Use of HSPF and SWAT Watershed Models for Climate Response Simulation

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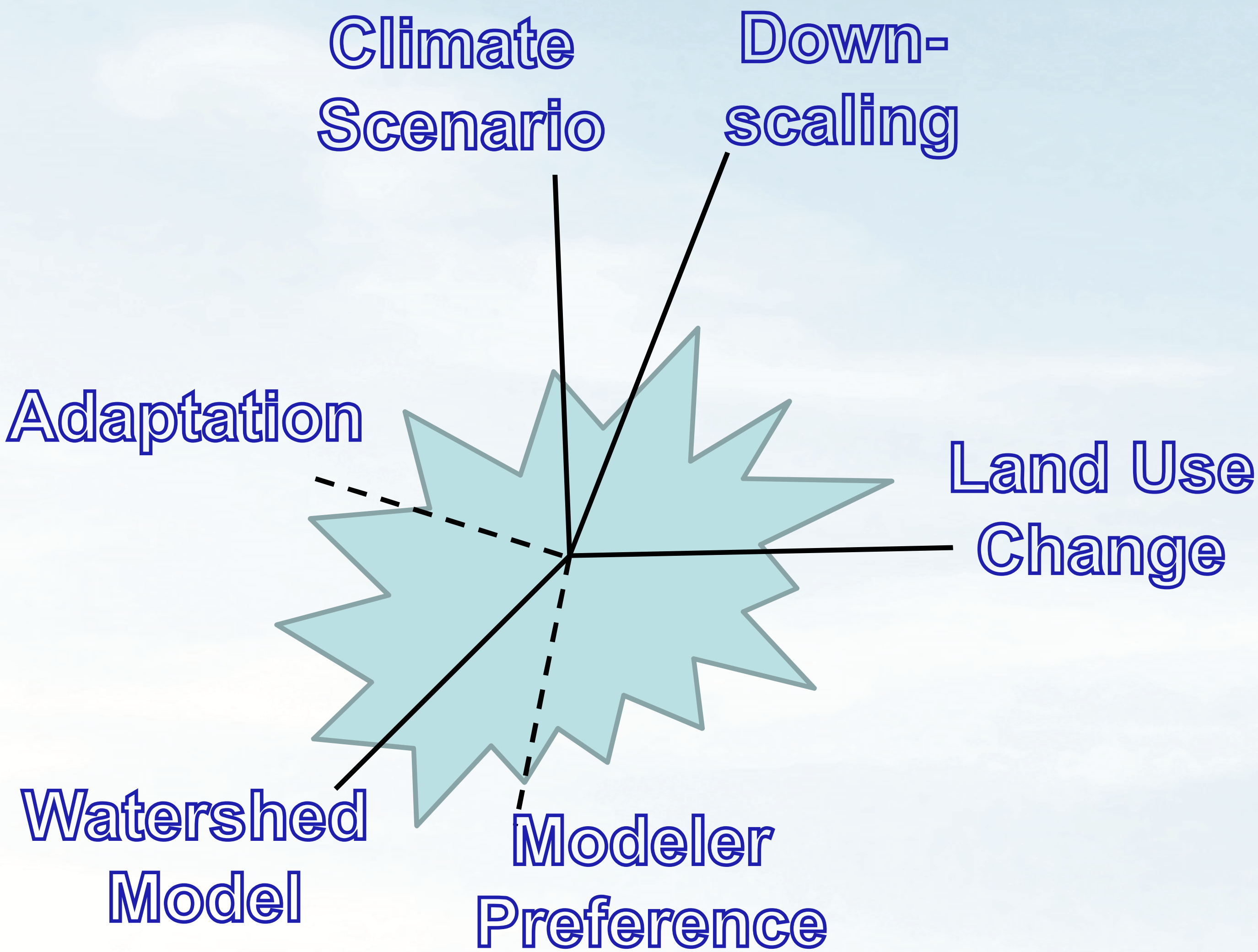
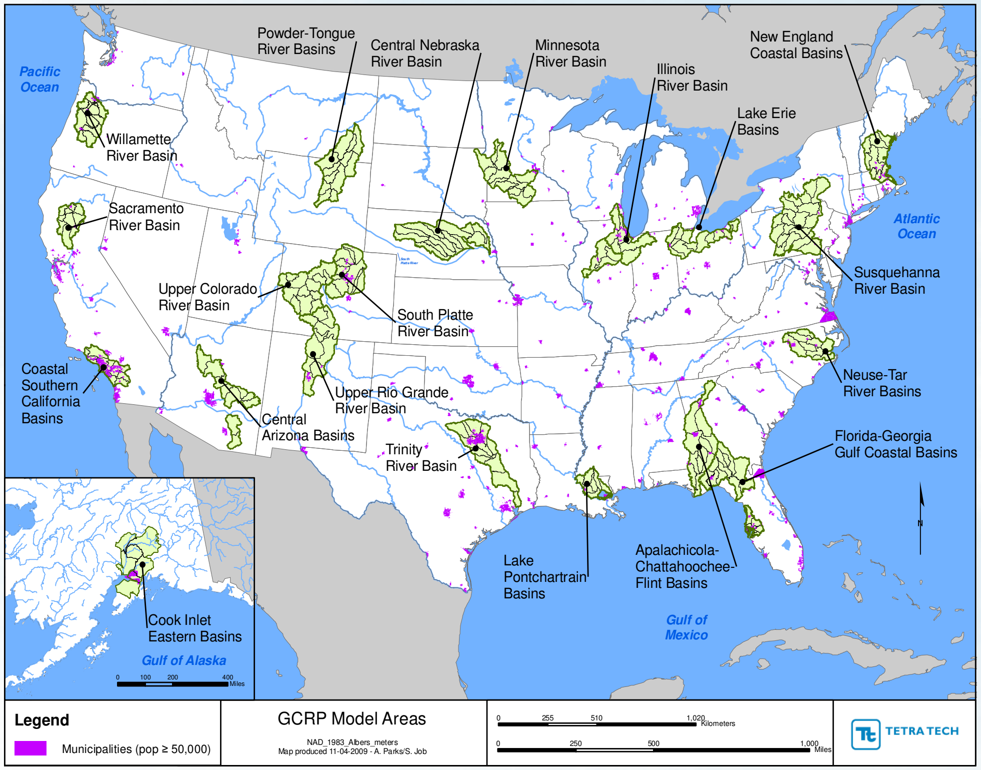
Axes of Uncertainty: Simulating the Future



