2012

Use of HSPF and SWAT Watershed Models for Climate Response Simulation

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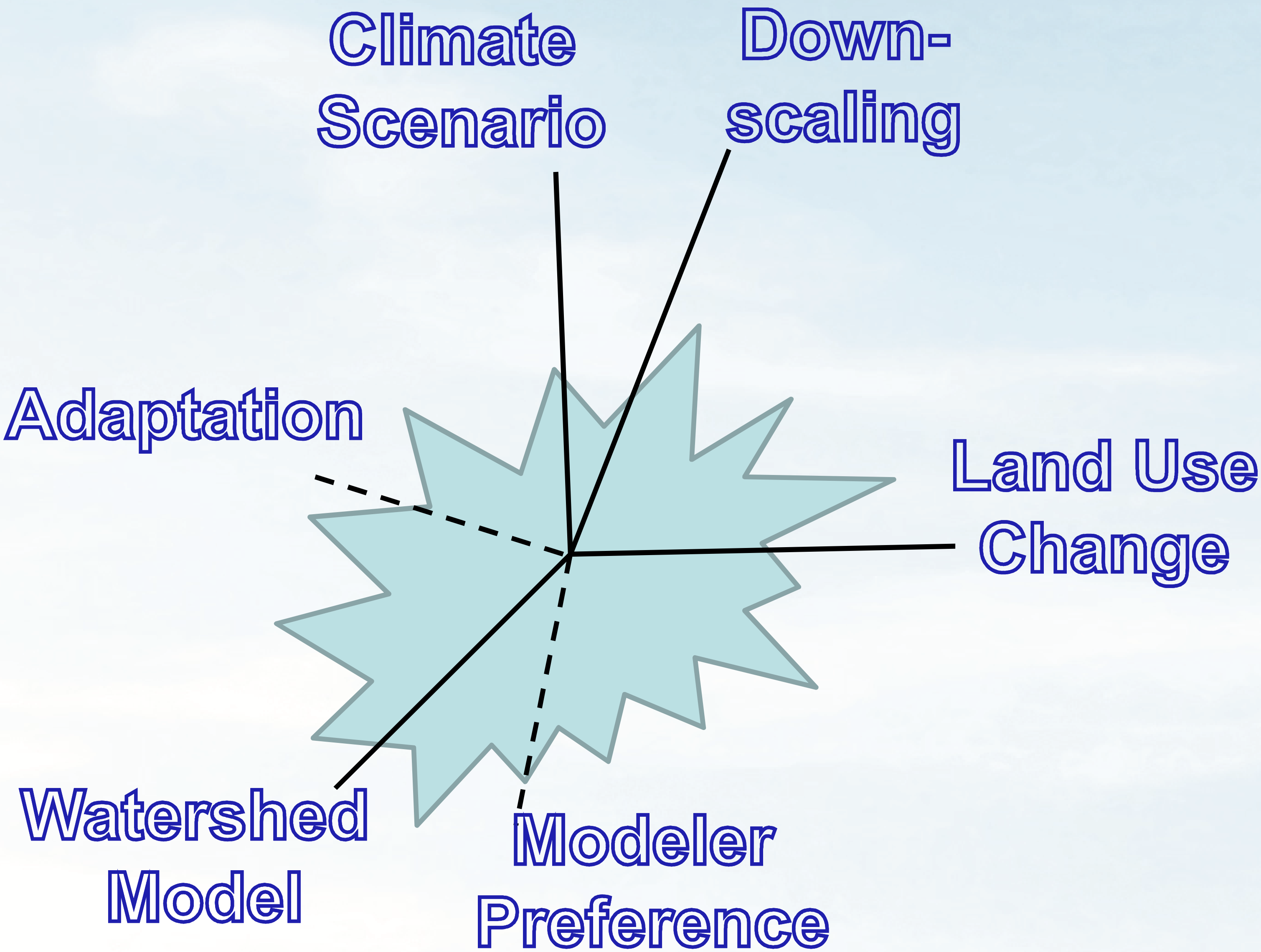
50 Years of Watershed Modeling, Boulder, 2012

Funding for this work was provided by the U.S. Environmental Protection Agency. 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 (EPA).

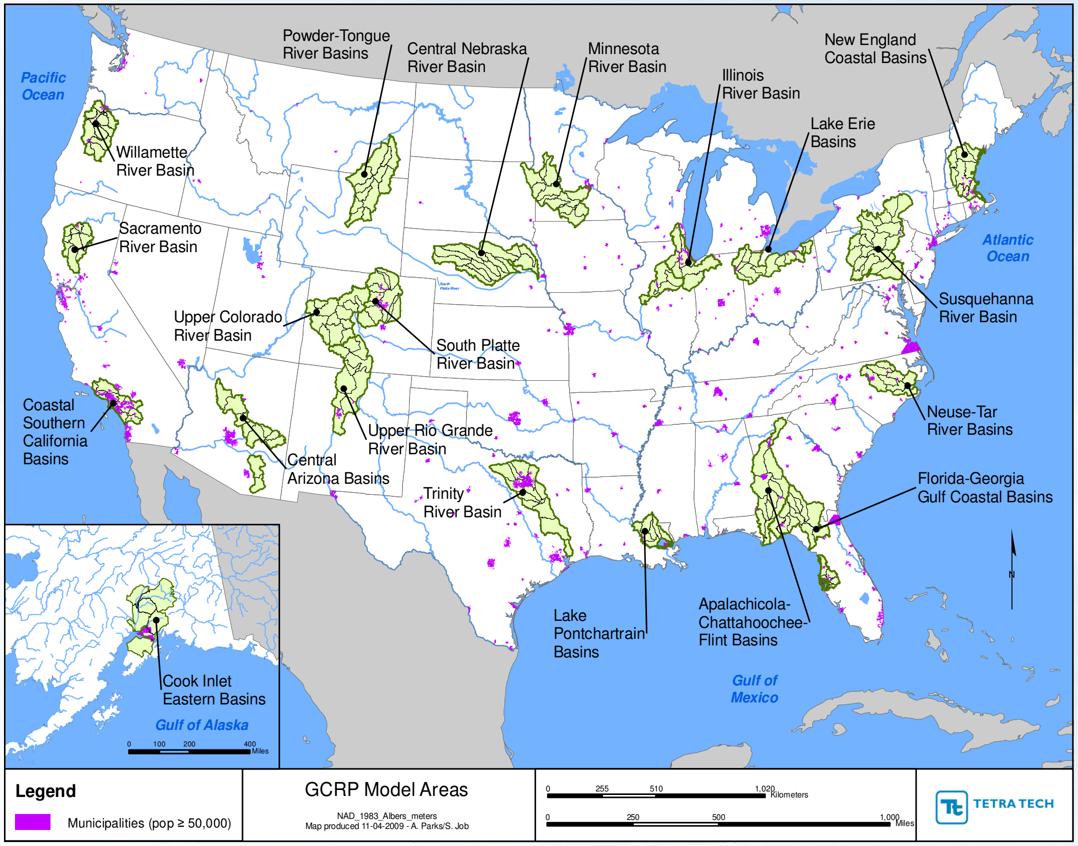
Axes of Uncertainty: Simulating the Future



