



## QUANTIFYING UNCERTAINTY IN ECOSYSTEM STUDIES

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## 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

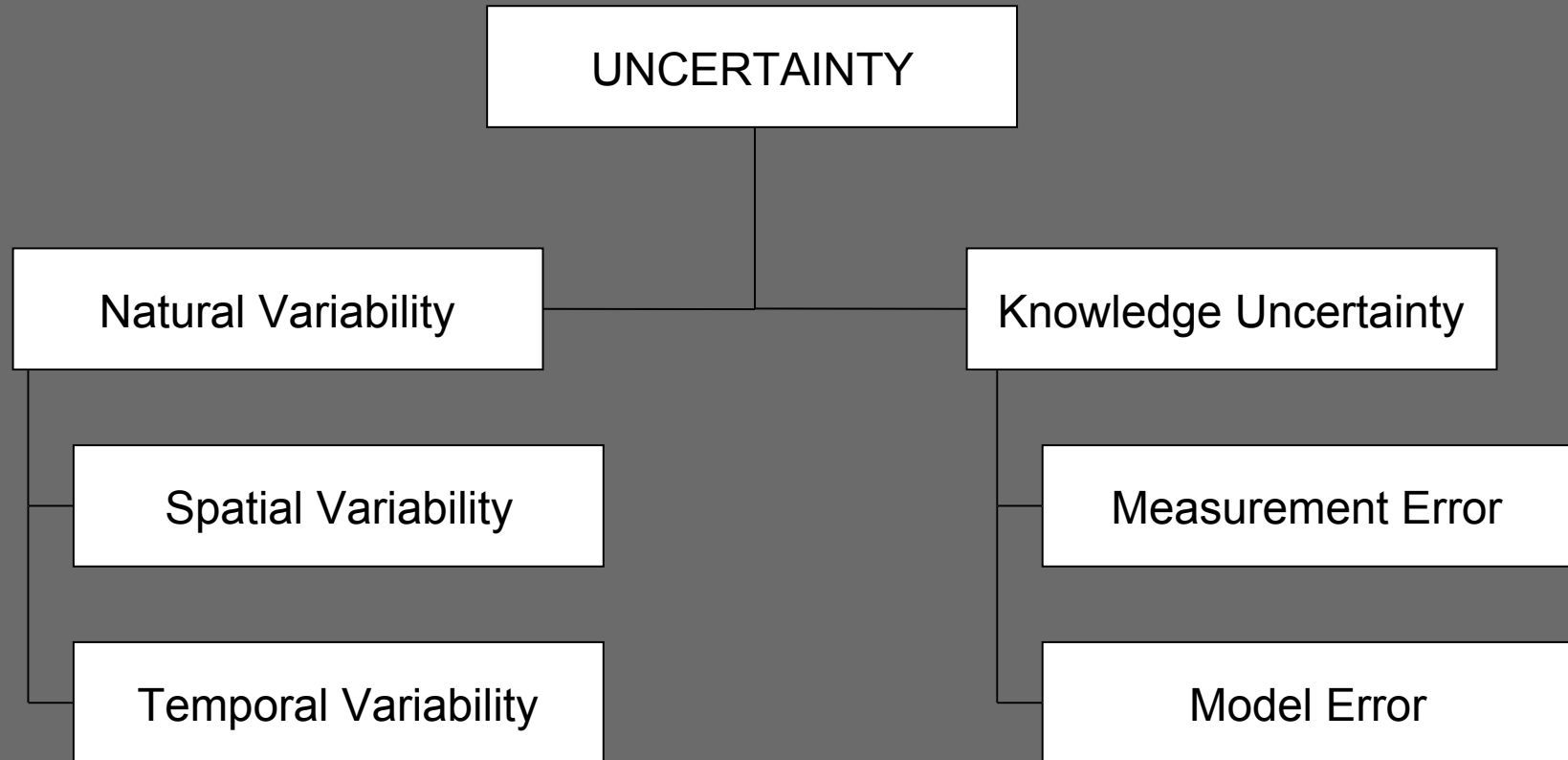
# Ecosystem Budgets have no error.

Table 3. Phosphorus budget for the 70-yr old northern hardwood forest: P pool sizes, P accumulation rates and P transfer rates. Insignificant digits for many values are shown to facilitate reproduction of the calculations.

Phosphorus pool sizes (kg P ha <sup>-1</sup> )		Phosphorus transfer rates (kg P ha <sup>-1</sup> yr <sup>-1</sup> )	
<b>Living biomass</b>		Precipitation	0.04
Aboveground biomass	31.6	Streamwater export	0.02
Roots in the forest floor	9.6	Litterfall	4.0
Roots in the mineral soil	9.7	Throughfall and stemflow	0.57
Total	50.9	Root death (forest floor)	1.66
<b>Forest floor</b>		Root death (mineral soil)	1.88
Available	0.68	Root exudation (forest floor)	0.10
Organic matter	61	Root exudation (mineral soil)	0.12
Primary mineral	20	Leaching from forest floor	0.30
Secondary mineral	4		
Total	85		
<b>Mineral soil</b>			
Available	0.13		
Organic matter	540		
Primary mineral	670		
Secondary mineral	390		
Total	1600		
Ecosystem total	1756		
<b>Phosphorus accumulation rates (kg P ha<sup>-1</sup> yr<sup>-1</sup>)</b>			
in Aboveground biomass	0.96		
in Roots in the forest floor	0.21		
in Roots in the mineral soil	0.16		
in Forest floor	0.16		
Total	1.49		

