Solutes and water cycling in catchments

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Carbon and Nitrogen Cycling in the Forest Water Cycle

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Background

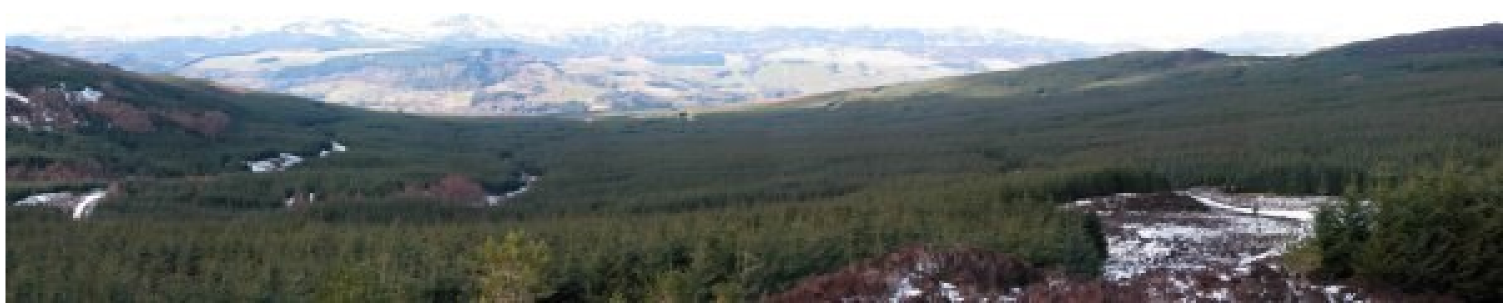
- Climate change; increasing atmospheric CO_2 concentrations => carbon (C) sequestration in biomass
- Forests apparent C sinks BUT sink strength affected by:
  - Release from soil
  - Loss of C through water flux
  - Nutrient availability
  - Forest age and management

Research questions

- How do C losses in water compare with C uptake by forest?
- What is the relationship between C sequestration and forest nitrogen cycling?
- How to scale from point measurements to forest-wide fluxes?

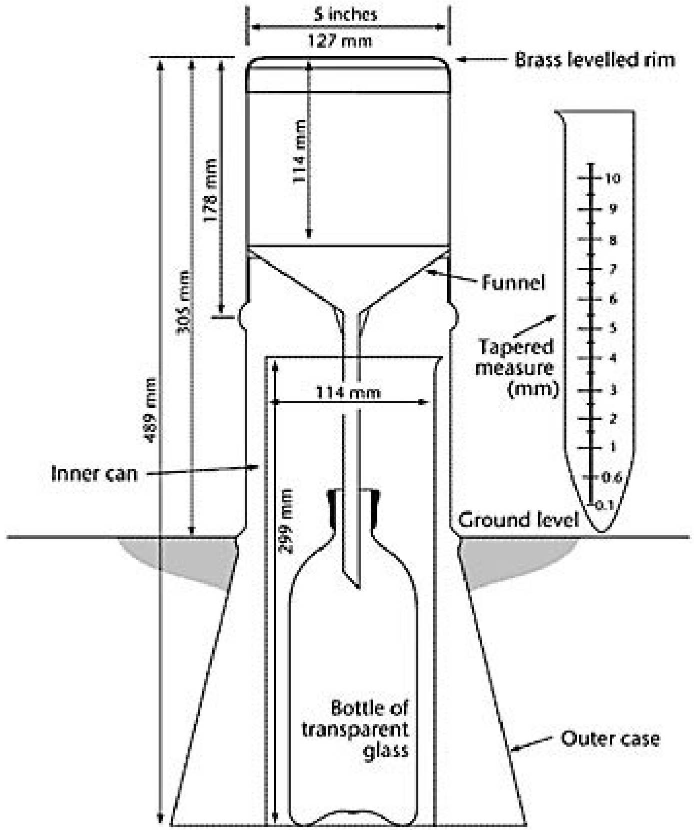
Study site: Griffin Forest (56.6^{o}N, 3.8^{o}W)

- Cool temperate climate
- Altitude: 275-532 m above sea level
- Catchment area 4.47 km^2
- Average slope 6^{o}
- Geology: Dalradian schist overlain by glacial till
- Soils: 0.7 m depth humic gley
- Forest planted 1980-1981
- Sitka spruce dominant
- C sequestration measured since 1997



