# Tracer-aided modelling to explore non-linearities in flow paths, hydrological connectivity and faecal contamination risk

Aaron J Neill[1], Doerthe Tetzlaff[1], Norval Strachan[2], Chris Soulsby[1]
[1]Northern Rivers Institute, University of Aberdeen, Contact: aaron.neill@abdn.ac.uk, [2]School of Biological Sciences, University of Aberdeen

## Introduction

Non-linearities in runoff generation known to be strongly influenced by hydrological connectivity and associated flow path dynamics.

Role of connectivity in faecal contamination of sources for potable water supplies is less clear, particularly in rural montane regions.


Mitigation and assessing potential variations in contamination risk in light of environmental change requires this understanding.

Dynamic tracer-aided hydrological models are robust frameworks within which faecal contamination (indicated by faecal coliforms – FC), hydrological connectivity and flow path dynamics can be linked.

## Objectives

1) Calibrate a parsimonious tracer-aided hydrological model to daily discharge and stream isotope data.
2) Couple a simple FC behaviour and transport model to the robust hydrological model and simulate daily FC loads.
3) Explore how in-stream FC dynamics relate to hydrological connectivity, flow paths and resulting runoff generation.

## Study Site and Data

### Bruntland Burn, NE Scotland (Figs 1 & 2)

- 3.2 km$^2$; 248 to 539 MASL
- Annual precipitation ~ 1000 mm
- Annual AET ~ 363 mm
- Up to 96 red deer (*Cervus elaphus*) / km$^2$
- Daily deuterium ($\delta^2H$) data for precipitation and stream water
- Daily FC load in colony forming units (CFU) for stream water

*Fig 1: The Bruntland Burn*

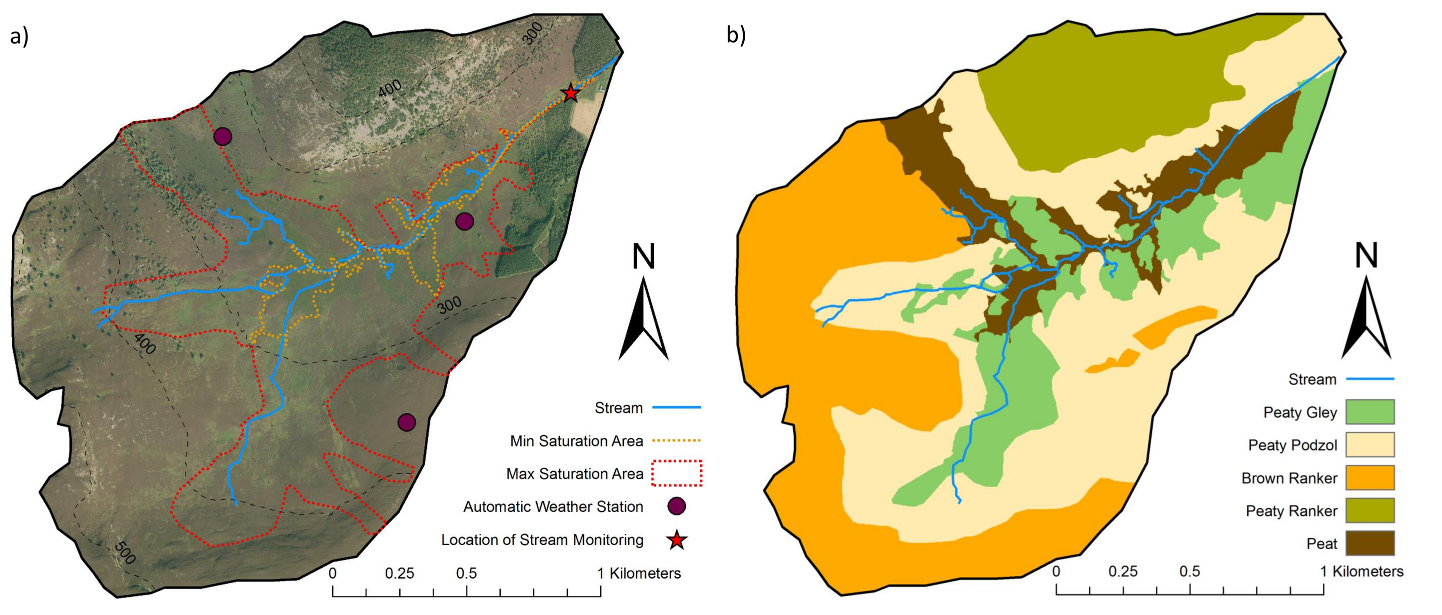


*Fig 2: The Bruntland Burn catchment showing a) Topography, saturated riparian zone extent and locations of data collection; b) Main soil classes*

## Modelling Approach

### Tracer-aided hydrological model (Fig 3)

- Dual calibration on discharge and stream isotopic composition using NSGA2[1].

