QUANTIFYING UNCERTAINTY IN ECOSYSTEM STUDIES:
Using long-term data from small watersheds

Mary Beth Adams, Ruth Yanai, John Campbell, Mark Green, Doug Burns, Don Buso, Mark Harmon, Trevor Keenan, Shannon LaDeau, Gene Likens, Carrie Rose Levine, Bill McDowell, Jordan Parman, Stephen Sebestyen, James Vose, Mark Williams

www.quantifyinguncertainty.org / quantifyinguncertainty@gmail.com
What is QUEST?

**QUEST** is a research network interested in improving understanding and facilitating use of uncertainty analyses in ecosystem research.

- Currently funded project is an analysis of hydrologic input-output budgets in small headwater catchments throughout the US
- Includes researchers and students in the US, Canada, and Japan
Ecosystem Budgets have no error.

Figure 2. July nitrogen budgets for WS3 (treatment watershed) and WS7 (control watershed), Forssow Experimental Forest. Values are kg ha⁻¹.

Adams et al. 1995
What contributes to uncertainty in nutrient budgets?

Uncertainty

Natural Variability
  - Spatial Variability
  - Temporal Variability

Knowledge Uncertainty
  - Measurement Error
  - Model Error
Sources of Uncertainty in Stream Export of Nutrients

Measurement Uncertainty

• Uncertainty in analysis of water chemistry
Analysis of water chemistry

Precision over range (POR): repeatability

Method detection limit (MDL): lowest detectable concentration

Note:
Uncertainties are generally small except near detection limits.
Sources of Uncertainty in Stream Export of Nutrients

Measurement Uncertainty

• Uncertainty in analysis of water chemistry

• Uncertainty in height-discharge relationship at the weir
At Hubbard Brook, discharge was measured at low flow and compared to the predictions of the theoretical curve ($Q = 2.49H^{2.48}$). The rating table is corrected according to this hand-drawn curve.

There are no such validation measurements at high flows.
Sources of Uncertainty in Stream Export of Nutrients

Measurement Uncertainty

- Uncertainty in analysis of water chemistry
- Uncertainty in height-discharge relationship at the weir
- Uncertainty in filling gaps in the discharge record
Gaps in the discharge record are filled by comparison to other streams at the site, using linear regression.
Sources of Uncertainty in Stream Export of Nutrients

Measurement Uncertainty

- Uncertainty in analysis of water chemistry
- Uncertainty in height-discharge relationship at the weir
- Uncertainty in filling gaps in the discharge record
- Uncertainty in watershed area
Sources of Uncertainty in Stream Export of Nutrients

Measurement Uncertainty

Natural Variability

• Spatial variation (multiple streams sampled at each site)
• Temporal variation (multiple years of sampling)
Natural variability: Temporal and Spatial
Sources of Uncertainty in Stream Export of Nutrients

Measurement Uncertainty

Natural Variability

Model Uncertainty

• Flux = concentration * discharge

• Model selection: how to interpolate between sampling dates for water chemistry
Comparing methods for estimating flux of Si at Hubbard Brook:

- **Linear interpolation**: concentrations for the week are linearly estimated between the two sampling dates
- **Weekly average**: One value applied to the entire week (many ways to do this)
- **Composite method**: model including a concentration-discharge relationship which is driven through the measured points

- Annual Si fluxes varied by ~5%
Sources of Uncertainty in Precipitation

Precipitation:

• Most uncertainty is in spatial variability.

• Varies with landscape factors; often shows orographic effects

• Low temporal uncertainty: generally measured cumulatively, most uncertainty in this area arises from analytical error

• Many spatial models can be used to predict precipitation amount in watersheds
Alternative spatial models for precipitation in the Hubbard Brook Valley

Coefficient of variation between models

Thiessen: 0.36%
Spline: 0.58%
IDW: 0.24%
Kriging: 0.77%
Regression: 0.83%

Avg. annual precip. (mm)
Uncertainty and Monitoring Efficiency

• Long-term monitoring (LTM) data sets are very important for detecting change over time

• Uncertainty analysis can be a tool for assessing the efficiency and coverage of LTM programs

• Want to determine if current monitoring efforts are:
  
  • **Excessive:** requiring more effort than is justified by the results produced
  
  • **Inadequate:** producing results that are not sufficiently accurate or precise to meet science or policy needs
• Test how sampling intensity contributes to confidence in the annual precipitation estimates by sequentially omitting individual precipitation gauges.

• Median annual precipitation estimates varied little until five or more of the eleven precipitation gauges were ignored.
Using uncertainty to assess monitoring efficiency: Streamflow

- Standard error of the slope increases as the number of sampled years decreases
- Trade off between less sampling (lower cost) and higher error around regression
Future QUEST projects:
• Hydrologic budget of QUEST sites including uncertainty in inputs and outputs
• QUEST workshops on soils, vegetation, and ecosystem budgets
• Ecosystem nutrient budgets including uncertainty in all pools and fluxes

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• Find more information at: www.quantifyinguncertainty.org
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Ecosystem nutrient budgets often report values for pools and fluxes without any indication of uncertainty, which makes it difficult to evaluate the significance of findings or make comparisons across systems. QUEST is a research network that has evolved around the idea that uncertainty analysis should be an accepted and expected practice in the construction of ecosystem budgets.
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