Field measurements of hydrological flux

Storage raingauges



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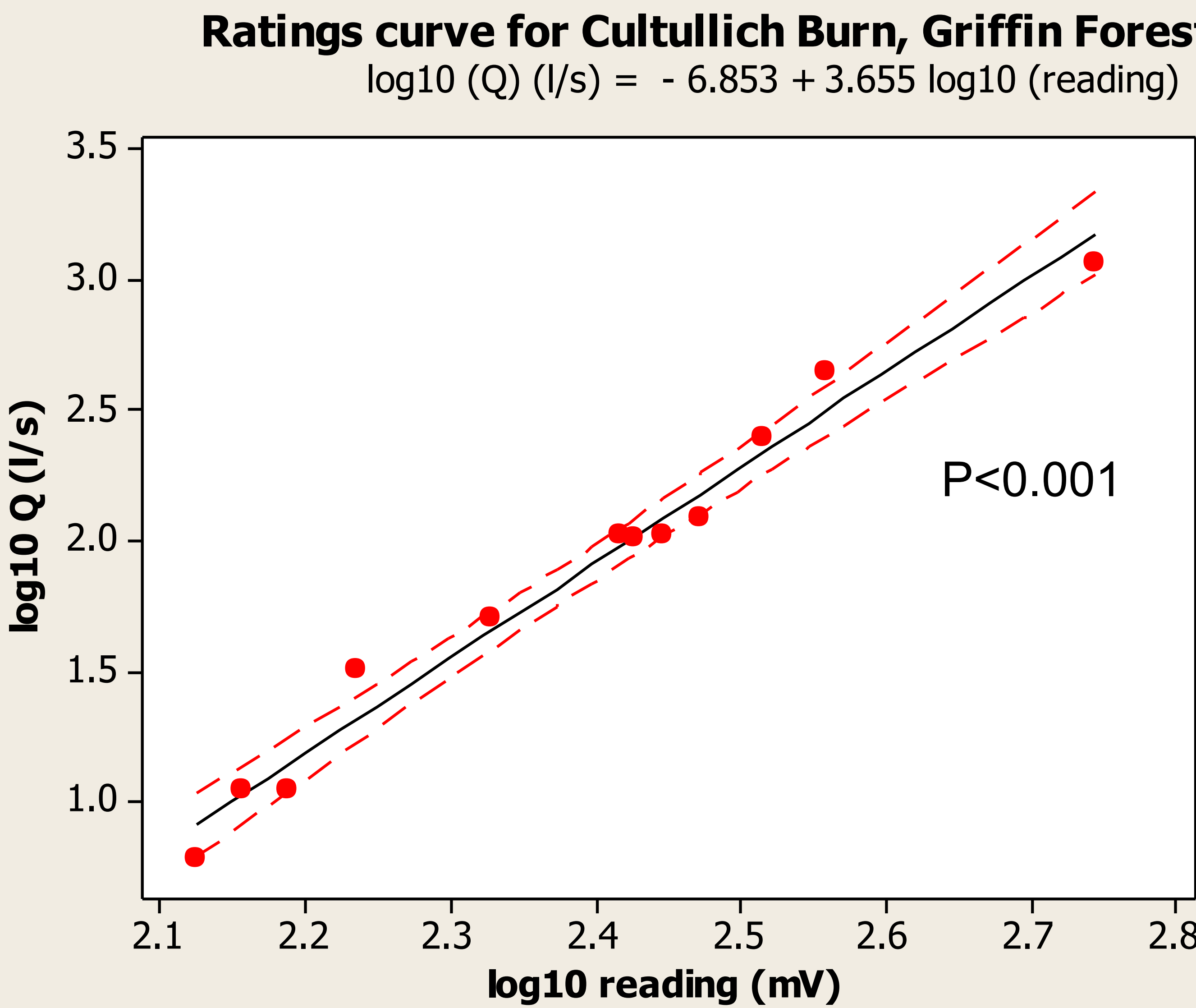
Stream outflow



Water depth readings every 15 minutes recorded electronically by data logger

Other measurements

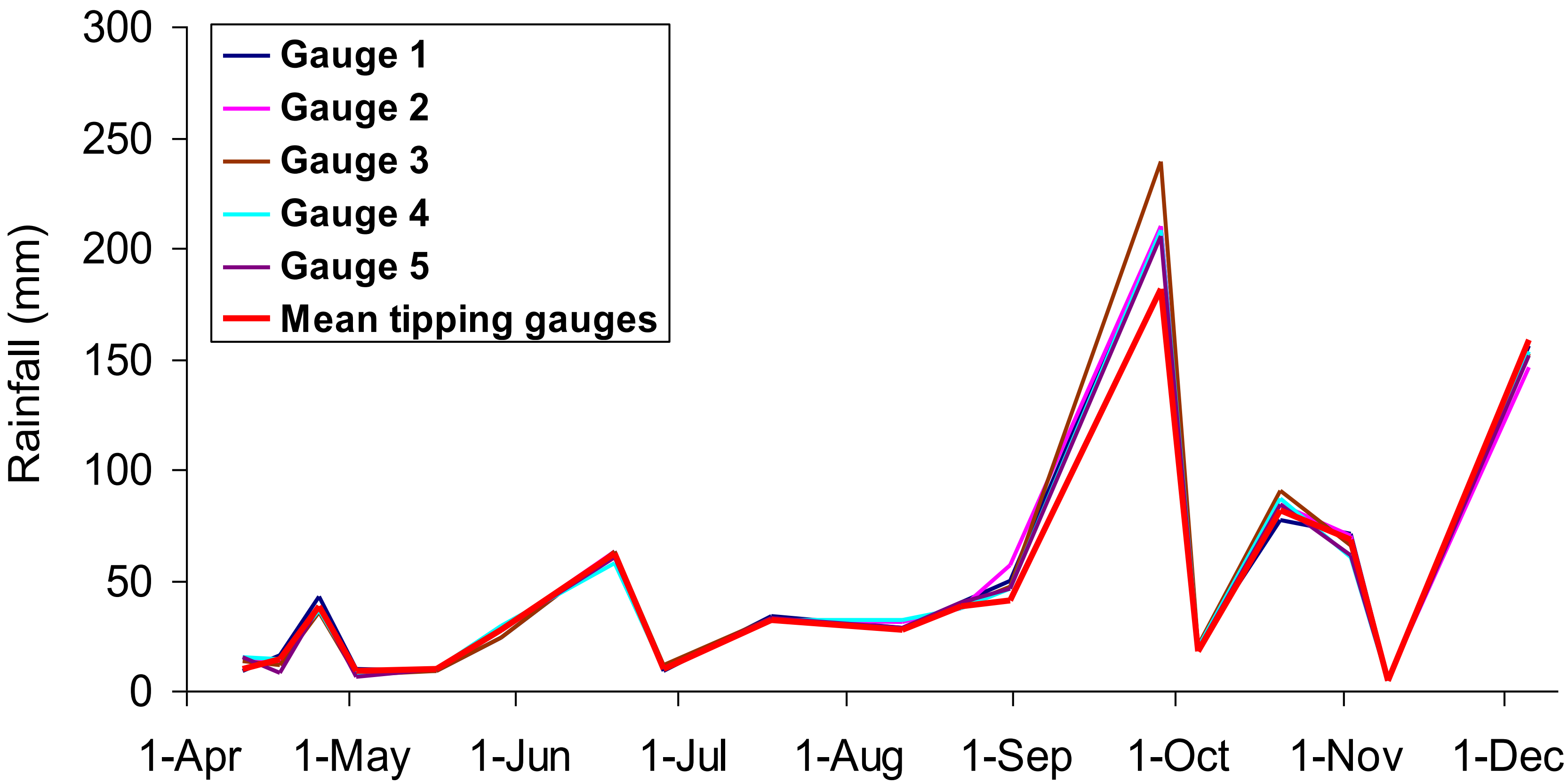
- Chemical analyses of water samples
  - pH
  - NO_3-N, NH_4-N
  - Total carbon (TC), dissolved organic carbon (DOC), total inorganic carbon (TIC = TC-DOC)
- Forest characterisation
  - tree DBH (diameter at breast height) surveyed