## Hubbard Brook P Budget Yanai (1992) Biogeochemistry

# What contributes to uncertainty in hydrologic budgets?



# Sources of Uncertainty in Stream Export of Nutrients

## Measurement Uncertainty

- Uncertainty in analysis of water chemistry



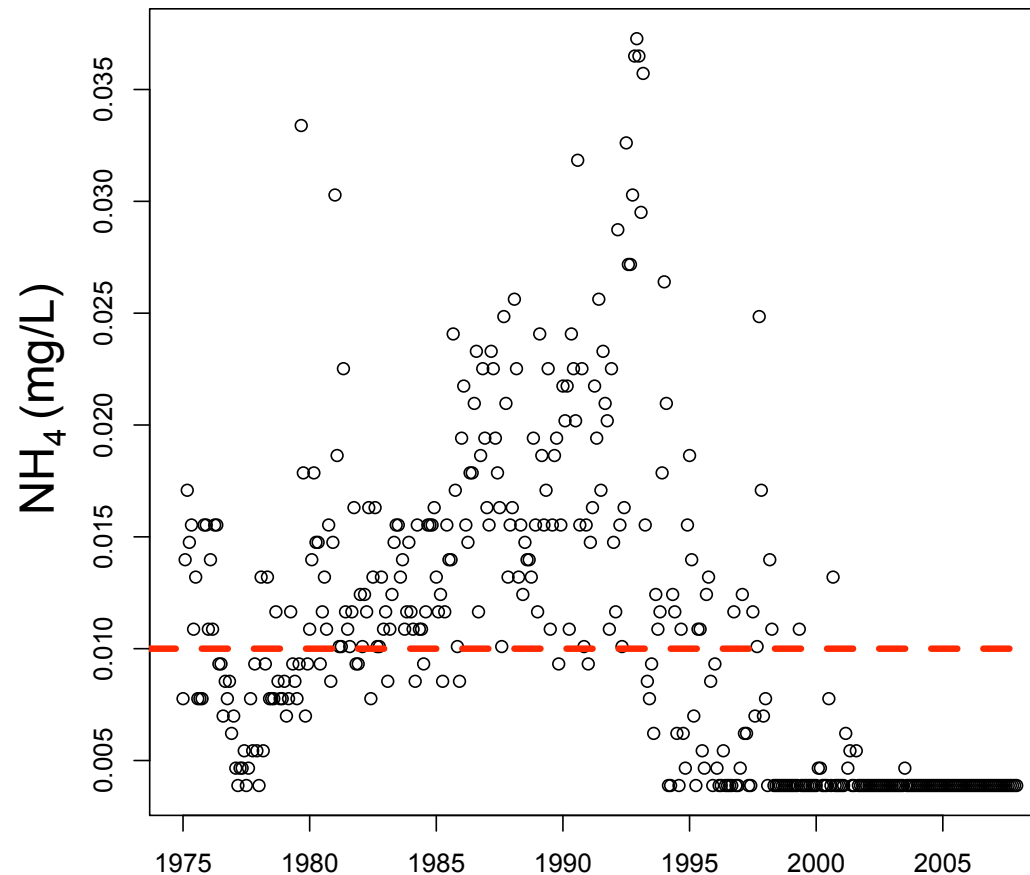
# Analysis of water chemistry

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

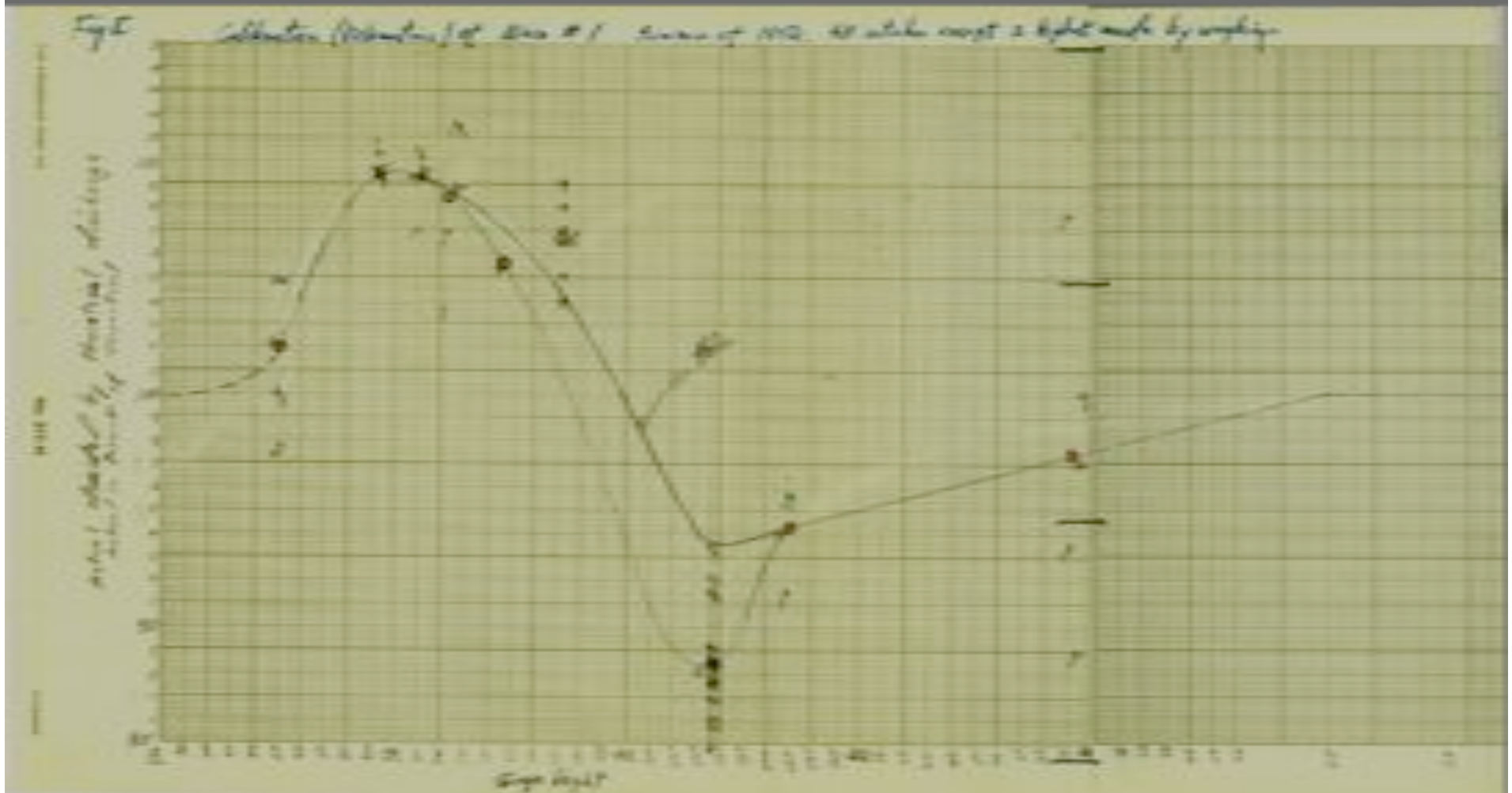
## Measurement Uncertainty

- Uncertainty in analysis of water chemistry
- Uncertainty in height-discharge relationship at the weir



## Height-discharge relationship

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.