The 20 Watersheds Study

- ► National scale study – 20 watersheds
- ► Funded by USEPA Office of Research and Development (ORD) – Global Change Research Program (GCRP)

- Assess the sensitivity of hydrologic and water quality endpoints to ~2055 climate and land use conditions
- Evaluate the effects of different watershed models and methods of downscaling climate change information on the variability of outcomes
- EPA Report in peer review



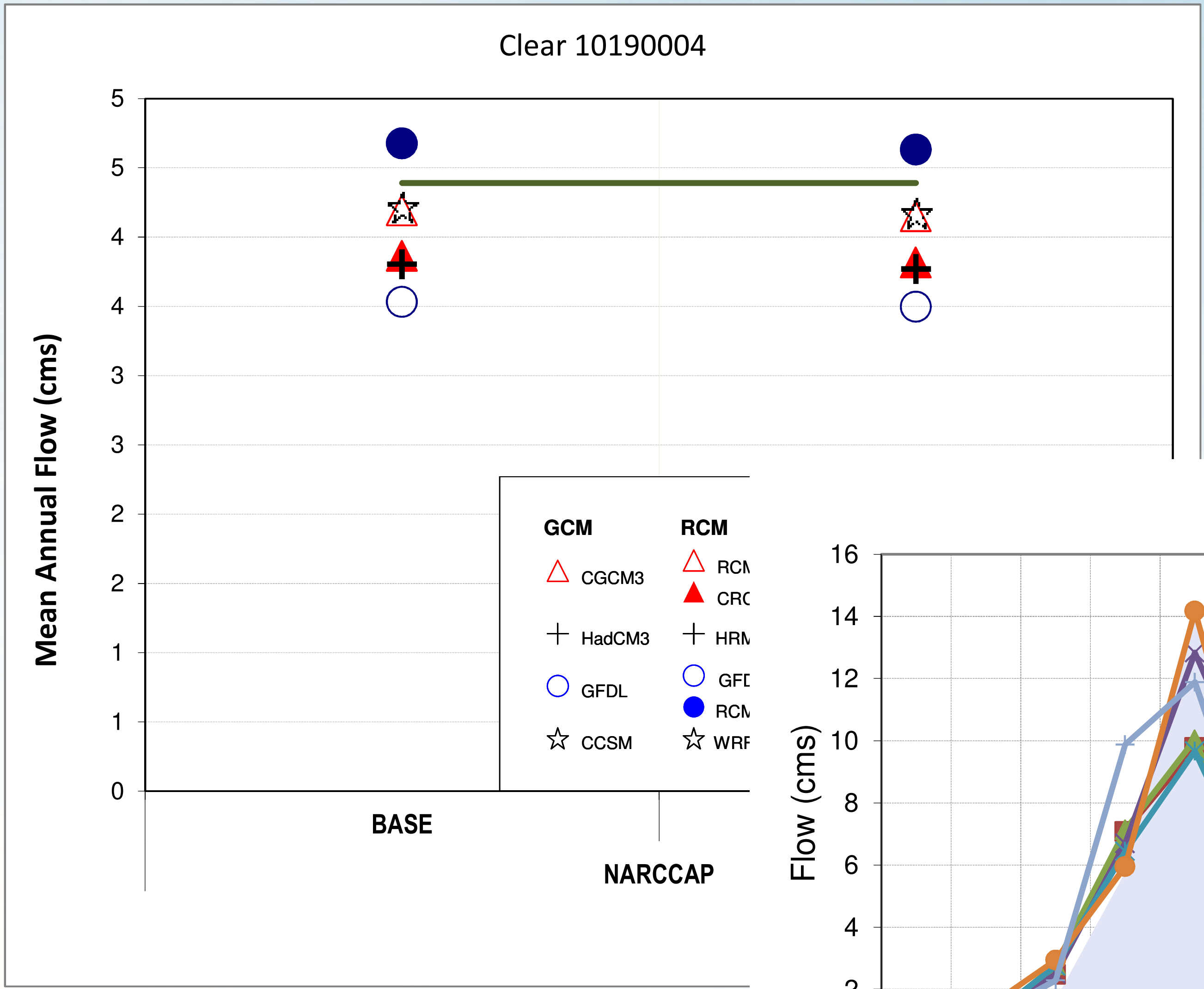
Approach

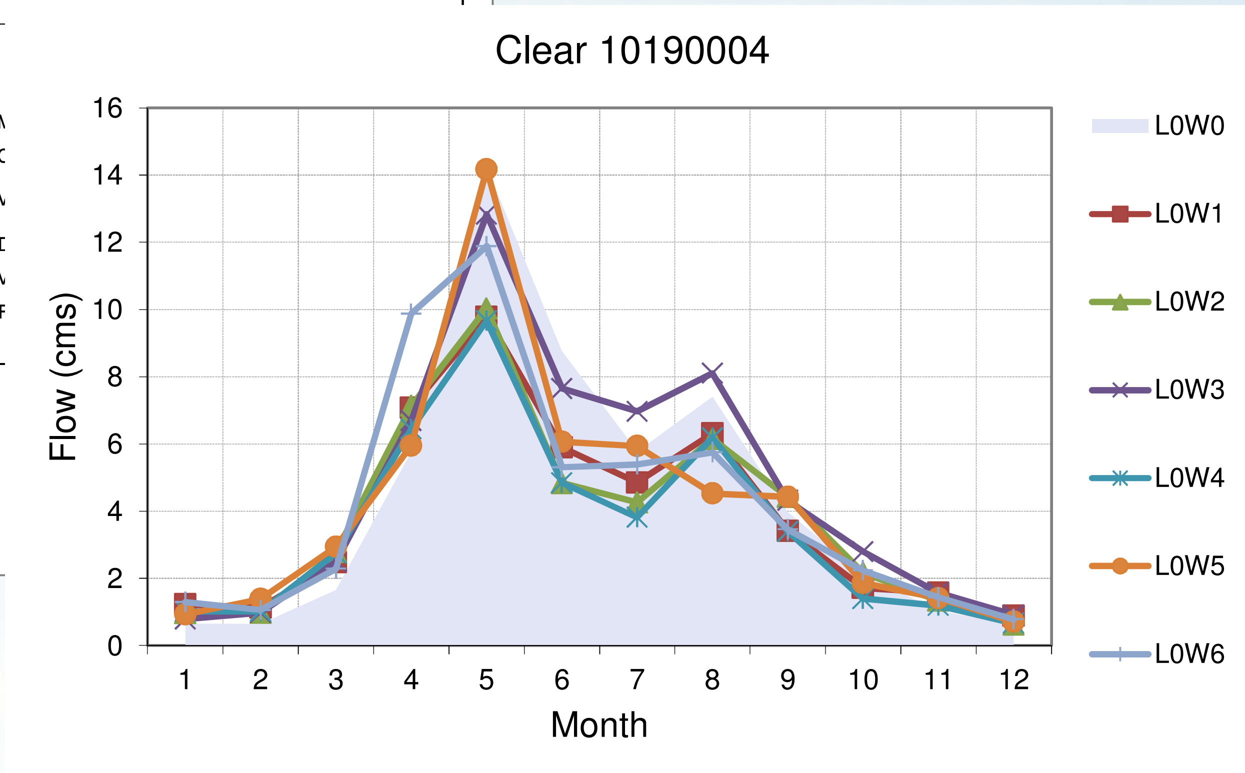
- Develop and calibrate dynamic watershed models at a daily or sub-daily time step
  - Models typically employed for water quality and quantity management
  - Hydrology and water quality (nutrients and sediment)
- Access and process an ensemble of climate change modeling data
- Ensemble approach: simulate range of potential futures to which adaptation may be required
  - Assess sensitivity of different endpoints to range of plausible climate futures