Image credit: Michael Spencer

Measurement of C uptake by the forest

- Measured as flux of CO_2 up and down from forest
- Eddy covariance (micrometeorological method)
- Movement of air parcels measured in 3 dimensions using a sonic anemometer
- Air analysis => flux of CO_2 calculated
- Other micrometeorological measurements to check energy balance and calculate evapotranspiration

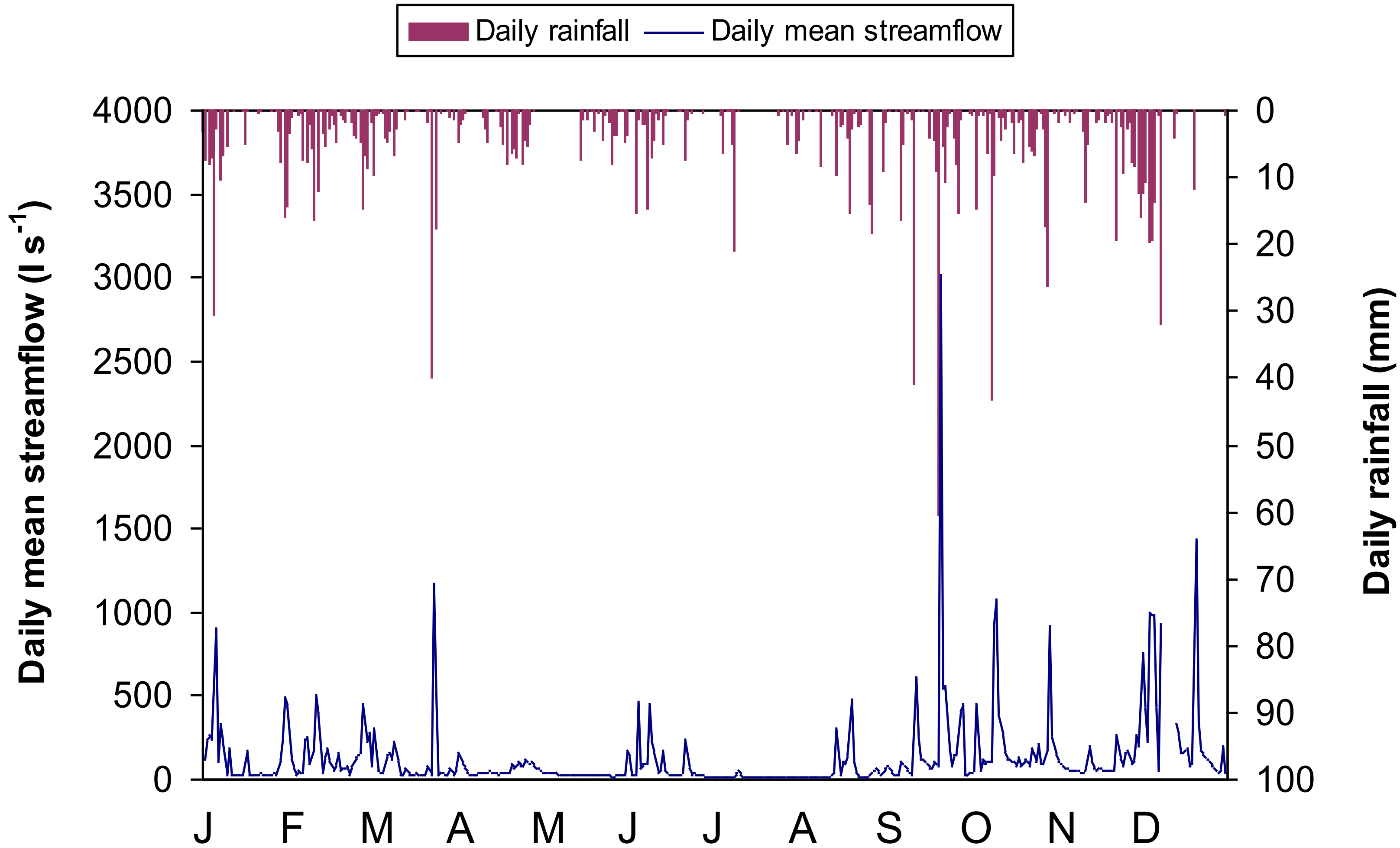
Rainfall amount results



No spatial variation in rainfall totals in catchment