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



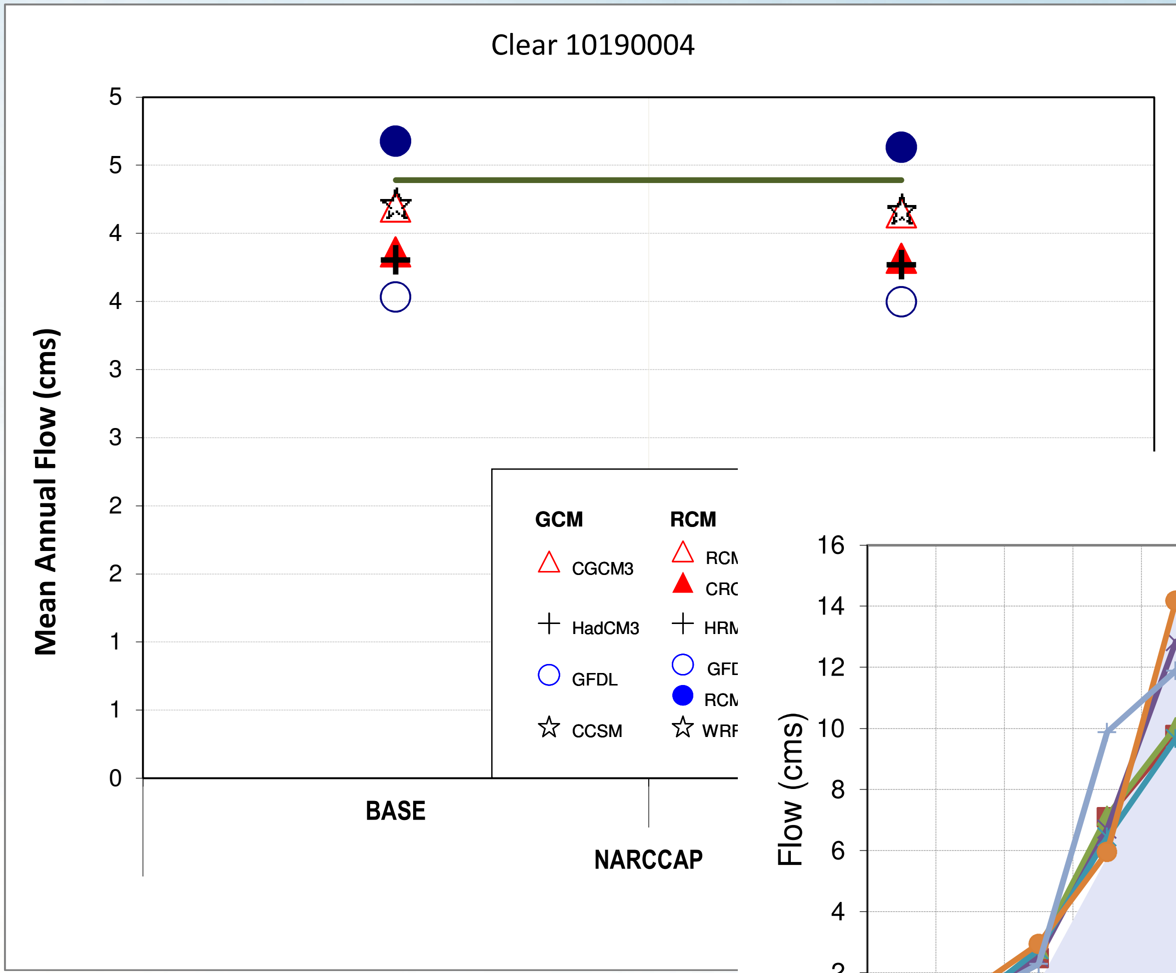
Approach

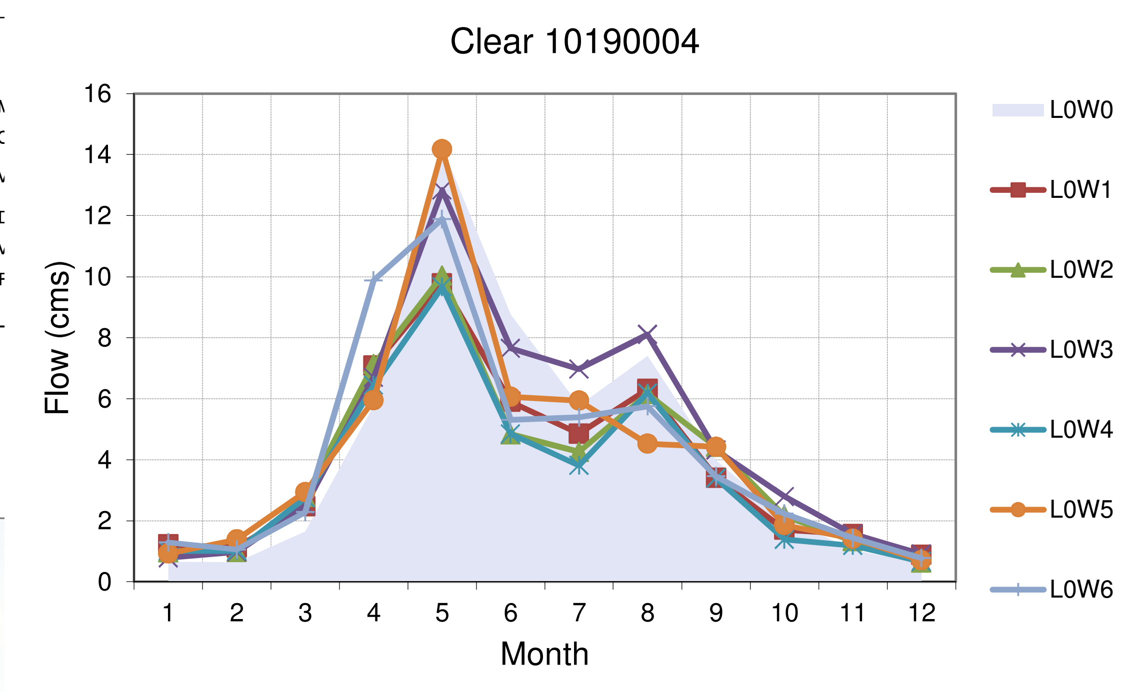
- Develop and calibrate dynamic watershed models at a daily or sub-daily time step
  - Models typically employed for water quality and quantity management
  - Hydrology and water quality (nutrients and sediment)
- Access and process an ensemble of climate change modeling data
- Ensemble approach: simulate 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





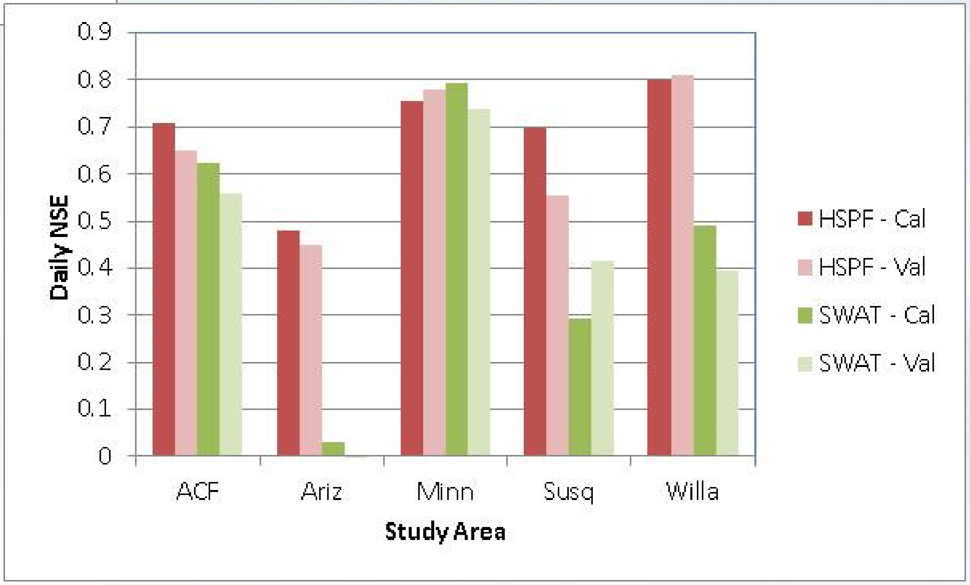
Watershed Model Selection

- *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)