Study Areas

- 10,000-30,000 mi^2 total area (~10 HUC-8s)
  - Subwatersheds at HUC-10 scale (~10 per HUC-8)
- USGS 2001 National Land Cover Data
- Hydrologic Response Unit (HRU) approach with overlay of land use, soils, slope
- Calibration (generally 1991-2001) and validation (generally 1981-1991) for both flow and water quality
- Five "pilot" sites used to compare watershed model selection effects across multiple change scenarios

Typical Results





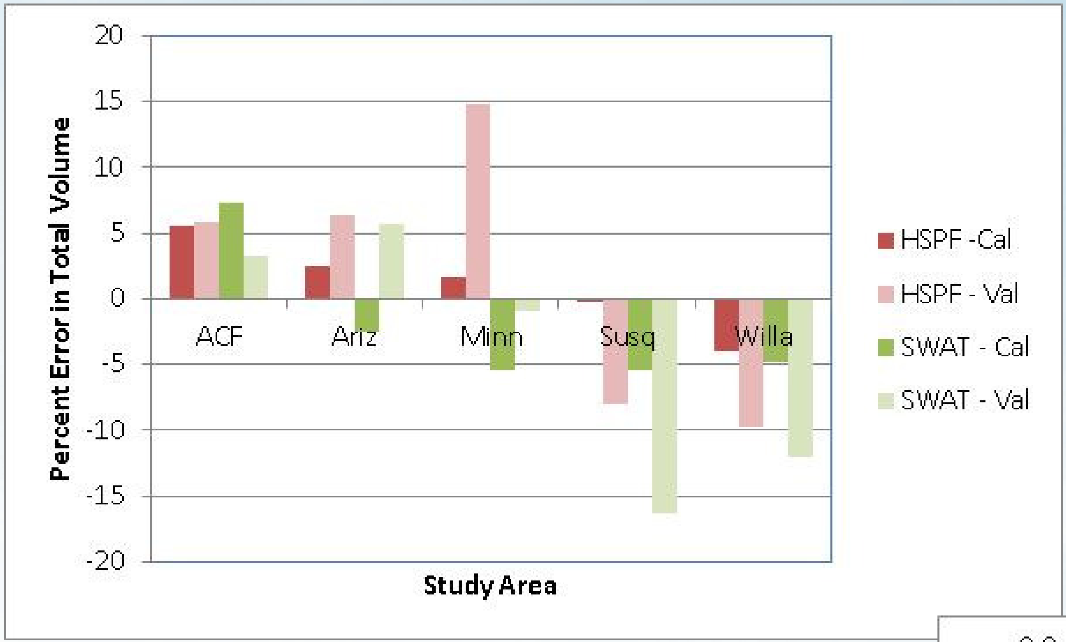
Watershed Model Selection

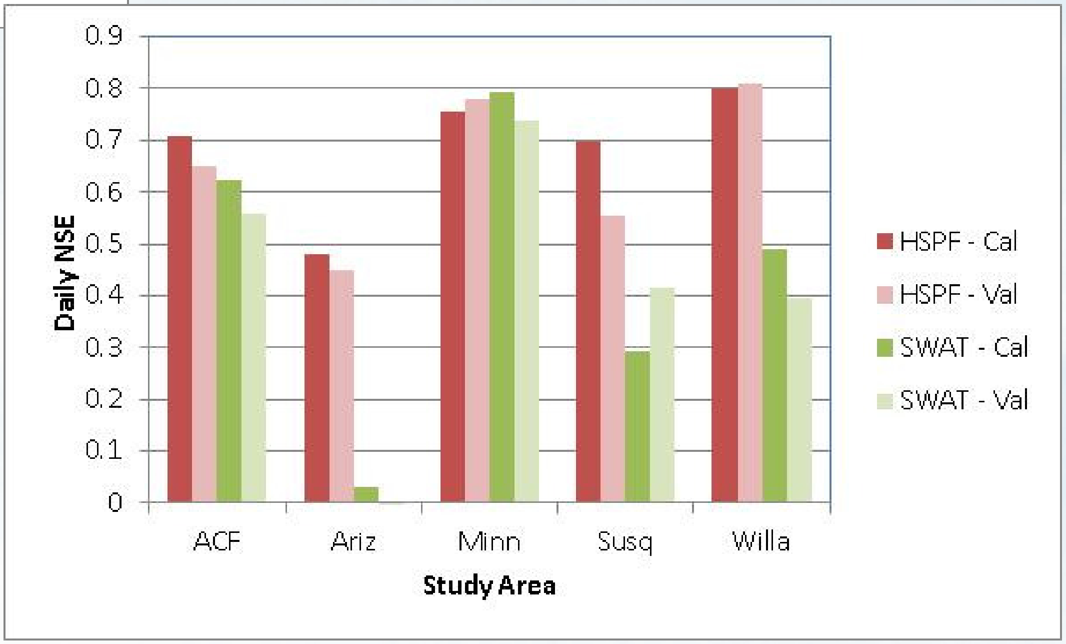
- *Management* models that address both quantity and quality
- Selected HSPF and SWAT as models most frequently used in TMDLs and water supply protection studies
  - Common basis:
    - Same subbasins, reach network
    - Common HRU overlay
  - WinHSPFLt (stable code)
  - SWAT2005 (evolving code)

