United States Environmental Protection Agency

Investigating the Sensitivity of U.S. Stream Water Quality to Climate Change: EPA's 20 Watershed Study

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SRBC Water Quality Advisory Committee
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Office of Research and Development
National Center for Environmental Assessment

The views expressed in this presentation are those of the authors and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency

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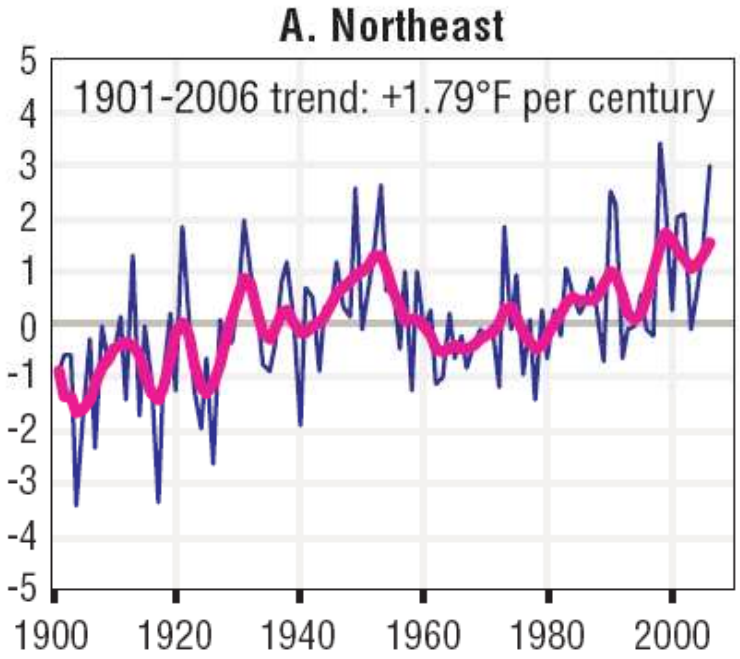
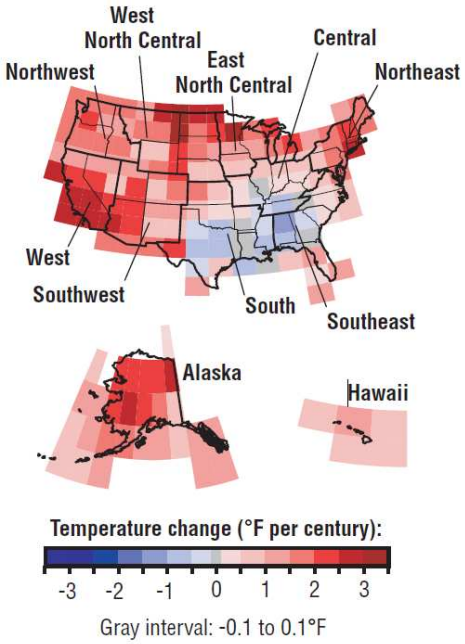
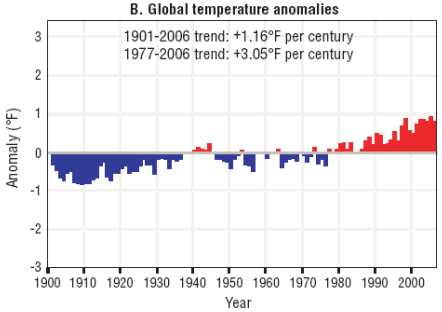
Annual temperature anomalies in the U.S. by region, 1901-2006



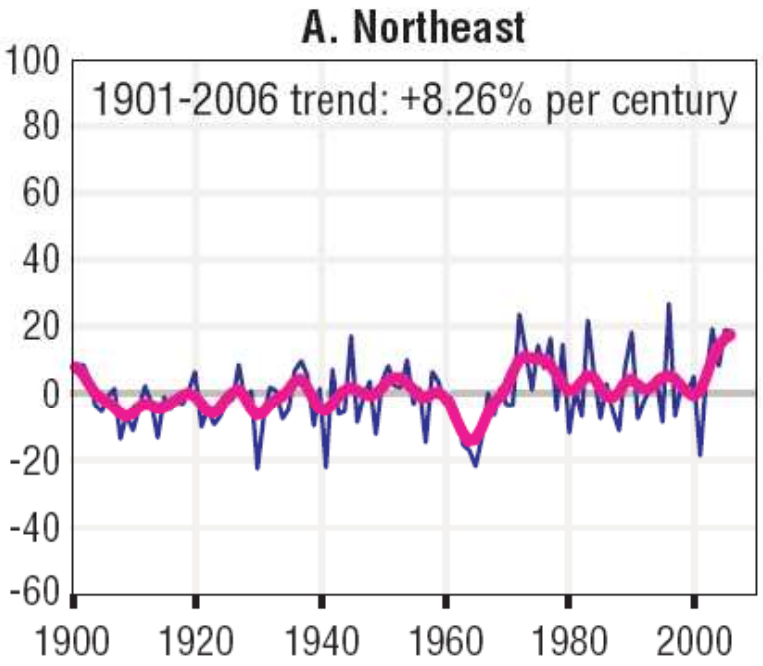


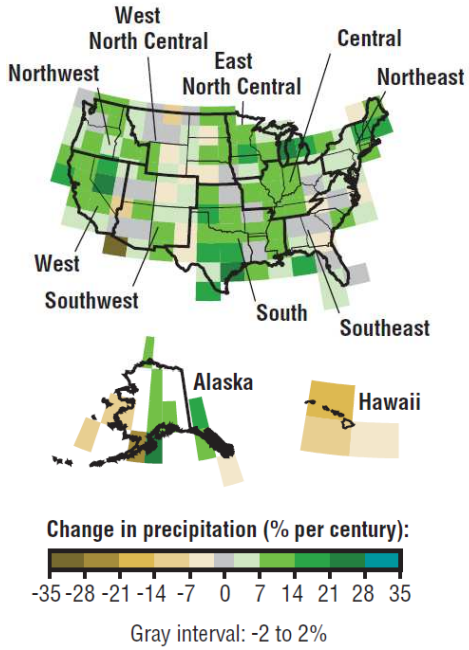
Data source: NOAA NCDC (figures from EPA 2008 Report on the Environment)

- Anomalies are calculated with respect to the 1961-1990 mean
- Time series were smoothed using a 9-point binomial filter



Annual precipitation anomalies in the U.S. by region, 1901-2006





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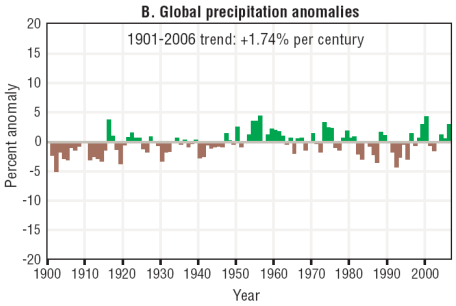
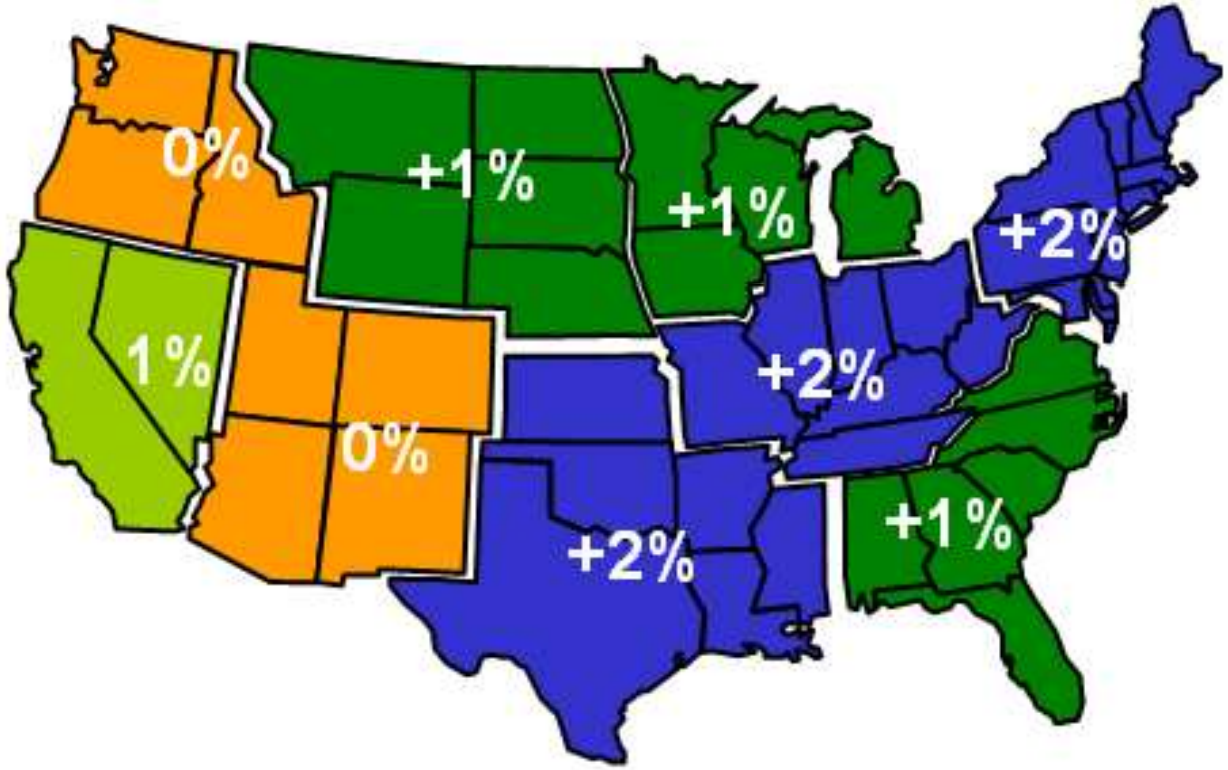


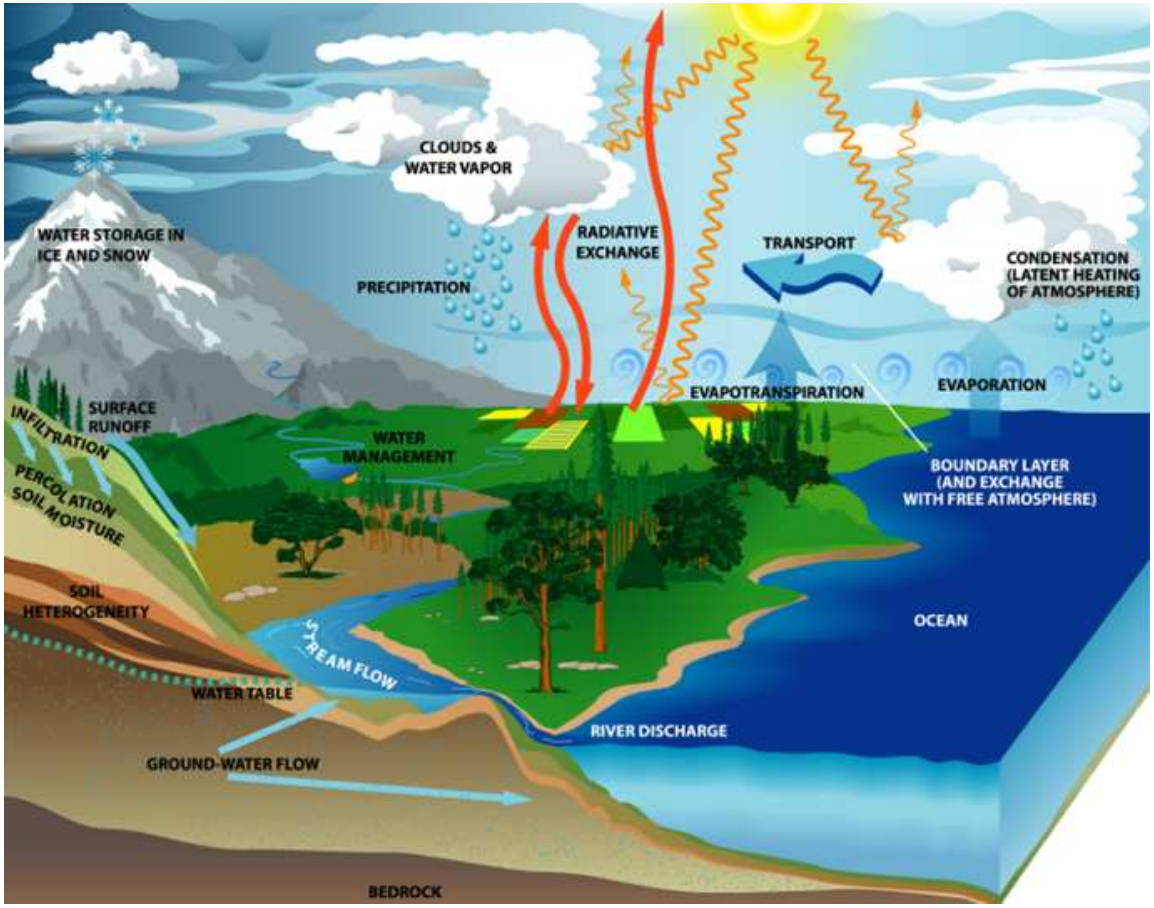
Changes in precipitation intensity during last century

Trends in proportion of annual precipitation occurring as extreme events (more than 2 in. per day), 1910-1995



Source: Karl and Knight, 1998. BAMS, Vol 79(2), pg 231-41

Potential effects of climate change on watersheds



Major flows and storage of water characterized by water balance:

Ppt = RO + Et + **Δ**S

Each term affected by climate

Specific effects on:

- Streamflow
- Water quality
- Infrastructure
- Ecosystems

What can we do?