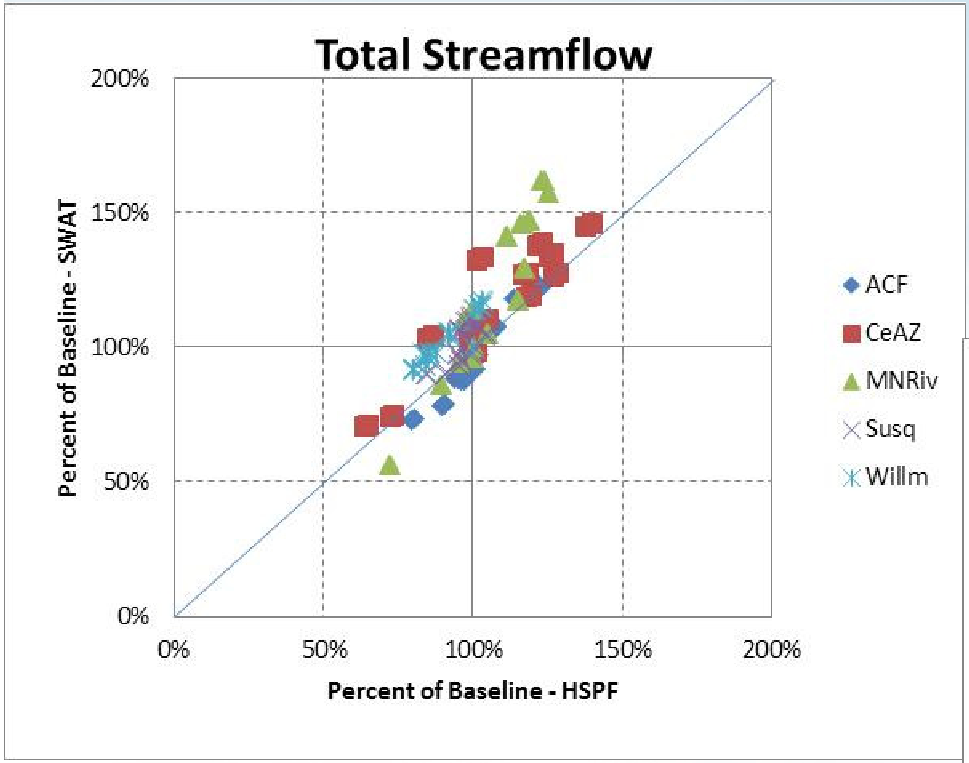
Model Calibration (artistic biases)

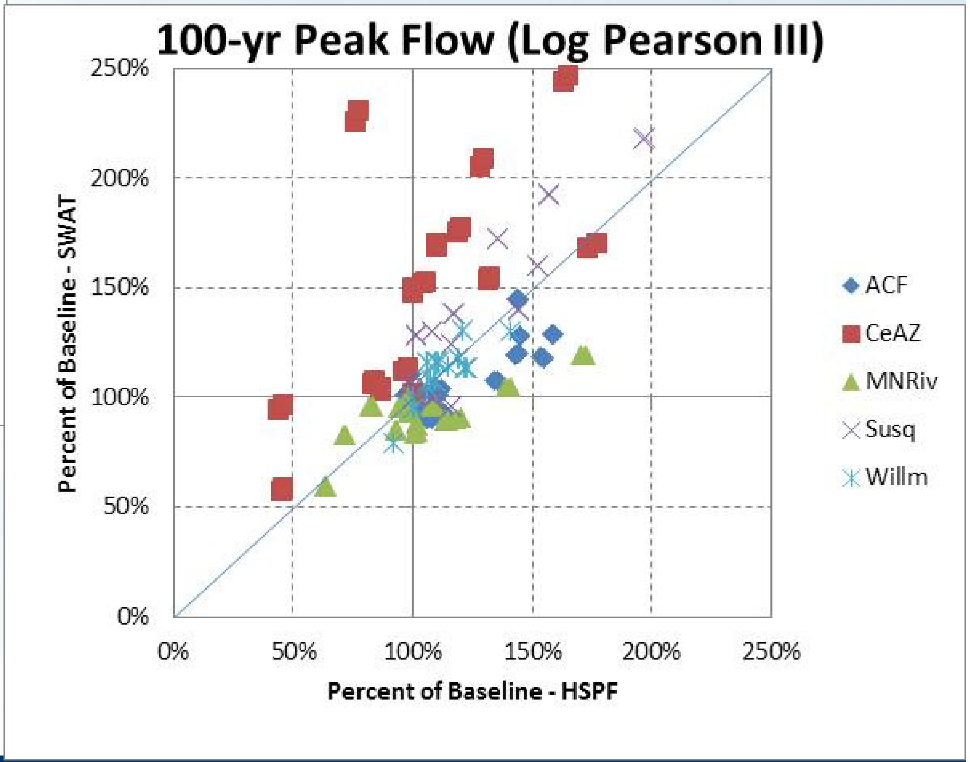
- *It's not news, but:* Neither model performed particularly well without site-specific calibration
  - Calibration and validation according to model QAPP
  - Multi-firm teams of modelers
  - Calibration to multiple sites within an area improved performance (overfitting?)
  - Modeler style and preference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