Model Calibration (artistic biases)

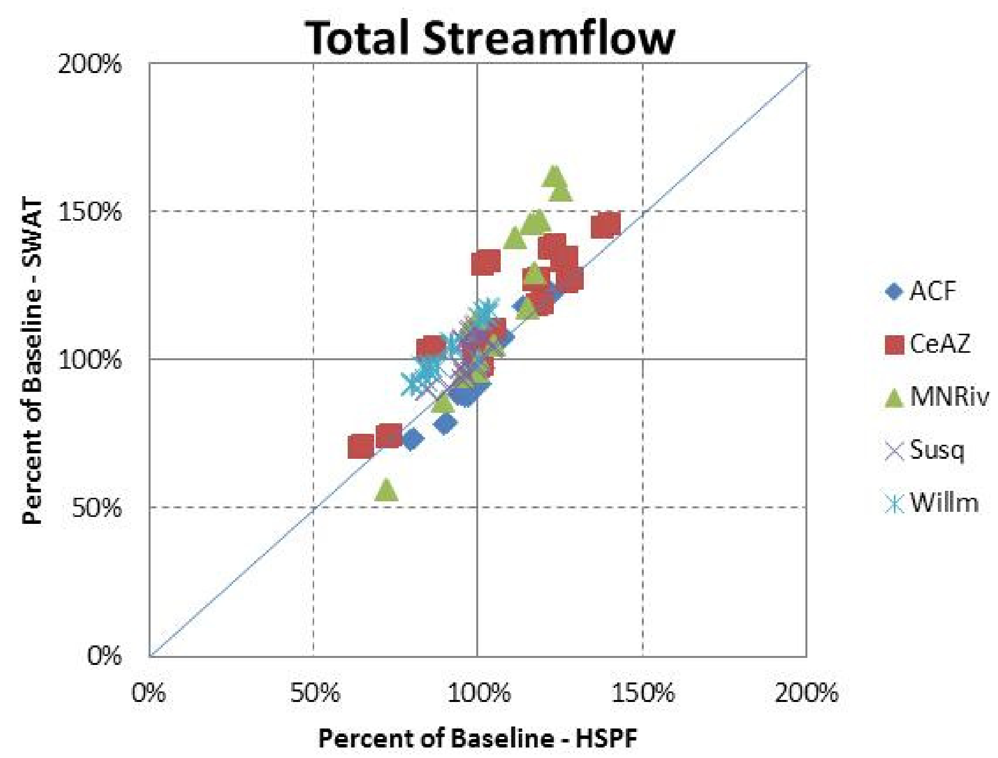
- *It's not news, but:* Neither model performed particularly well without site-specific calibration
  - Calibration and validation according to model QAPP
  - Multi-firm teams of modelers
  - Calibration to multiple sites within an area improved performance (overfitting?)
  - Modeler style and preference plays a role in results