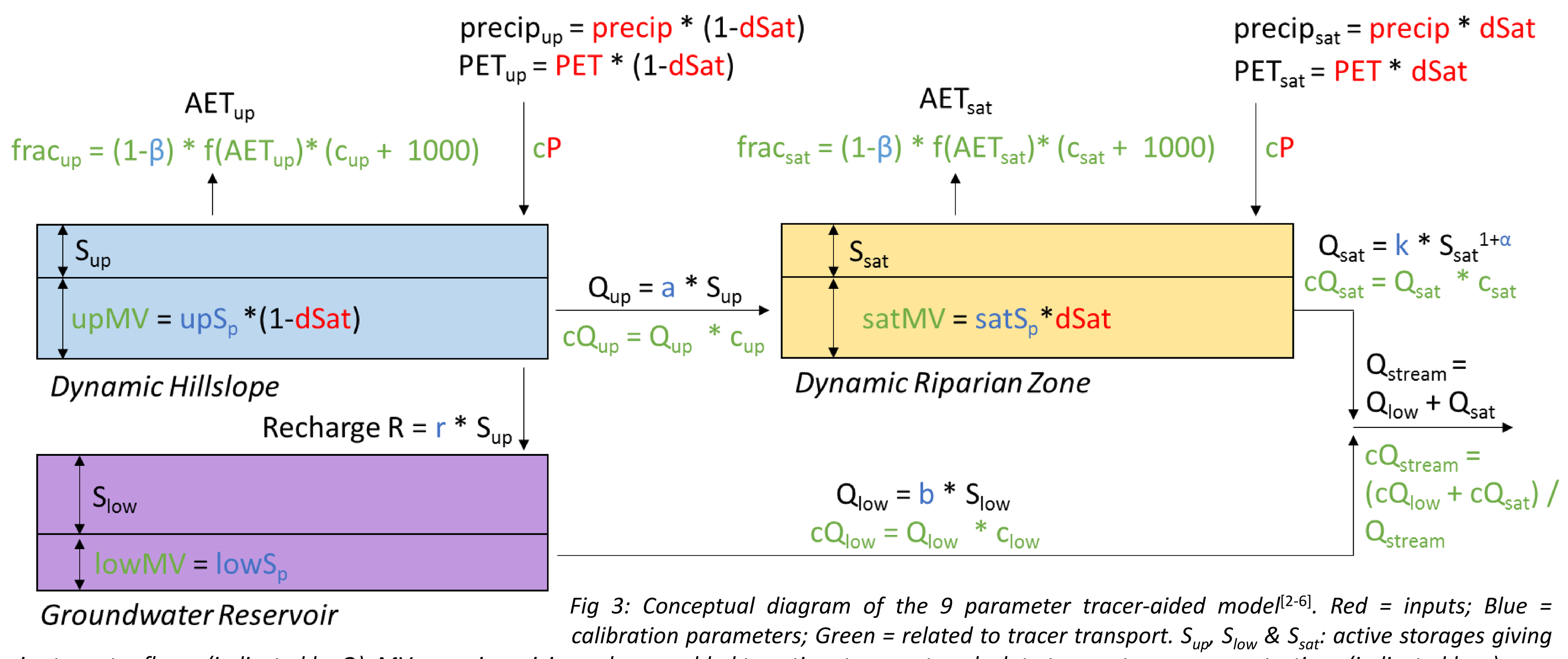


*Fig 3: Conceptual diagram of the 9 parameter tracer-aided model[2-6]. Red = inputs; Blue = calibration parameters; Green = related to tracer transport. $S_{up}$, $S_{low}$ & $S_{sat}$: active storages giving rise to water fluxes (indicated by Q). MVs: passive mixing volumes added to active storages to calculate tracer storage concentrations (indicated by c).*

### Faecal coliform behaviour and transport model (Fig 4)

- FC storages flushed based on simulated water flux : max. observed discharge[7].
- Temperature-dependent die-off rates (*ks*; *kw*) based on Arrhenius expression[8].