Flow Calibration



Model Consistency: Flow





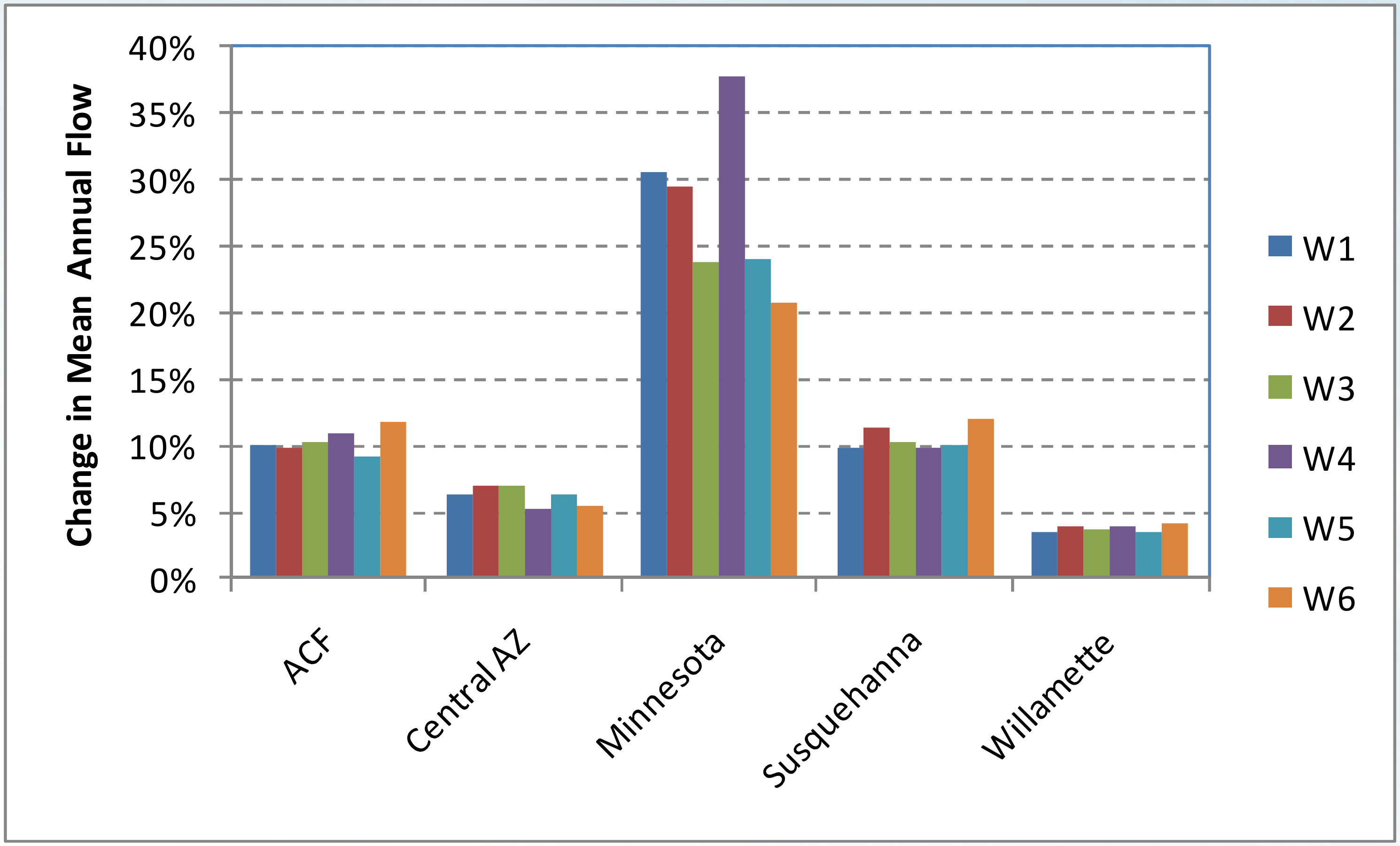
Why does SWAT yield a consistent increase?

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):



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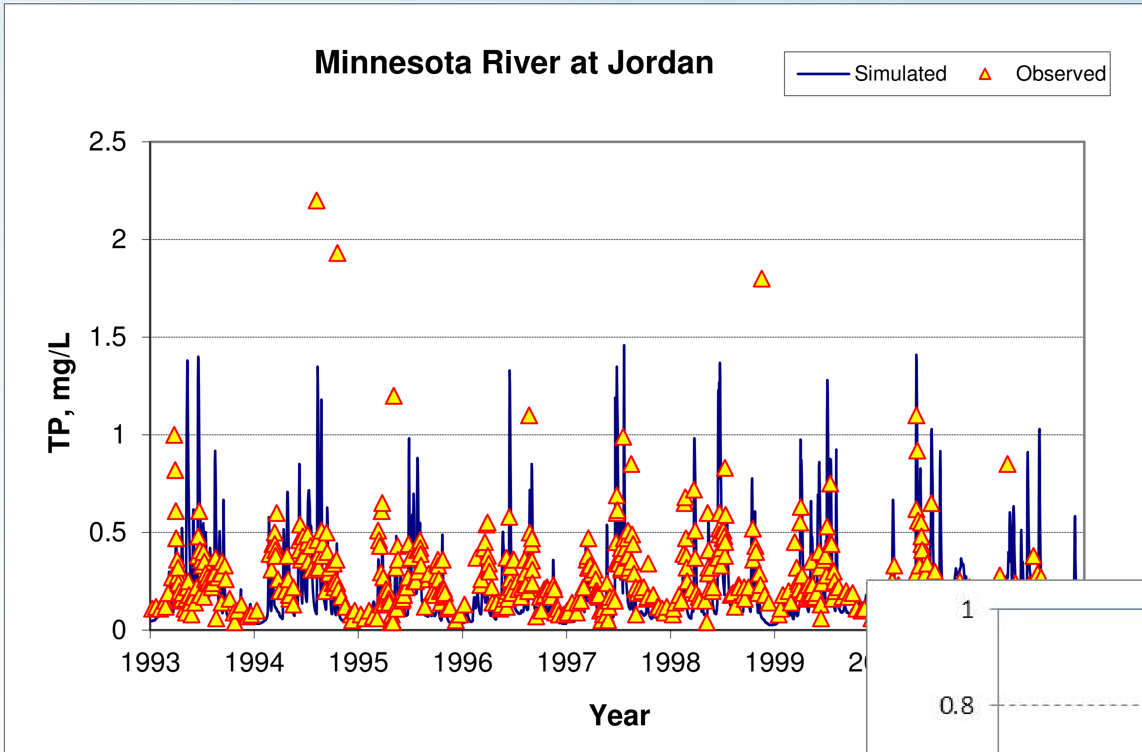
Representation of Intensification

