Food – Water Nexus: Towards Improved Spatial Analysis and Geospatial Information

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Food-Water Nexus Characterized by Broad Connections
Watersheds as integrators of activities and process complexities

- Water coupling with elemental cycles; flow paths drive chemical mass flux across multiple spatial scales
- Physical scales relevant to understanding cumulative process effects and observing management impacts
- Progress in watershed analyses can inform remaining challenges and issues in need of attention
Progress in understanding water- and land-use connections to terrestrial and aquatic ecosystems

Catchment and Watershed Research

Multi-Scale Water Monitoring

Multi-Scale Watershed Modeling

Neitsch et al. 2001
Progress, challenges, and needs in spatial interpretative methods and geospatial data

Proposed approach: More seamless sharing of information via integration of models and geospatial data across space-time scales, institutions, environmental media

The illustrated approaches are data-driven, process-informed
Watershed Modeling Challenges and Solutions

Modeling / prediction challenges:
• Need to describe vast heterogeneity, nonlinear processes, coupled processes, preferential flowpaths, and cumulative effects over large spatial / temporal scales
• Need for upscaling to large watersheds and predicting in ungauged, diverse catchments

Emerging solutions:
• Parsimonious model specifications
• Identification of key scaling variables
• Spatially explicit models
• Parameter and uncertainty estimation
• Multi-scale, coupled models (e.g., community and modular modeling)
• Process and statistically informed meta-analyses
Watershed Modeling Continuum and Tradeoffs

Data Driven

Statistical

- Artificial Neural Networks (ANN)
- Kriging
- Linear Regression (steady state)
- Spatially Referenced Non-Linear Regression
- SPARROW

Optimal fit to data, but limited process understanding

Complexity (process interpretability), but possible over-specification and parameter non-uniqueness

Greater model complexity does not necessarily translate into greater accuracy in predictions and process understanding

Increasing recognition of value of less complex, robust models

Physically Based

Deterministic

- GWLF (Generalized Watershed Loading Function)
- SWAT (Soil Water Assessment Tool)
- HSPF (Hydrologic Simulation Program-Fortran)

Greater model complexity does not necessarily translate into greater accuracy in predictions and process understanding

Increasing recognition of value of less complex, robust models
Reactive Nitrogen as an Informative Example

N is highly reactive and mobile w/ water

2x increase in reactive N over past 60 years

N has cascading effects, from landscape to headwaters to coastal waters

Many complexities and tradeoffs in food production and water-N interactions and management

Progress in watershed modeling enabled by information sharing across large spatial scales

- Large geospatial data aggregation (e.g., mining of NWIS and STORET)
- Empirical estimation of terrestrial and aquatic N losses; process structure informed by catchment research

Robertson and Saad, JEQ, 2013 (USGS SPARROW water-quality model)
Evidence for reduced efficiency in N removal from denitrification in nitrate-enriched streams, informed by meta-analysis of 3 leading catchment studies

Hydrological and biogeochemical controls have nearly equal influence over N removal rates, based on modeling and sensitivity analyses.

LINX – Mulholland et al. 2008, Nature
USGS – Smith et al., 2006, Ecol Apps.
ODR – Royer et al. 2004, JEQ; others

Biogeochemical controls lead to greater downstream connectivity in agricultural, N-enriched watersheds

Greater connectivity leads to more far-reaching downstream impacts from land use, but also a more efficient response to land-use management than in less N-enriched watersheds.

To remove 1 kg at outlet requires removal of 4 kg (1 / 0.25)

To remove 1 kg at outlet requires removal of 1.25 kg (1 / 0.8)

Advancing Watershed Modeling
Towards Greater Information Sharing

**USGS Water Census:** systematic national hydrological budgeting modeling underway:

--estimating flow at ungauged locations
--groundwater information
--evapotranspiration
--ecological water science
--water use

**USGS Regional Water-Quality Modeling Studies**

**USGS National Water Census (Secure Water Act)**
Integration of surface and ground water transport:

- PIHM (Penn State Integrated Hydr. Model)
- Nitrogen source-transport: coupling of USGS MODFLOW with SPARROW (Potomac River Basin)

Land Use in Midwest

Integration of USDA APEX farm-level mechanistic model predictions with USGS SPARROW nutrient model
Hierarchical Bayesian methods

- Allows sharing of information
  - identify “sweet spot” in functional relations
  - account for prior knowledge
  - inform data-poor areas by borrowing data (high utility for developing countries)

- Improved model accuracy, interpretability, and uncertainty estimates (parameters, model structure, and observations)

- New-generation Bayesian methods (Stan)
  - 10x faster, with improved sampling of parameter distributions
  - e.g., recent USGS regional and continental applications
Stream Water-Quality Data Challenges
Requires more strategic sampling, data integration and filtering

- Scale mismatches: routine stream monitoring vs. catchments with intensive field studies (limits data mining; need to integrate field and public monitoring data)
- Declines in federal, increase in state monitoring
  - STORET: limited metadata; off-line state data missing
  - Limited seasonal sampling and poor co-location with streamflow gauges
  - Increased use of sensor technologies, but can be expensive to maintain

Nitrate Monitoring

- Number of Sites
- Year: 1970 to 2012
- Federal (black) vs. State (red)

Graph shows the increase in monitoring sites, with a notable rise from 1990 onwards.
Filtering of Nitrogen Stream Data for SPARROW

Percent of sites with sufficient WQ and streamflow data
(10,500 sites with minimum 2 years of quarterly WQ data)
Stream Water-Quality Data Challenges

Increased use of sensor technologies, but expensive to maintain
Agriculture Geospatial Data Challenges
Requires improved spatial / temporal resolution and analysis methods for water use and land practices

- Water use
- Farm fertilizer use/sales
- Changes in soil N storage and fertility (C-N availability)
- Tile drains – location, management
- Livestock wastes and management
- Atmospheric emissions from soils and wastes: ammonia, nitrous oxides, dry forms
- Conservation practices
  - structural, nutrient management
  - USDA CEAP survey data (section 1619 of 2008 FCE Act restricts disclosure of location, extent, and types of practices)
  - Need methods for data dis-aggregation and smoothing protected data

Farm fertilizer use, by county
Dubrovsky and others, 2010
Hively and others, 2013

Integrating Federal and State Data Records to Report Progress in Establishing Agricultural Conservation Practices on Chesapeake Bay Farms

Agriculture Management Practices

USGS
Smoothed Irrigation Data from USDA NRI

Probability of occurrence based on 844,000 sample points modeled as $f(\text{land use, soils, climate, hydrology, other catchment attributes})$

USGS, unpublished, 2015
Additional Geospatial Information Challenges

- Subsurface transport of nutrients
  - Fate of N – denitrification vs. leaching to GW
  - Legacy effects, time lags, subsurface flowpaths
- Food consumption: wastewater loads to streams from municipal and industrial facilities – requires modeling limited data
- Hydrography (National Hydrologic Data) – development of ancillary data for stream reach networks
  - Channel properties (flow, velocity, morphology)
  - Riparian conditions (floodplains)
  - Reservoirs

![Distribution of Base Flow Age](image)

Chesapeake Bay Watershed Coastal Plain (Sanford and Pope, ES&T, 2013)

Projected N response to load reductions (in Thousands of Metric Tons per year)

- 0% load reduction
- 13% load reduction
- 40% load reduction
- 100% load reduction
Food – Water Nexus: Towards Improved Geospatial Information and Spatial Analysis

SUMMARY

Considerable progress has been made in data access and information sharing

Need improved sharing of information via integration of models and geospatial data across space-time scales, institutions, environmental media

Questions?