Multi-proxy indices of hydrological connectivity at multiple scales

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Doerthe Tetzlaff
Ecohydrological connectivity across scales

Catchment scale (Local scale)

Hillslope scale

Instream hydraulics / Ecological habitats
Outline

• Accidental use of connectivity as a framework
• Structural Connectivity
• Functional Connectivity
• Tracers as scaling tools
• Travel times as connectivity indices
• Integration in models
• Utility in management
Scotland – wet, well-connected environments

P = 1000mm
ET = 350mm
P - 70% (<20mm)
Dynamic connectivity drives hydrologic variability

Saturation zone under wet conditions

Saturation zone under dry conditions
Dichotomy in soil connectivity?

“Responsive” Peat soils
- Saturation overland flow
- Shallow sub-surface storm flow

“Freely draining” podzols
- Sub-surface storm flow
- Groundwater recharge

30 km² Girnock Burn catchment
3 km² Bruntland Burn Sub-catchment

Soulsby et al. (2006a). J. of Hydrol. 325
Soulsby et al. (2006b). Hydrol. Proc. 20,
Structural connectivity – combine soils and TWI

Riparian wetlands connectivity

Tetzlaff et al., HP, 2007.
Functional hillslope connectivity

http://www.abdn.ac.uk/nri/
Hillslope scale: consistently wet vs non-linear

Tetzlaff et al. *WRR*, 2014

Close to saturation

\[ \sim 80\% \]

Wet and dry – small deficits

25 - 40%

Tetzlaff et al., *WRR*, 2014
Tracers: **Spatial** functioning of connectivity

**Tracers for geographic sources**

- Alkaline groundwater
- Acidic soilwater

*Soulsby et al., JoH 2007.*

**Spatial hydrograph separation**

*Sayama and McDonnell, 2009 WRR*
Tracers: Temporal functioning of connectivity

Tracers for flow paths and travel times (change only through mixing)

Temporal hydrograph separation

after McGuire and McDonnell, 2006

Sayama and McDonnell, 2009 WRR
Travel time distributions as connectivity metrics

Integrating across flows:
Short TT (high flows) / Longer TT (low flows)

Fast responding catchments
Deep-subsurface flow dominated catchments

Isotopes as indices for scaling functional connectivity

Empirical data

Isotopes as “fingerprints” of water

Modelling with tracers to test hypotheses
Isoptope input-output – connectivity proxy

**Precipitation Input**

**Discharge Output**

*Birkel et al., WRR, 2014*
Spatial variability in connectivity

Wetland soils / GW “bracket” streamwater signal

Tetzlaff et al., WRR, 2014
Isotopes – time variance in connectivity

![Graph showing isotopic composition](image)
Evolution of connectivity

MTT streamwater ~2 yrs

Waters from different sources drain through riparian storage
Hillslope Conceptualisation in model Hydrological connectivity via expanding and contracting saturation zones.

Saturation area extent
\[ d\text{SAT} = f(\text{API, ET, Soil}) \]

Minimum saturation

Maximum saturation

Estimated dynamic saturation area extent (Dyn_fSat)

Mapped saturation zone

Saturation area extent dSAT (−)

Meters

0 125 250 500
Isotopes in connectivity based model

Rain and potential ET

$E_{act}$

Dynamic hillslope

$f_Hill = 1 - f_{SAT}$;

Outflow

Dynamic saturation area

$S_{Sat}$

$E_{act}$

$S_{up}$

Tracer concentration

Recharge

$S_{low}$

Tracer concentration

Nonlinear near-surface runoff (+concentration)

Streamflow (+concentration)

Baseflow (+concentration)

Dual calibration and validation

Soulsby et al., 2015, WRR
Water ages in connected fluxes

Soulsby et al., 2015, WRR
Model tested against “soft” connectivity data

Soulsby et al., 2015, WRR
Model tested against “soft” connectivity data

Soulsby et al., 2015, WRR
A generic spatially distributed model

- Spatially distributed model Bruntland Burn

van Huijgevoort et al, In prep
Connectivity parameterization is spatially explicit

- DEM: distributed precipitation and temperature, slope, aspect, drainage network
- Different parameters soil module based on TWI
- Vegetation: ET and interception module
Spatially distributed storage - connectedness

Soil storage (mm)

Groundwater storage (mm)

van Huijgevoort et al, In prep
Preliminary results – for tracers and ages

van Huijgevoort et al, In prep
Regionalisation – 50 catchments in 7 geomorphic provinces
Map-based water age (MTT) estimates

Multiple Linear Regression model

\[
\ln(\text{MTT}) = -1.65 \times x_1 - 1.03 \times \ln(x_2) - 0.21 \times x_3 + 0.50 \times x_4
\]

- \(x_1\) = %-responsive soil cover
- \(x_2\) = drainage density
- \(x_3\) = precipitation intensity
- \(x_4\) = topographic wetness index

<table>
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<tr>
<th></th>
<th>(R^2)</th>
<th>(R^2_{\text{adj}})</th>
<th>(p)</th>
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<tbody>
<tr>
<td>Median absolute cross validation error [d]</td>
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<tr>
<td>Median absolute % cross validation error [%]</td>
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Map-based TT estimates in Dee headwaters

- **a)** % Responsive soils
  - 100%
  - 0%

- **b)** Drainage density
  - 2.8 km/km²
  - 0.8 km/km²

- **c)** Precipitation intensity
  - 8.8 mm/d
  - 6.7 mm/d

- **d)** Median TWI
  - 6.9 ln(m²)
  - 4.8 ln(m²)

Scale: 0 2.5 5 10 km

Image: Aerial view of Dee headwaters area with mountainous terrain.
Spatial variation of connectivity based on MTT


260km²
Upper Dee catchment in Cairngorms

Landscape resilience
Isotopes and impacts - Urbanization

A MASTERPLAN FOR BANCHORY SITES: M1, M2 AND H2

Soulsby et al., 2014, Geophys Res Lett.
Urban impacts on TTDs and connectivity

Urban - young

Rural - old

Impact

Summary

• Connectivity as a unifying theme
• Variety of approaches, metrics
• Utility of tracers and travel times
• Multi-scale approach from profile to catchment
• Integration in models – being refined
• Potential tools for management
# Soil moisture/groundwater functional indices

<table>
<thead>
<tr>
<th></th>
<th>Peat</th>
<th>Peaty Gley</th>
<th>Peaty Podzol</th>
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<tbody>
<tr>
<td><strong>GW table</strong> (rel. to surface)</td>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
<td><img src="image3.png" alt="Graph" /></td>
</tr>
<tr>
<td><strong>GW response</strong> (rel. to stream)</td>
<td>Several hours before</td>
<td>Few hours before</td>
<td>Several hours after</td>
</tr>
</tbody>
</table>

*Blumstock et al., JoH 2015*