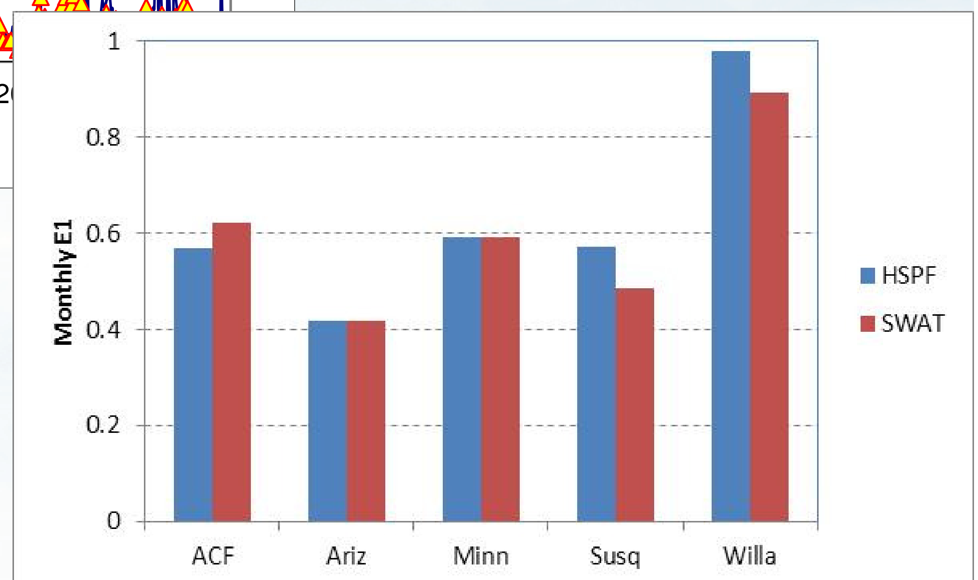
- Climate models suggest intensification of precipitation (greater volume in extreme events)
- Approach modifies existing series with intensification of top 30% events based on bin analysis of GCM/RCM 3-hr output
- HSPF (Philip infiltration) captures intensification directly with hourly rainfall
- SWAT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