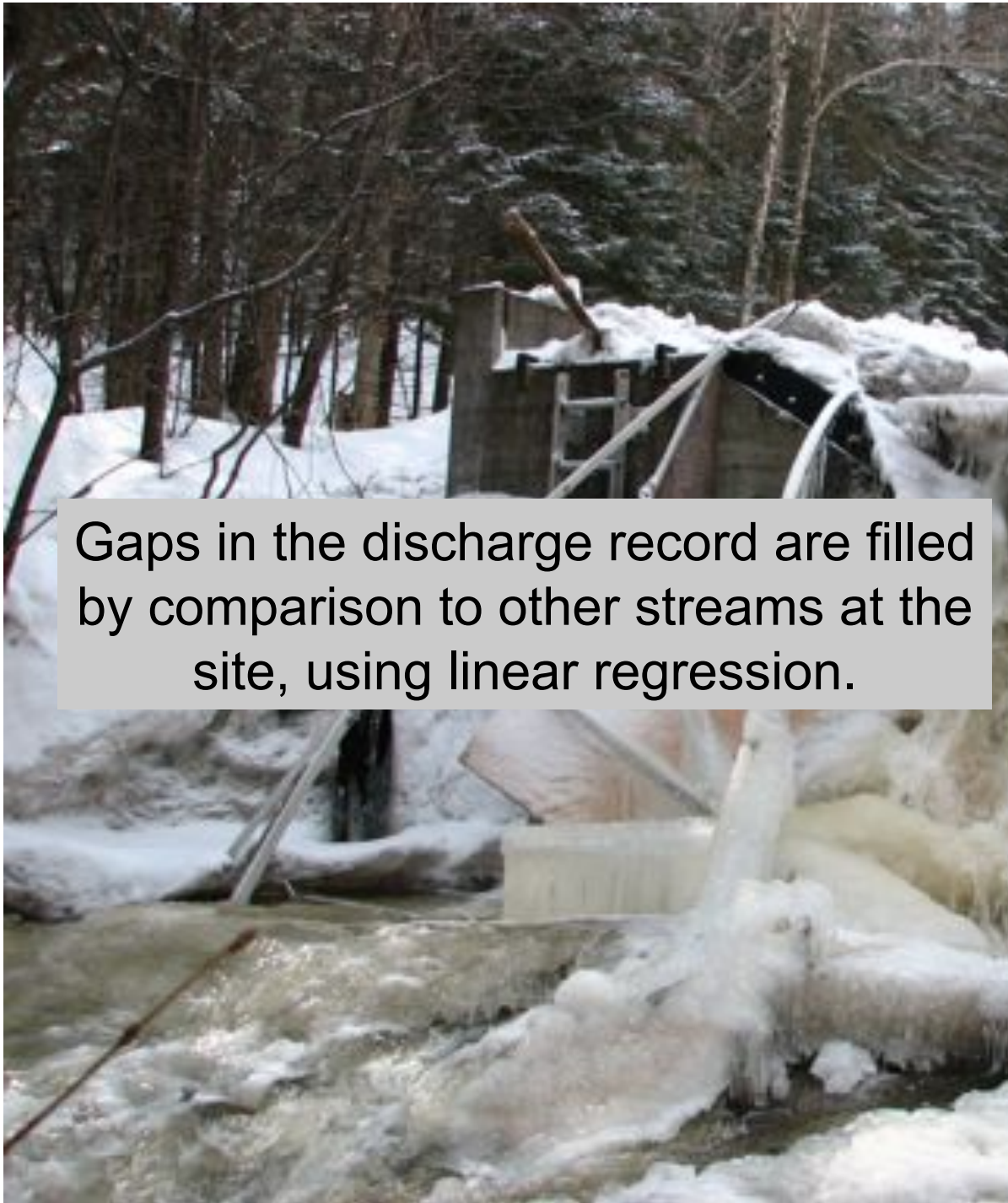


# Sources of Uncertainty in Stream Export of Nutrients

## 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.

Year	Discharge (mm)	ST	ST2	ST4	ST7	ST8
1018	5.2398	10.1784	6.70796	4.86028	6.86834	7.43254
1019	9.2838	7.23184	4.86862	4.36897	5.32914	4.83076
1020	5.2398	5.36885	3.18668	1.88070	2.86589	4.14428
1021	4.3038	6.88878	2.88888	0.88888	1.88888	3.88888
1022	5.2398	4.11394	2.86882	0.27880	1.78894	3.23880
1023	9.2838	1.88885	2.17888	0.28888	1.88242	2.88888
1024	5.2398	3.78883	1.78888		1.18884	2.47881
1025	9.2838	8.2337	1.88888	0.78888	0.88788	2.23778
1026	9.2838	3.88885	1.28887	0.11324	4.77828	1.8228
1027	6.188	1.88887	1.88788		0.88884	1.88788
1028	6.238	2.42282	0.88888		0.58888	1.78888
1029	6.238	2.58337	0.88788		0.88888	1.88888
1030	6.488	1.88884	0.7228		0.42583	1.78881
1031	6.188	1.78888	0.82288		0.37877	1.82278
1032	6.688	1.78882	0.88788		0.32717	1.88888
1033	6.188	1.88882	0.71778	0.88888	0.27888	1.88888
1034	6.488	1.88315	0.88847	0.88888	0.28888	1.41882
1035	6.188	1.27888	1.28887	0.82888	0.32824	1.88788
1036	6.188	1.88888	0.88788	1.88888	0.28888	1.88888
1037	6.188	1.88328	0.88888	0.72277	0.28384	1.88888
1038	6.238	0.88887	0.88888	0.78888	0.18888	1.28878
1039	6.238	0.88288	0.71883	0.78888	0.18381	1.38778
1040	6.248	0.78887	0.70788	0.88888	0.18888	1.28888
1041	6.188	1.88882	0.18881	2.88888	0.28387	2.82882
1042	6.188	1.78887	0.88888	0.78888	0.18888	1.88888
1043	6.188	0.88888	2.88888	2.82888	1.18787	1.88888
1044	6.188		0.18888	1.18888	1.52371	1.82888
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1119	6.238		1.88888	1.88888	0.88888	1.88888
1120	6.238		1.88888	1.88888	0.88888	1.88888

# 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

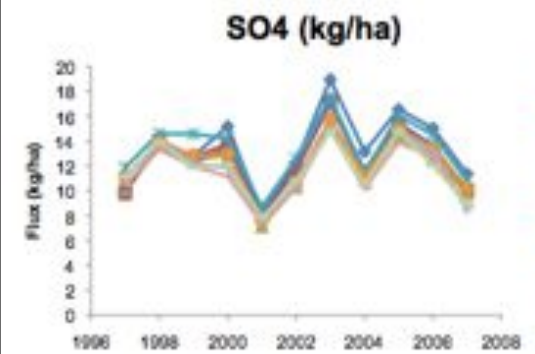
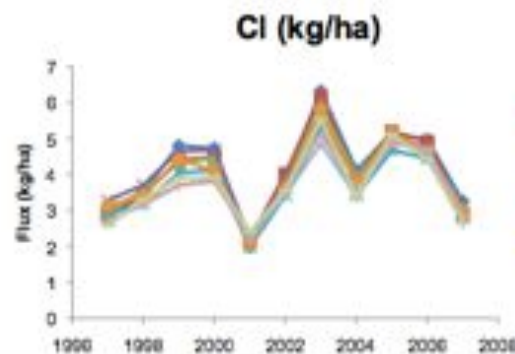
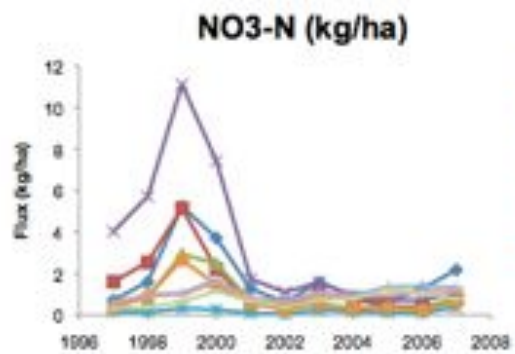
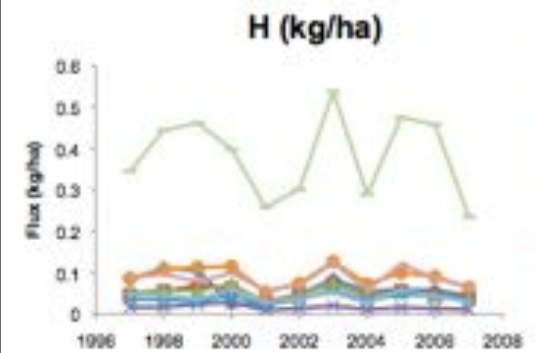
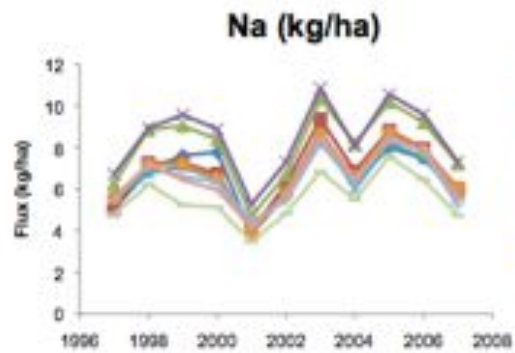
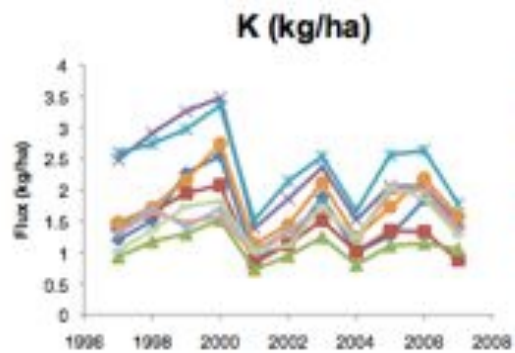
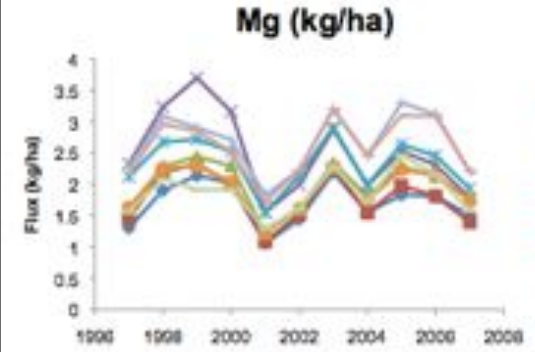
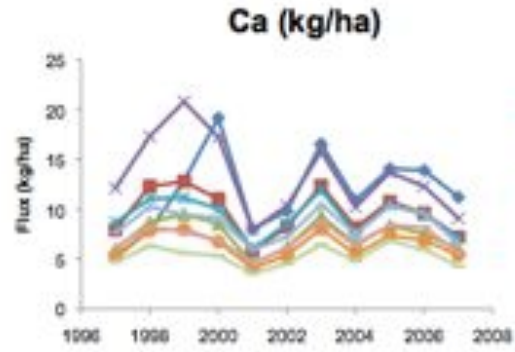
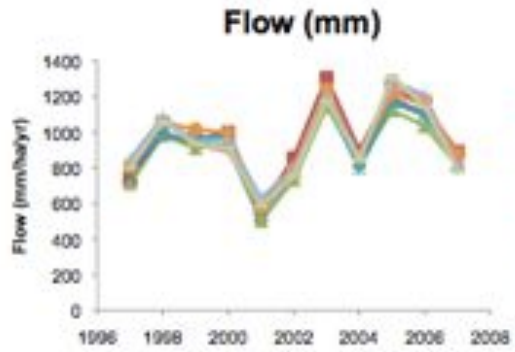
## Measurement Uncertainty