- Planning for climate change is confounded by uncertainty; we don't have accurate, multi-decadal forecasts at local to regional spatial scales
- Simulation models (e.g., climate, hydrology) are excellent tools, however, for understanding system behavior; can be used to explore the implications of alternative futures, actions, policies on management/regulatory goals (scenario analysis)
- We can use this understanding to help identify how we are most vulnerable, and guide development of strategies for reducing risk
  - Goal to be robust across a wide range of plausible climate futures

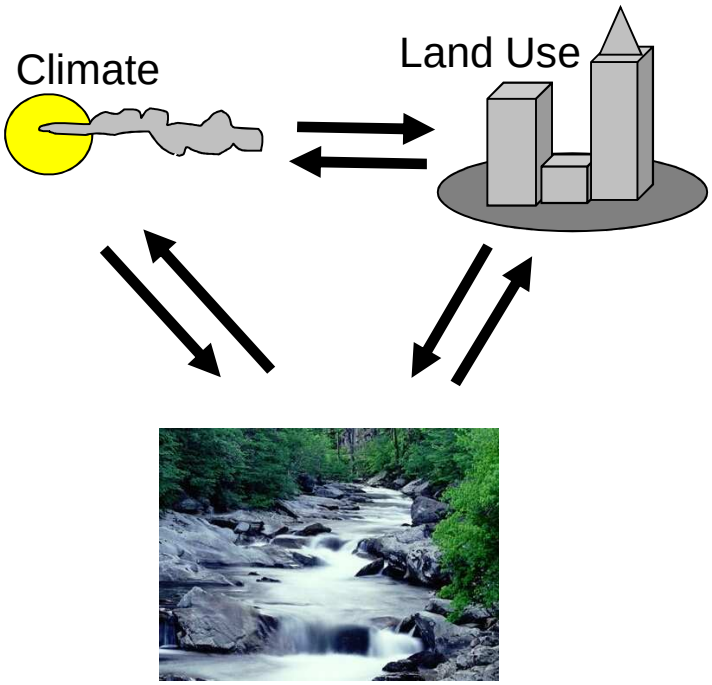
The “20 watershed” modeling project

Goal to assess:

• Sensitivity of U.S. streamflow, nutrient (N and P), and sediment loading to climate change across a range of plausible mid-21st Century climate futures

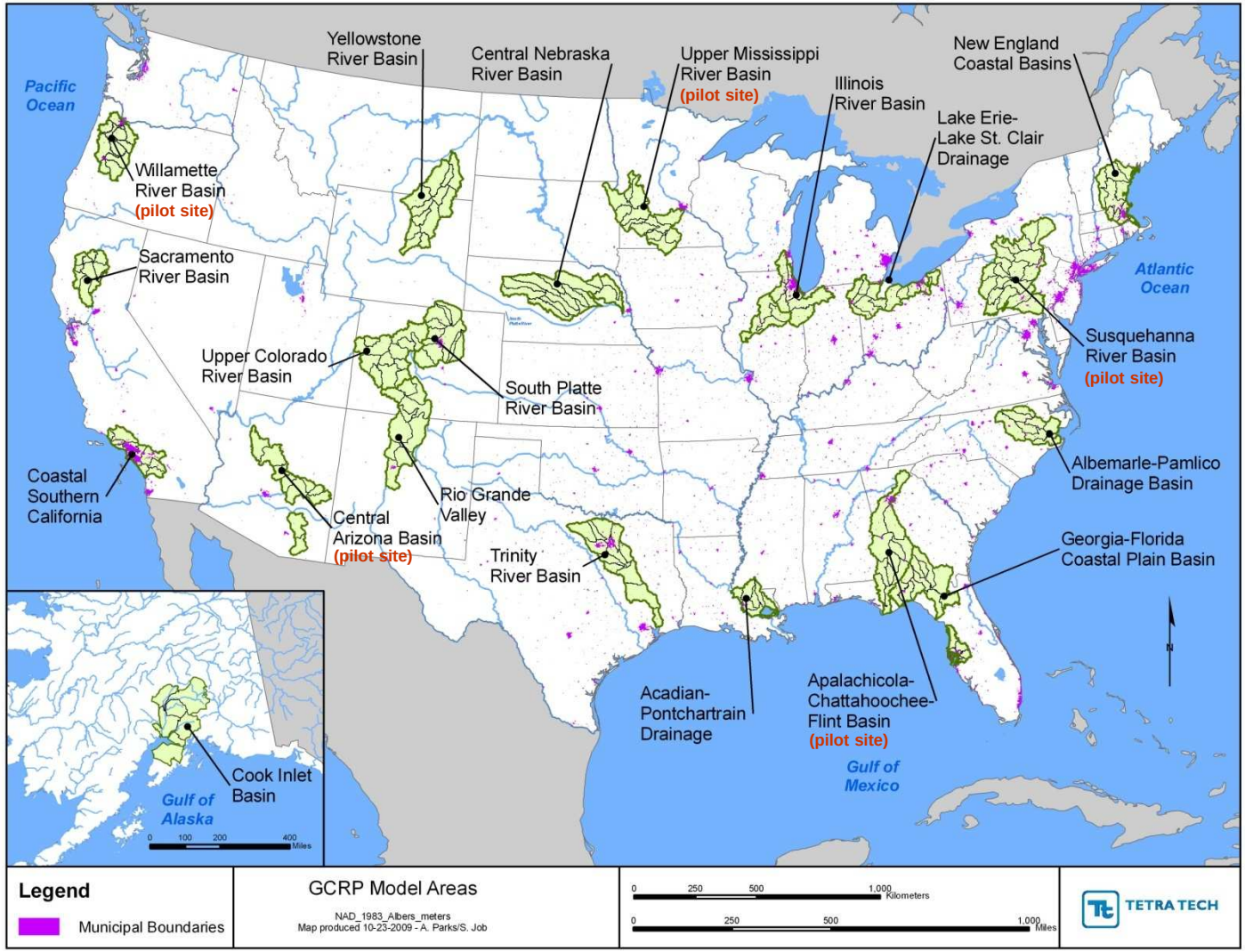
• Potential interactions of climate change with increasing urbanization in these watersheds

• Methodological challenges associated with integrating existing tools (e.g., climate models, land-use models, watershed models) and datasets to address these scientific questions



Hydrology, Ecosystems, Human Communities

20 Watersheds – Study Sites



Modeling Approach

Daily simulations of streamflow, N, P, sediment for historical (1970-2000) and future (2040-2070) periods

Spatial resolution about HUC8 (~ 1000-2000 sq. miles)

<u>In 5 pilot watersheds:</u>

- Use 2 watershed models, HSPF and SWAT
    - 14 climate change scenarios (NARCCAP, raw GCM, BCSD; A2 emissions scenario)
    - 2 land-use scenarios, current and future (EPA ICLUS)
- Simulated effects of climate change, land-use change, coupled C-L change
- Sensitivity studies to assess influence of different methods of downscaling

<u>In 15 non-pilot watersheds:</u>

- Use 1 watershed model, SWAT
    - 6 climate change scenarios (NARCCAP; A2 emissions scenario)
    - 2 land-use scenarios, current and future (EPA ICLUS)
- Simulated effects of climate change, land-use change, coupled C-L change

Status and Timeline

Status

- Modeling complete for the 5 pilot watersheds

- Currently working on models for the remaining 15 watersheds

Timeline

- Summer/Fall 2011: Data analysis and QA/QC

- Fall 2011 and beyond: Produce papers and reports

- Early 2012: Datasets available

Climate change scenarios

Climate Change Scenarios Evaluated

Scenario #	Climate Model(s)
NARCCAP scenarios	
1	CRCM_CGCM3
2	HRM3_HadCM3
3	RCM3_GFDL
4	GFDL high res_GFDL
5	RCM3_CGCM3
6	WRFP_CCSM
Driving GCMs of the NARCCAP scenarios (i.e., no downscaling)	
7	CGCM3
8	HADCM3
9	GFDL
10	CCSM
Bureau of Reclamation BCSD statistically downscaled scenarios	
11	CGCM3
12	HADCM3
13	GFDL
14	CCSM

Representation of climate scenarios:

- GCM/RCM projections interpolated to NCDC weather stations

- “delta change” method to create hydro model inputs

- PET calculated using Penman-Monteith

Climate Change Scenarios:

North American Regional Climate Change Assessment Program (NARCCAP)

http://www.narccap.ucar.edu/

<u>Dynamically downscaled</u>

6 international modeling teams (Partner: NCAR)

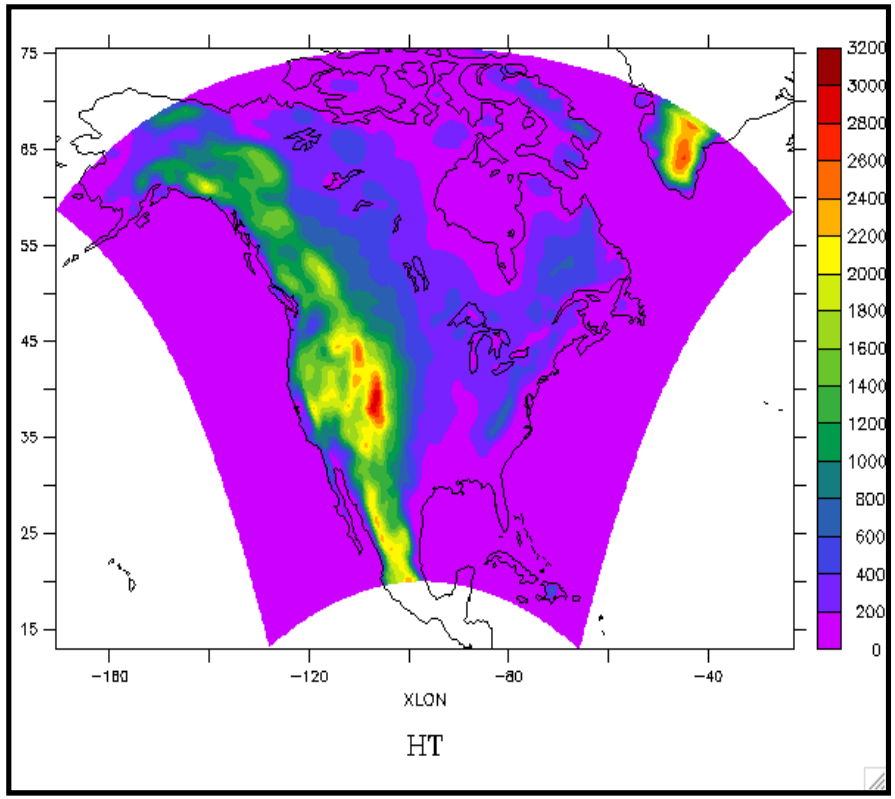
IPCC A2 emission storyline (pessimistic)

Future: 2040-2070
Historical: 1970-2000

Spatial grid: 50-km

Time freq: 3-hourly

Change in average amount, seasonality, intensity, extremes for T, P, winds, clouds, etc.