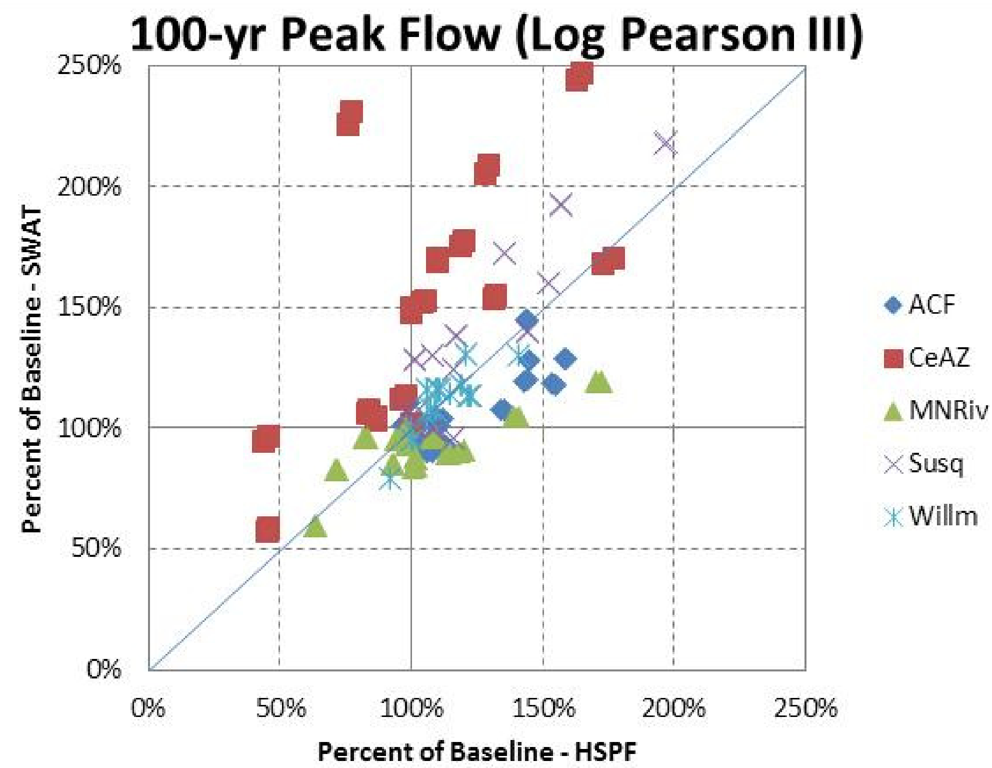
Flow Calibration





Model Consistency: Flow





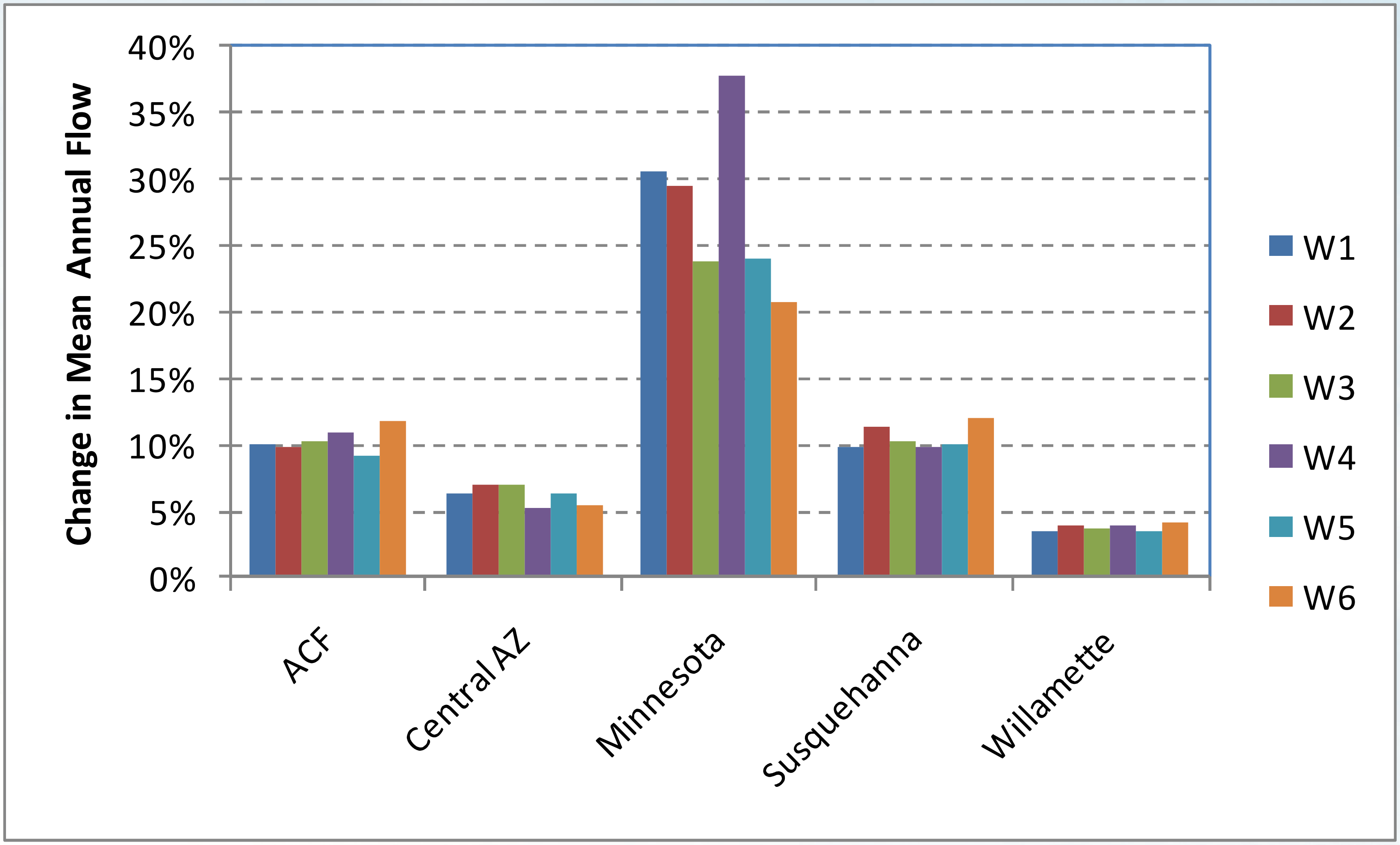
Why does SWAT yield a consistent increase?

Effects of Increased CO_2 on Plant and Watershed Response (SWAT)

- ► CO_2 expected to increase from about 370 to 530 ppmv by 2055
- ❖ Plants do not need to transpire as much water to obtain CO_2 for growth
- ► Effects on ET may help counterbalance increased temperature
- ► Experimental work suggests mid-21st century CO_2 increases could reduce ET water losses by around 10%
- ► SWAT can incorporate this ***if*** Penman-Monteith ET is used
- ► Response to increased CO_2 is complex and not fully understood

Effects of Increased CO_2 on Plant and Watershed Response

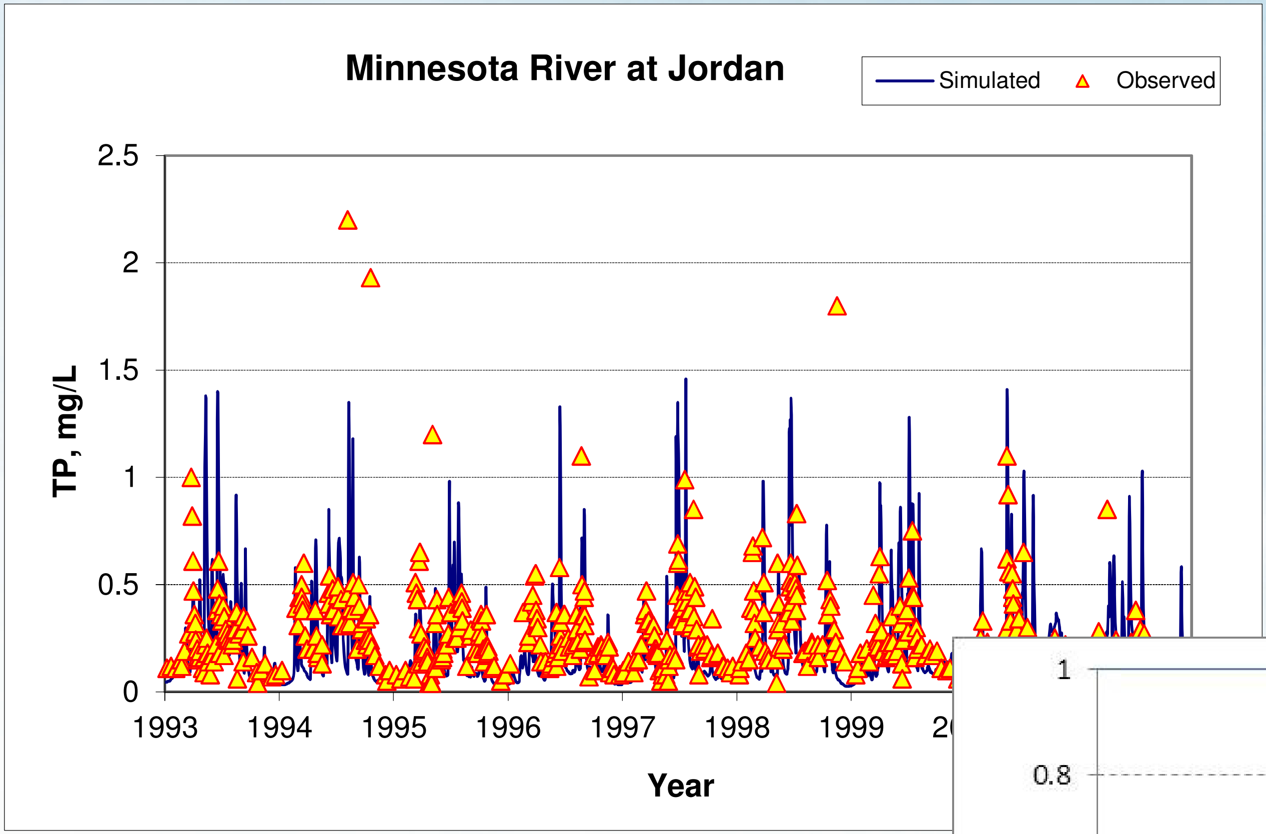
- Six NARCCAP GCM/RCM combinations across five watersheds (SWAT with and without CO_2 increase):



