British Hydrological Society

Modelling water quality in UK upland streams using high-frequency observations

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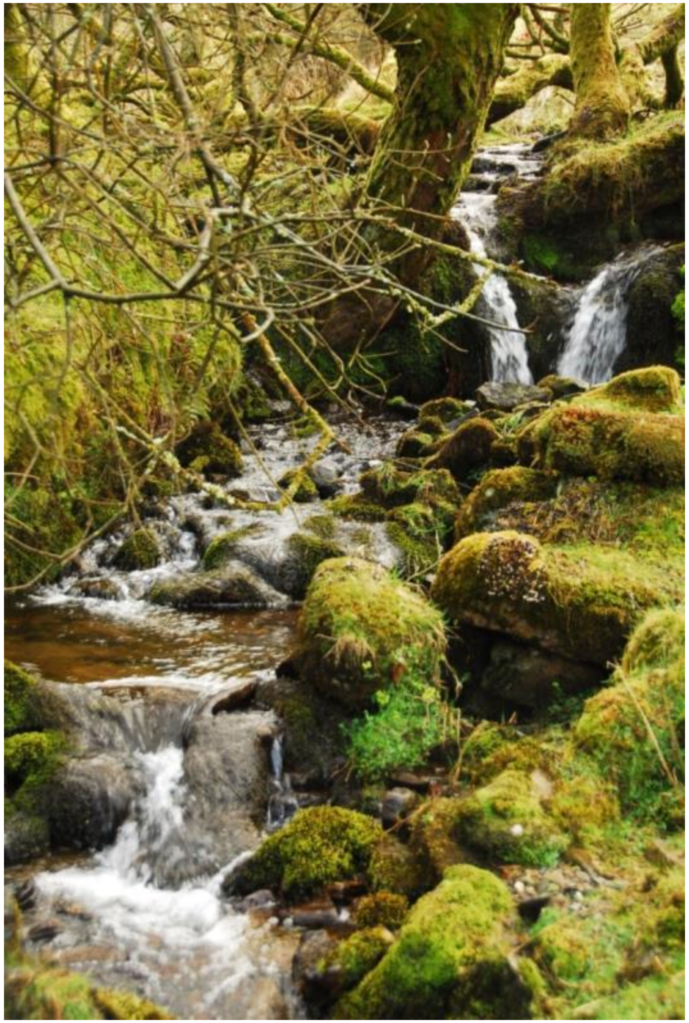


Nant Rhesfa (LI7) stream at Llyn Brianne basin

OVERVIEW:

- **High–frequency water quality** monitoring in upland Wales
- Novel **continuous-time transfer function modelling** of H^+, DOC & NO_3-N from rainfall
- Developing understanding of the relationship between catchment **hydrological functioning & bio-geochemical response**
- Fundamental importance of sub-daily to sub-hourly observations

NERC DURESS project

Diversity in Upland Rivers for Ecosystem Service Sustainability

One of 4 UK national projects under NERC Biodiversity & Ecosystem Service Sustainability

Affect of **water quality (& quantity) variables on aquatic biodiversity** & visa versa

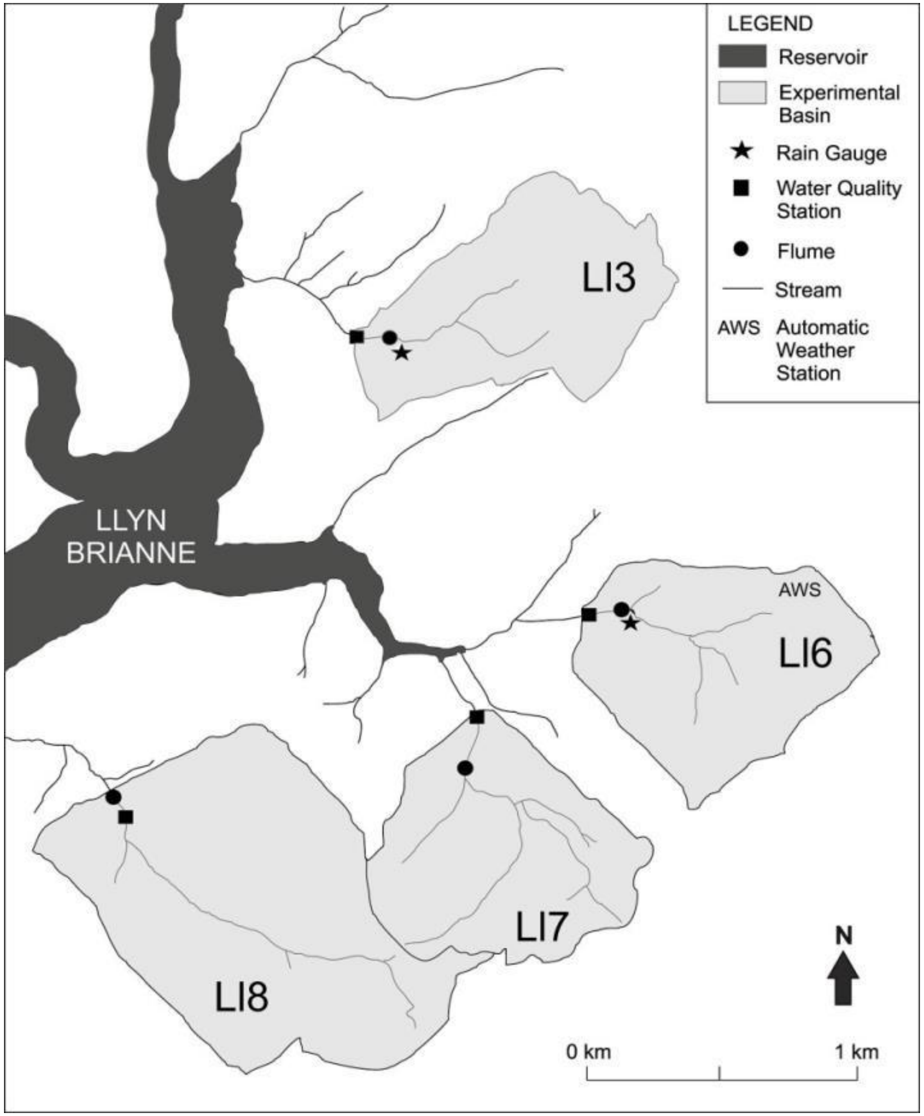
upland streams with/without affects of conifer plantation – resultant impact on ecosystem service delivery