Climate Change Scenarios:
Bias Corrected and Downscaled
WCRP CMIP3 Climate Projections

http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html

<u>Statistically downscaled</u>

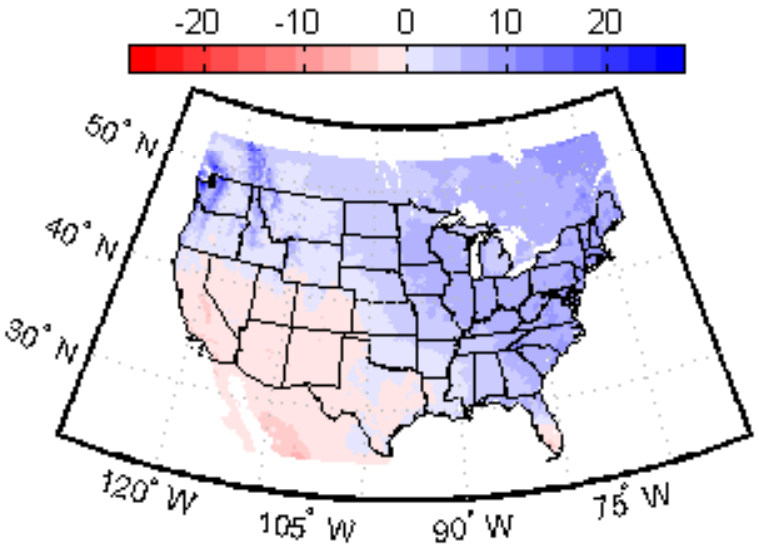
All IPCC modeling groups

Time Period: 1950-2100

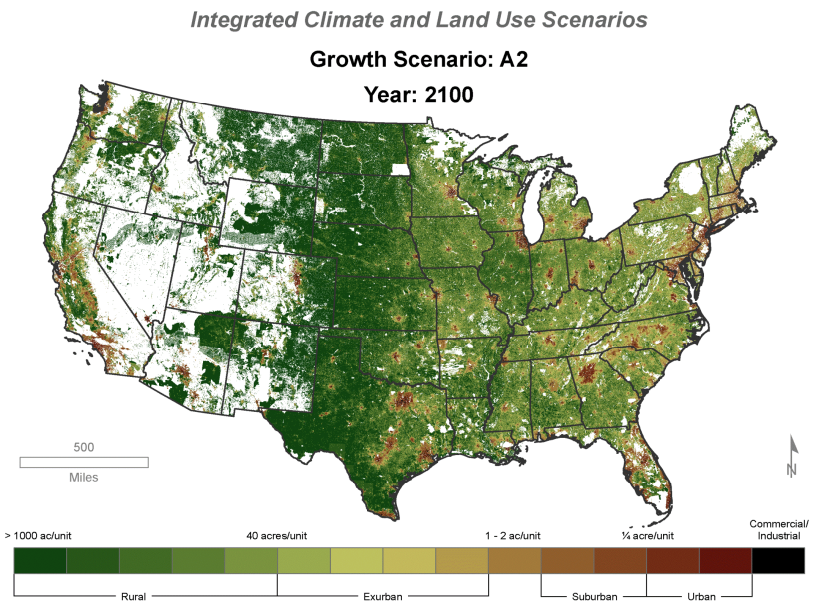
Spatial grid: 1/8-degree

Time freq: Monthly-mean

Temp and precip only



Land-use change scenarios



<u>Representation of land-use scenarios:</u>

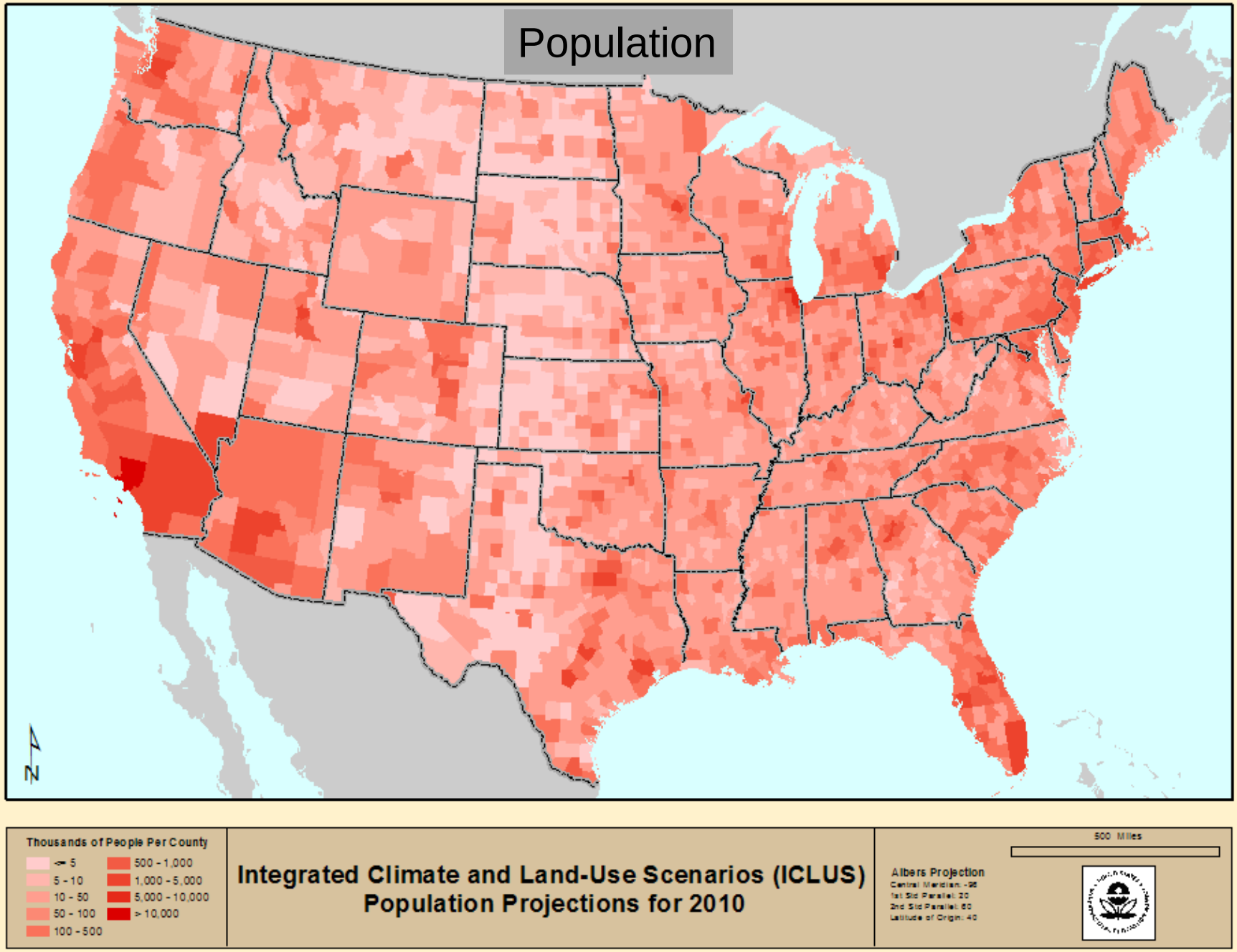
- 2001 NLCD

- EPA ICLUS; projected 2050 land-use change (developed land)

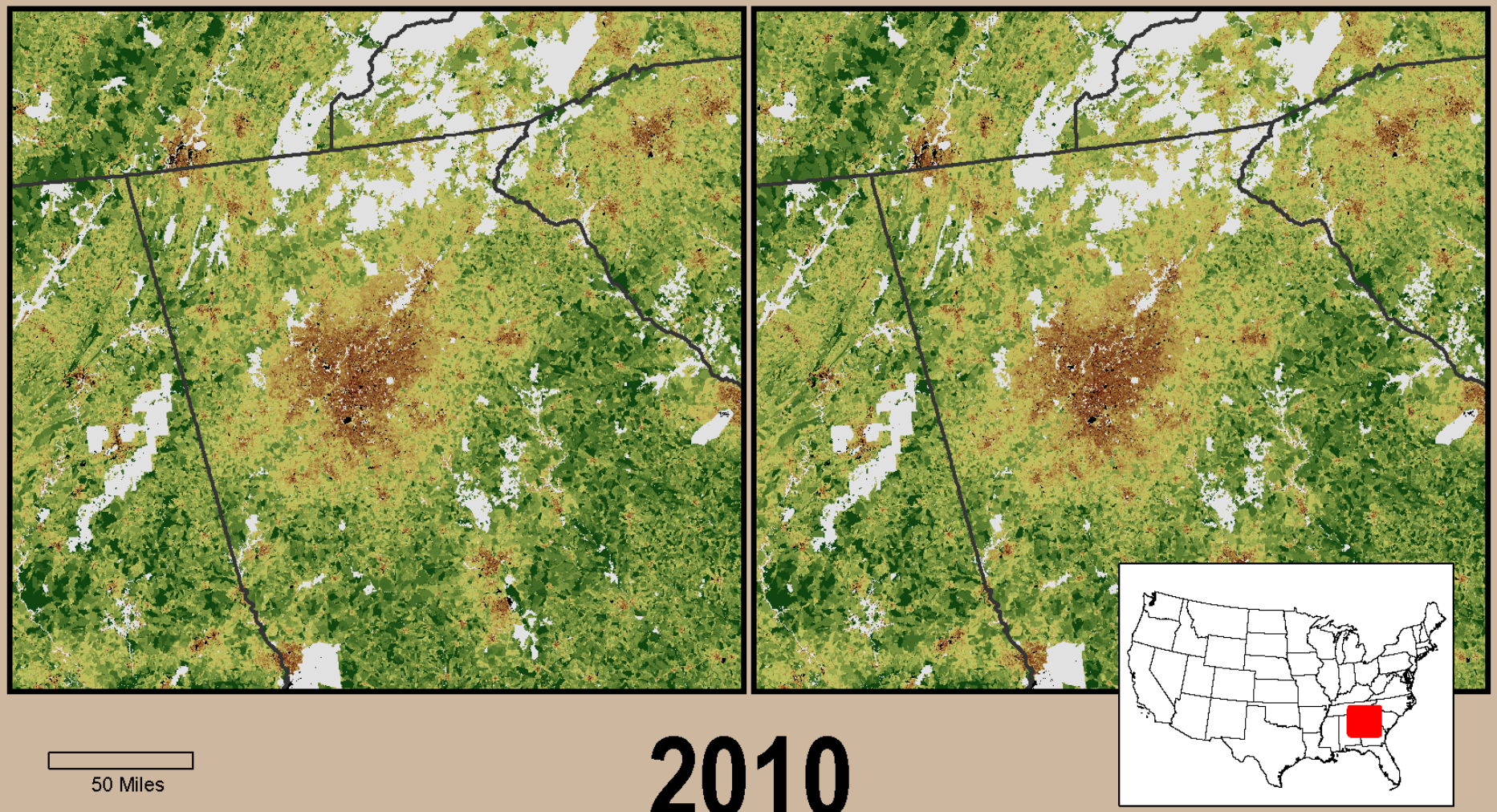
Land-use Change Scenarios:

EPA Integrated Climate and Land-use Change Scenarios (ICLUS)

- Housing density (100m res) and impervious cover (1km res)
- Five scenarios,
  - 4 consistent with the different assumptions underlying the IPCC SRES A1, A2, B1, B2 IPCC greenhouse gas storylines
- Coverage for the conterminous US; from 2000 to 2100
- Also working on GIS tools to generate custom scenarios


Population
N
Thousands of People Per County
<= 5
5 - 10
10 - 50
50 - 100
100 - 500
500 - 1,000
1,000 - 5,000
5,000 - 10,000
> 10,000
Integrated Climate and Land-Use Scenarios (ICLUS)
Population Projections for 2010
500 Miles
Albers Projection
Central Meridian: -96
1st Std Parallel: 20
2nd Std Parallel: 60
Latitude of Origin: 40