Representation of Intensification

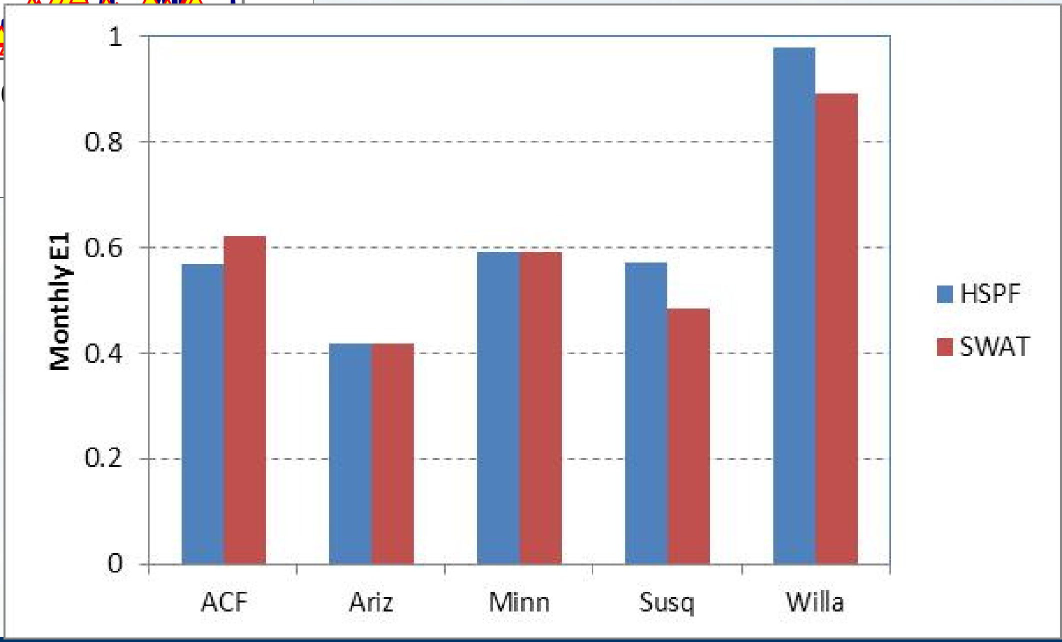
- Climate models suggest intensification of precipitation (greater volume in extreme events)
- Approach modifies existing series with intensification of top 30% events based on bin analysis of GCM/RCM 3-hr output
- HSPF (Philip infiltration) captures intensification directly with hourly rainfall
- SWAT (w/ daily curve number) represents volume change; intensification through the RAINHHMX parameter – which is not reliably available from climate models