Component of NERC DURESS

Necessarily inter-disciplinary project

Research / academic institutions e.g.:

Practitioners in water sector (in Wales) e.g.:



4 identically instrumented micro-basins

Llyn Brianne
Upland Wales, UK

Typical upland land-uses

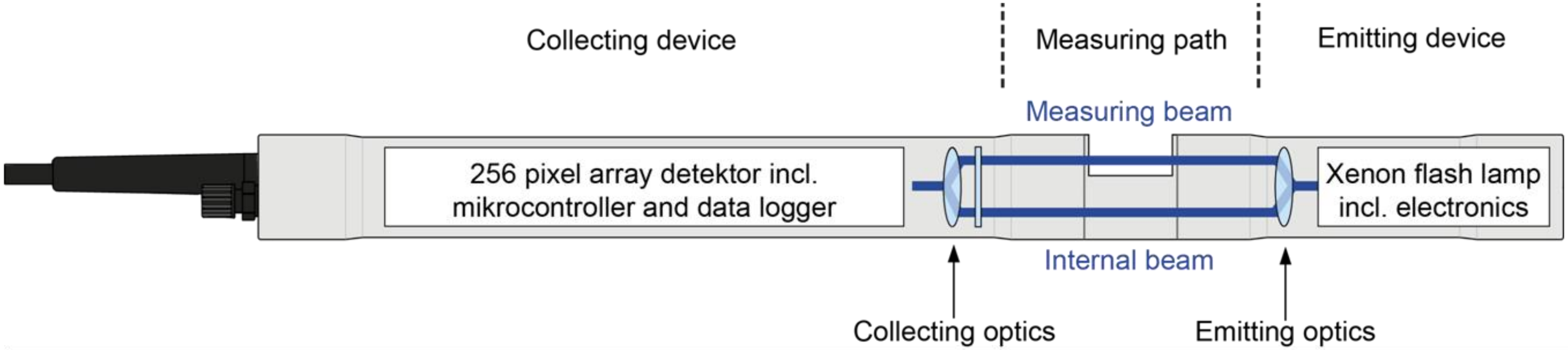
Improved moorland (x2)
Conifer plantations (x2)

Hydrometric station (LI6)

Water quality station (LI7)

Monitoring stations

- **High frequency (15-min continuous monitoring) using state-of-art water quality & hydrometric sensors e.g.**

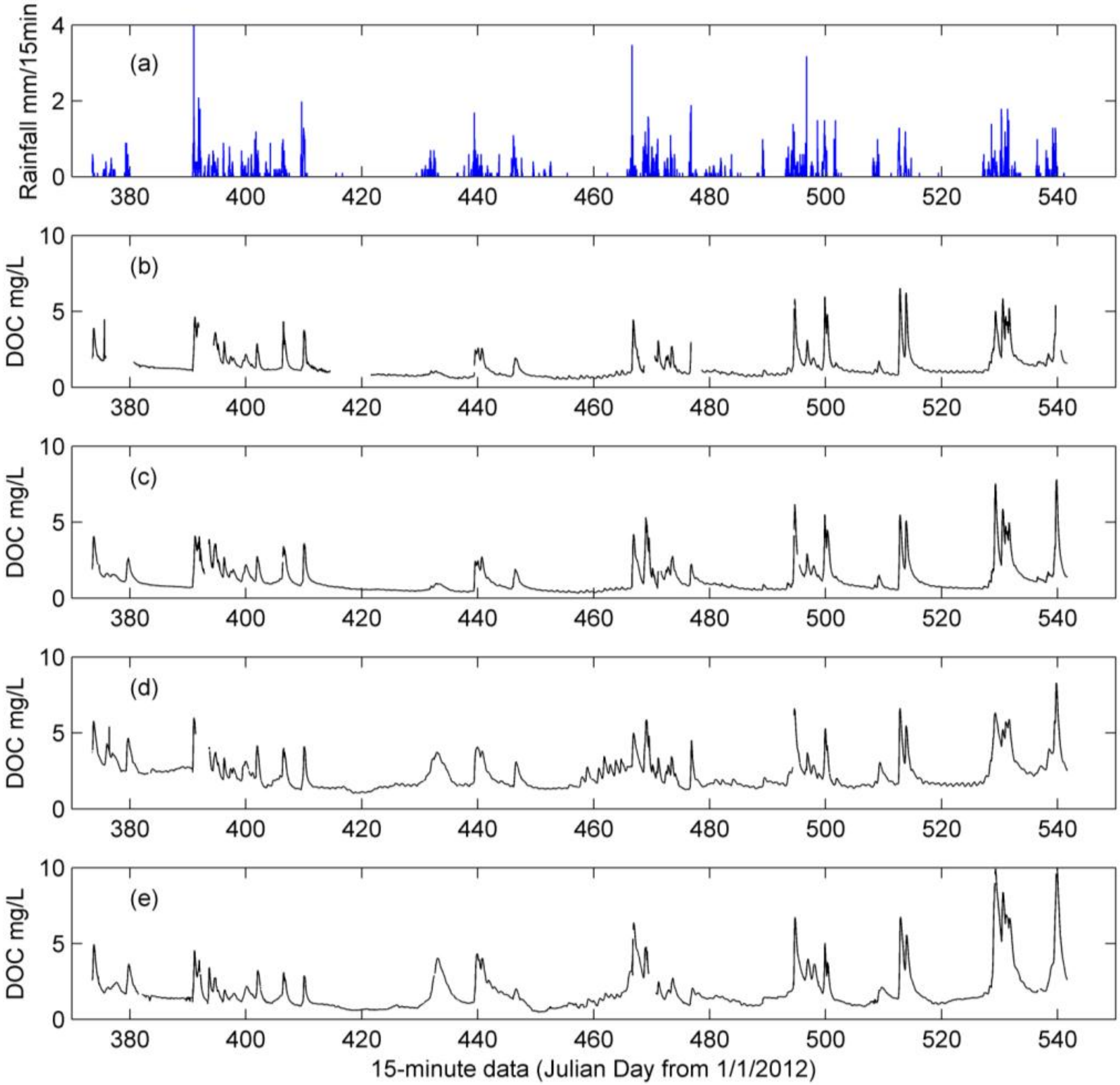


S::CAN spectrolyser (DOC, TOC, NO_3-N, turbidity, colour)