No relationship between rainfall and altitude

Rainfall and streamflow 2000



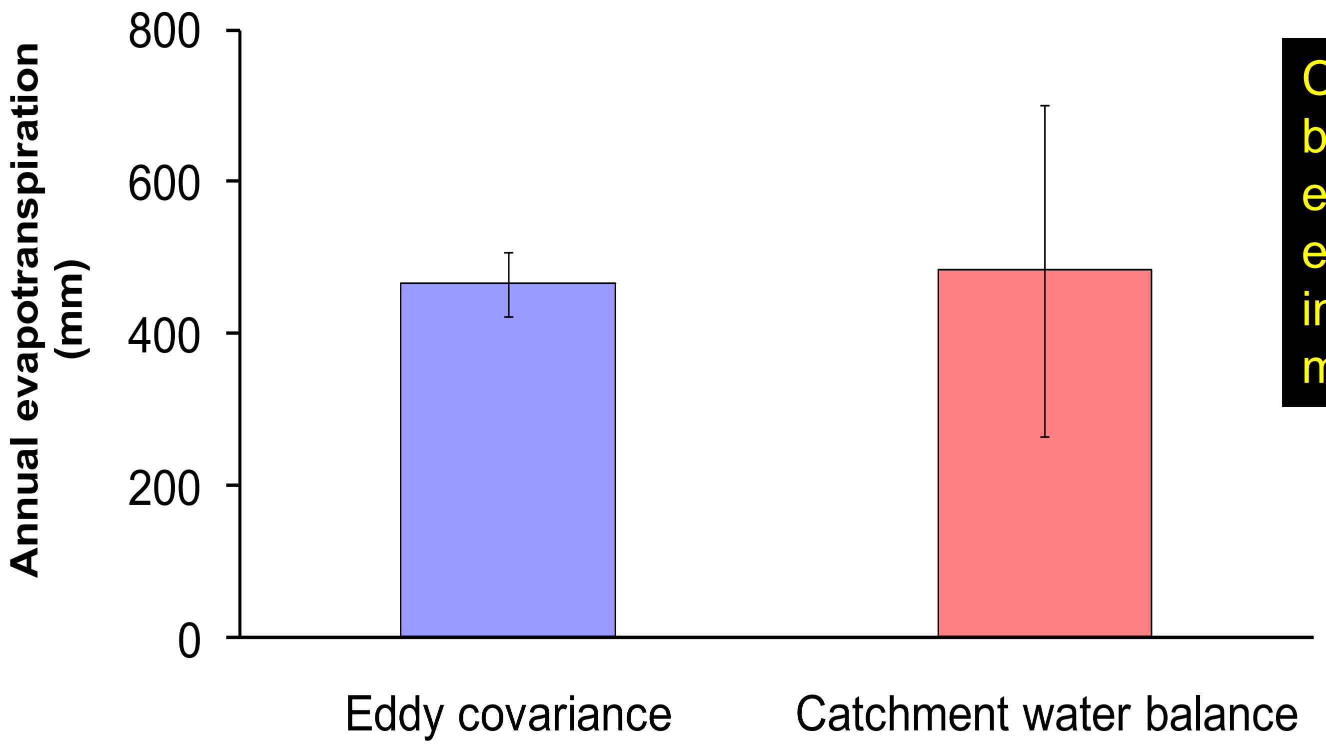
Annual evapotranspiration estimates 2000

- <u>Catchment water balance method</u>

  E = precipitation – streamflow

- <u>Eddy covariance</u>

$$E = \frac{Measured\ latent\ energy}{Latent\ heat\ of\ energy\ of\ evaporation\ of\ water}$$



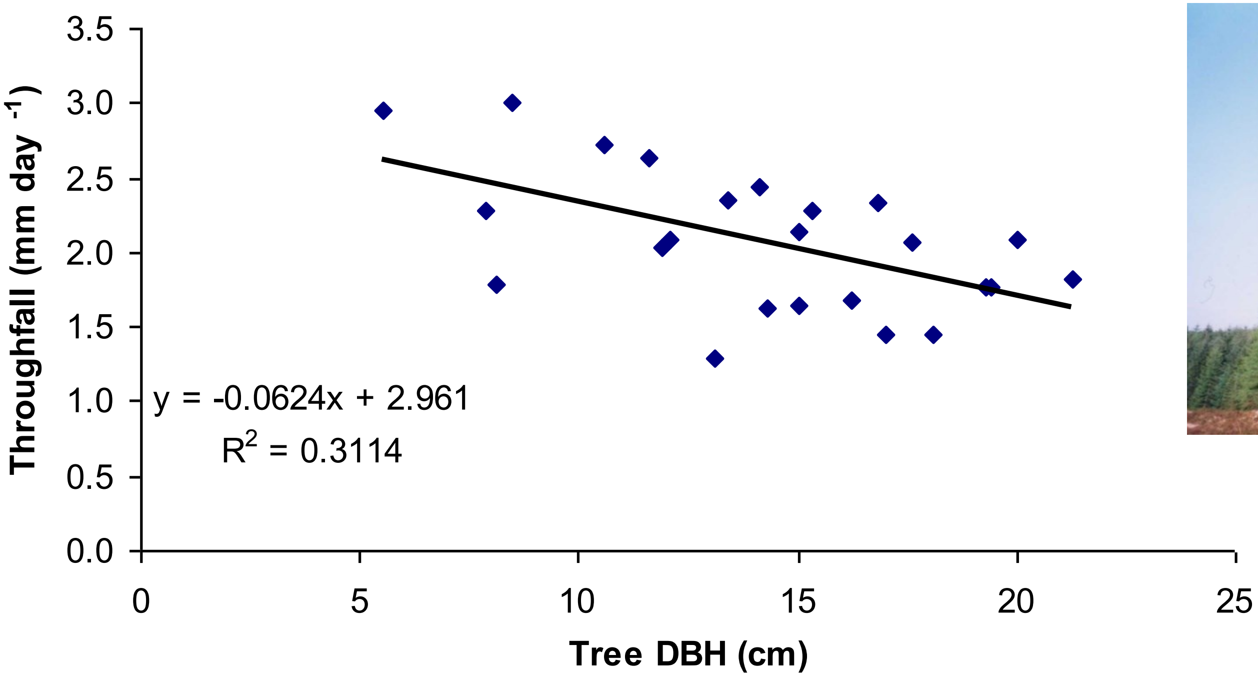
Close agreement between evapotranspiration estimates => confidence in hydrological flux measurements