### 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

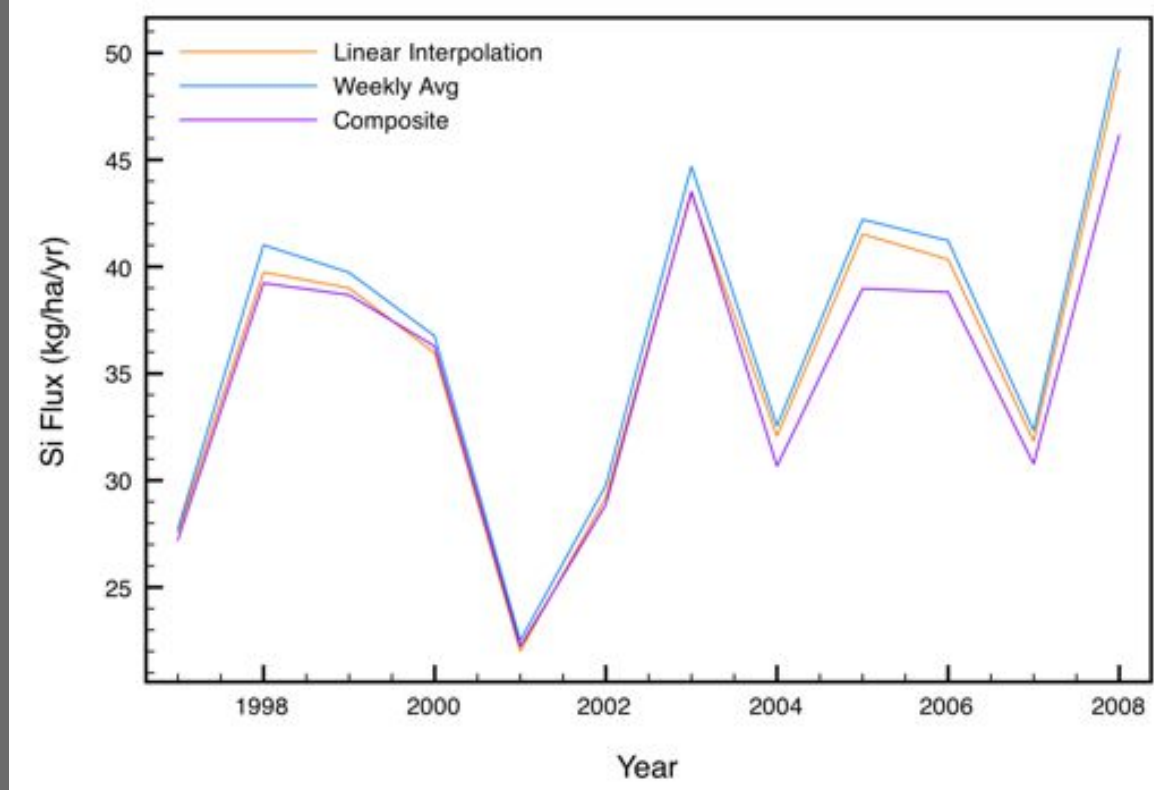
Natural Variability

**Model Uncertainty**

- Flux = concentration \* discharge
- Model selection: how to interpolate between sampling dates for water chemistry



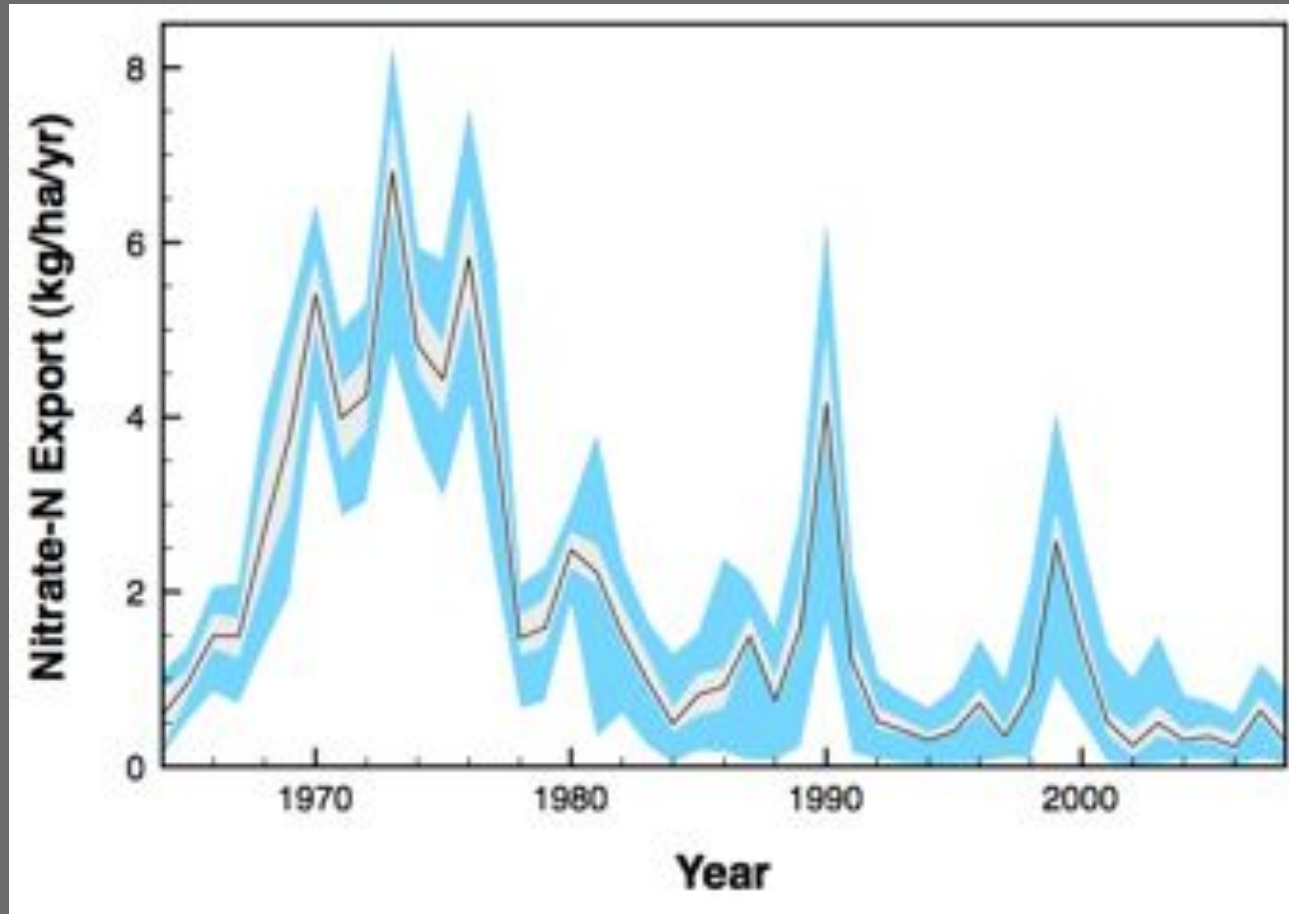
## Uncertainty in streamwater chemistry estimates: Methods comparison