Accurate measurement of water quality variables now possible *in situ* (& cost effectively) following **sensor advances** (Hipsey & Arheimer 2013 *IAHS Publ* 361: 17-29)

Digital differential pH probes
e.g., Hach DPS1

DOC conc. time series



LI6

LI7

LI3

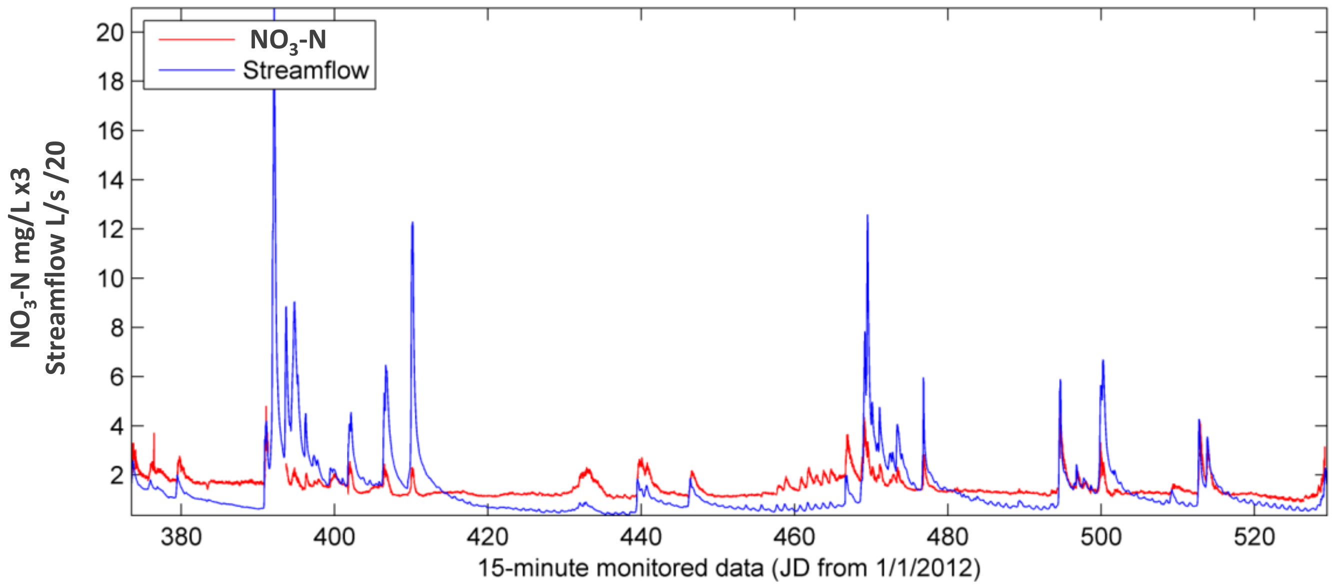
LI8

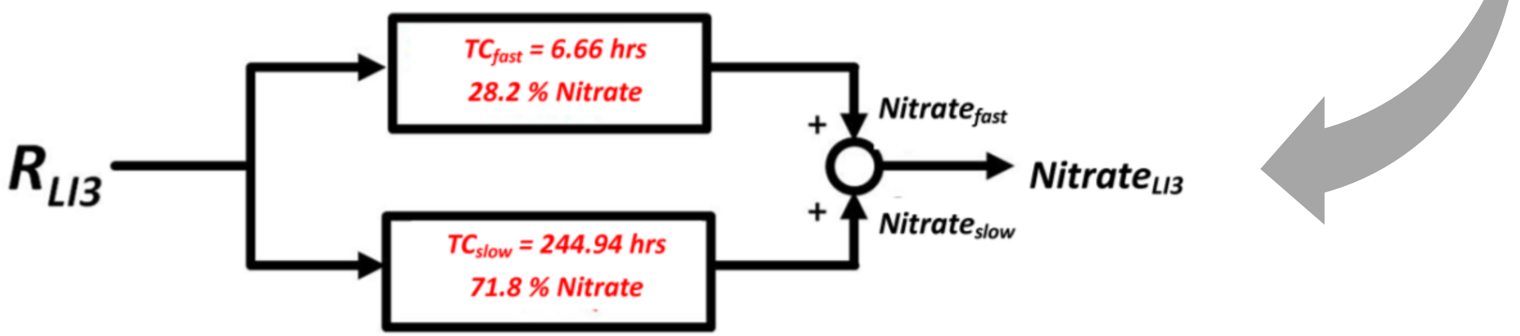
from Fig. 1

Jones, Chappell & Tych ES&T (submitted)

High quality time-series of hydrochemistry

To develop understanding of catchment hydrological functioning from water quality time-series…





…need **high quality data** & numerical **tools capable of extracting** dominant dynamics

Requires high quality time-series of hydrochemistry & robust numerical methods

Numerical tools...

Some water quality time-series (often non-conservative variables) are **information rich** (e.g., H^+, DOC) - methods available to **extract dynamics** contained e.g.,

RIVC

Refined **I**nstrumental **V**ariable **C**ontinuous-time
Box-Jenkins identification algorithm

Taylor, Pedregal, Young & Tych (2007) *Environ. Model. Software* 22: 797–814

CAPTAIN
TOOLBOX

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Numerical tools...