(Nick Forrest)

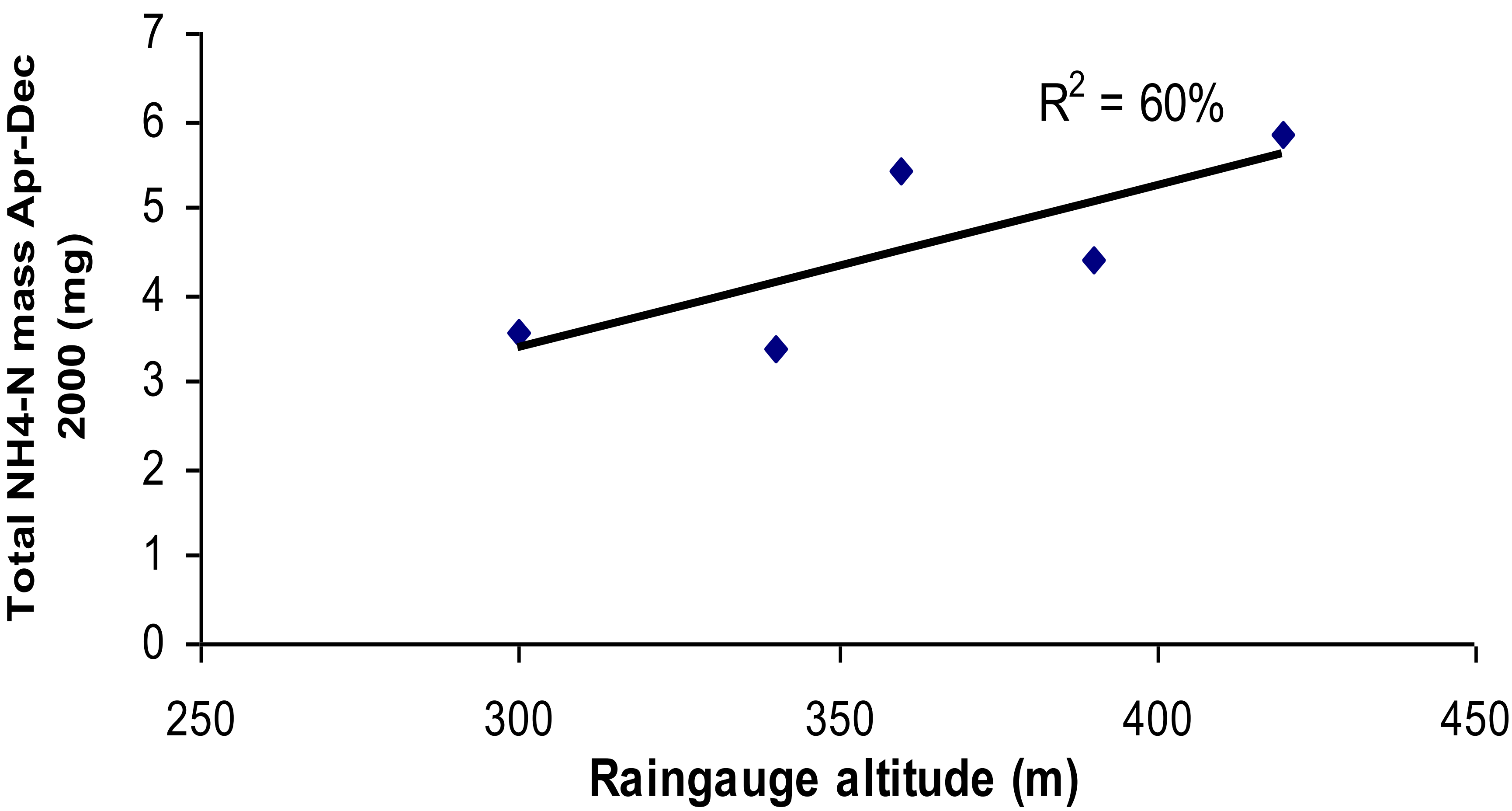
Problems of scaling up throughfall/stemflow fluxes

Need to take account of factors such as:

– Depth/volume vs. tree properties relationships



Relationship between N in rainfall and altitude



Increased N deposition with altitude well-documented

Streamwater carbon and nitrogen flux calculations

- Mass flux = concentration x flow
- Frequent flow measurements BUT infrequent concentration measurements => different flux calculation methods