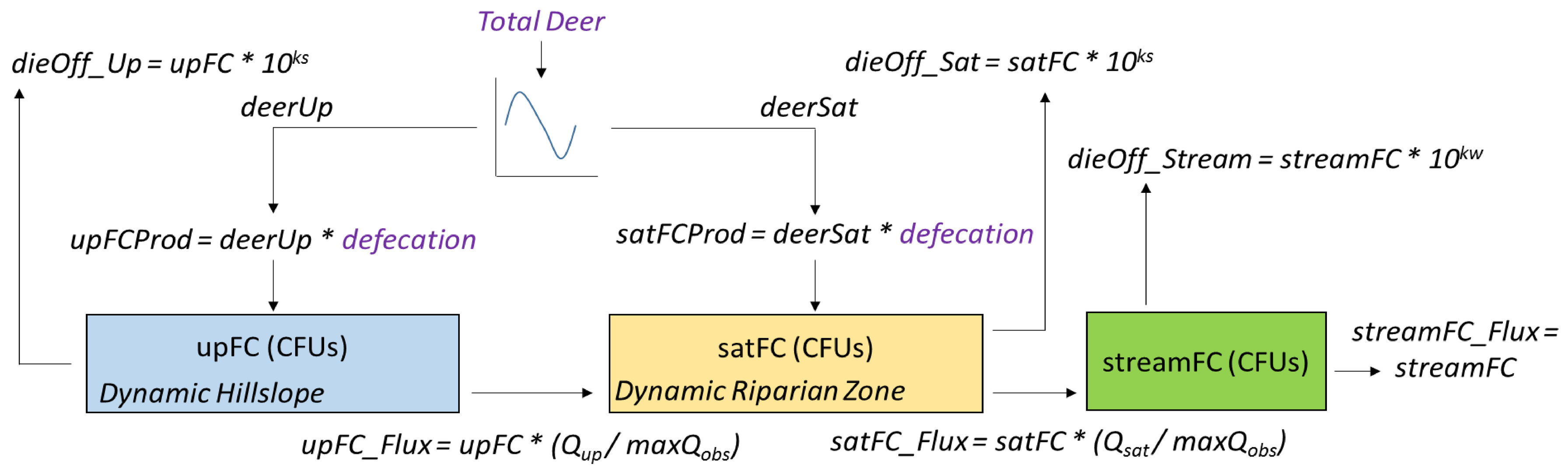


*Fig 4: Conceptual diagram of the FC behaviour and transport model. Purple = random variables selected at each timestep.*

## Results

### Hydrometric, isotope and FC dynamics (Fig 5)

- Clear, non-linear discharge response to precipitation. Re-wetting in early July.
- Stream isotopic signal damped but still reflects precipitation signal.
- FC load varies most strongly with discharge; no clear dependency on temperature.