RIVC applied within a

Data-Based Mechanistic philosophy

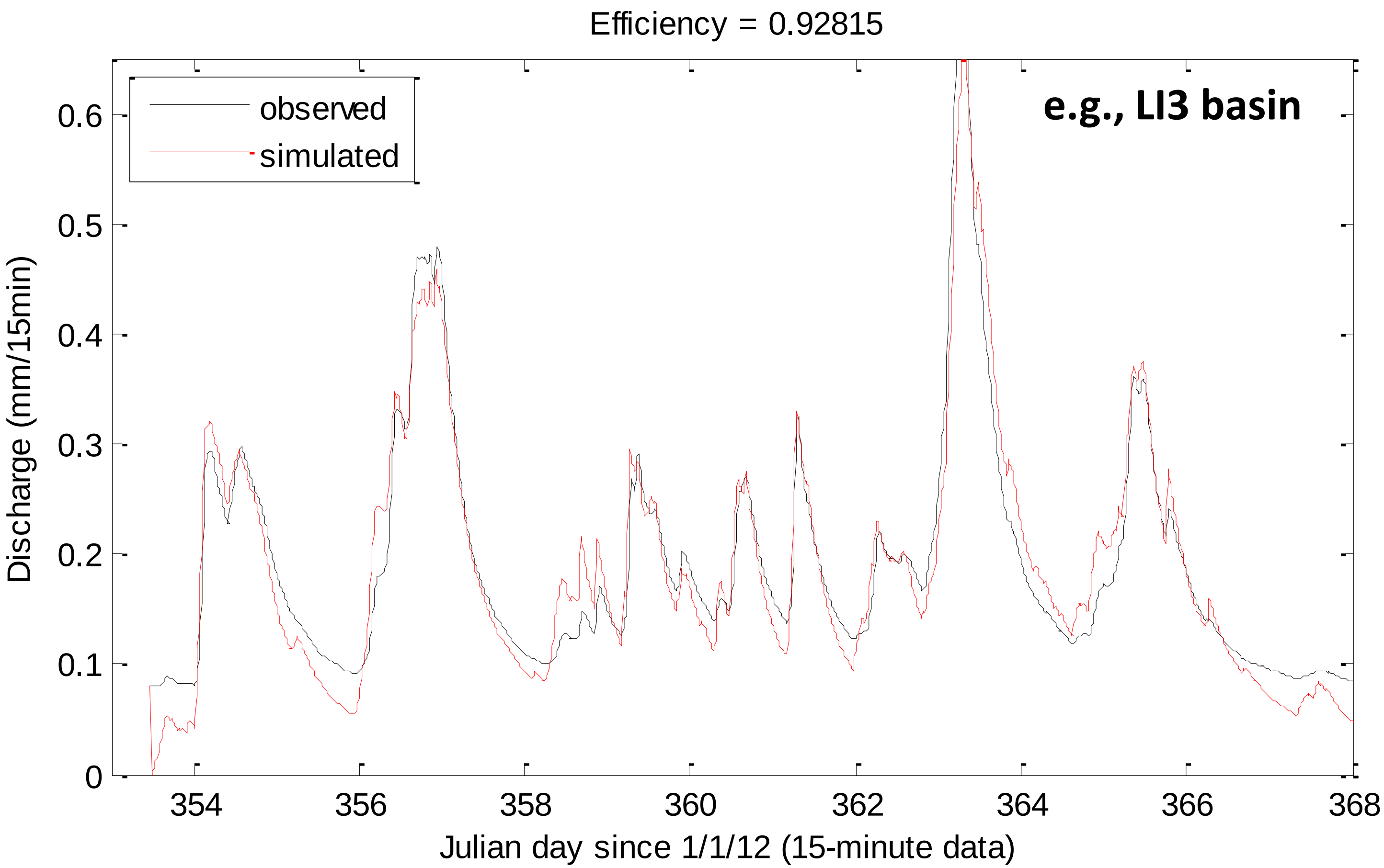
(1) Identification of many potential model structures, minimising prior assumptions about processes – that are often unknown ('**Data-Based**')

(2) Rejection of most using objective statistical & mathematical criteria (incorporating '**Principles of Parsimony**' via heuristic measures)

(3) Rejection of further models that have no physical (e.g., hydrological) interpretation ('**Mechanistic**') – giving models for testing against independent observations (e.g., dynamics within component flow paths)

rainfall-streamflow models identified linear 2nd order CT-TFs*

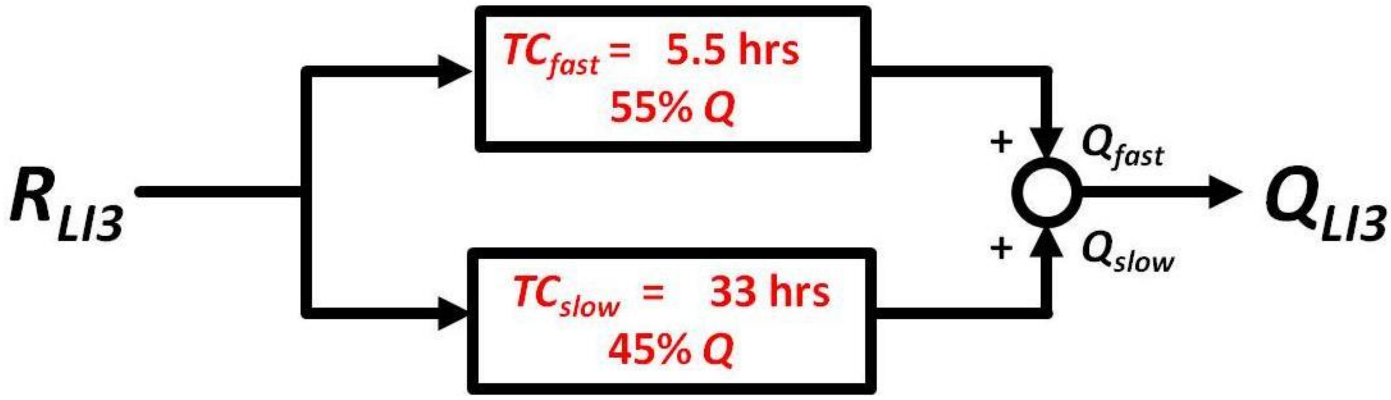
*given high efficiency, no marked drop in YIC, no complex roots etc



e.g., for LI3 basin (in winter)