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%

## Bootstrapping approach to estimating uncertainty in streamwater flux



- Estimated fluxes of dissolved inorganic nitrogen (DIN) via a bootstrapping methodology:
  - Produces a daily series of DIN concentrations using daily flow values and resampling existing DIN samples from similar flow rates, and is repeated 1000 times to determine the uncertainty in the DIN fluxes.



# Sources of Uncertainty in Precipitation

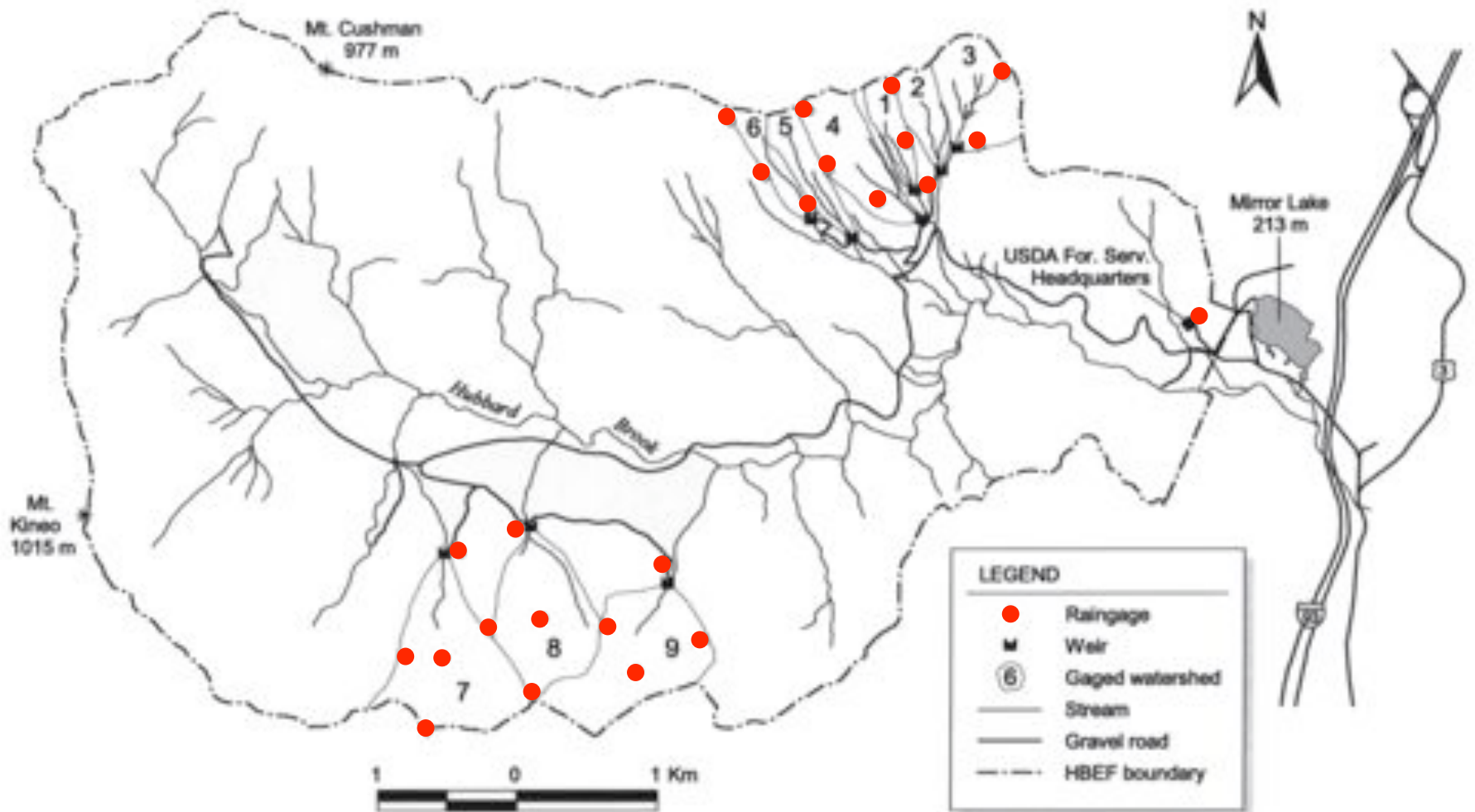
## Precipitation:

- 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

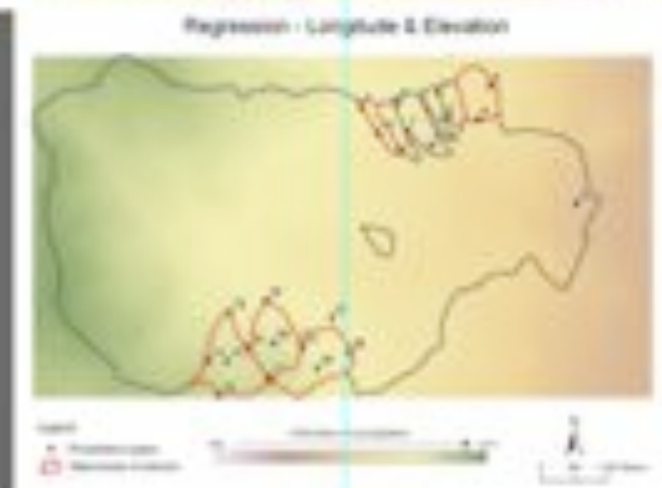
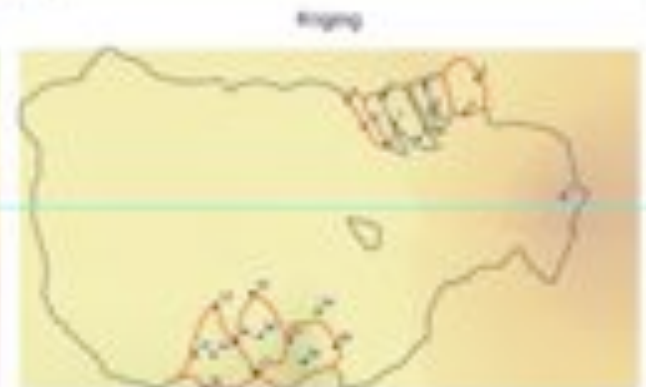
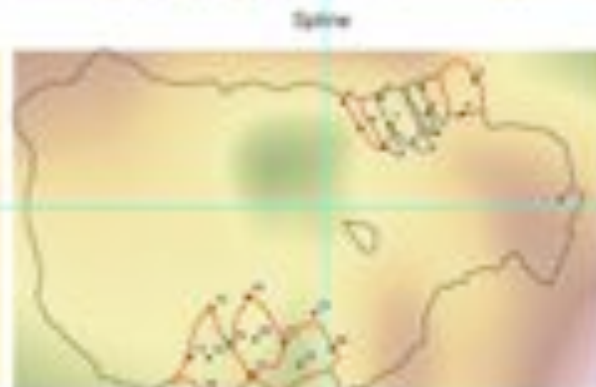