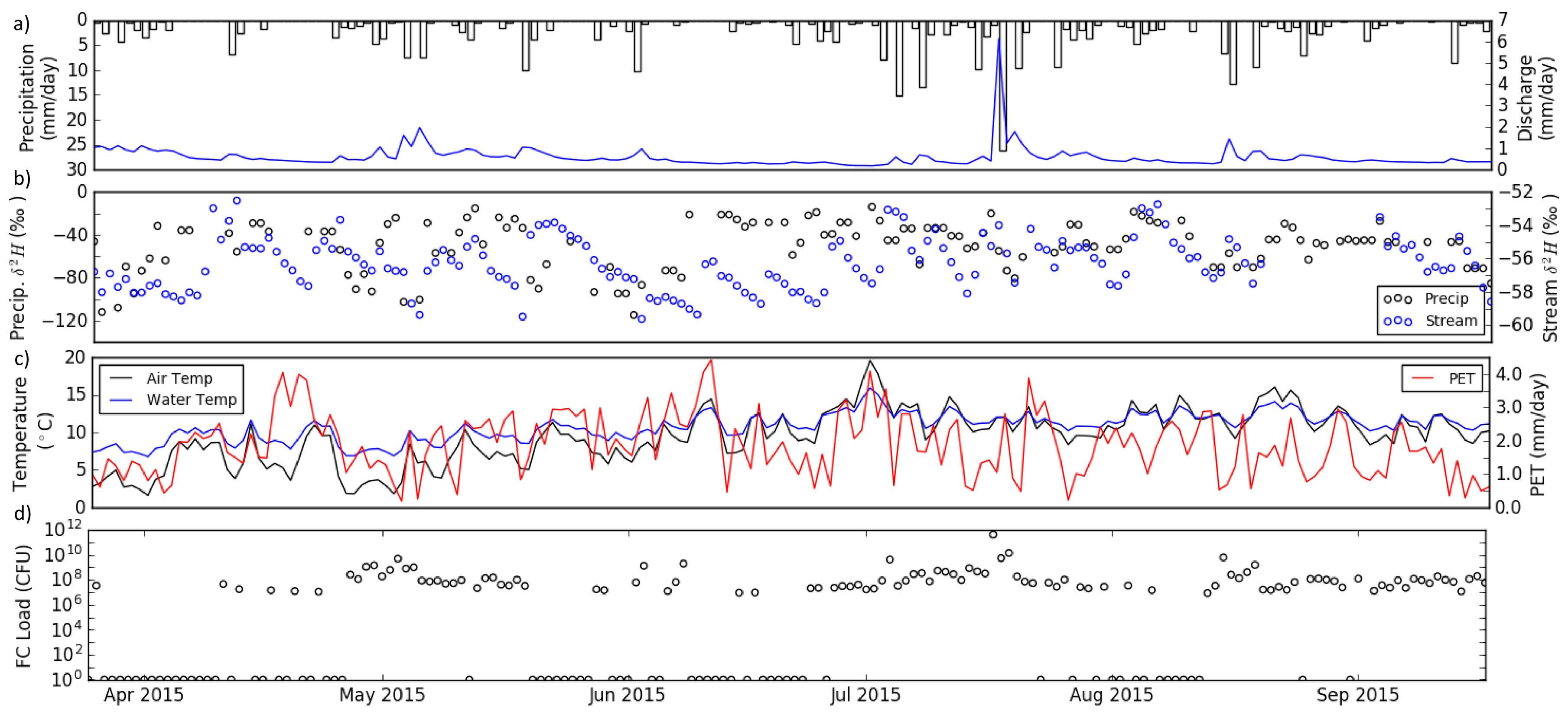


*Fig 5: Time-series of a) Precip. & stream discharge; b) Isotopic composition of stream & precip.; c) Air & stream temperature, & PET; d) Stream FC load*

### Tracer-aided model performance (Fig 6)

- Good discharge simulation ($\overline{KGE}$: 0.80); reasonable isotope simulation ($\overline{KGE}$: 0.40).
- Runoff generated by groundwater in baseflow conditions.
- Riparian zone connects to channel in response to precipitation, becoming main source of runoff in larger events. Hillslope - riparian zone connectivity limited.