1) Mean value

   Flux = flow volume (from mean flow) x mean concentration for whole study period

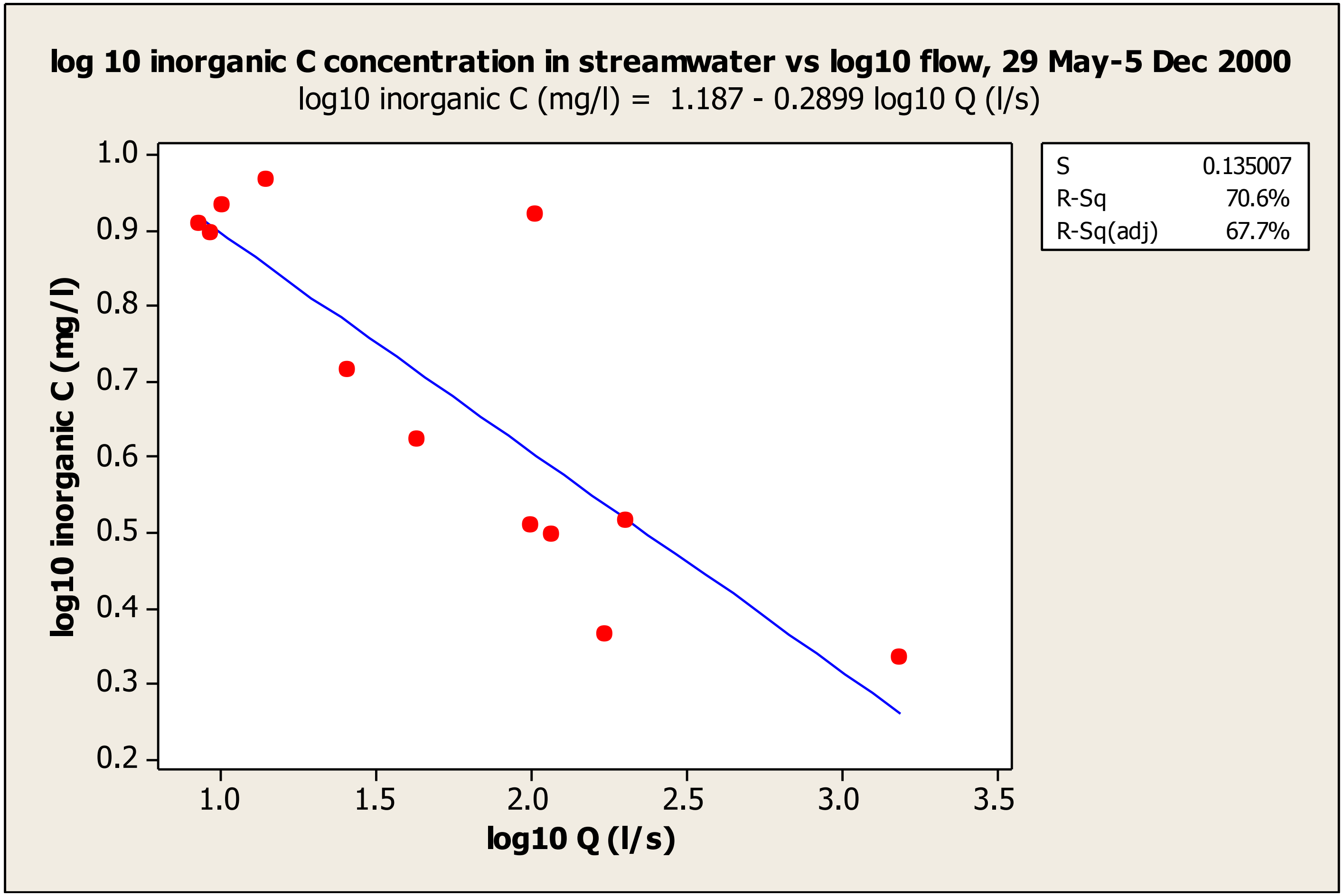
2) Individual time periods

$$\boldsymbol{Flux} = \sum_{t=1}^{t=n} (flow\ volume\ (from\ mean\ flow) \times mean\ concentration)$$

3) Continuous

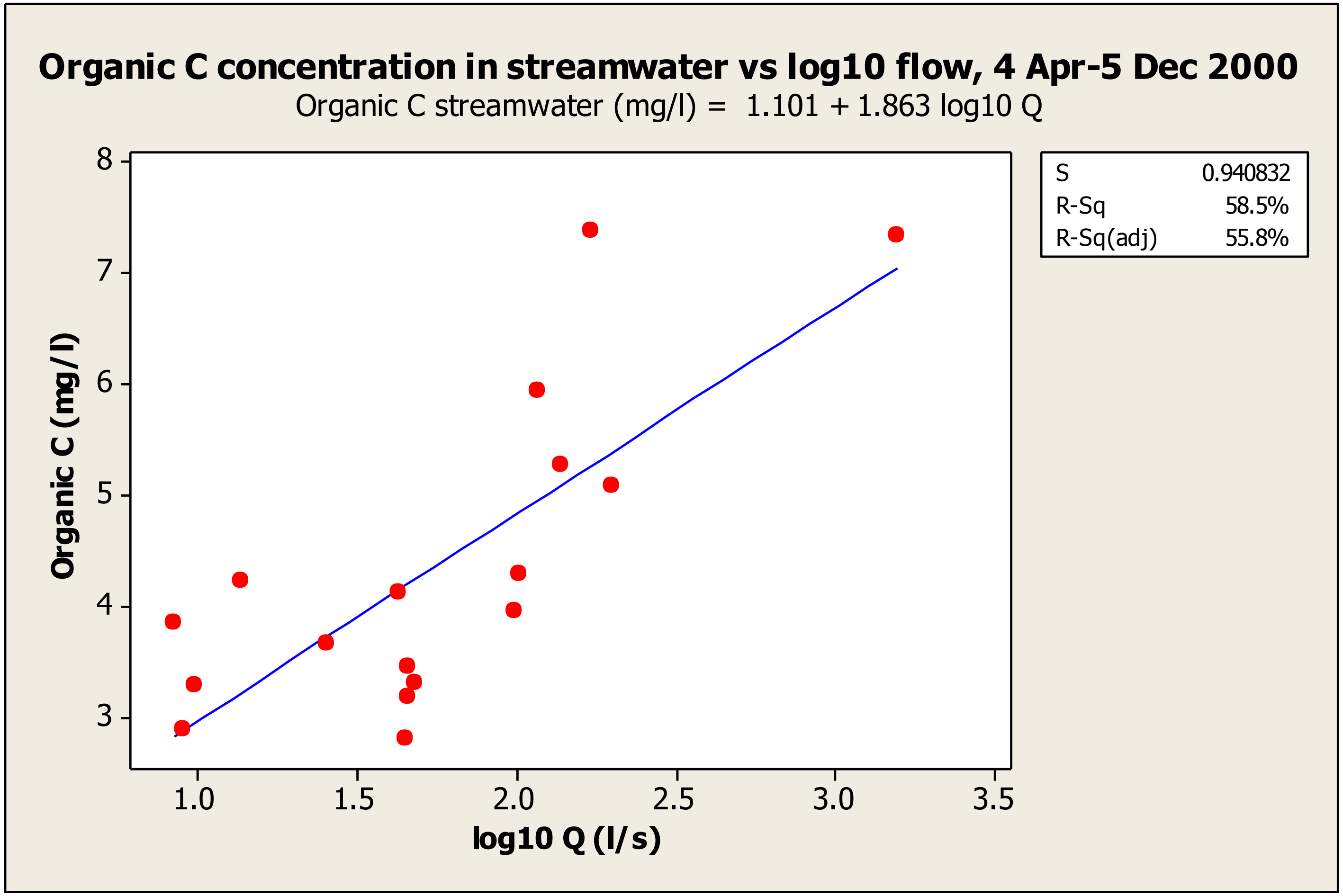
   Where relationship between concentration and flow, concentration estimated for every streamflow measurement