A2 Housing Density B1



50 Miles

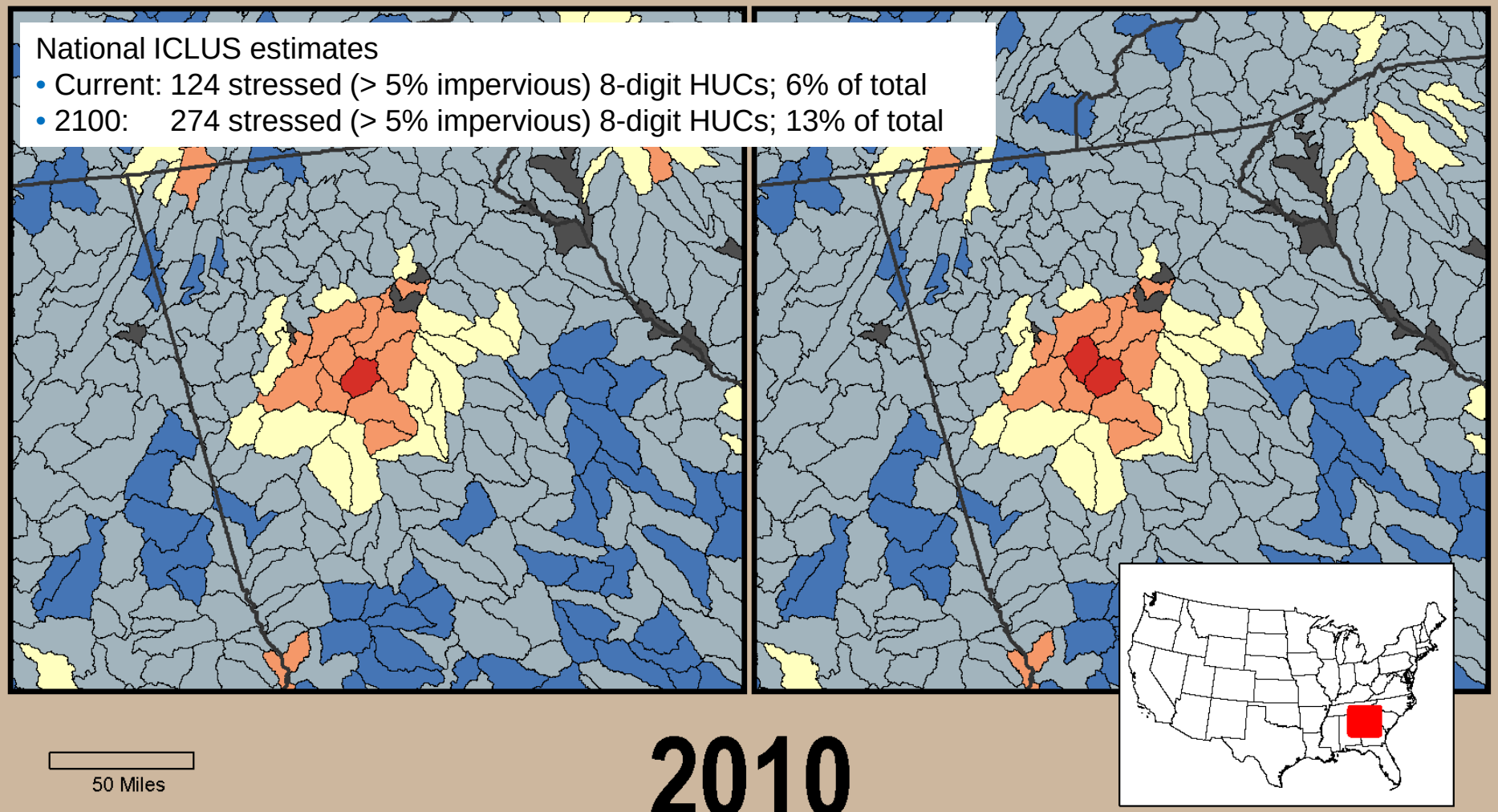
2010

> 1000 ac/unit | 40 acres/unit | 1 - 2 ac/unit | ¼ acre/unit | Commercial/ Industrial

Rural | Exurban | Suburban | Urban

A2 Impervious Cover B1

National ICLUS estimates
- Current: 124 stressed (> 5% impervious) 8-digit HUCs; 6% of total
- 2100: 274 stressed (> 5% impervious) 8-digit HUCs; 13% of total



50 Miles

2010

Unstressed	Lightly Stressed	Stressed	Impacted	Damaged
< 1%	1 - 5%	>5 - 10%	>10 - 25%	>25%

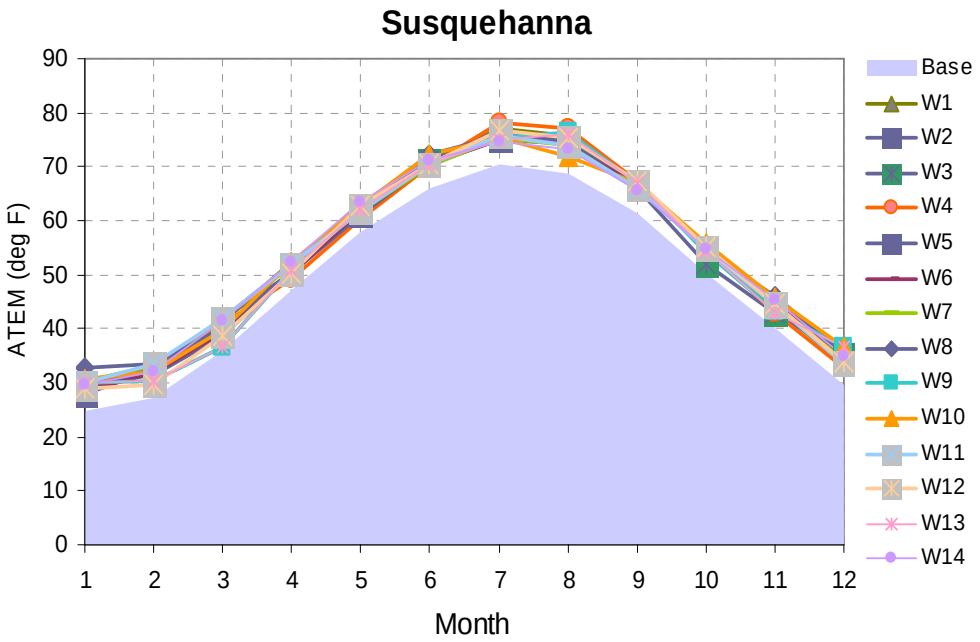
Results - 5 Pilot Sites

Results illustrate key methodological issues, sensitivities, uncertainties associated with CC-hydrologic impacts assessments:

1. Sensitivity of simulated changes to the watershed model used;
2. Sensitivity of simulated changes to climate model and downscaling approach used;
3. Interaction of climate change with other key forcing factors:
   a. Urban development
   b. Change in atmospheric CO2 concentration

Also provides overview of:

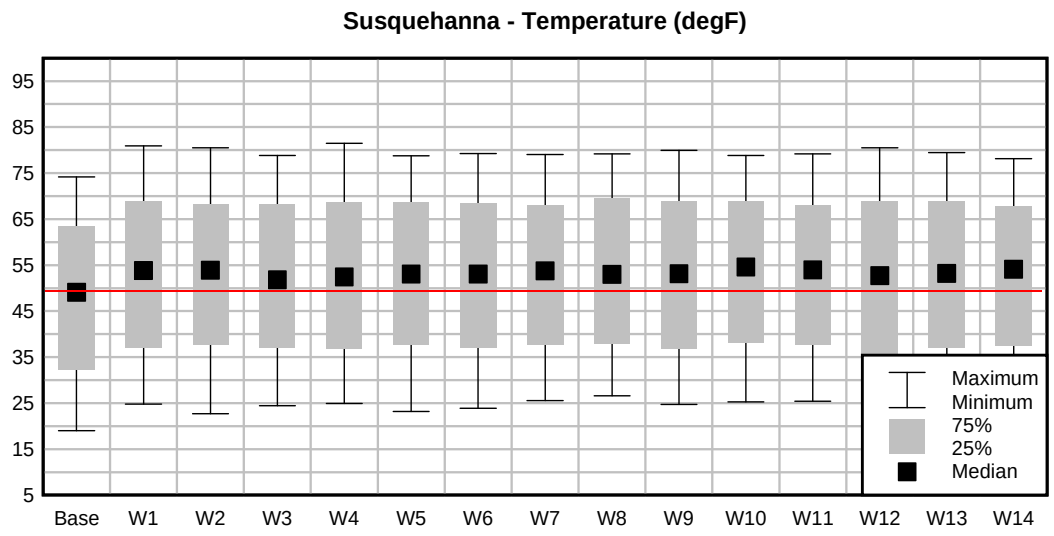
1. Overall hydrologic and WQ response to climate change
2. Geographic differences in response
3. Different sensitivities of different flow and WQ endpoints