Water Quality Simulation

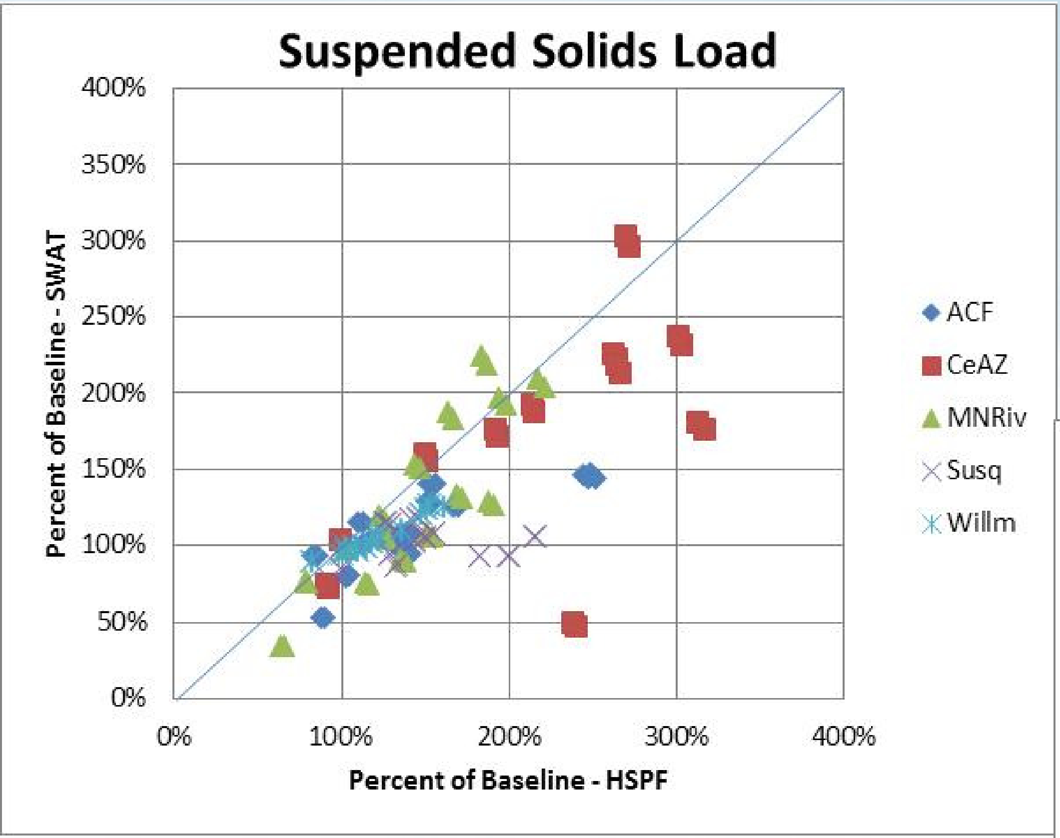


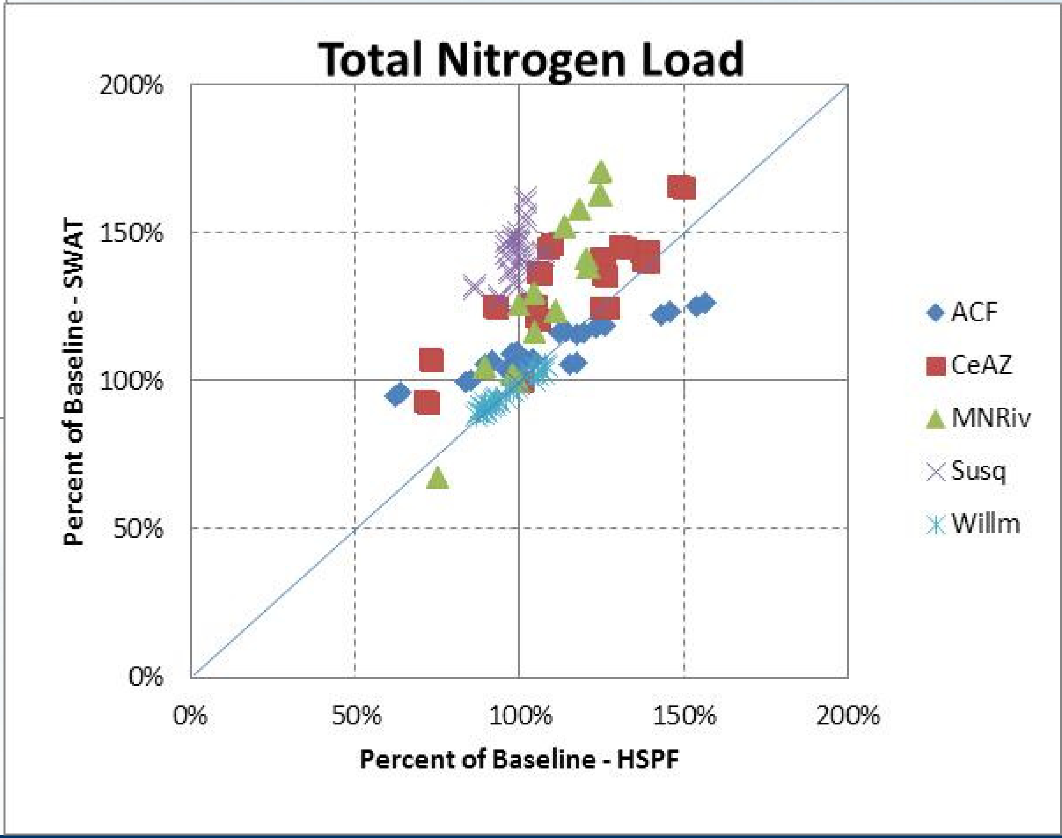
Concentration

Load



Model Consistency: Water Quality





Model Consistency: Water Quality

- Sediment transport
  - MUSLE (SWAT) vs. detachment/transport
  - Channel processes play a big role at the large basin scale
- Phosphorus yield
  - Largely follows sediment transport simulation
- Nitrogen yield
  - Mostly dependent on baseflow simulation
  - Plant growth simulation yields advantages in future climate evaluations
- CO_2 fertilization impacts
  - Greater antecedent soil moisture and runoff -> greater solids and nutrient loads

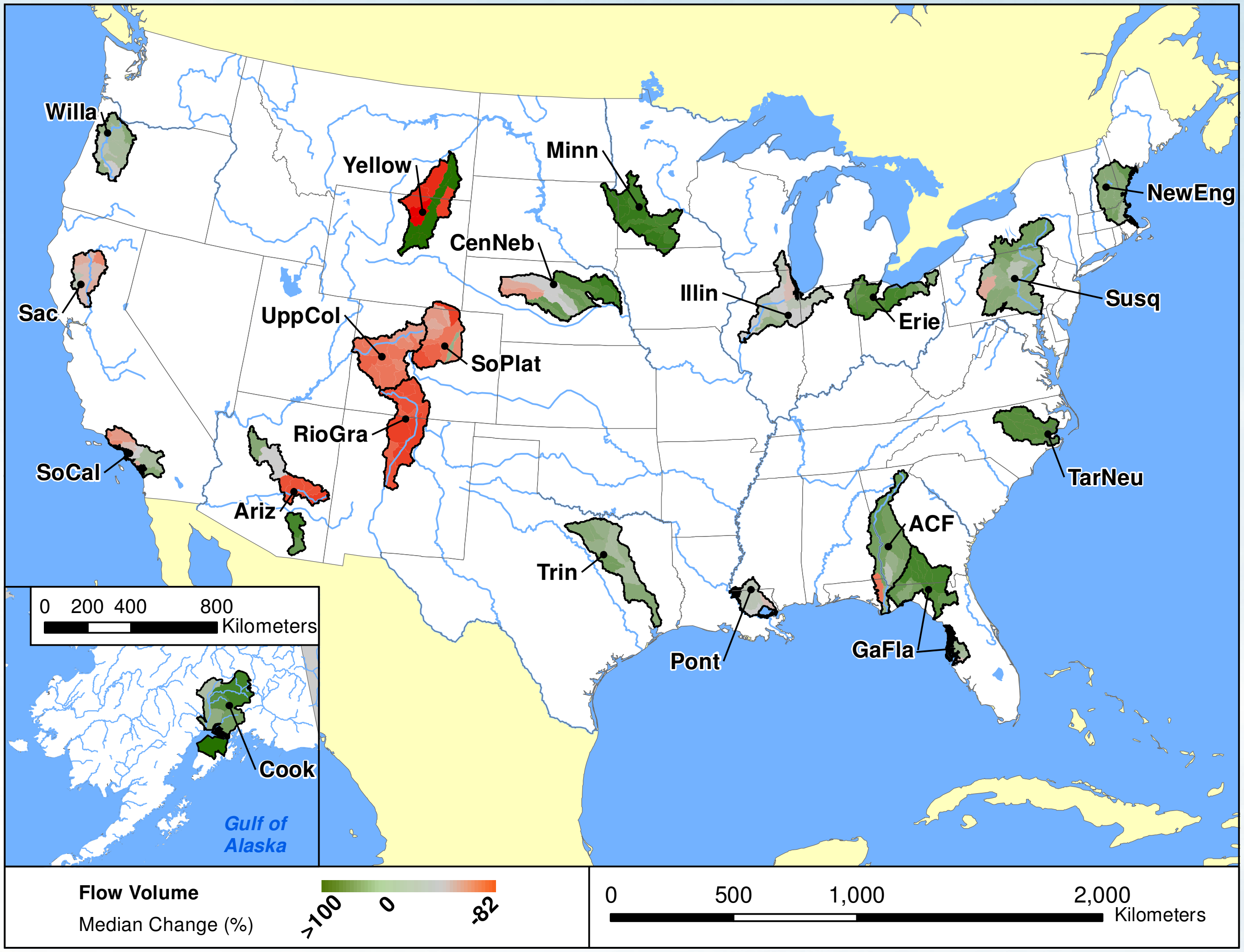
Improving the Models for Simulating Climate Response

- HSPF:
  - addressing CO_2 fertilization effects: systematic modification of LZETP?
  - Climate impacts on plant nutrient requirements
  - Heat units scheduling of Special Actions, cover
- SWAT:
  - Need better accounting for precipitation intensity changes?
  - Improve erosion simulation through implementation of Green-Ampt; MUSLE adjustments, channel processes
  - Energy balance impacts on snow melt
- Can we get a combo?

