Use of HSPF and SWAT Watershed Models for Climate Response Simulation

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Axes of Uncertainty: Simulating the Future

- Climate Scenario
- Down-scaling
- Adaptation
- Land Use Change
- Watershed Model
- Modeler Preference
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 mi² 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
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-21$^{st}$ 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):

![Bar chart showing change in mean annual flow for different watersheds and CO$_2$ increases.](chart.png)
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

Minnesota River at Jordan

Simulated vs. Observed Concentration and Load

Concentration

Load

Monthly ET
Model Consistency: Water Quality

**Suspended Solids Load**

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- CeAZ
- MNRiv
- Susq
- Willm

**Total Nitrogen Load**

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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

► CO₂ fertilization impacts
  ▪ Greater antecedent soil moisture and runoff -> greater solids and nutrient loads
Improving the Models for Simulating Climate Response

► HSPF:
  - addressing CO₂ 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 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

All A2 emissions; (1,5) and (3,4) from same GCM
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.ucnlnl.org/downscaled_cmip3_projections (Maurer et al. (2007))
Questions?

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