THE ROLE OF HEADWATER STREAMS IN WATER QUALITY ASSESSMENT AND MANAGEMENT

K.M. Fritz[1], B.R. Johnson[1], R.A. Burke[1], B.H. Hill[2], C.T. Nietch[3], P.J. Wigington[2], and R.J.F. Bruins[1]

NERL[1], NHEERL[2], and NRMRL[3]

LTG 1 Poster 11

Science Question

How can stressor levels, biological-response relationships, classification schemes, bioassessment methods, ecological risk assessments, and indicators be applied across U.S. surface water to set criteria for identifying/restoring impaired waters and maintaining designated uses?

How Research Addresses the Water Quality MYP Goals

Provide States, Regions, Tribes and other stakeholders with methods, guidance and indicators for correctly assessing the ecological integrity of headwater streams.

Provide sound science that validates the need for protecting and restoring headwater streams to improve water quality in all our Nation's water bodies.

Research Objectives

- Provide realistic mileage estimates and factors controlling the extent of headwater streams across the landscape.
- Develop field protocols for assessing the ecological condition of headwater streams.
- Identify physical, chemical and biological indicators of hydrologic permanence and impairment.
- Demonstrate direct linkages between the ecological condition of headwater streams to downstream water bodies.
- Assess the effectiveness of management policies associated with headwater streams across multiple spatial scales.

Research Methods & Collaboration

Through independent and collaborative studies, ORD researchers are investigating headwater streams from multiple fronts across the nation.

- Headwater Intermittent Streams Study (HISS)
  - 113 sites across 9 states varying in hydrologic permanence
  - Physical habitat and biological assemblages sampled.
  - Collaborators: Regions 1,2,3,4,5 & 10, KYDEP-DW, NYDEC, VTDEC, The Nature Conservancy, Univ. KY, and USFS.
- Extent of Headwater Streams
  - Position of channel origins & hydrologic transition zones (HISS sites).
  - Estimate extent of headwater streams within surrounding HUC.
- Biogeochemical Indicators of Ecological Condition - Georgia Piedmont
  - >20 sites; rapid human population growth & major poultry production in region
  - Evaluating impacts of land use and in-stream processes on C, N, and DO cycling
  - Results suggest that dissolved gases, DOC, sediment denitrification activity, and plant stable N isotope ratios are useful indicators of organic waste pollution.
- Linking Management to Headwater Stream Processes
  - East Fork of the Little Miami River, OH.
  - Combining studies in natural and artificial channels to better link Best Management Practices (BMPs) and stormwater drainage design to headwater stream processes.
  - Collaborators: Clermont County OEQ.
- Influence of Headwater Streams on Downstream Water Quality
  - Quantify the spatial dependence of downstream water quality on headwater the water quality using semi-variograms.
  - Use existing state biological data (KY, IN, OH, TN, & WV) .
  - ORD-collected data at frequent intervals (100 to 400-m intervals).
  - Cross-ORD collaboration (NERL, NHEERL & NRMRL).

Map showing headwater stream study locations. Symbol color correspond to research objectives and descriptions above. Numbers correspond to EPA Regions.

Research Results

Extent of Headwater Streams

In conjunction with our ecological condition work, ORD scientists are using GPS and GIS methods to generate predictive maps of headwater streams. These data are being compared to existing databases and are being used to better understand what factors govern the development and spatial position of stream channels. The goal of this work is to provide a more accurate picture of our Nation's stream networks that can be applied to problems such as non-point source pollution.

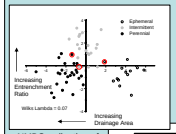
National Hydrographic Database (NHD) total stream length : 233 km

Generated prediction total stream length: 527 km

Location	HUC drainage area (km²)	Total stream length (km) NHD	Generated	Percent additional length
Robinson Forest, KY	7.5	12	28	+133.3
Wayne N.F., OH	45.4	17	49	+188.2
Hoosier N.F., IN	91.4	39	49	+25.6
Edge of Appalachia, OH	77.5	2	28	+130.0
Shawnee N.F., IL	128.7	233	527	+126.2
Sullivan Co., NH	76.3	151	317	+109.9

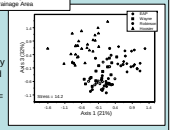
Ecological Condition

Indicators of Hydrological Permanence

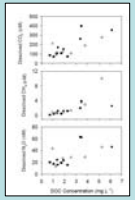


Canonical discriminant analysis of physical habitat measures illustrate distinct separation across 3 class of hydrologic permanence.

NMDS ordination of macroinvertebrate data illustrating assemblage composition primarily driven by region and secondarily by permanence (open = intermittent and closed = perennial).



Biogeochemical Indicators

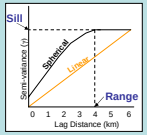


Significant positive relationships between concentrations of trace gases and dissolved organic carbon Georgia Piedmont headwater streams. These relationships indicate that trace gas concentrations could be useful regional indicators of organic waste contamination.

