$2.0
Leather and allied product manufacturing	-\$2.3	Social assistance	-\$2.0
Paper manufacturing	-\$2.5	Performing arts and spectator sports	-\$2.0
Printing and related support activities	-\$0.6	Museums, historical sites, zoos, and parks	-\$0.2
Petroleum and coal product manufacturing	-\$3.6	Amusement, gambling, and recreation	-\$5.9
Chemical manufacturing	-\$18.2	Accommodation	-\$3.8
Plastics and rubber product manufacturing	-\$4.5	Food services and drinking places	-\$19.9
Wholesale trade	-\$45.3	Repair and maintenance	-\$4.9
Retail trade	-\$127.2	Personal and laundry services	-\$11.2
Air transportation	-\$4.1	Membership associations and organizations	-\$2.0
Rail transportation	-\$3.2	Private households	-\$1.0

# Limitations and Comments

- Shown impacts are in the absence of policy, but with market responses to climatic conditions
- Only looks at a single dimension of largest uncertainty (precipitation). Omits extreme weather and many others
- Interactions among states, volatility, and shifts in direction/timing with exceedance probability alter results
- A net benefit is a mix of negative and positive impacts
- Costs are in accounting terms. How, when, or if to mitigate/insure against them is when discount rates apply



# The Next Step: Policy Issues

- The speed to turn-over the US energy infrastructure to low-carbon technologies is sensitive to uncertainty in regulation, strategic-resource availability, complex infrastructure constraints among many others
- Probabilistic uncertainty quantification (UQ) of “consequences” can assess technology policy risks and robustness
- Policy needs are determined by “tail” risks, not best estimates
- UQ on best-estimate (parameters) is sensitivity analysis, not risk assessment



## The Next Steps: Global Context

- The model boundary was the continental US holding the world at business as usual, clearly an inadequate assumption
- Current work focuses on the humans consequences globally using uncertainty quantification of the dynamic interaction of trade, strategic material availability, and geo-political instability
- Assessing the risk from “tail” phenomena rather than the best estimate



# Thank You

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