

Conceptualising and upscaling process understanding of the hydrological and biogeochemical functioning of larger catchments

M. Speed (1), D. Tetzlaff (1), J.J.C. Dawson (1), M. Hrachowitz (1), S. Waldron (2), I.A. Malcolm (3), S.M. Dunn (4) and C. Soulsby (1)

(1) Northern Rivers Institute, School of Geosciences, University of Aberdeen, AB24 3UF, Scotland, UK (e-mail: markspeed@abdn.ac.uk),
 (2) Department of Geographical and Earth Sciences, University of Glasgow, Glasgow, G12 8QQ, UK.
 (3) FRS Freshwater Laboratory, Faskally, Pitlochry, PH16 5LB, UK.
 (4) The Macaulay Institute, Craigiebuckler, Aberdeen, AB15 8QH, Scotland, UK.

1. INTRODUCTION

- Understanding hydrological functioning at a range of spatial and temporal scales is fundamental to catchment science.
- Need for greater process understanding at larger scales.
- Heterogeneity in both space and time creates problems when assessing large scale behaviour from small scale processes.
- Need for tools that allow process understanding to be extrapolated from one scale to another.
- Geochemical and isotopic tracers are useful tools for identifying hydrological source areas, flow paths and mean residence times.
- This poster reports the first twelve months of a two year tracer study of the ca.2,000km² catchment of the River Dee in northern Scotland directed towards such quantification.

2. STUDY OBJECTIVES

- To characterize the hydrology and tracer chemistry of the River Dee and its tributaries.
- Investigate the input – output relationships of isotopic tracers in precipitation and runoff to assess differences in the response of the catchment system.
- To provide a tracer based conceptualisation of the hydrological and biogeochemical functioning.

3. STUDY AREA

- The Dee flows ca.140km east from its headwaters to the North Sea in Aberdeen (Figure 1a).
- Annual precipitation: ca.1500mm in the west – 800mm in the east.
- Mean annual discharge decreases downstream, from 42.11 s⁻¹ km³ at Mar Lodge and 25.47 s⁻¹ km³ at Park (Table 1).
- Geology: catchment dominated by Precambrian metamorphic and igneous rocks. Highly variable in tributaries (Table1)
- Montane and alpine vegetation found at the highest altitudes and heather moorland (*Calluna vulgaris*) on upper and middle slopes in the west/south.
- East: intensively managed for agricultural (grassland/arable) purposes.
- Hydrologically responsive soils (peat gley and blanket peat) dominate where low permeability till is the main parent material in south and west (Figure 1b).
- Responsive, thin alpine soils and rankers widespread in glacially eroded terrain above 800m.
- Freely draining humus iron podzols dominate eastern lowlands.



Dye at Charr (11)

ID	Site	Area (km ²)	Mean elev. (m)	Mean annual flow (km ³ yr ⁻¹)	Responsive soils (%)	Igneous Rock (%)	Metamorphic Rock (%)
1	Dee Mainstem	293.4	683	42.4	75	37	61
2	Mar Lodge (MAR)	699.8	821	33.8	62	41	50.5
3	Bullator (BAL)	962.9	603	31.22	60	46	50
4	Pitlochry (PIT)	1346.4	618	27.52	51	46	48.5
5	Banchory (BAN)	1712.1	618	27.52	49	51	44.5
6	Park (PAR)	1836.6	446	25.5	47	51	44.5
7	Gairn (GAI)	143.3	561	25.9	60	61	38
8	Mar Lodge (MAR)	102.4	600	34.1	48	50	48.5
9	Gimock (GIR)	30	409	17.5	73	54	65
10	Strathfield Burn (SB)	3.4	359	N/A	65	46	52.5
11	Dye at Charr (DYE)	23.3	357	30.93	94	76	24
12	Heugh at Heugh Head (HH)	232.5	396	25.24	65.2	85	18

Table 1. Catchment characteristics of the 12 sampling sites at mainstem sites of the Dee (1-6) and catchment tributaries (7-12); all sites are sorted along a west-east direction.

3. STUDY AREA (continued)

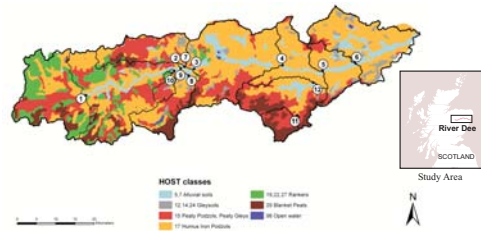


Figure 1a- Topography of the Dee Catchment and Figure 1b - HOST soil classes in the Dee Catchment: 1-6 main stem, 7-12 tributaries (mapped according to the UK Hydrology of Soil Types (HOST) database)

4. METHODOLOGY AND DATA ACQUIRED

- Weekly grab water samples from six sites along main stem of River Dee (ID: 1- 6) and six tributaries (ID: 7-12) (Table 1).
- Discharge and precipitation data provided by Scottish Environment Protection Agency (SEPA) at nine sites, 15 minutes resolution.
- Precipitation data collected weekly at the Gimock (and daily at three other sites).
- Samples analyzed for δ¹⁸O (mass spectrometry), Gran alkalinity (titration) and Dissolved Organic Carbon (DOC).
- Alkalinity and Dissolved Organic Carbon (DOC) used as hydrochemical tracers to determine spatial variation in runoff sources and biogeochemical processes.
- Input/output relationship of δ¹⁸O will be assessed by various residence time models.