Things not addressed in either model

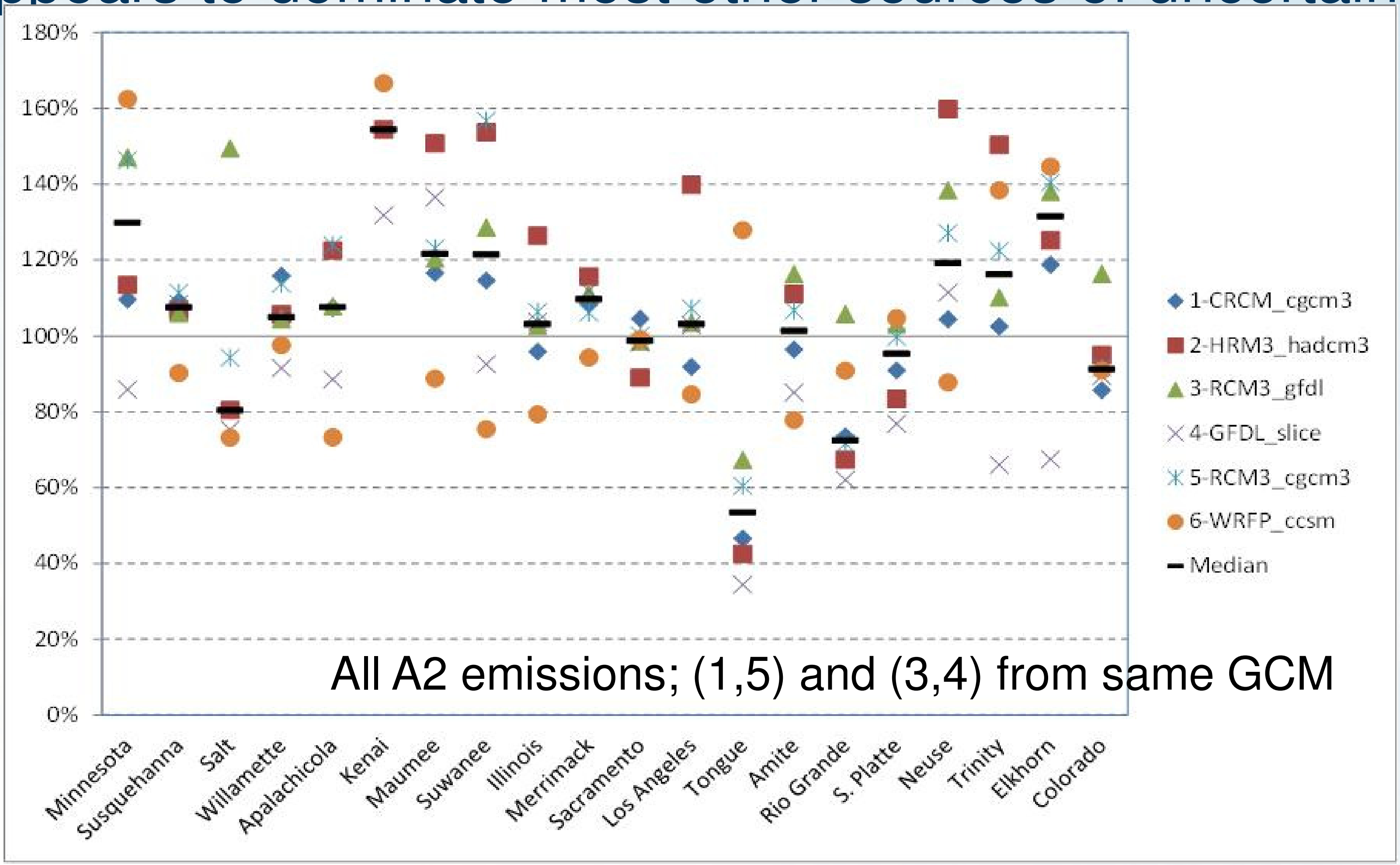
- System feedbacks and adaptation
- Climate change can lead to
  - Changes in crop type
  - Changes in crop management (HU approach a plus here)
  - Fire regime
  - Flood regime
  - Pest/disease intensity
  - Water availability impacts on agriculture and development
- Other changes in human use and management
- Purpose is to explore vulnerability, not predict specific o outcomes

Central tendency suggests the possible risk envelope for adaption



But…

- Uncertainty in downscaled climate projections still appears to dominate most other sources of uncertainty



Conclusions

- ► Ensemble approach needed to evaluate risk across range of potential outcomes
- ► Watershed model "filter" is one of the axes of uncertainty
- ► Attention to model assumptions (and modeler assumptions) is important
- ► Complexity (process detail) versus simplicity (rapid evaluation of many options) is an ongoing debate
- ► There is room for improvement in our existing tools for converting climate signals to watershed responses

Acknowledgments

- Thanks to the following co-investigators and contributors:
  - Thomas Johnson, Christopher Weaver (USEPA ORD GCRP)
  - John Imhoff, Brian Bicknell, Paul Duda, Jack Kittle, Paul Hummel, Tony Donigian (AQUA TERRA)
  - R. Srinivasan, Pushpa Tuppad, Deb Debjani (Texas A&M)
  - Mustafa Faizullabhoy, Scott Job, Jeremy Wyss (Tetra Tech)
- *Funding for this research was provided by the U.S. Environmental Protection Agency (EPA) through its Office of Research and Development. 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.*
- *We wish to thank the North American Regional Climate Change Assessment Program (NARCCAP) for providing the data used in this presentation. NARCCAP is funded by the National Science Foundation, the U.S. Dept. of Energy, the National Oceanic and Atmospheric Administration, and the U.S. Environmental Protection Agency Office of Research and Development.*
- *We also acknowledge the use of bias-corrected and spatially downscaled climate predictions derived from CMIP3 data and served at: http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections (Maurer et al. (2007))*

Questions?

- Contact: Dr. Jon Butcher, Tetra Tech, jon.butcher@tetratech.com
- Johnson, T., Butcher, J., Parker, A., and Weaver, C. (2012). "Investigating the Sensitivity of U.S. Streamflow and Water Quality to Climate Change: U.S. EPA Global Change Research Program's 20 Watersheds Project." *J. Water Resour. Plann. Manage.*, 138(5), 453–464. doi: 10.1061/(ASCE)WR.1943-5452.0000175