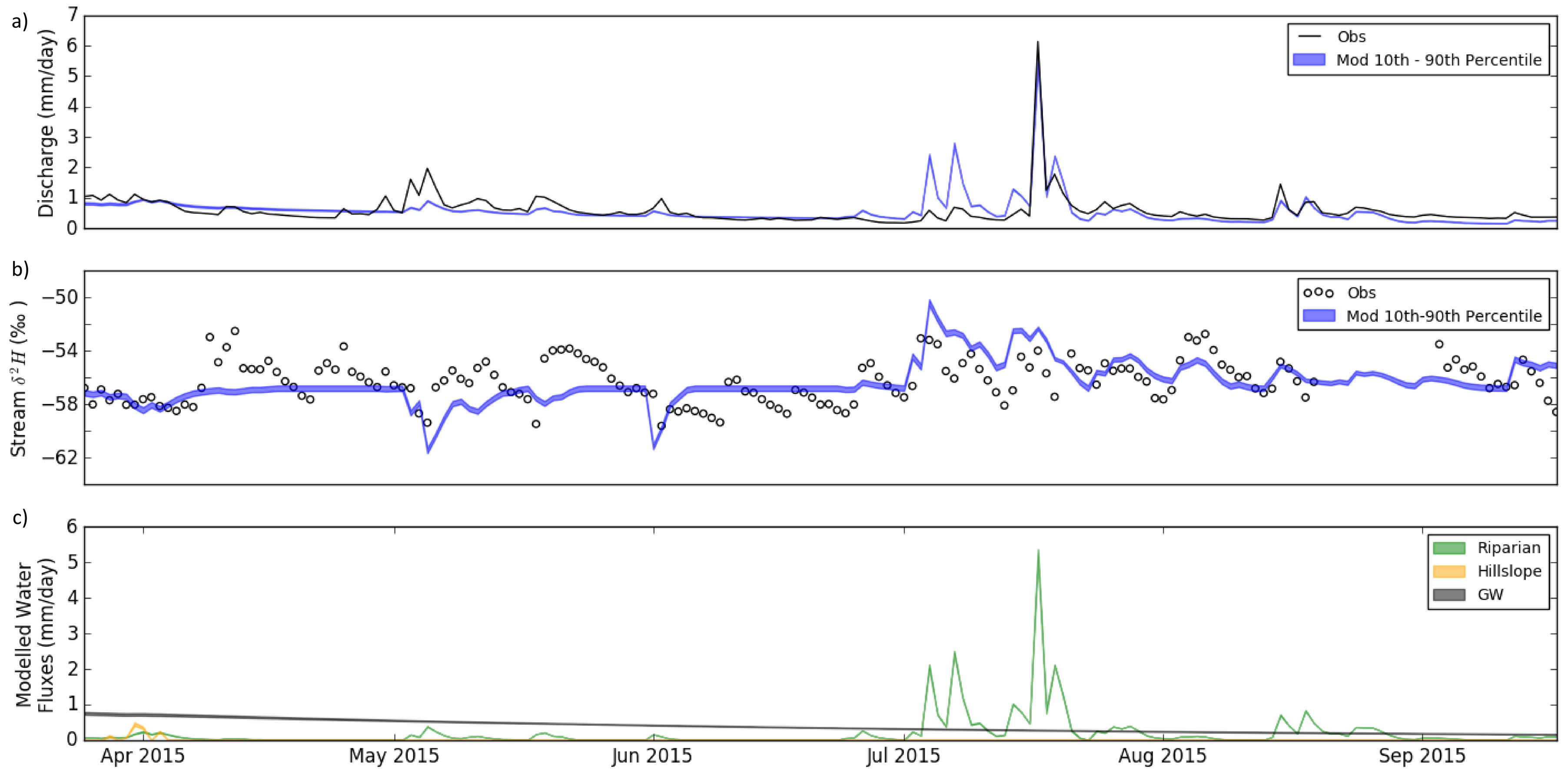


*Fig 6: Time series of a) Obs. & mod. discharge; b) Obs. & mod. stream isotopic composition; c) Mod. water fluxes from hydrological source areas.*

### Linking faecal contamination and connectivity (Fig 7)

- Elements of observed FC dynamics captured with simple model ($\overline{R2}$: 0.58).
- Substantial stream FC loading whenever riparian zone connects to channel.
- Hillslope FC contributions minimal due to limited connectivity.
- No FC loading from groundwater seems a reasonable assumption.