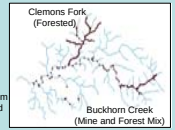
- residential/developed
- pasture
- mixed
- forested

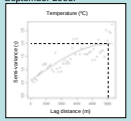
Downstream Influence

Spatial patterns of water quality are being assess with statistical tools that model spatial dependence within stream networks. Semi-variograms are one tool being used to assess the downstream influence of water quality at headwater streams. The theoretical semi-variogram below, illustrates typical spatial dependence, where points closer together tend to be more similar than points further apart. In spherical model the sill represents where variation associated with separation distance asymptotes. The lag associated with the sill is called the range and represents the distance where measurement values are no longer spatially dependent (i.e, the downstream distance of influence).



Map showing sampling locations within a stream network in east-central Kentucky. Water quality parameters were collected at 200 to 400-m intervals from forested and mined drainages in September 2005.

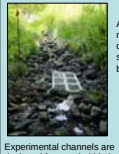




Water temperature data along Clemons Fork were sufficient to fit a spherical model. The data indicate that temperature was spatially dependent within 5.1 km.

Management Effectiveness

Characterizing and linking land use and hydrologic conveyances within 14 sub-catchments draining into the East Fork of the Little Miami River, OH. Water quality data across this network is combined with runoff simulations (USEPA's Stormwater Management Model (SWMM)) to assess headwater stream preservation as a viable and effective alternative for stormwater mitigation in urbanizing watersheds.



An in-situ cobble tray method is under development for linking sedimentation with stream biogeochemistry and biota.

Experimental channels are designed for coupled biotic & water quality monitoring. Data is centralized and integrated with field monitoring stations.

Research Conclusions & Future Directions

- The predictive maps generated indicate that existing spatial coverages of streams may substantially underestimate headwater stream mileage. There was substantial variation in the discrepancy (25–188%) between predicted and NHD distances in the areas studied. The majority of the additional stream length was also predicted to have flow regimes that are intermittent or ephemeral.
- Validation of the predicted headwater extent and identification of factors that account for the variation seen across regions are the future steps planned. In addition, a collaborative study (ORD, Region 3 and other organizations in the Chesapeake Bay area) has been proposed to assess the utility of LiDAR (Light Detection And Radar) for mapping headwater streams and isolated wetlands.
- Land use has a more direct impact on headwater streams than further downstream because they drain smaller areas with less land use heterogeneity than their larger counterparts. Replicate and reference streams are also more available for studies.
- We hope to broaden condition assessments to incorporate a wider range of land use practices and more physiographic regions.
- Future and ongoing studies are developing rapid functional assessment methods for headwater streams (e.g., nutrient uptake, organic matter retention). In addition to characterizing functional changes across disturbance and permanence gradients, we hope to better link biocriteria and traditional structural measures (e.g., Tired Aquatic Life Uses, community metrics) to ecosystem processes and services.
- Attempts to use state biological data to assess spatial relationships between headwater and downstream condition were unsuccessful. We determined that the sampling sites were limited in number and spatial distribution.
- Water quality data from a stream network in east-central Kentucky. showed severe discontinuities in specific conductance that appear to be associated with mountain-top coal mining and valley filling. Although the discontinuities of conductivity in the network prevented valid trend fitting using semi-variograms, results clearly identify the downstream influence of valley filling of headwater streams.
- Future directions include characterizing observed discontinuities utilizing graph theory and Bayesian models. We would also like to investigate the potential influence of stream network complexity on downstream conveyance of upland disturbance and how this may be used in predicting impairment across networks and planning watershed development.
- State/County design criteria for stormwater management in developing areas is expected not to scale to typical headwatershed sizes, with higher frequency of effective discharge for sediment transport as a primary form of ecosystem stress.
- We hypothesized that changes to flow exceedence/duration curves for headwaters control carbon and nutrient biogeochemistry and, therefore, landscape scale nutrient retention.
- Through the combined field effort to quantify small channel processes and employing calibrated/validated models we plan to explore alternative landscape development scenarios, network designs, and planning objectives/policies that could enhance nutrient sequestration and habitat preservation in headwatersheds for consideration in TMDL development and implementation.

Interactions with Customers

- Communication among the ORD scientists, Regional biologists, and EPA Office of Water from the onset of the HISS project & continue as the products become implemented.
- 4 workshops on field protocols held at either national or regional meetings; >100 state, regional, & tribal professionals trained.
- Training lead to an expansion of the headwater sampling from only 3 states to include 9 states across the US.
- Poster at 2005 Science Forum co-authored by ORD and Regional scientists.

How Research Contributes to Outcomes

The field protocols developed have already been provided to several state, tribes and private sector groups interested in monitoring the ecological condition of headwater streams. Ultimately, our research will provide quantitative information and relationships that will allow policy makers to make informed decisions about prioritization of headwater stream protection and restoration.