[http://www.hubbardbrook.org/image\\_library/images/Precip\\_Sampler.jpg](http://www.hubbardbrook.org/image_library/images/Precip_Sampler.jpg)

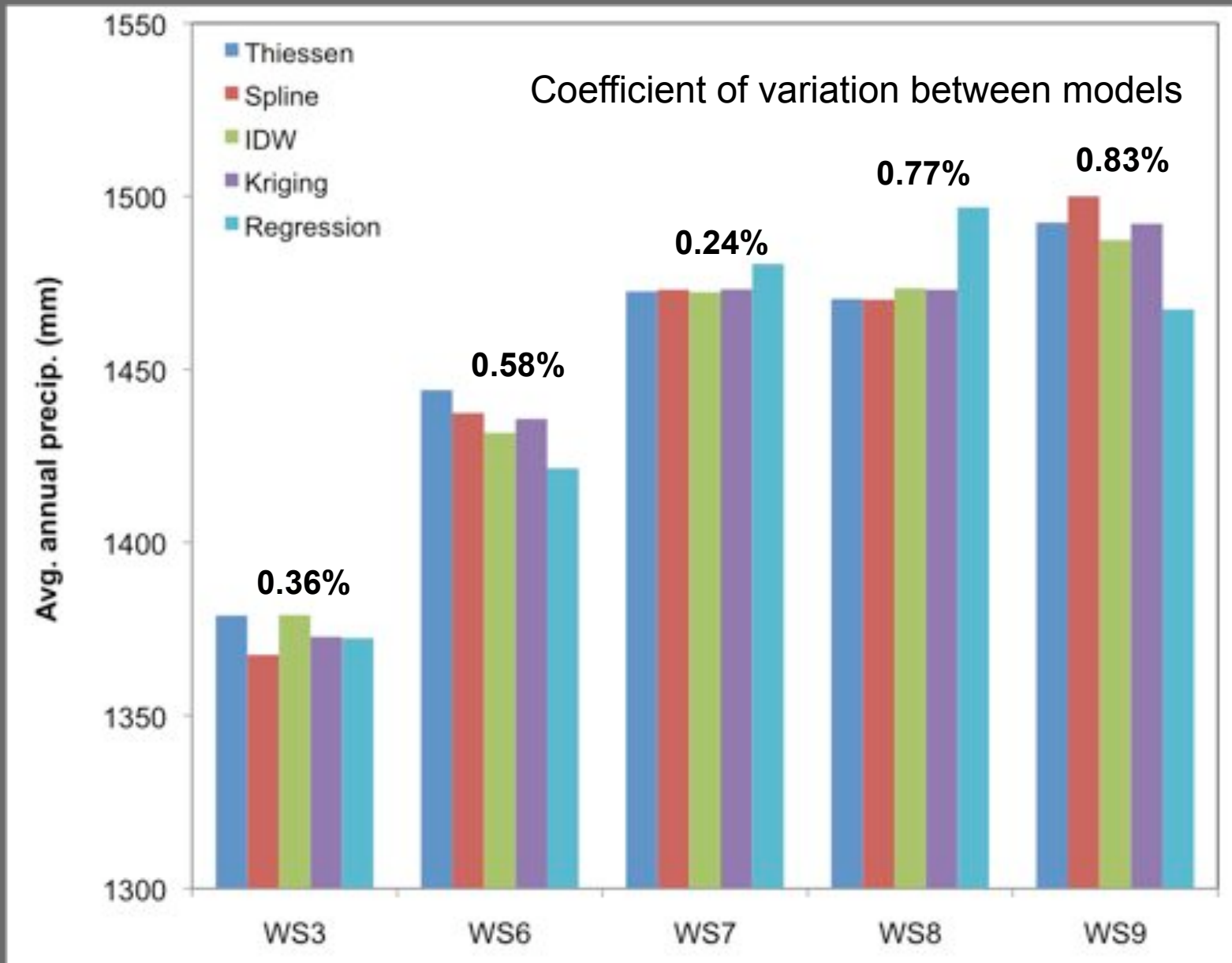
# Hubbard Brook Valley



# Alternative spatial models for precipitation in the Hubbard Brook Valley

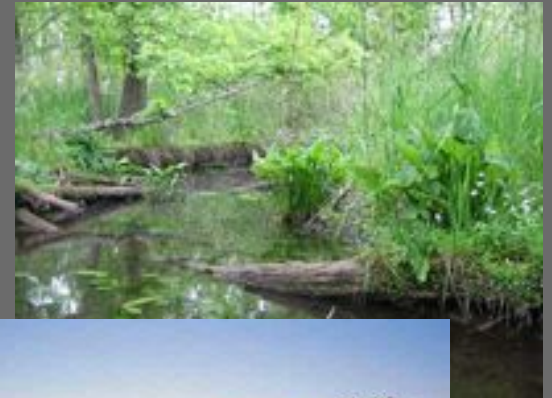


## Alternative spatial models for precipitation in the Hubbard Brook Valley

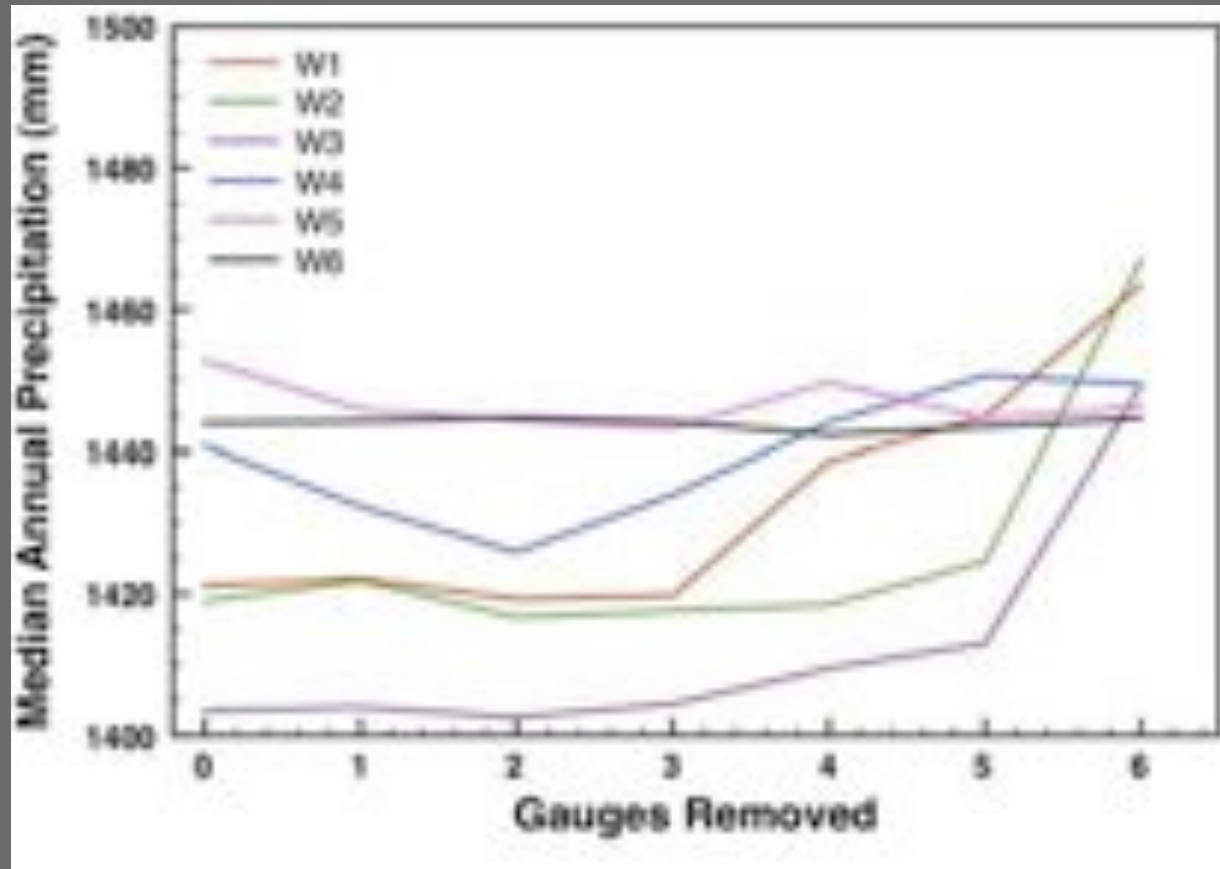


# Uncertainty and Monitoring Efficiency

- 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

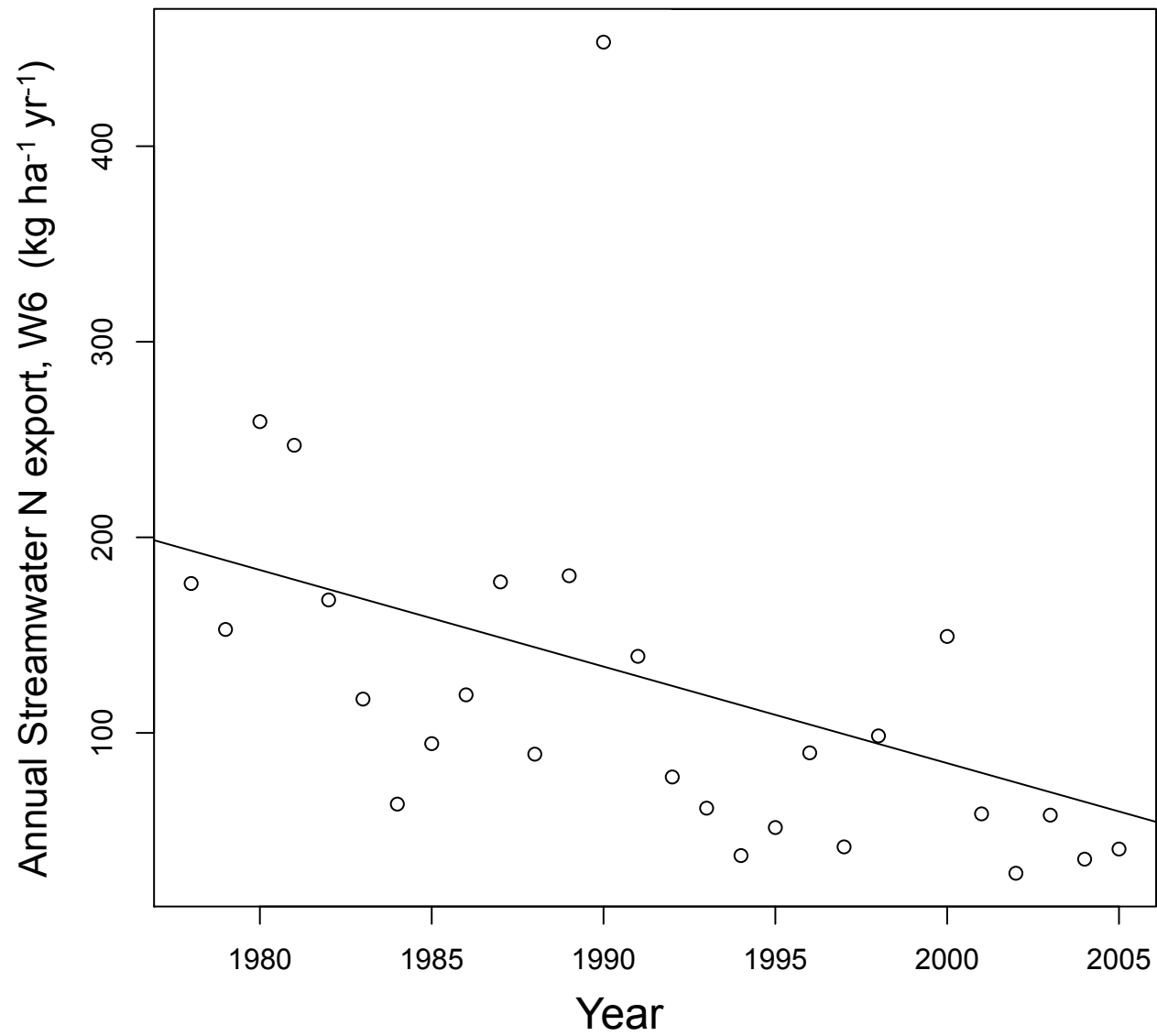


## Using uncertainty to assess monitoring efficiency: Precipitation

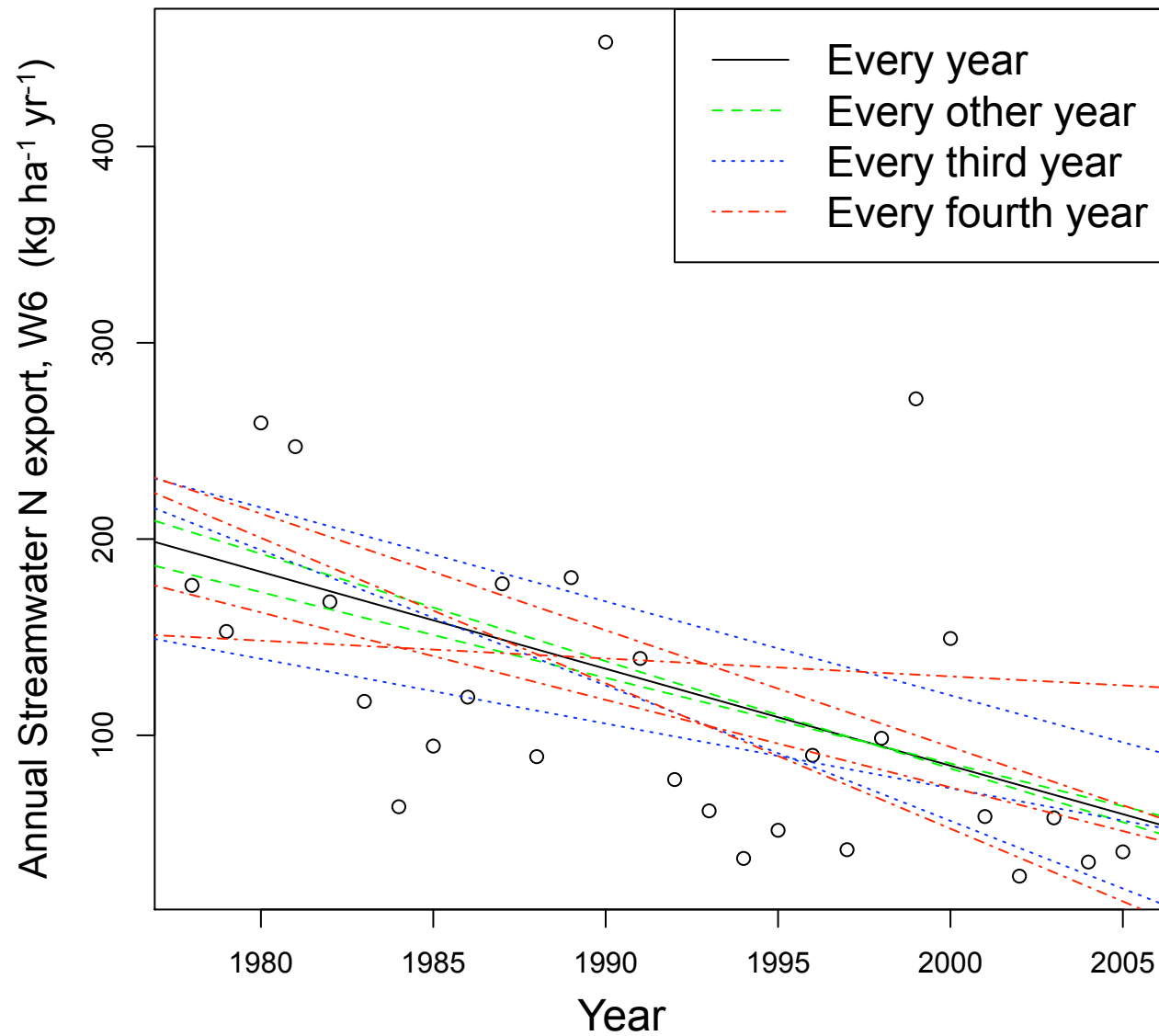