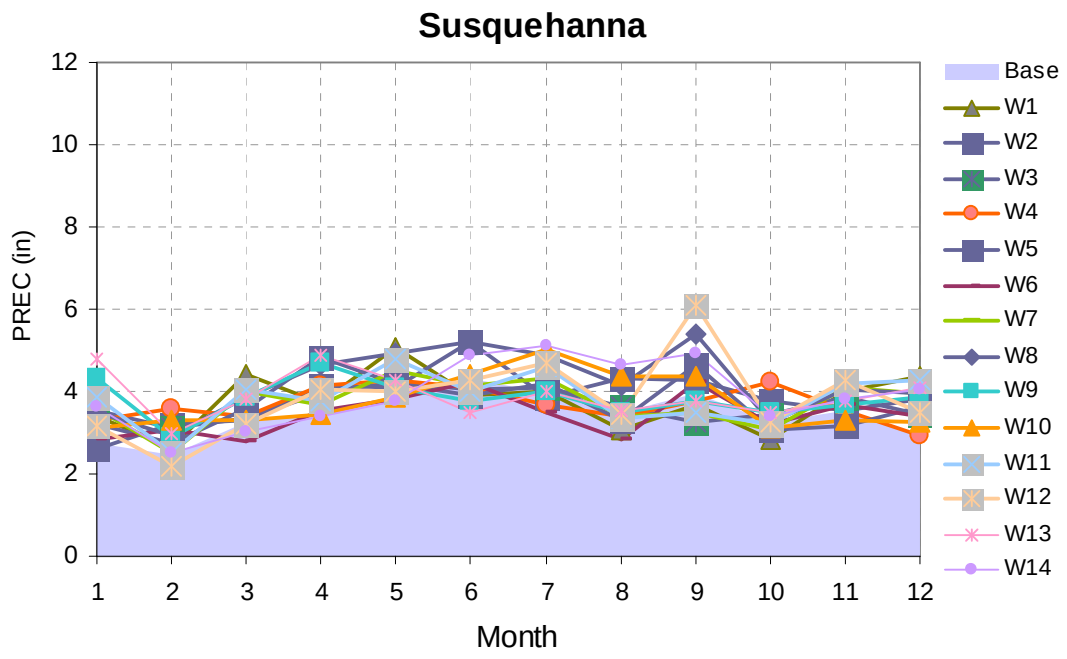


Temperature

2040-2070 compared to 1970-2000

All 14 Climate Scenarios

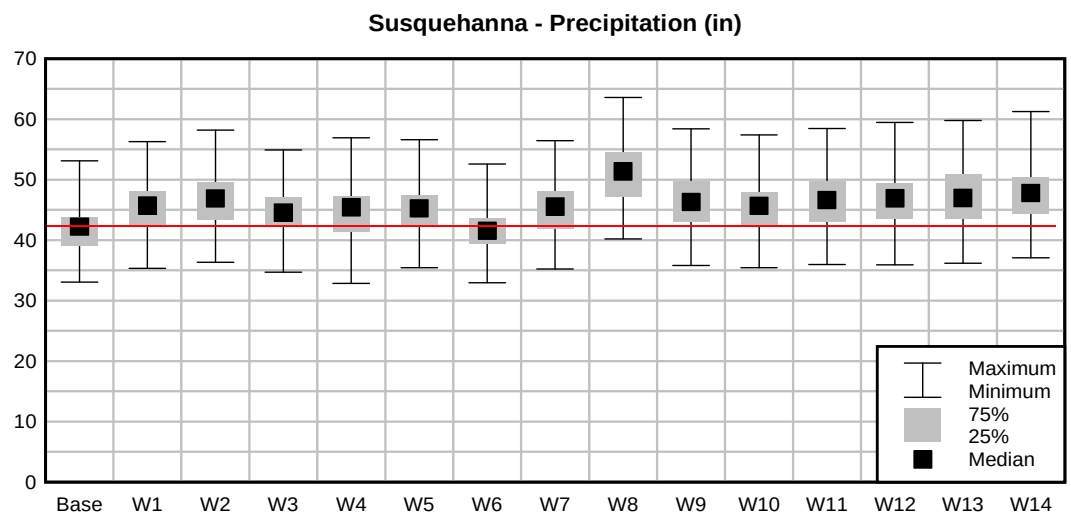


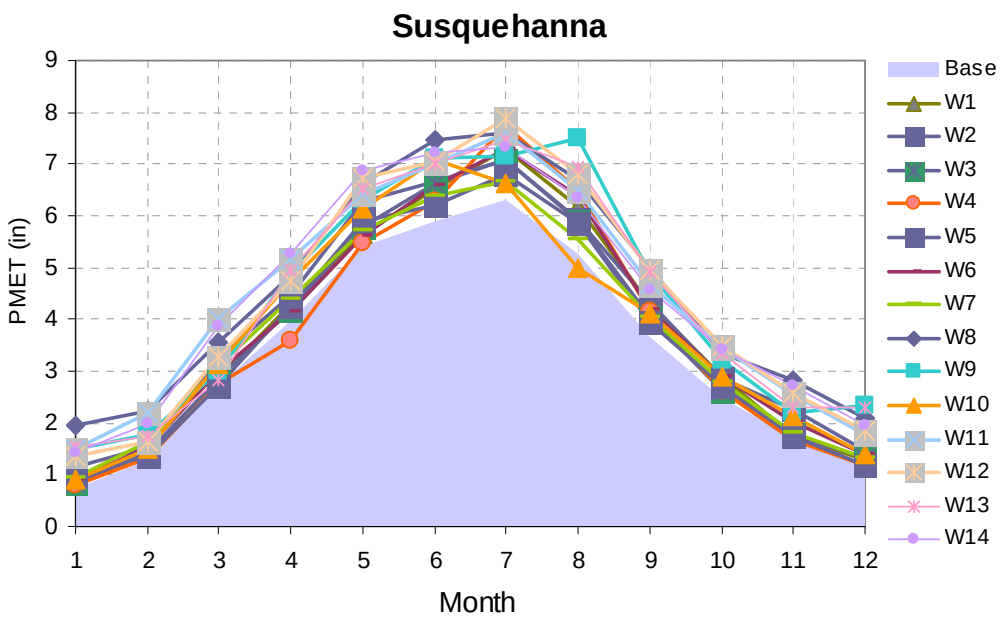


Precipitation

2040-2070 compared to 1970-2000

All 14 Climate Scenarios

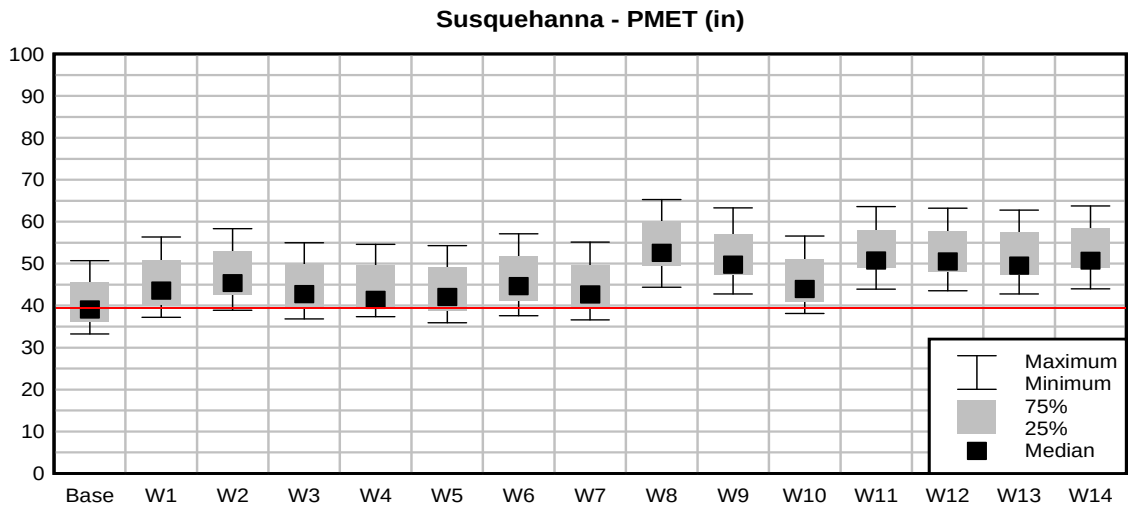




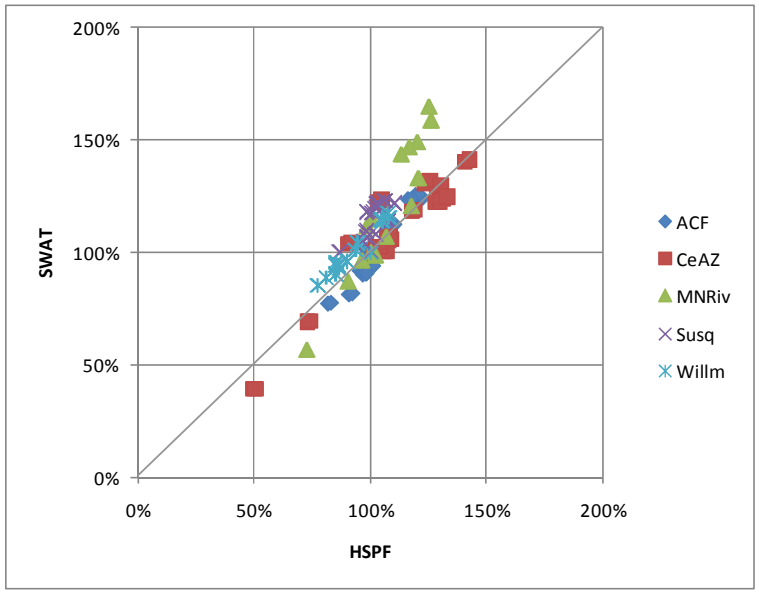
PET

2040-2070 compared to 1970-2000

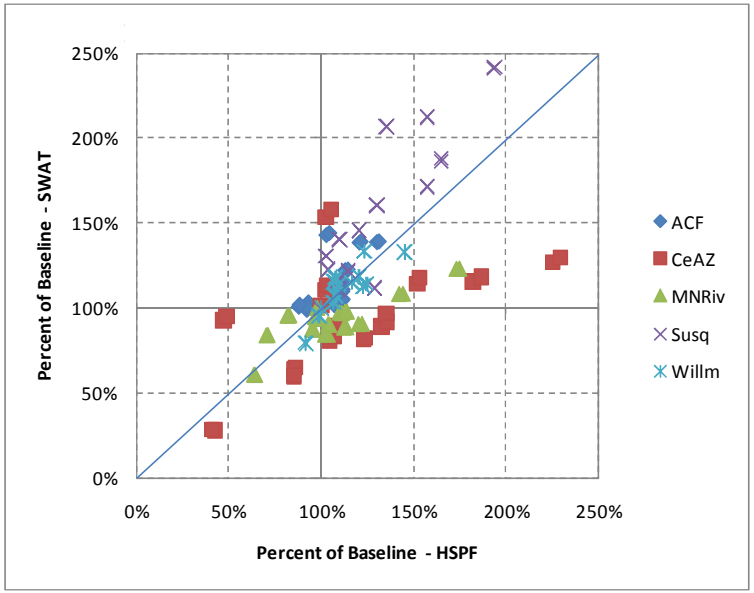
All 14 Climate Scenarios



Comparison of HSPF and SWAT-simulated future changes relative to current conditions (5 pilot basins; all 28 scenarios)



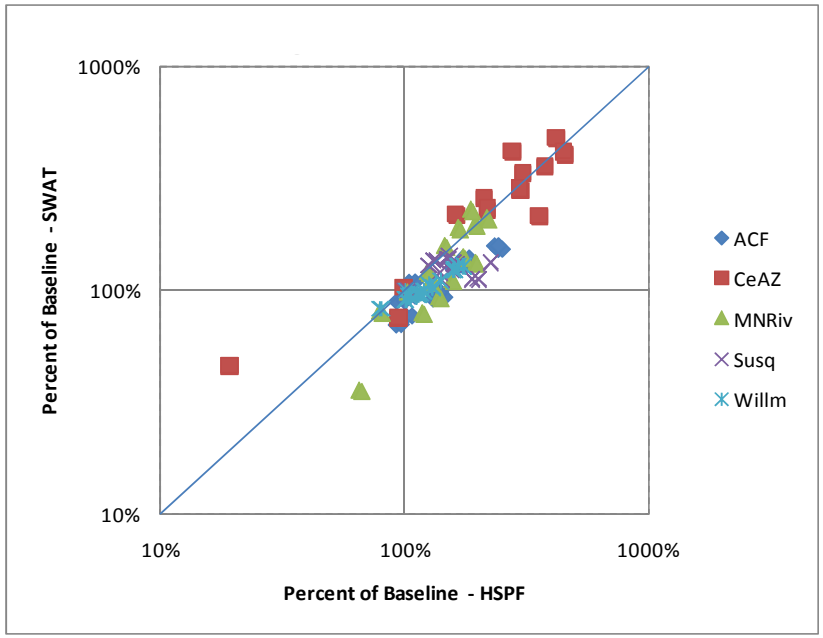
Total Streamflow



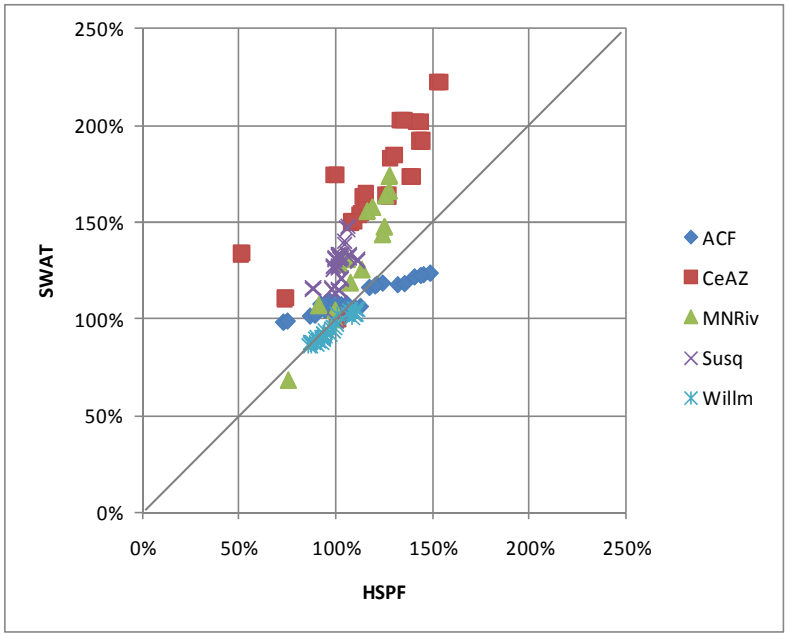
100-yr Flood

United States Environmental Protection Agency

Comparison of HSPF and SWAT-simulated future changes relative to current conditions (5 pilot basins; all 28 scenarios)

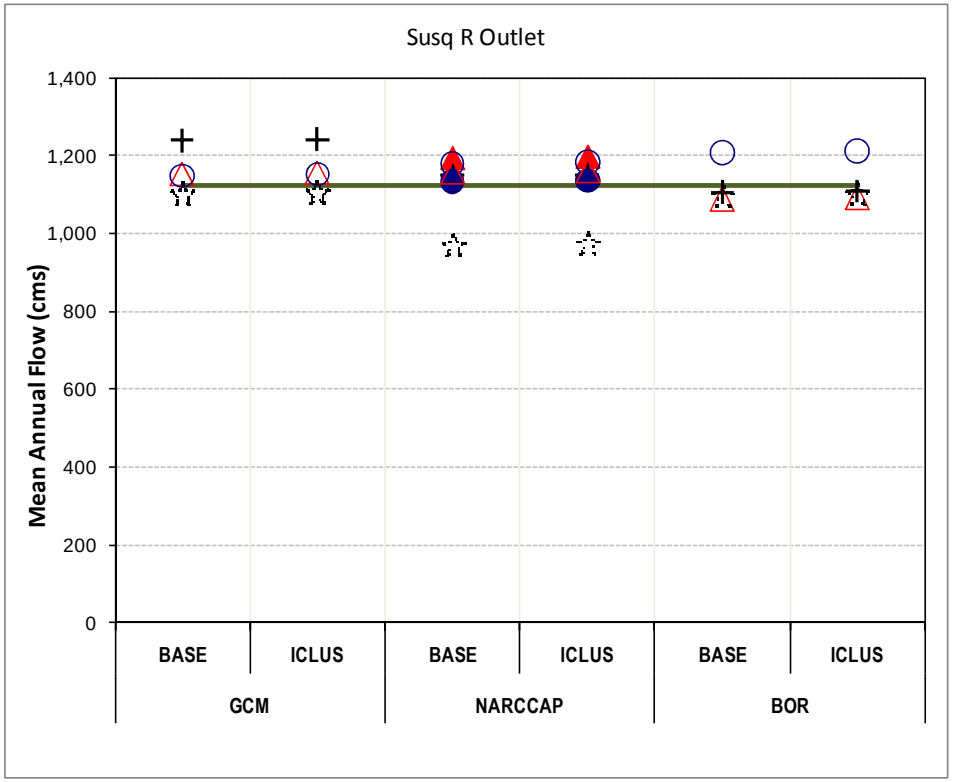


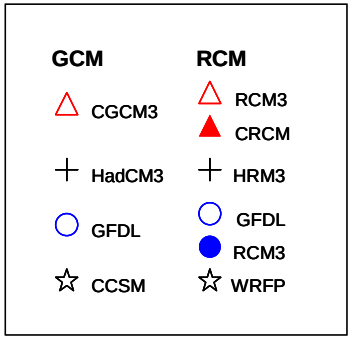
TSS Loads



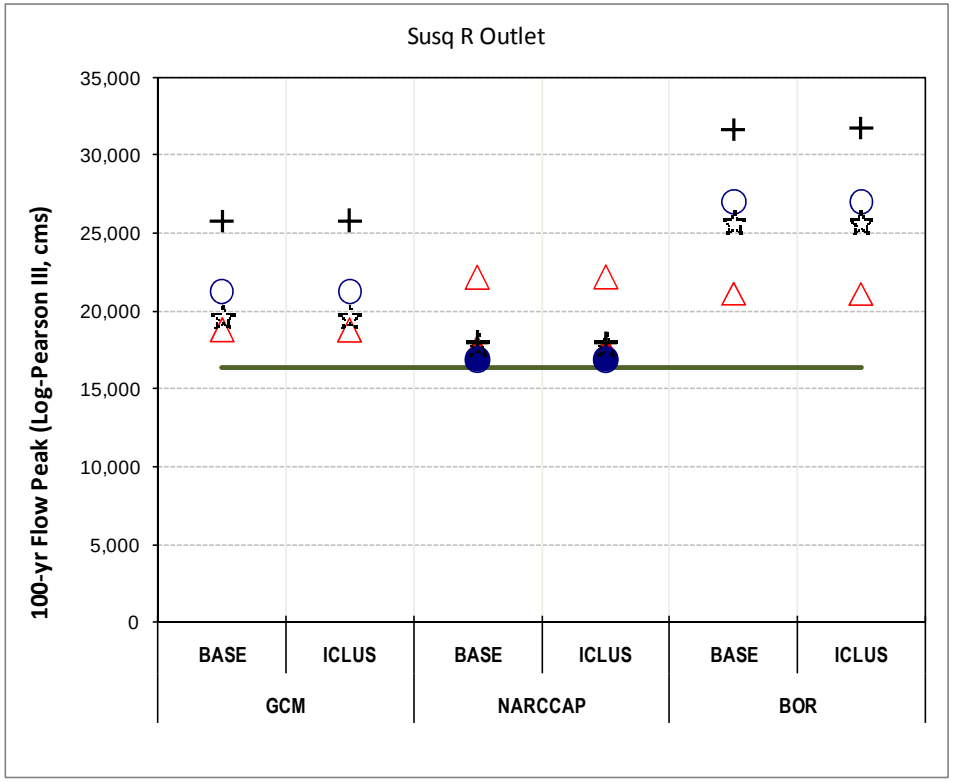
Total Nitrogen

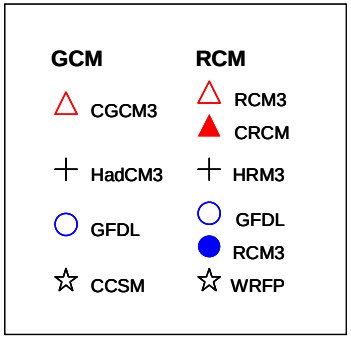
Mean Annual Flow (cms)
Susquehanna River at Outlet (HSPF)