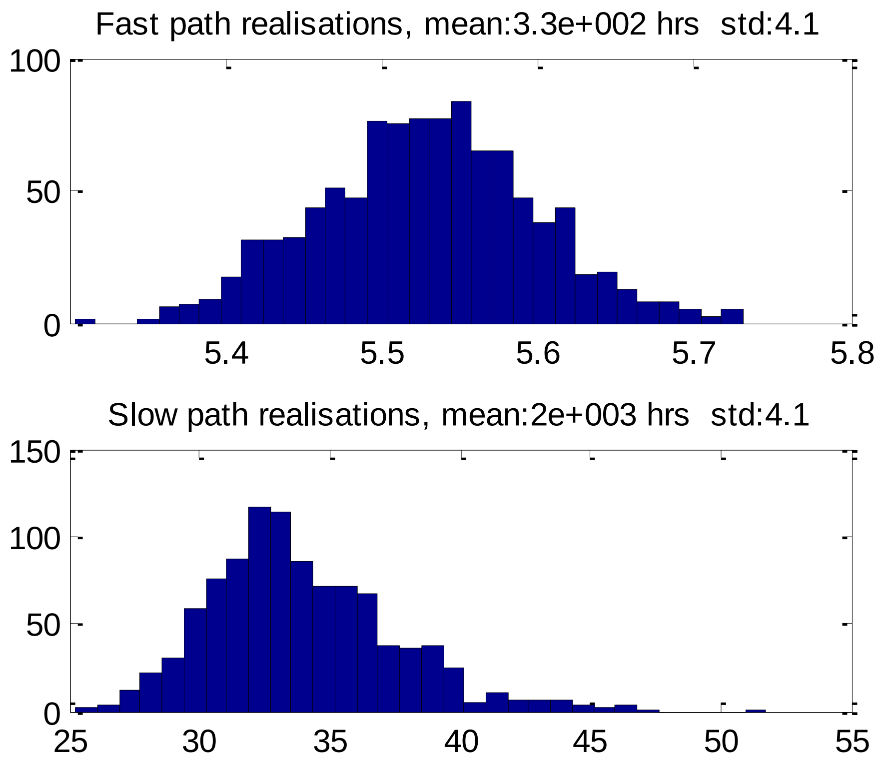
$$Q_{LI3} = \frac{0.0248s + 0.0003}{s^2 + 0.0527s + 0.0003} e^{-s1} R_{\overline{LI3\&6}} \qquad s = \frac{d}{dt}$$

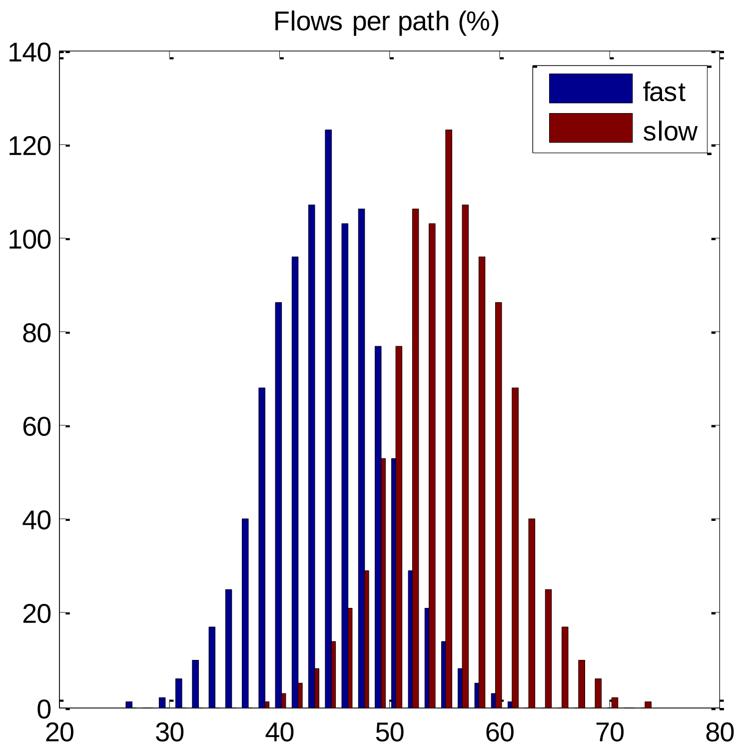
Decomposition of 2nd-order rainfall-streamflow model to **two parallel pathways** usually considered to have most robust physical interpretation (via **Dynamic Response Characteristics**, DRCs)