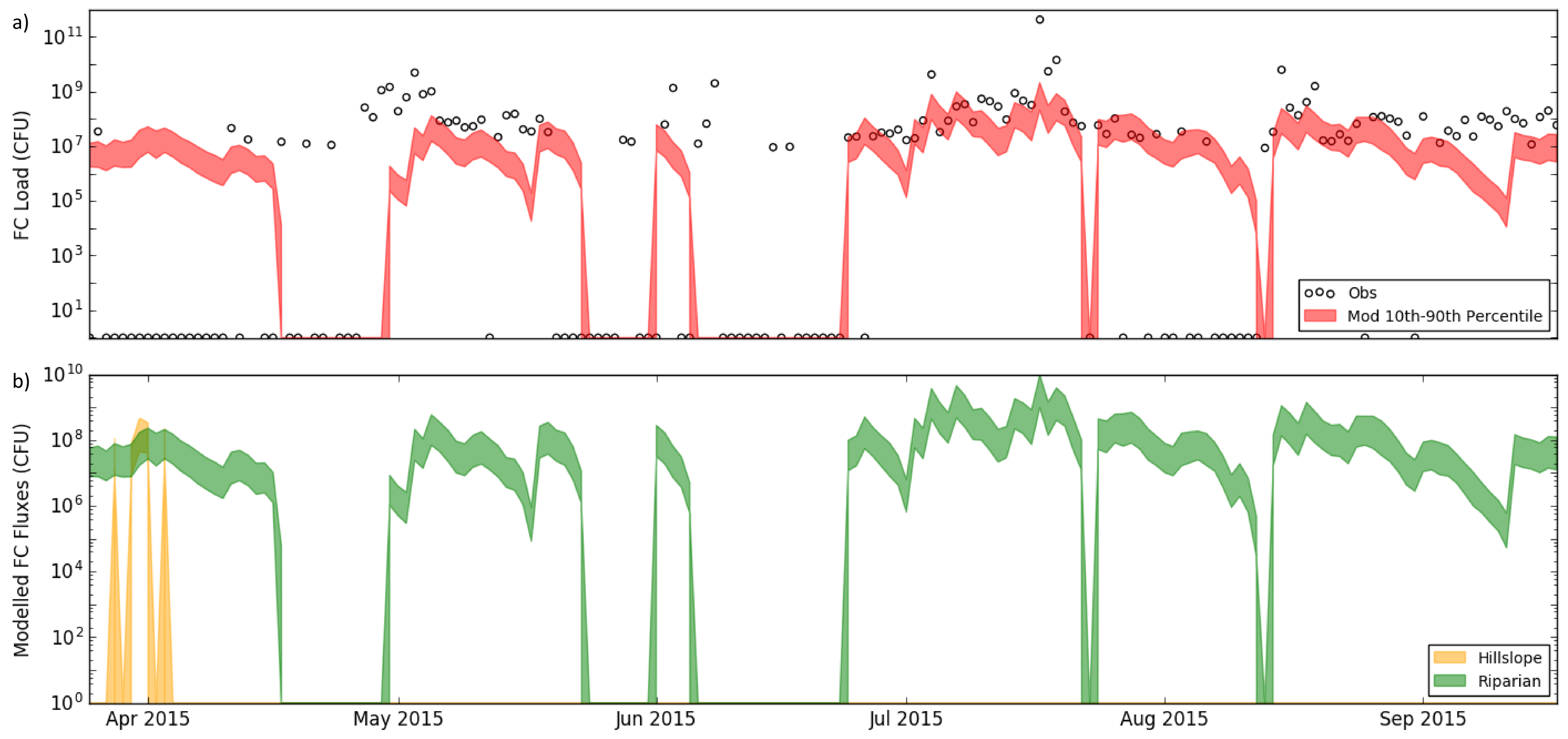


*Fig 7: Time series of a) Obs. & mod. Stream FC load; b) FC fluxes from riparian zone and hillslope.*

## Conclusions

Elements of observed FC dynamics could be simulated with a simple FC behaviour and transport model coupled to a robust, dynamic tracer-aided hydrological model.

Stream FC sourced principally from riparian zone with large fluxes transferred whenever riparian zone - channel connectivity established.

Improved simulation of stream FC dynamics through more complete representation of FC behaviour and transport a future avenue of work.

www.abdn.ac.uk/nri
aaron.neill@abdn.ac.uk
Twitter: @aaronhydro

University of Aberdeen
Scottish Government gov.scot
Hydro Nation Scholars Programme

References: 1: Deb (2002) *IEEE Trans. Evol. Comput.* 6: 182-197; 2: Birkel *et al*. (2010) *Hydrol. Process* 24: 260-275. 3: Birkel *et al*. (2011a) *Hydrol. Process* 25: 3924-3936. 4: Birkel *et al*. (2011b) *WRR* 47: 1-15; 5. Birkel *et al*. (2014) *WRR* 50: 3481-3501. 6: Birkel *et al*. (2015) *Hydrol. Process* 29: 2956-2969. 7: Wilkinson *et al*. (2011) *New Zeal J Mar Fresh* 45: 369-393. 8: Hipsey *et al*. (2008) *WRR* 44: W07408

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Northern Rivers Institute

School of Geosciences
University of Aberdeen
Aberdeen, AB24 3FX