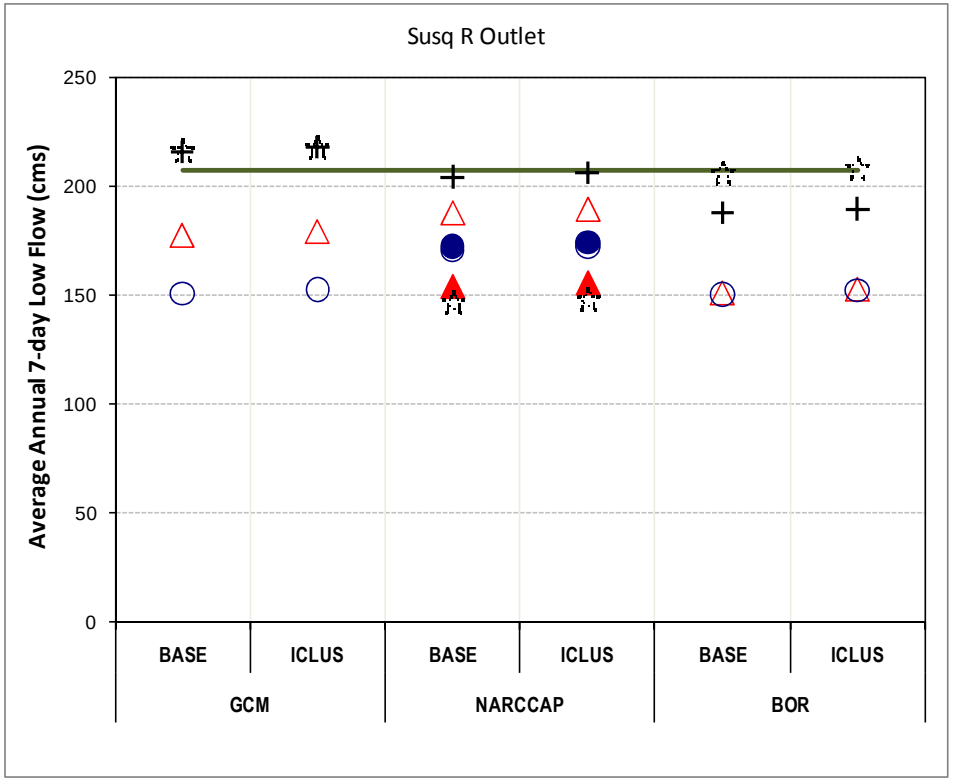


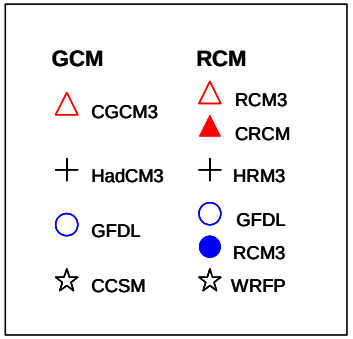
100-yr Flow Peak (Log-Pearson III, cms) Susquehanna River at Outlet (HSPF)



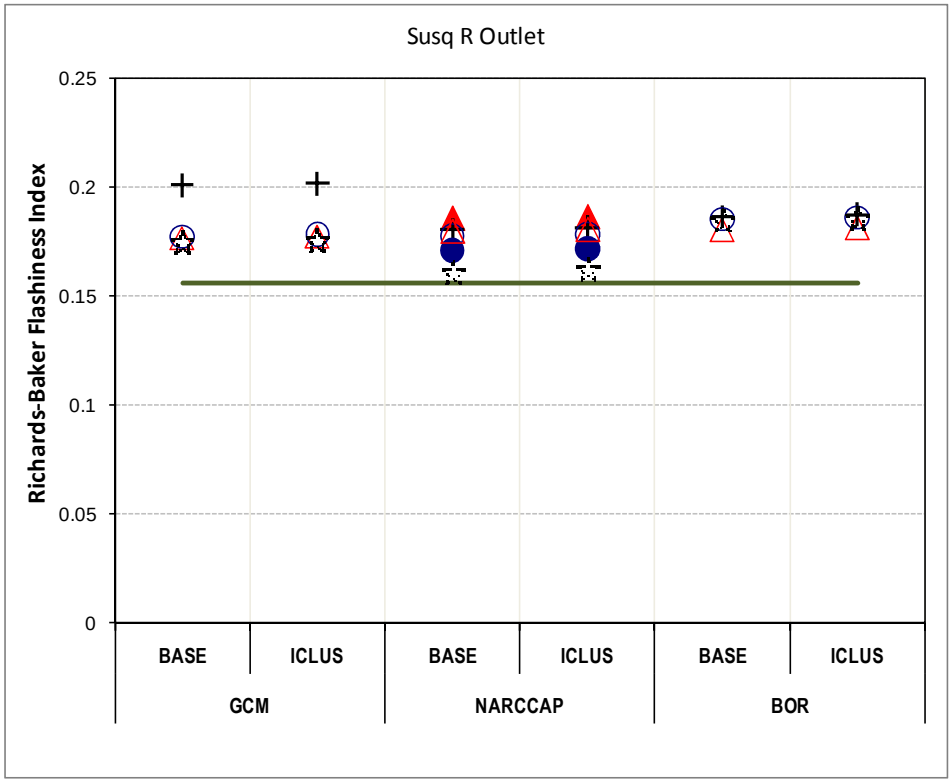


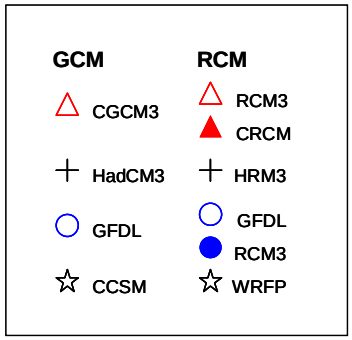
Average Annual 7-day Low Flow (cms)
Susquehanna River at Outlet (HSPF)



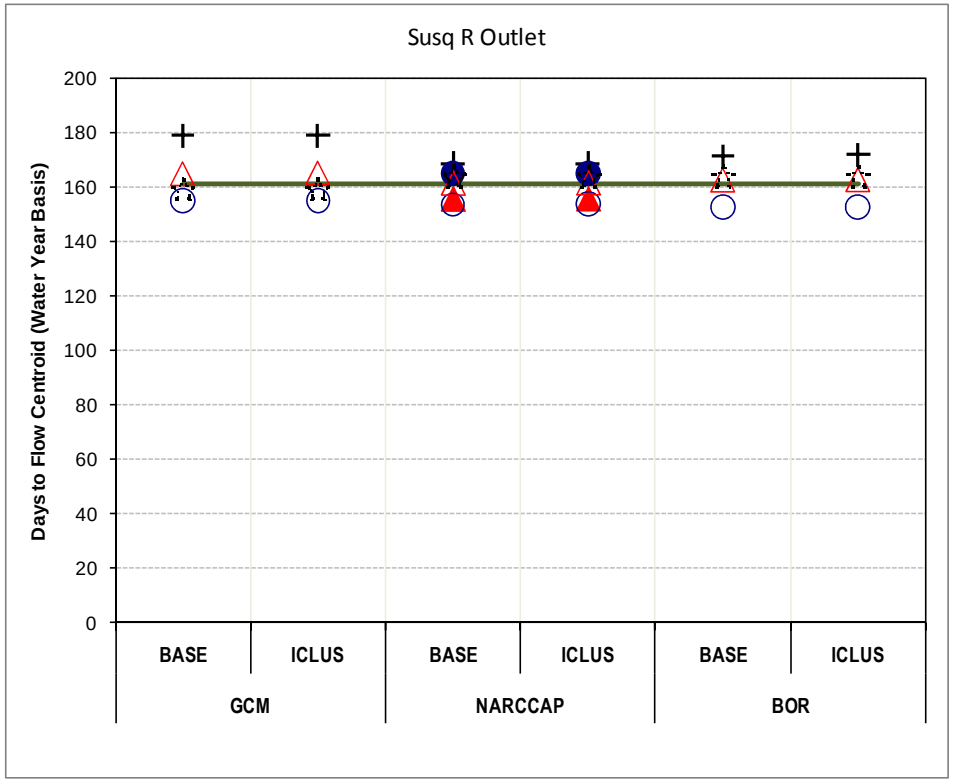


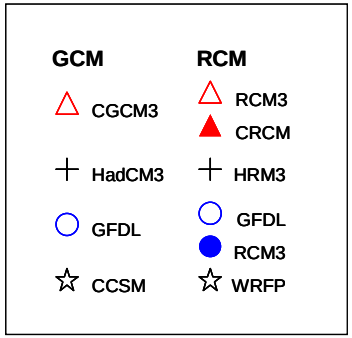
Richards-Baker Flashiness Index
Susquehanna River at Outlet (HSPF)



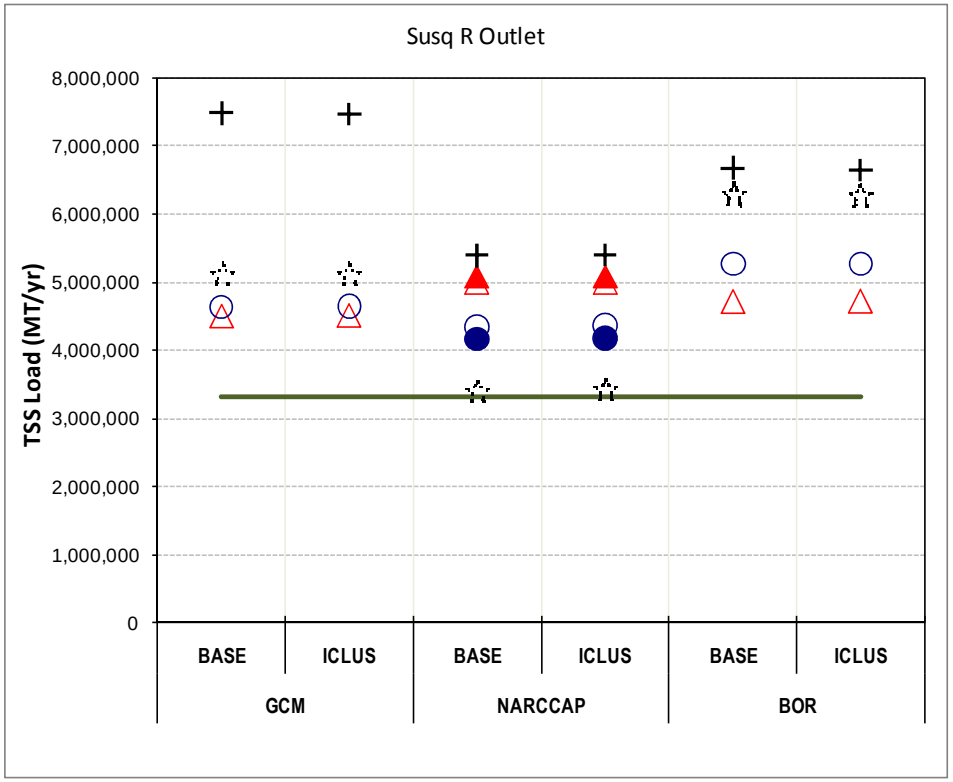


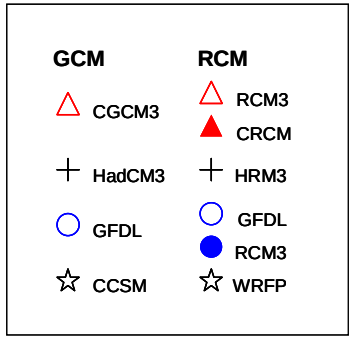
Days to Flow Centroid (Water Year Basis)
Susquehanna River at Outlet (HSPF)