Uncertainty in DRCs (1000 Monte Carlo realisations) – allow **DRC comparison**

e.g., for LI3 basin





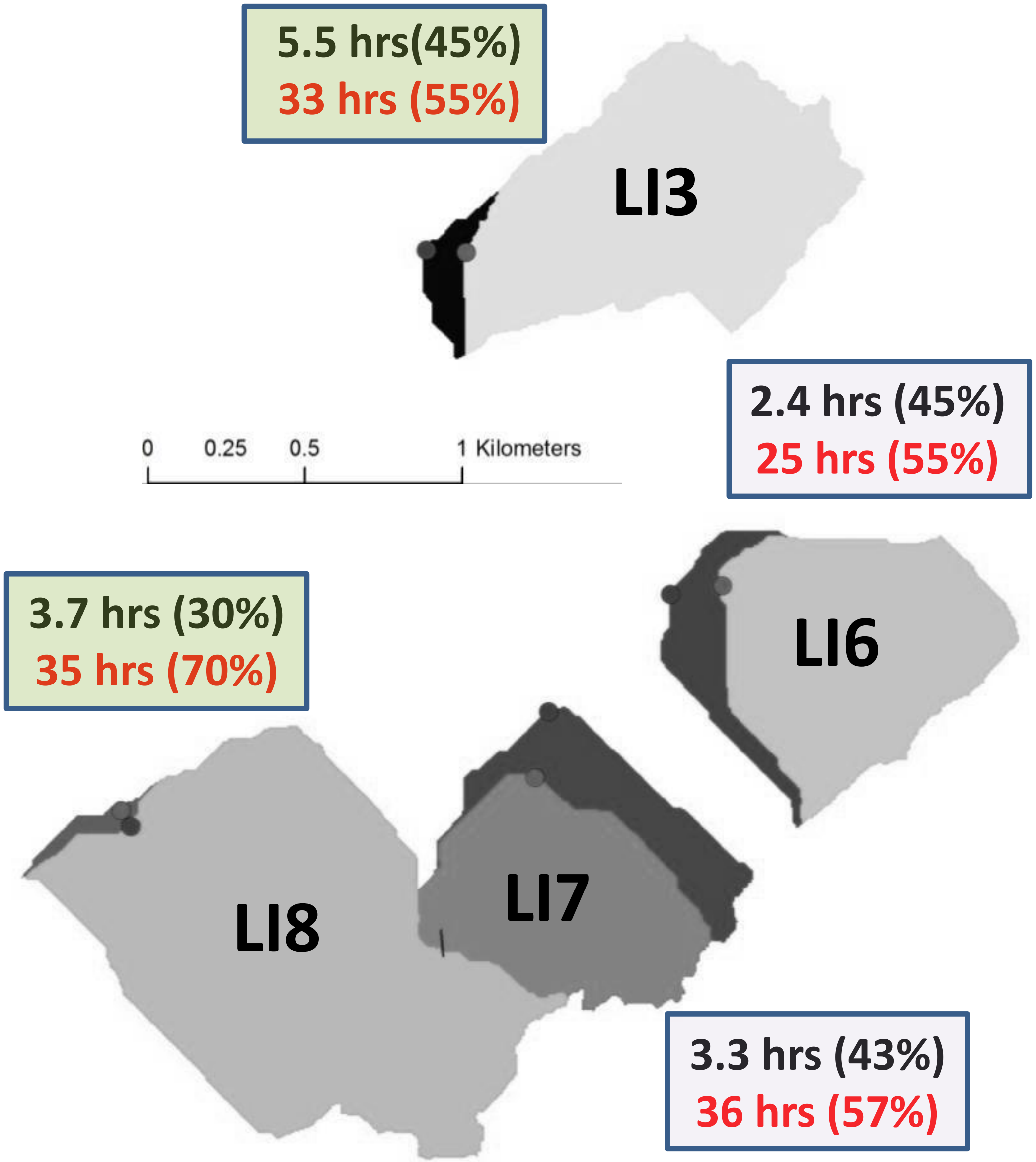
li3qmodel3_tj2.m (Fig. 70 & 73)

Comparison of model characteristics between catchments

e.g., TC (time constant)

TC	Dominant runoff process associated	Flow path reference
5 mins	overland flow (infiltration-excess primarily)	Chappell *et al*. (2006)
2.9 hrs	shallow subsurface flow from a hillslope	Chappell *et al.* (1990)
100 hrs	fracture flow in Lower Devonian slate	Chappell & Franks (1996); Birkinshaw & Webb (2010)
107 dys	deep pathway through a chalk aquifer	Ockenden & Chappell 2011

from Jones & Chappell (2014) *Hydrology Research* doi: 10.2166/nh.2014.155



Time constant (*TC*) of hydrometric responses are similar

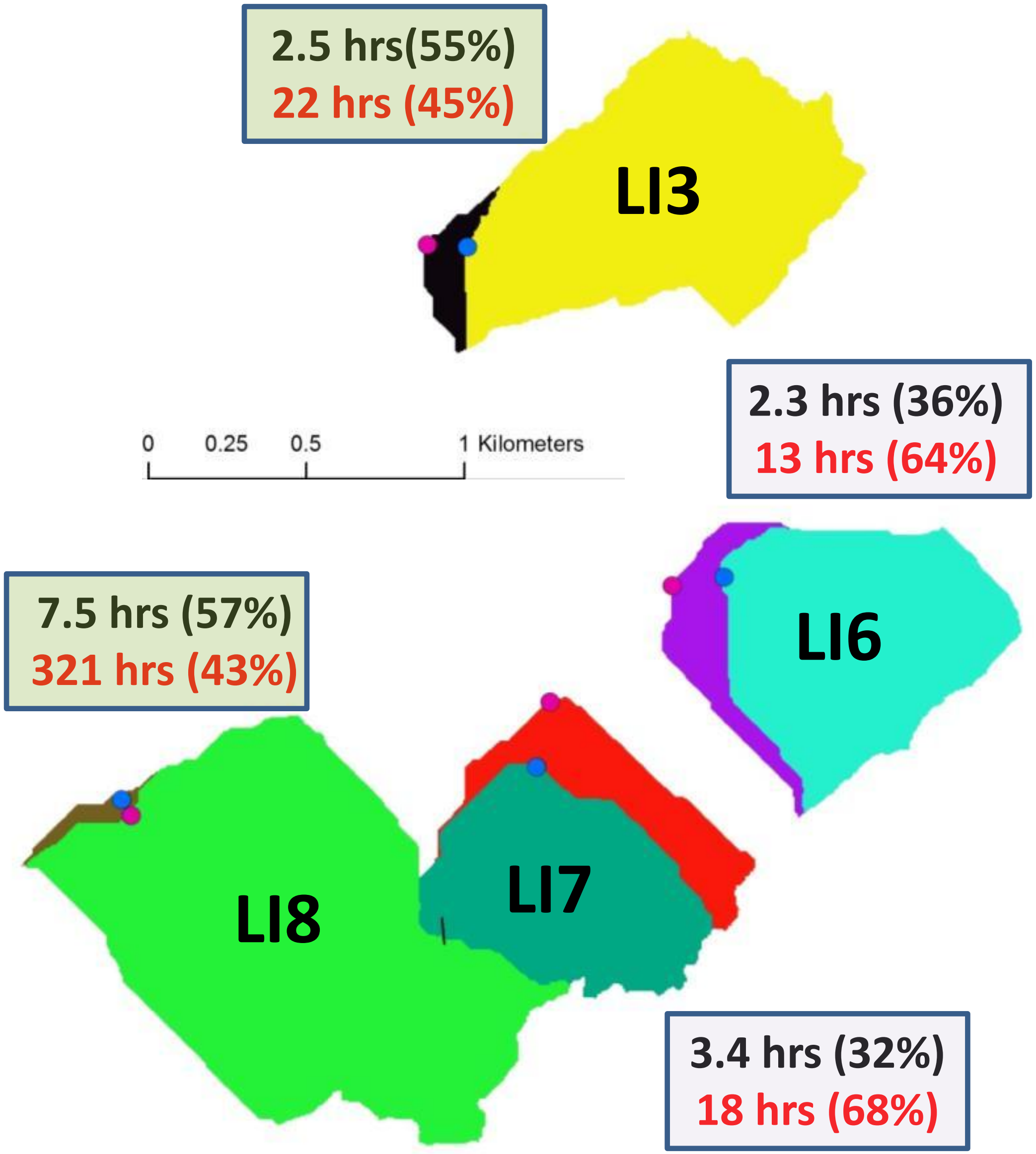
Basins behave similarly despite land use

e.g., presence of a slower 25-35 hr component (in winter response)

Source?