Water Quality Simulation

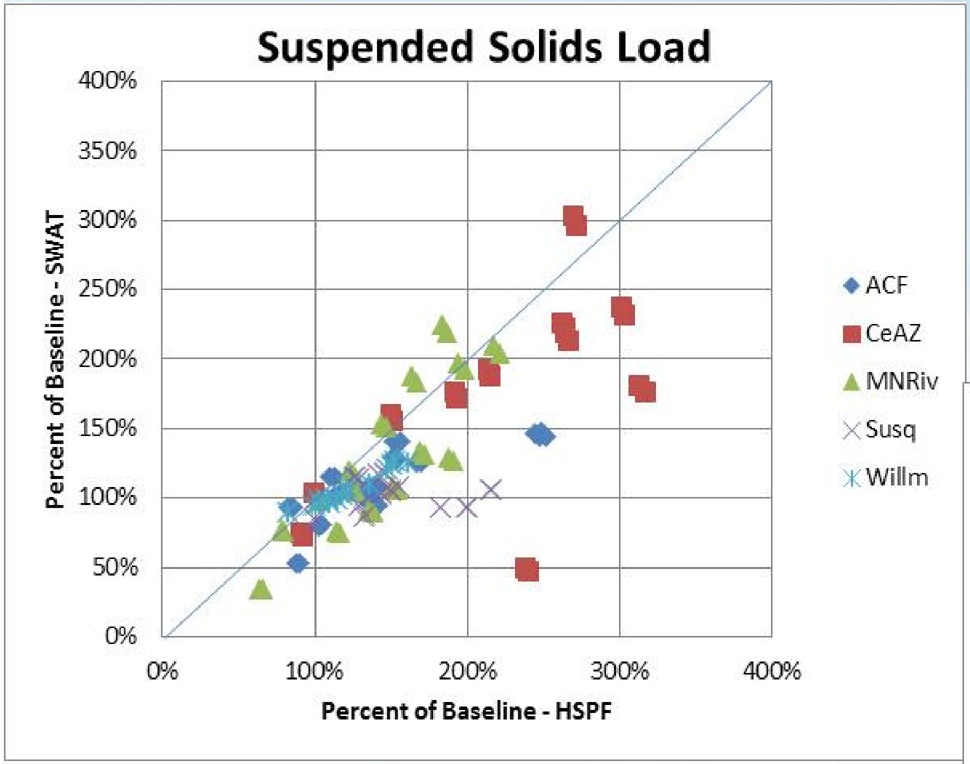


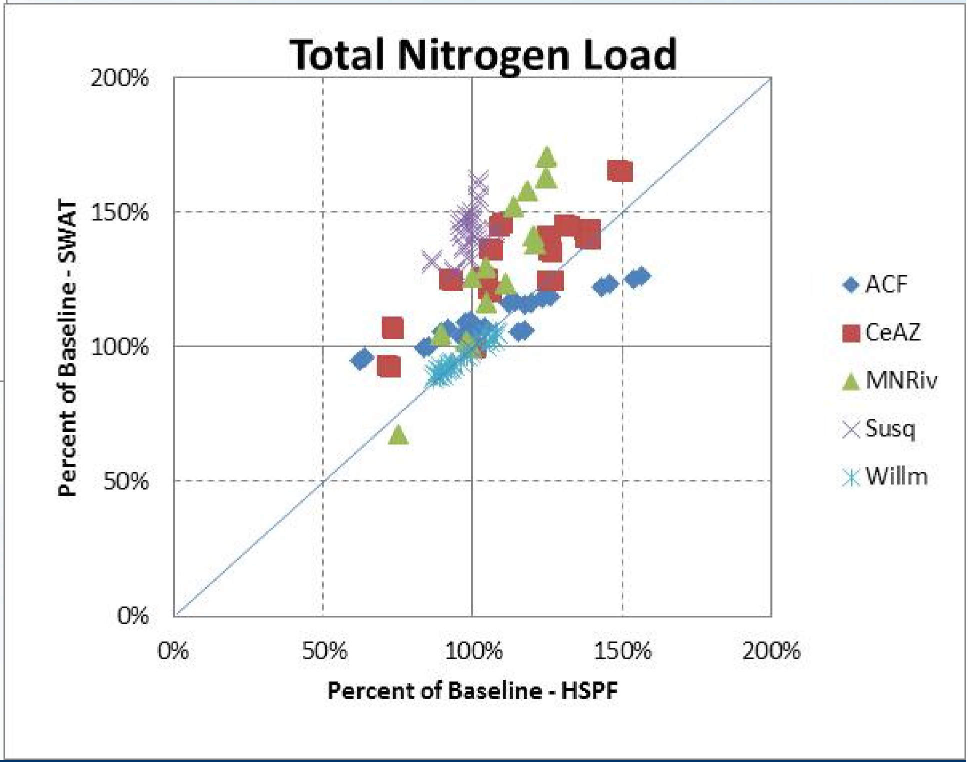
Concentration