Flow-concentration relationships for TIC in stream water



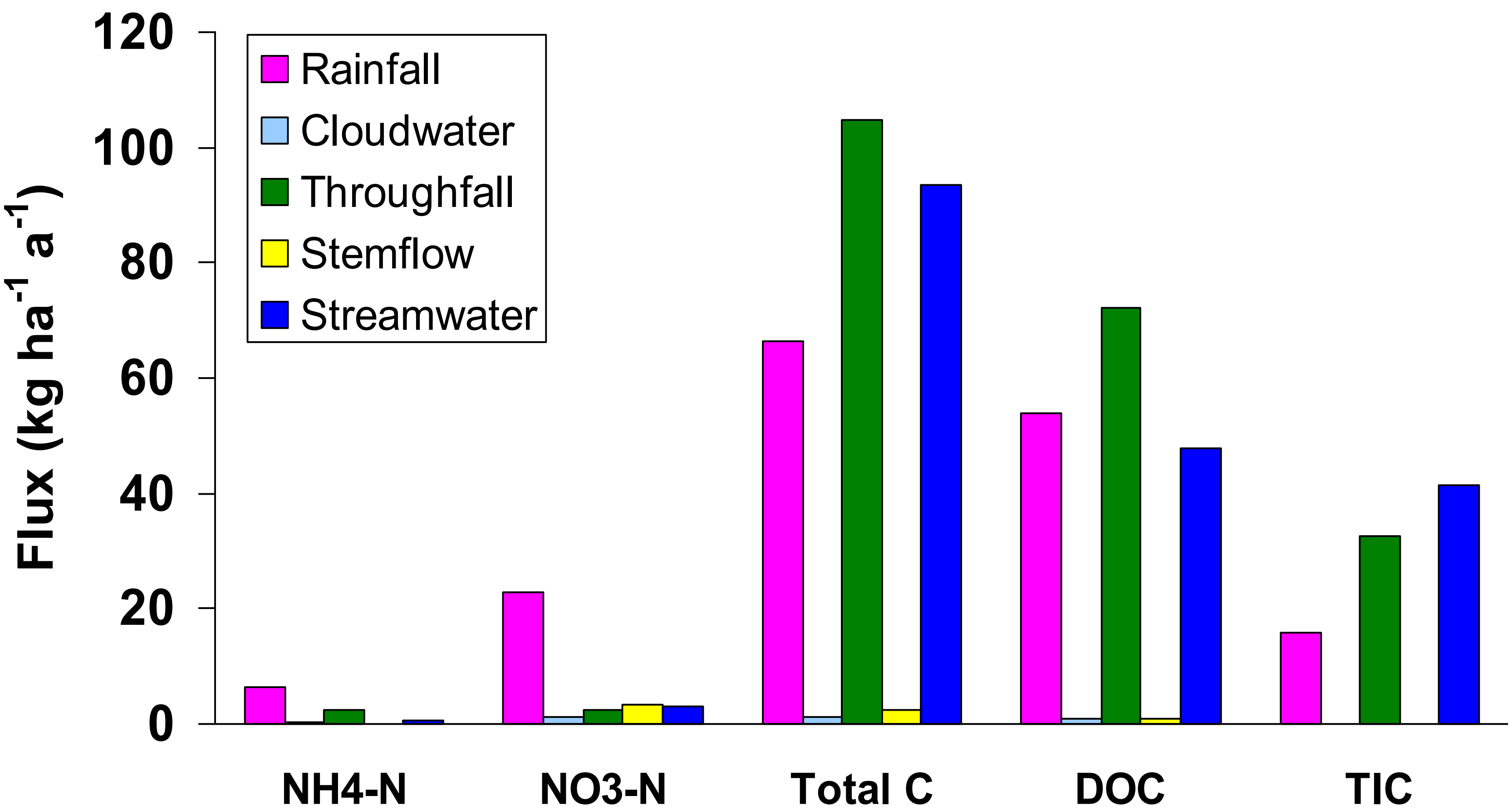
At low flows TIC inputs from mineral weathering in deeper soil horizons less diluted

Flow-concentration relationships for DOC in stream water



DOC flushed from organic near-surface soil horizons at high flows

Annual hydrological N and C fluxes, 2000



Net nitrogen gain by catchment (0.027 t ha^{-1} a^{-1})

Net carbon loss from catchment (0.026 t ha^{-1} a^{-1})

Comparison of C losses in water to C sequestration

Parameter	Study site		
	Griffin Forest (Scotland)	**Hokkaido (N Japan)**	**Moor House (N England)**
Reference	*This research*	*Shibata et al. (2005)*	*Worrall et al. (2003)*
Vegetation	Sitka spruce plantation	Temperate deciduous forest	Heather (dwarf shrub)
C loss in water ($t\ ha^{-1}\ a^{-1}$)	-0.026	-0.04 (incl. POC)	-0.348 (-0.149 without POC)
C sequestered ($t\ ha^{-1}\ a^{-1}$)	6.1	2.6	0.55
% sequestered C lost in water	0.43	1.5	63 (27 without POC)