Deep soil pipes path
Drift (C) path
Rock-fracture path

Compare rainfall-streamflow response between nearby basins



Rainfall-H^+ load models identified: linear 2nd order CT-TFs optimal

Residence times of H^+ load response to rainfall (TC)

Faster response than rainfall-streamflow

'Exhaustion' or ion exchange effect?

except mature conifer (LI8)

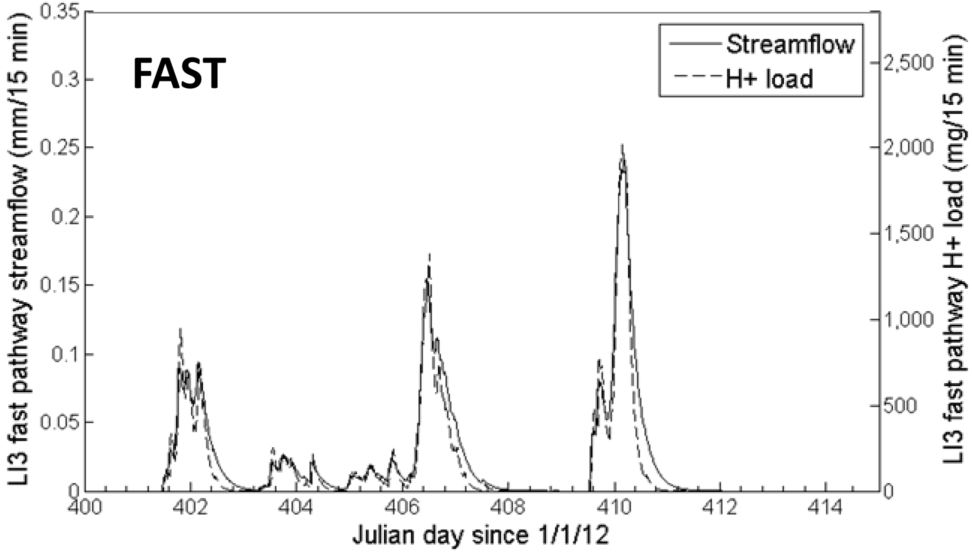
Compare rainfall-streamflow response with rainfall-H^+ response

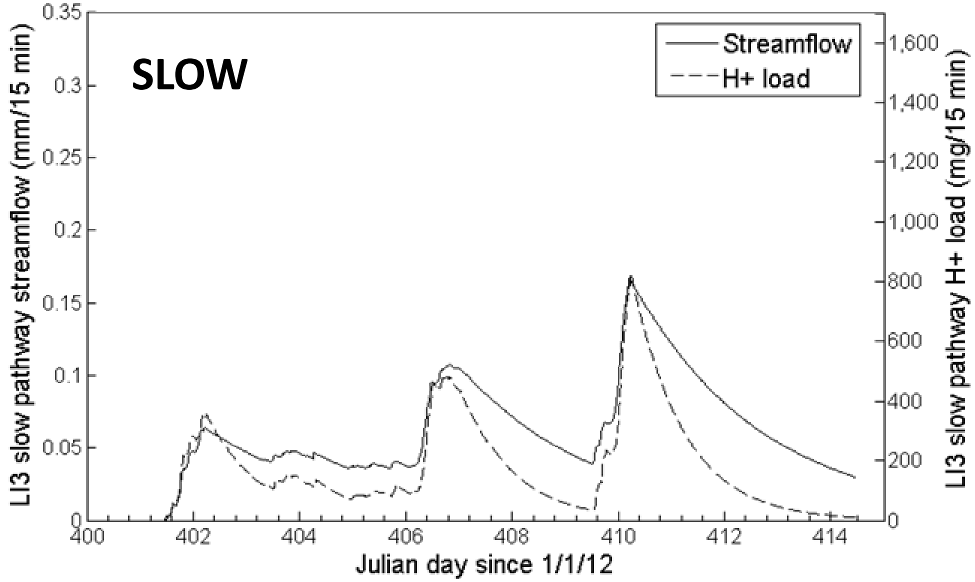
Also shown in model simulated data

e.g.,
Identified components of
Rainfall-streamflow (—)
Rainfall-H^+ load (- -)
LI3 models

from Jones & Chappell (2014) *Hydrology Research* doi: 10.2166/nh.2014.155

H^+ path exhausted faster than hydrometric response path (LI3, LI6, LI7) – flow path implications?