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

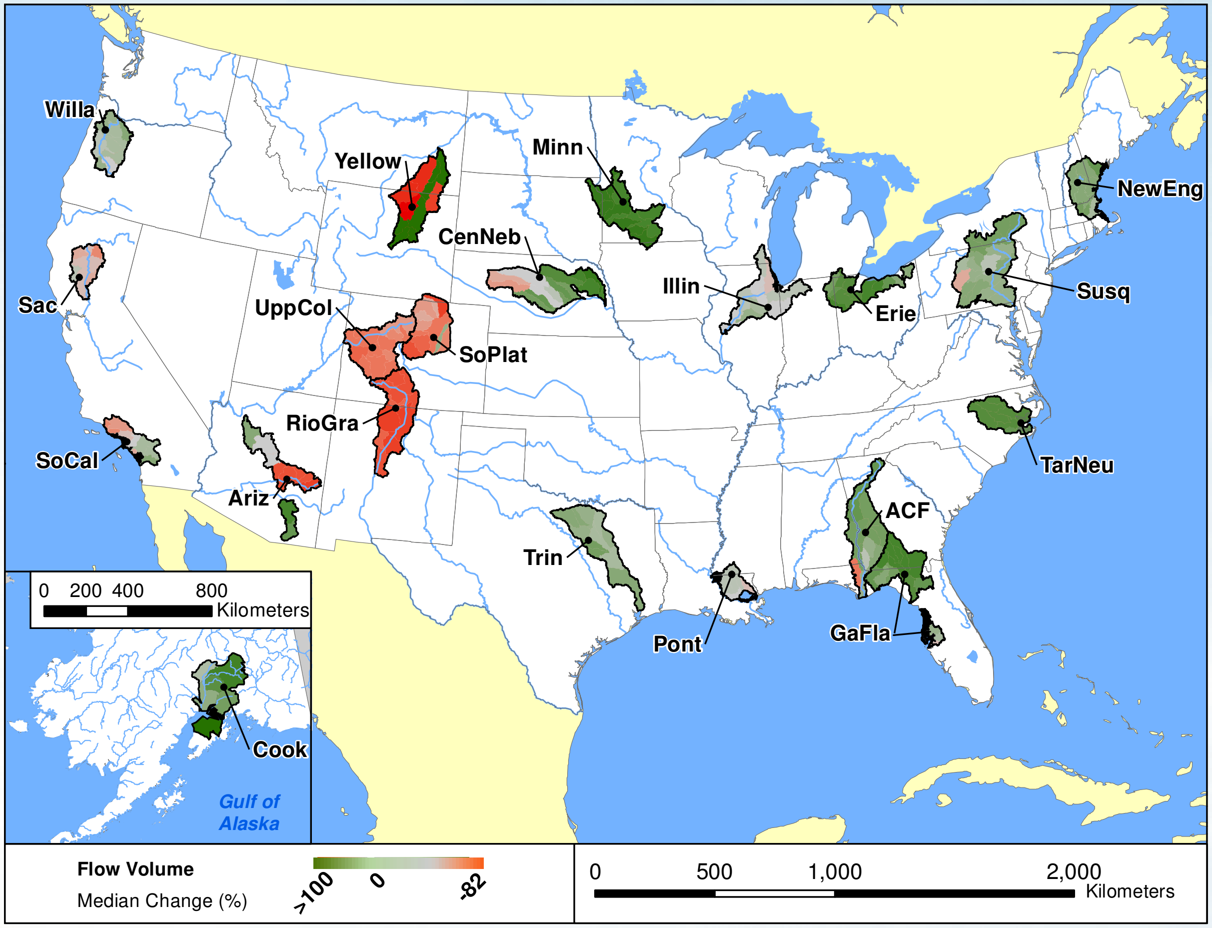
Improving the Models for Simulating Climate Response