Carbon losses in river water small % of C sequestered in forests, BUT may be more significant for shrub vegetation cover

Ongoing research focus on role of the forest canopy in nitrogen cycling

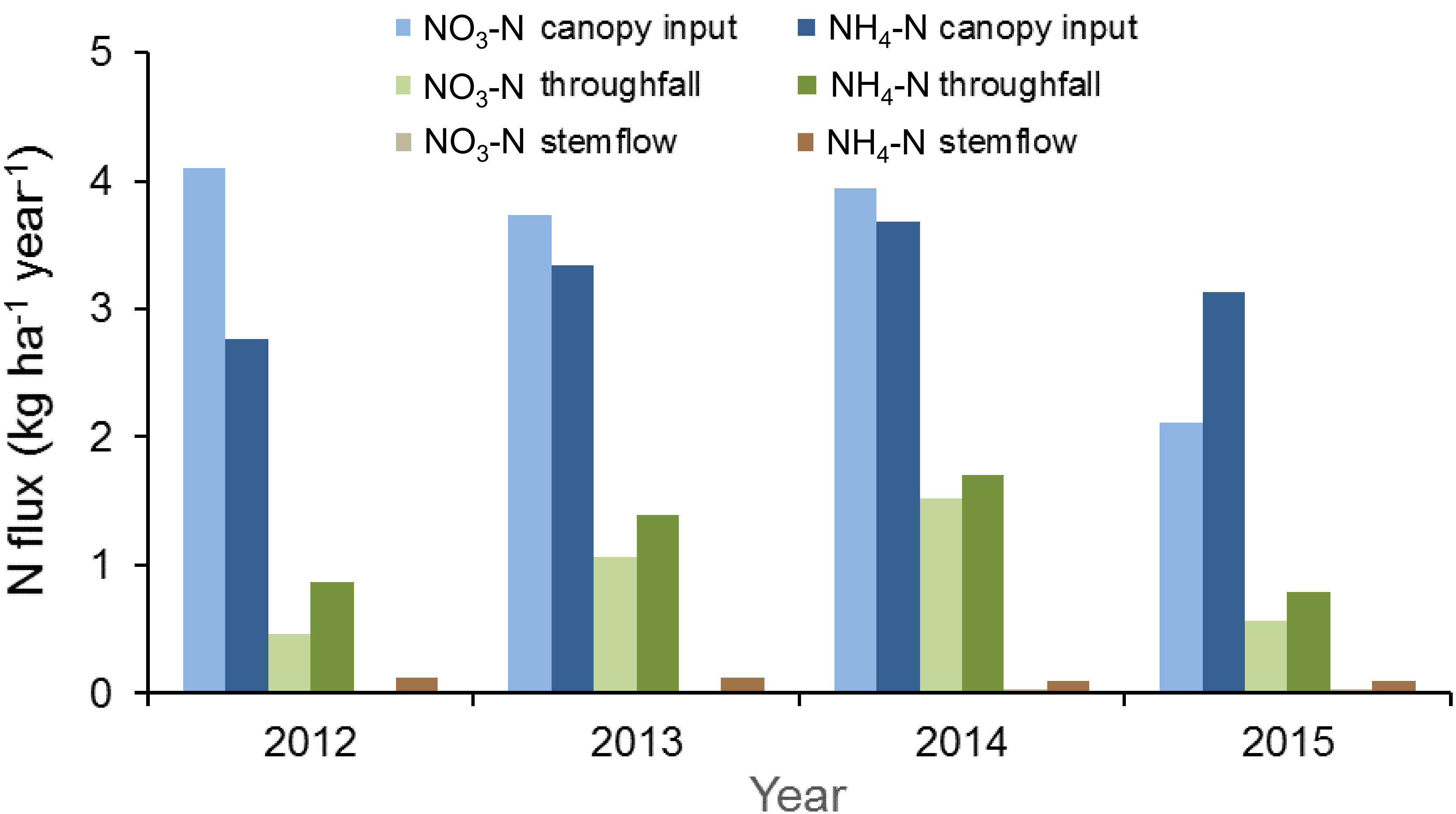
Rainfall and cloud water collection x 2

Stemflow collection x 22

Throughfall and litter collection x 18

Stream flow gauging x 4

Preliminary results for forest canopy N processing



Confirms c.70% N deposition intercepted by canopy
Stemflow insignificant for N fluxes

Interaction between atmospheric N and C sequestration by forests

- Possible explanations for atmospheric N uptake by forest canopy
  1. Foliar uptake by needles
  2. Cation exchange for NH_4-N
  3. Uptake by microfauna & algae in canopy (sometimes associated with aphid infestation)
- C sequestration per unit added N (*ΔC:ΔN*)
  - 210 (Magnani et al., 2007) – considering atmospheric N deposition (onto forest canopy)
  - 46 (De Vries et al., 2006) – considering N application onto forest soil
  - *c.*170 in 2000 at Griffin Forest
- Although atmospheric N deposition may enhance C sequestration it may => acidification of soils and disruption of nutrient cycling

Recommended papers with further information on this topic

Clement, R. J., Jarvis, P. G. and Moncrieff, J. B. (2012). Carbon dioxide exchange of a Sitka spruce plantation in Scotland over five years. Agricultural and Forest Meteorology, 153, 106-123.

Dail, D. B., Hollinger, D. Y., Davidson, E. A., Fernandez, I., Sievering, H. C., Scott, N. A. and Gaige, E. (2009). Distribution of nitrogen-15 tracers applied to the canopy of a mature spruce-hemlock stand, Howland, Maine, USA. Oecologia, 160, 589-599.

Magnani, F. et al. (2007). The human footprint in the carbon cycle of temperate and boreal forests. Nature, 447, 848-850.