- Test how sampling intensity contributes to confidence in the annual precipitation estimates by sequentially omitting individual precipitation gauges.
- Median annual precipitation estimates varied little until five or more of the eleven precipitation gauges were ignored.

## Using uncertainty to assess monitoring efficiency: Streamflow

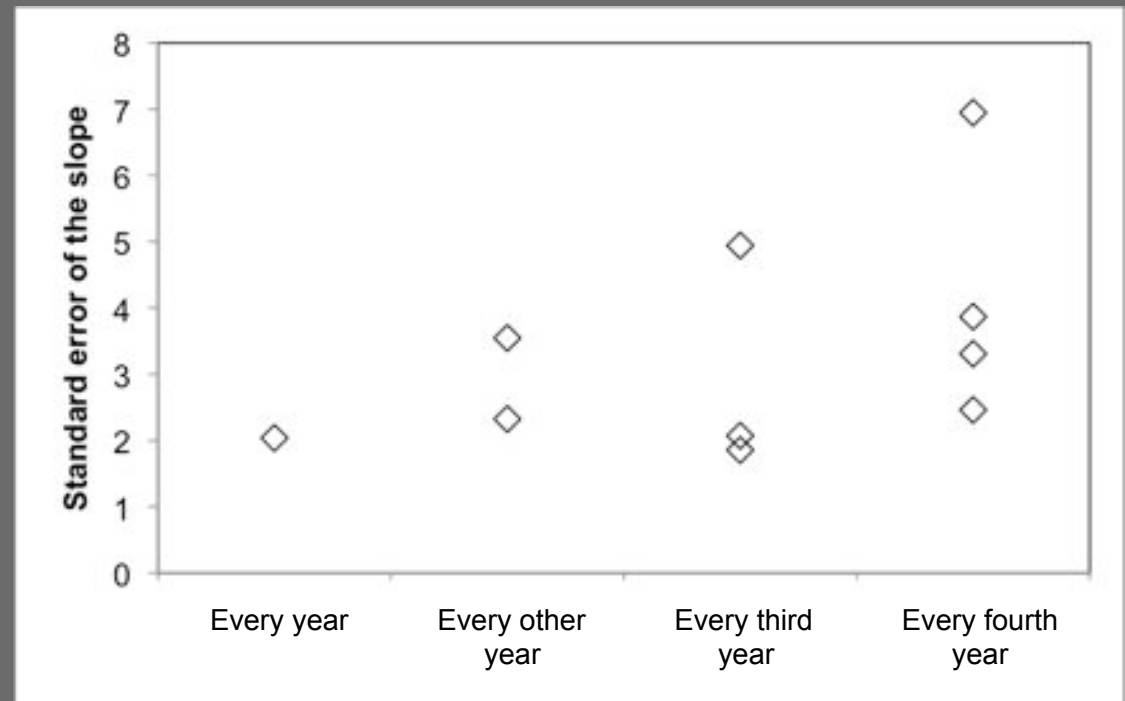
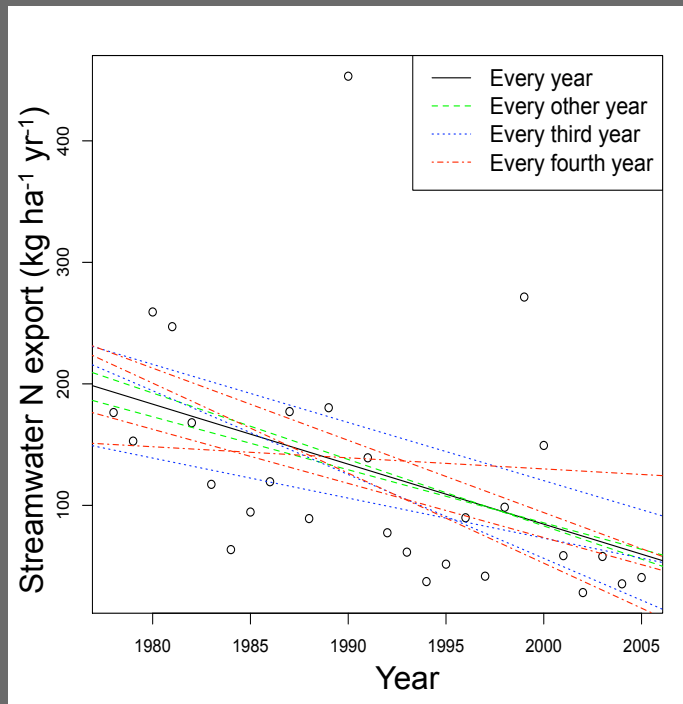


## Using uncertainty to assess monitoring efficiency: Streamflow





## 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

### **Be a part of QUEST!**

- Find more information at: [www.quantifyinguncertainty.org](http://www.quantifyinguncertainty.org)
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- Email us at [quantifyinguncertainty@gmail.com](mailto:quantifyinguncertainty@gmail.com)

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- Images
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Sitemap  
Recent site activity



## Welcome to QUEST

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.

## QUEST would like to thank:

- NSF, LTER, JSPS
- All QUEST sites for contributing data and many patient and accommodating data managers
- Many people who have contributed to collection of long-term data
- Everyone who has contributed papers, example code, presentations, and links to the QUEST website





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