- 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



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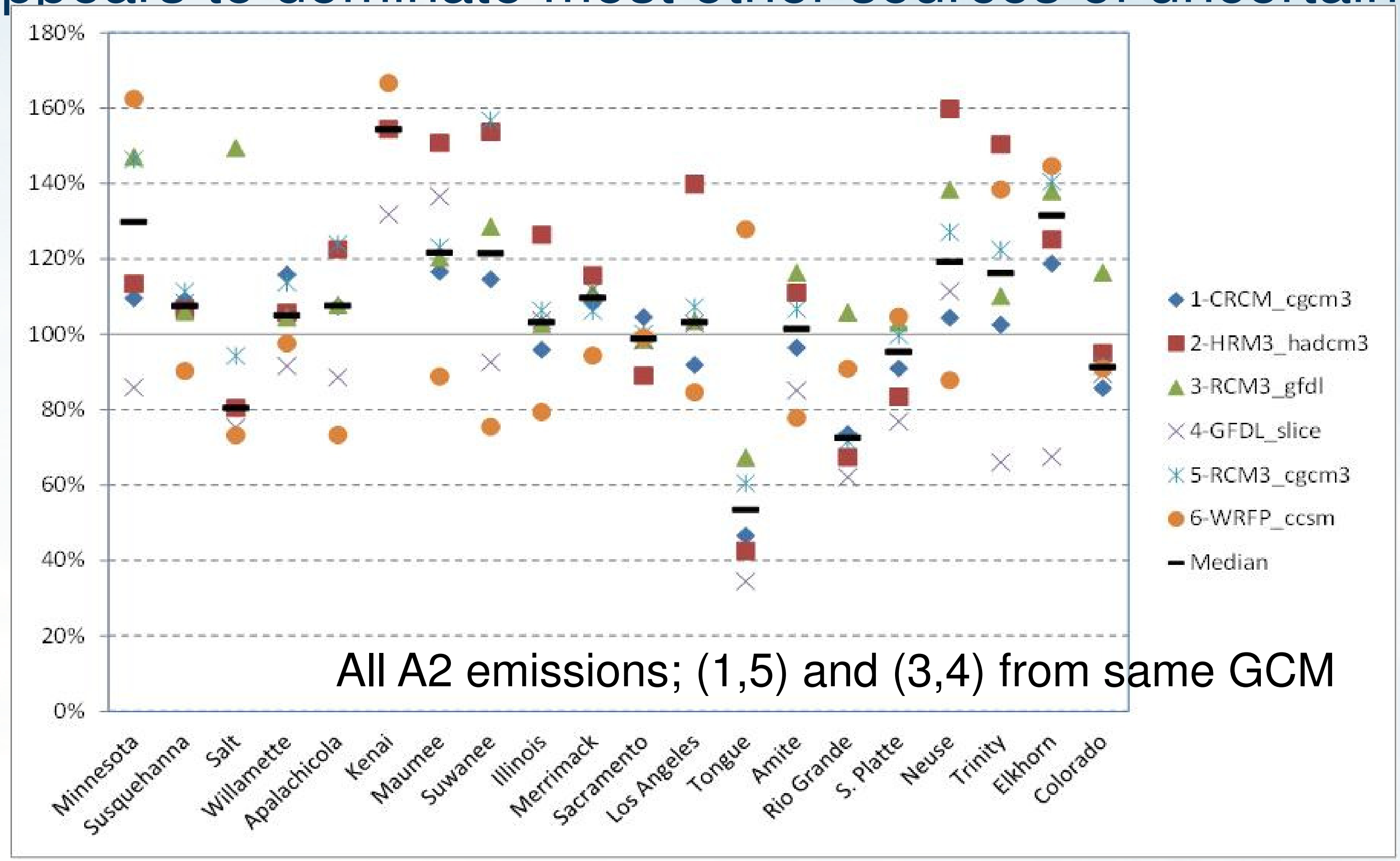
But…

► 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

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- *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