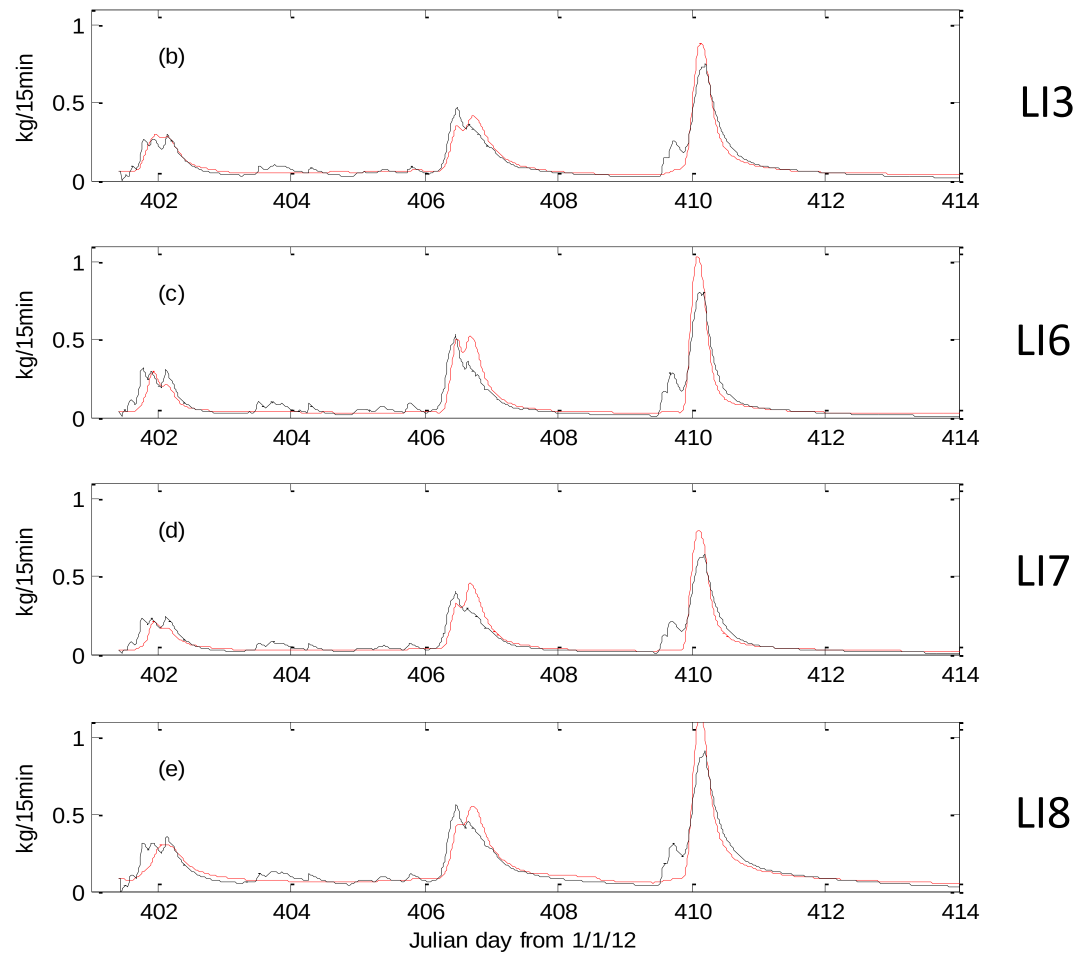
Compare rainfall-streamflow response with rainfall-H^+ response

Obtain similar linear 2nd order CT-TF models for rainfall-DOC load

observed DOC

simulated DOC

from Jones, Chappell & Tych (2014) *ES&T* submitted



Simulated DOC load from rainfall

How realistic are component path proportions & dynamics identified from whole-basin responses?

Next phase of independent observation & modelling of component flow paths

e.g., hydrometric & H^+ response in natural soil pipes, fracture flow, soil pathways

Observe & compare hydrometric & water quality response of component paths

Key message:

interpretation only possible if can avoid under-sampling water quality time-series

e.g. LI3

Rainfall-streamflow fast TC = 5.13 hrs

Rainfall-H^+ load fast TC = 2.50 hrs

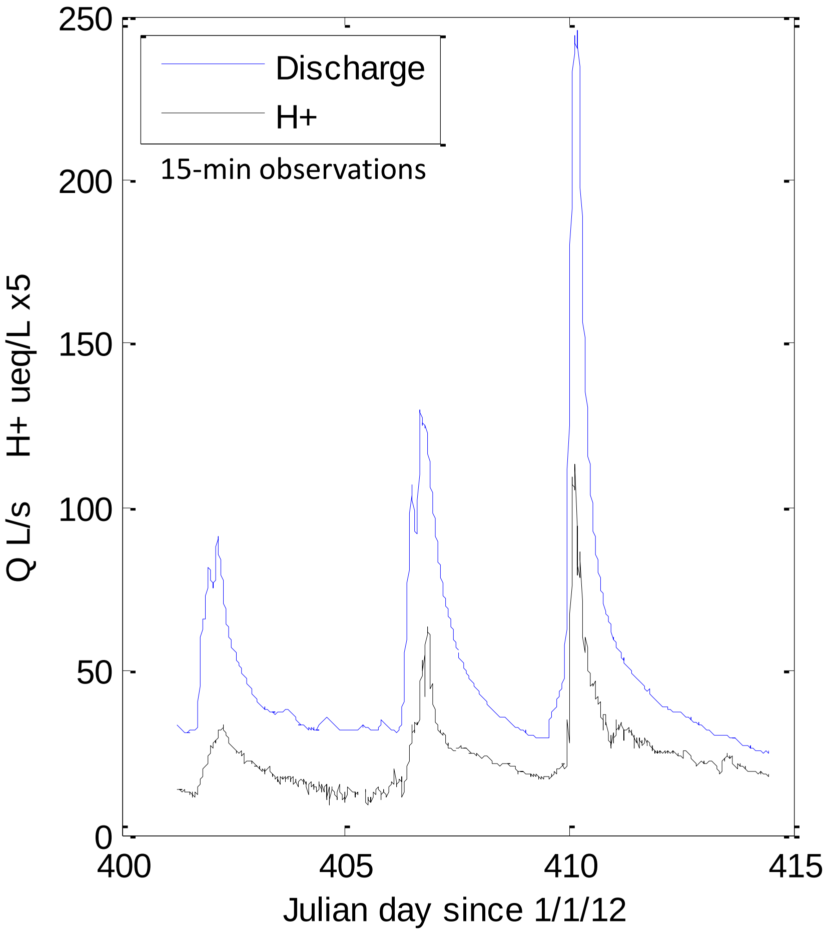
Time Constants (TCs) from li3q8.m

Minimum sampling for H^+ load

Nyquist-Shannon: fast TC/2 = 75 mins

Young (2010 *BHS*)*: fast TC/6 = 25 mins

*Young, P. 2010. The estimation of continuous-time rainfall-flow models for flood risk management. In: *Role of Hydrology in Managing Consequences of a Changing Global Environment*. BHS, Newcastle



Interpretation only plausible if sampling has been sufficent given the dynamics

Thank you - any questions?

Further information

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