5. RESULTS

5.1. Spatial distribution of ¹⁸O response

- Precipitation exhibits strong seasonal variation in δ¹⁸O values, ranging from -17.0‰ in the winter to 0.51‰ in the summer (Figure 2).
- Streamwater δ¹⁸O is typically more depleted at sites furthest upstream, probably reflecting altitudinal gradients in recharge signatures.
- Mainstem δ¹⁸O becomes more depleted as winter events progress and more enriched as summer develops, suggesting responsive runoff sources with seasonally variable isotope ratios.
- During high flow events, δ¹⁸O shows more marked declines in western headwater tributaries (e.g. Gimock and Gairn) which are dominated by responsive soils implying relatively rapid transfer of precipitation and snowmelt signals to the channel network.
- As summer progresses, mainstem δ¹⁸O values appear to converge at lower flows. This is consistent with mixed groundwater sources being the dominant contributors to runoff.

5.2. Spatial distribution of Gran alkalinity

- Low flow Gran alkalinity concentrations (Figure 3) reflect marked inter-catchment variations in geology (Table 1).
- Granite-dominated catchments, such as Heugh Head (HH), have much lower baseflow alkalinity concentrations than catchments with greater contributions of metamorphic and calcareous metasediments such as the Gimock (GIR).
- High flow alkalinity at all sites converges together as runoff generated in acidic, peaty soils provides the dominant runoff source (Figure 3).
- Mean tributary Gran alkalinity values ranged from 303μEq l⁻¹ in the Gimock to 165μEq l⁻¹ at Heugh Head.

5.3. Spatial distribution of DOC

- More DOC variability in smaller tributaries due to higher % of organic soils in upper headwaters.
- Main stem DOC values appear to be an average of tributary concentrations.
- Peak DOC concentrations occur in late summer/early autumn – while DOC production is greatest in summer, it is not exported until stream discharge is high enough to remove from system.
- During dry periods DOC values are much lower and similar at all sites consistent with low DOC groundwater contributions.
- Highest DOC concentrations in storm runoff seem to reflect catchments with the highest coverage of organic-rich peaty soils such as the Heugh Head (HH) and Gimock (GIR).

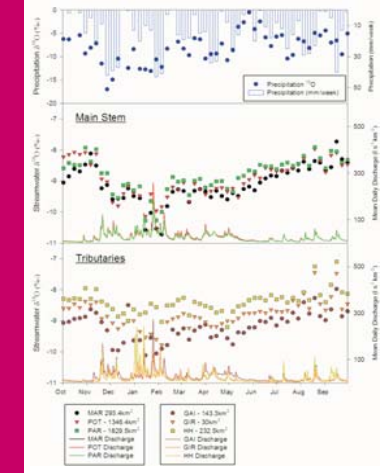


Figure 2. Weekly δ¹⁸O and discharge values between Oct 07 – Sept 08 at main stem sites Mar Lodge (293 km²), Pitlochry (1346 km²), Park (1836 km²) and tributary sites Gairn (143 km²), Gimock (30 km²) and Heugh Head (232 km²) with precipitation δ¹⁸O and amount at Banchory.

5. RESULTS (continued)

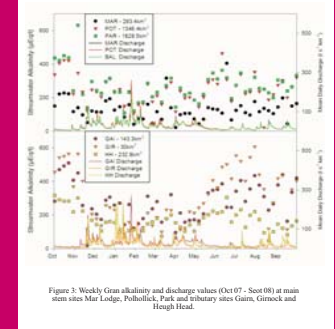


Figure 3. Weekly Gran alkalinity and discharge values (Oct 07 – Sept 08) at main stem sites Mar Lodge, Pitlochry, Park and tributary sites Gairn, Gimock and Heugh Head.

6. CONCLUSIONS AND FUTURE WORK

- Hydrologic and tracer data indicate that runoff from soil-derived hydrological pathways dominate high flows and facilitate a relatively rapid translation of precipitation isotope signatures into the channel network.
- This appears to be most marked in the catchment headwaters, which appear to have a disproportionate influence on the downstream network most likely reflecting higher precipitation and a greater coverage of more responsive soils.
- DOC data provides additional evidence for the dominance of soil-derived water sources at high flows.
- Variability between the hydrological and tracer responses within individual tributaries appears to be strongly influenced by catchment geology and soil type.
- δ¹⁸O input – output relationships between rainfall and runoff will be compared to assess catchment residence time distributions and relate this to dominant landscape controls.
- To incorporate δ¹⁸O and alkalinity data in hydrological models to examine changing response with scale and catchment characteristics in a more quantitative manner.
- Apply a Principal Component Analysis (PCA) to assess the similarity and differences of catchments based upon their physical characteristics.