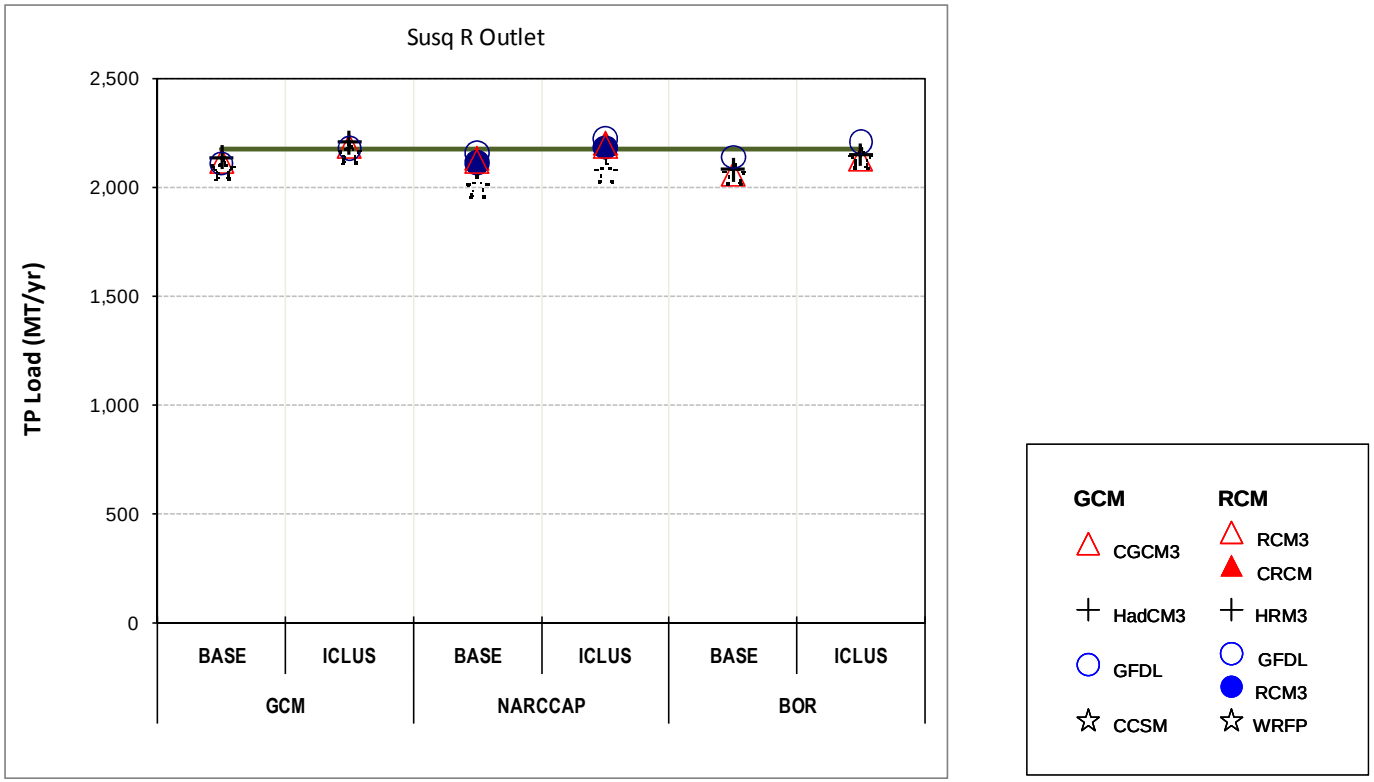


TSS Load (MT/yr)
Susquehanna River at Outlet (HSPF)

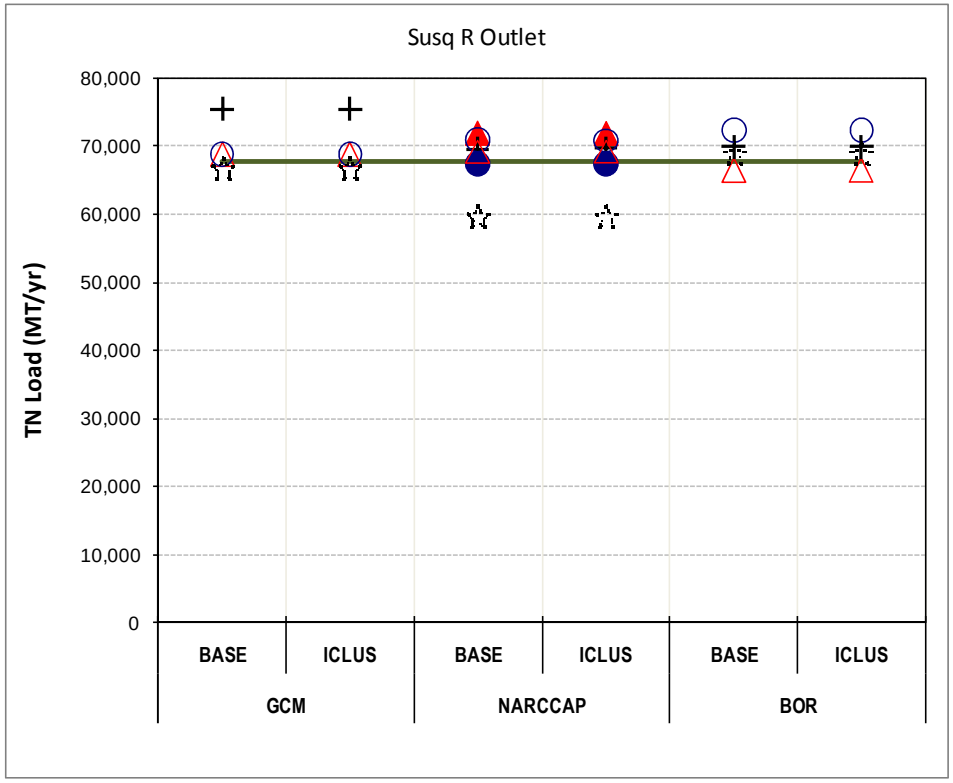


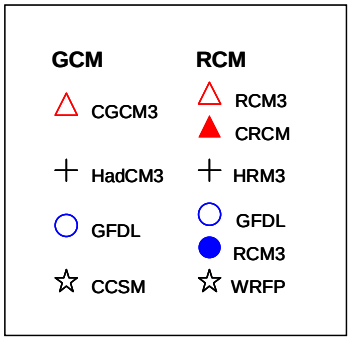


TP Load (MT/yr)
Susquehanna River at Outlet (HSPF)

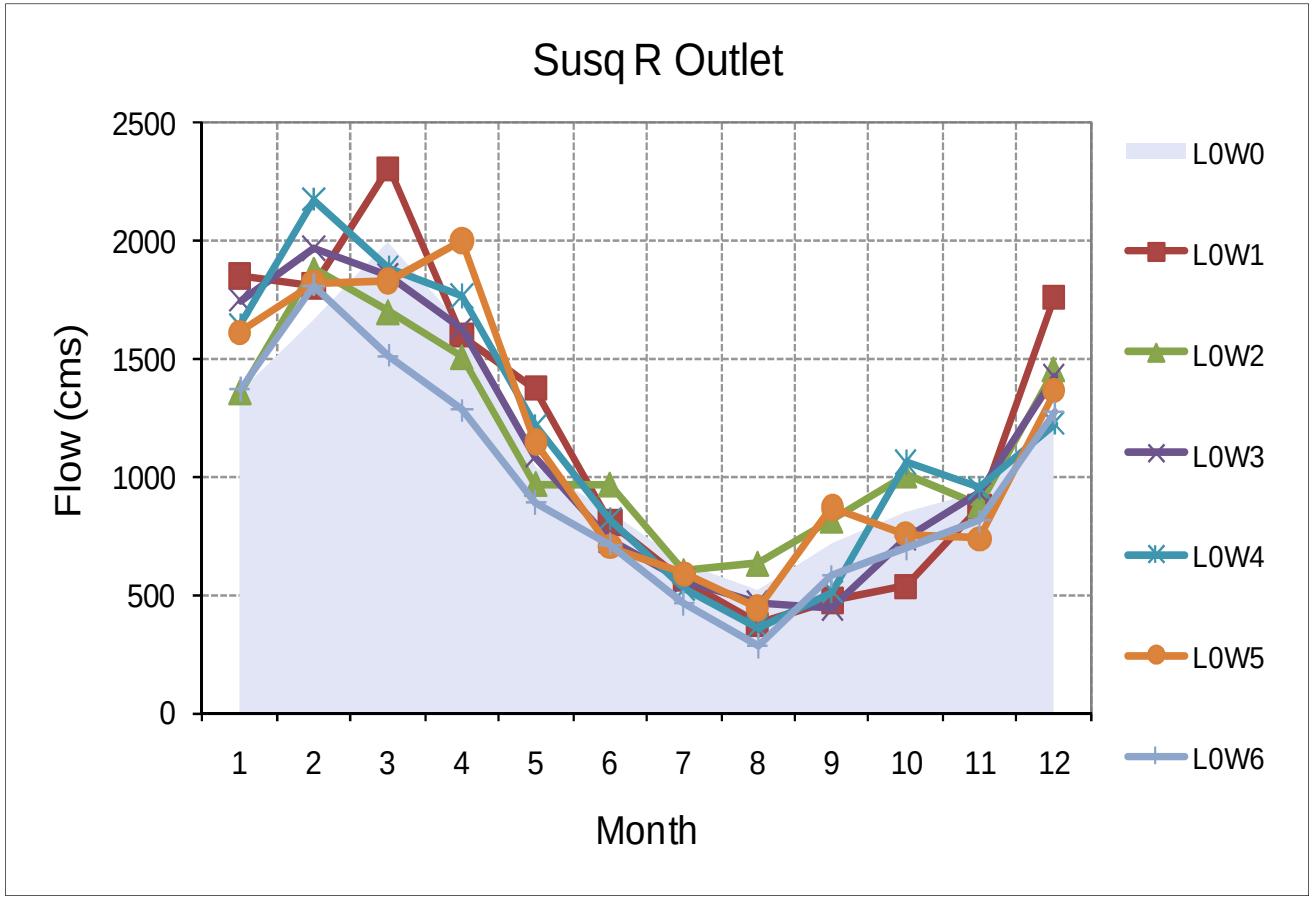


TN Load (MT/yr)
Susquehanna River at Outlet (HSPF)





Monthly Average Flow, Susquehanna River at Outlet; NARCCAP Scenarios W1-W6 (HSPF)



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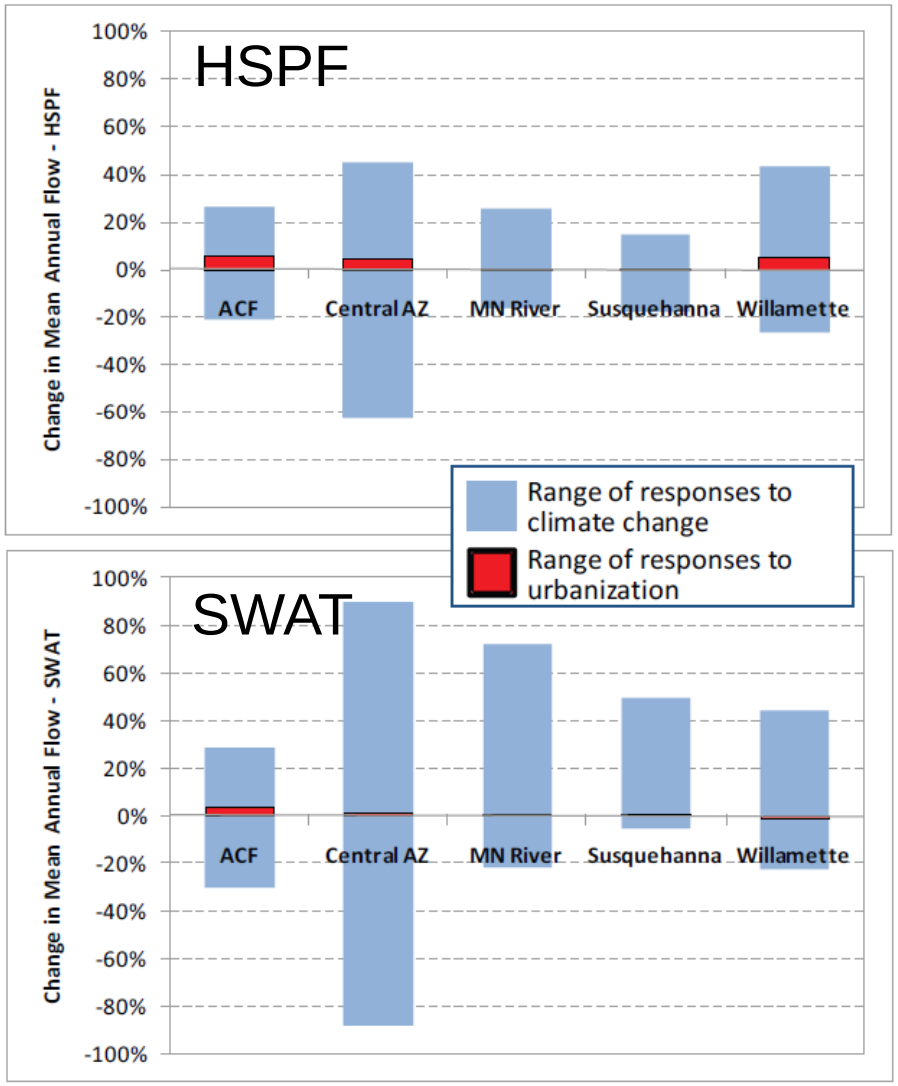
Summary of Future Changes Relative to Current Conditions: NARCCAP Scenarios (HSPF)

	Min	Median	Max
Raystown Branch Juniata River at Saxton			
Flow	-17.79%	-3.98%	14.61%
TN	-17.22%	-2.84%	16.35%
West Branch Susquehanna River at Lewisberg			
Flow	-16.72%	1.85%	7.70%
TN	-13.39%	1.60%	5.46%
Susquehanna River at Danville			
Flow	-11.32%	3.90%	5.02%
TN	-11.12%	1.82%	3.53%
Susquehanna River at Marietta			
Flow	-13.64%	2.41%	5.87%
TN	-12.36%	1.73%	5.10%
Susquehanna River Outlet			
Flow	-13.22%	2.62%	6.26%
TN	-11.69%	2.30%	6.05%

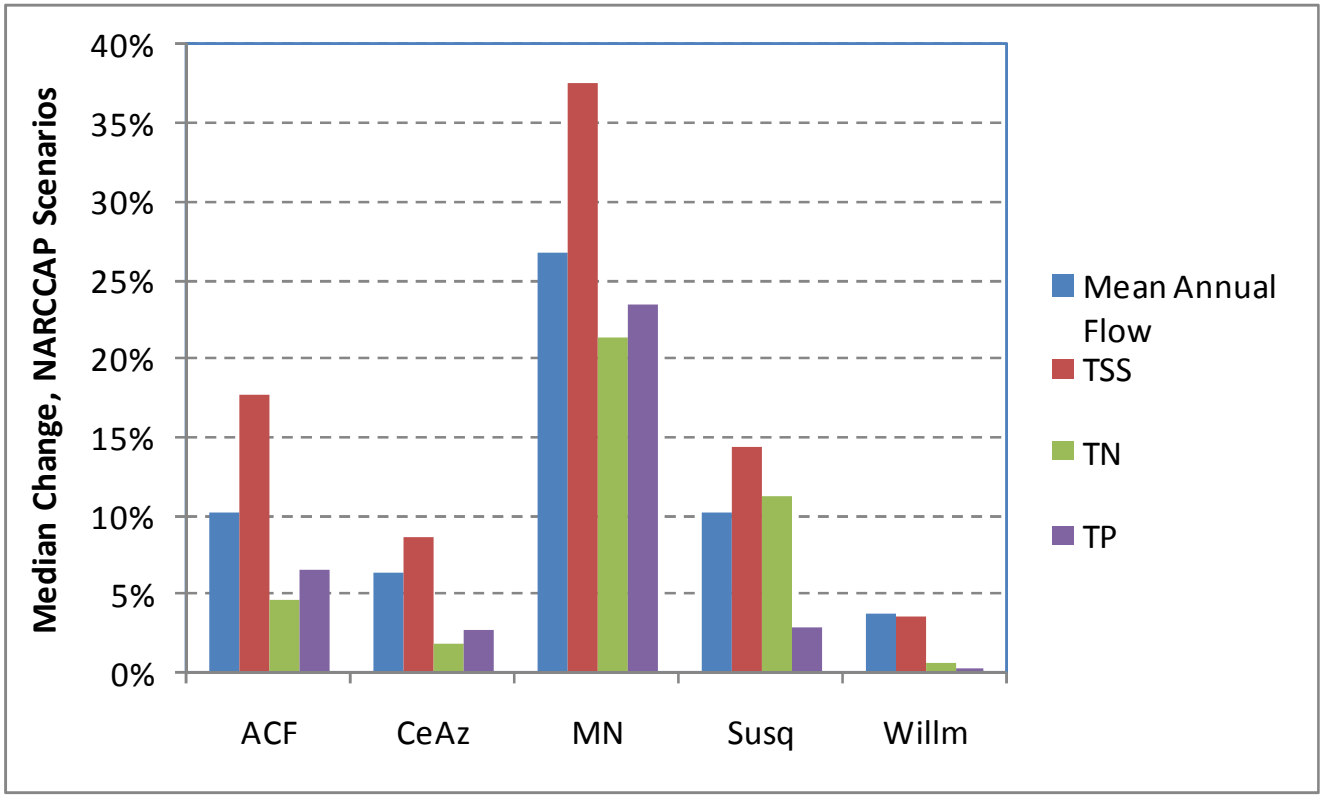
Range of simulated changes in mean annual streamflow in response to projected 2041-2070 climate change (blue) and projected 2050 changes in urban development (red)

Projected % changes in urban land (EPA ICLUS)

ACF	= 3.6
CentralAZ	= 0.5
Minn. River	= 0.7
Susque. R.	= 0.7
Willamette	= 1.4



SWAT Simulated Response to Increased Atmospheric CO_2 Concentration



Closing comments

- **Responding to climate change a challenge due to scale, complexity, and inherent uncertainty; no easy answer**

- **Climate change will occur over time along with significant, short-term variability; no single event will signal the arrival of climate change**

- **Although subject to uncertainty, we know enough to start identifying the range of potential impacts and, where necessary, developing strategies for managing risk**
  - **increasing resilience to a range of plausible future conditions**
  - **thinking holistically about climate in the context of other stressors affecting the Bay**
  - **useful to focus on specific vulnerabilities**

20 Watersheds Project – A Few Insights

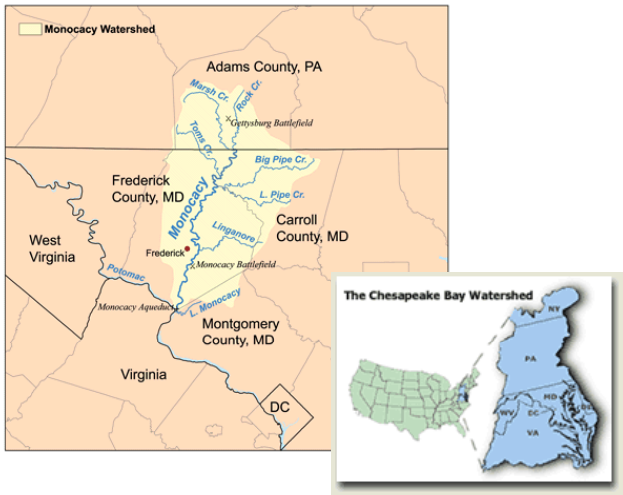
Simulated sensitivity to climate change varies with different endpoints – some scenarios result in reduced flow and increased loading

Different approaches for developing climate change scenarios can increase the variability of simulated watershed response to climate change (e.g., downscaling, change factors)

At the ~HUC8 scale considered here, projected mid-21st century climate change larger influence than urbanization; not true as scale decreases, needs further study

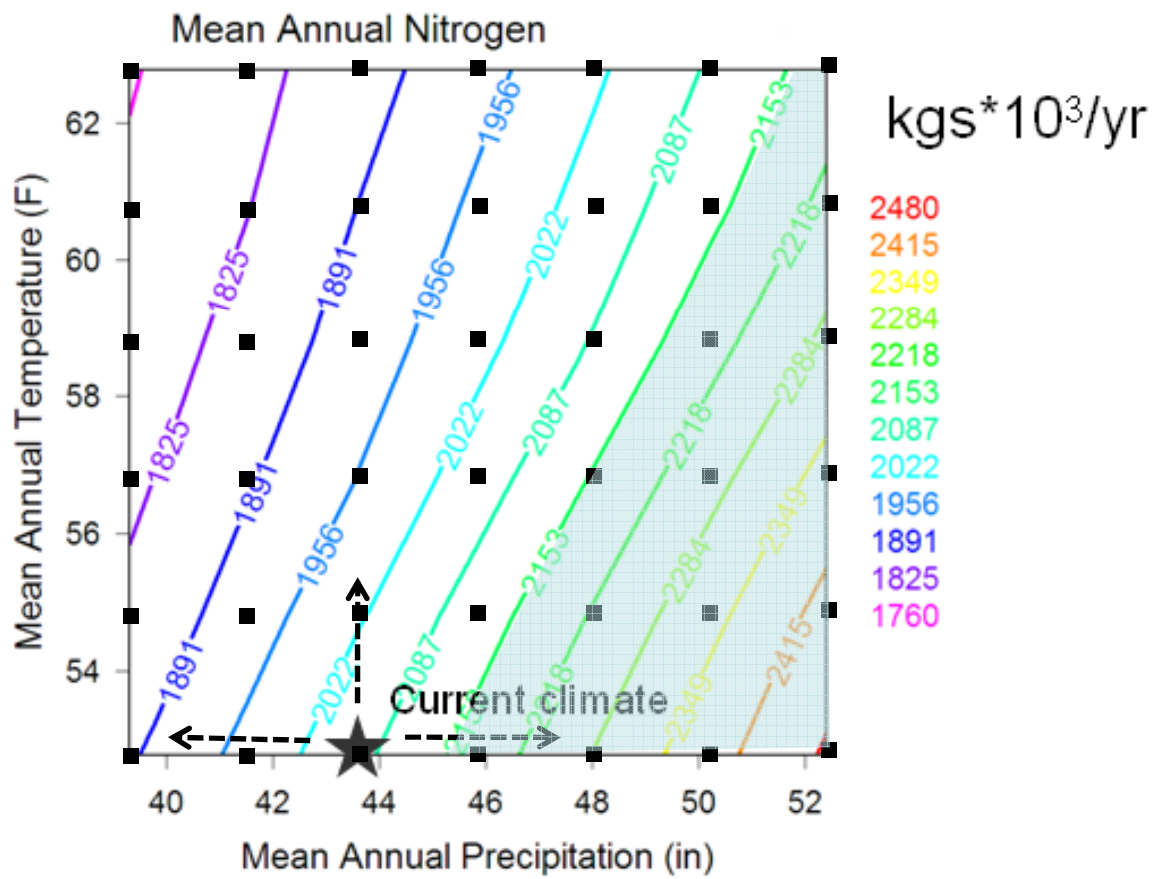
Climate change, urbanization, and increased atmospheric CO_2 can have synergistic effects on streamflow and pollutant loading

Sensitivity of the Monocacy River (MD) to changes in temperature and precipitation



~ 750 mi^2 drainage area

~ 60% ag, 33% forest, 7% urban



A few sources of additional information

- **Draft Report on Chesapeake Bay Watershed Climate Change Impacts: A draft report fulfilling Section 202(d) of Executive Order 13508, 2009.** (http://executiveorder.chesapeakebay.net/file.axd?file=2009%2F9%2F202(d)+Climate+Change+Draft+Report.pdf)

- **Climate Change and the Chesapeake Bay: State of the Science Review and Recommendations, 2008, STAC Report.** (www.chesapeake.org/stac/Pubs/climchangereport.pdf)

- **Penn State Univ. Consortium for Atlantic Regional Assessment (CARA) Web Page.** (www.cara.psu.edu/)

- **Confronting Climate Change in the U.S. Northeast, 2007, UCS.** (www.climatechoices.org/assets/documents/climatechoices/confronting-climate-change-in-the-u-s-northeast.pdf)

- **Johnson, T., J. Butcher, A. Parker, and C. Weaver, 2011. Investigating the Sensitivity of U.S. Streamflow and Water Quality to Climate Change: The U.S. EPA Global Change Research Program's "20 Watersheds" Project , J*. Water Resources Planning and Management* doi:10.1061/(ASCE)WR.1943-5452.0000175**

(http://ascelibrary.org/wro/resource/3/jwrmxx/129?isAuthorized=no)

- **Najjar, Ray, 1999. The water balance of the Susquehanna River Basin and its response to climate change, *Journal of Hydrology* 219:7-19**

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Thanks!

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