

How dynamic are flow contributions and mean water ages in a diverse group of regional rivers?

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Aotearoa – New Zealand



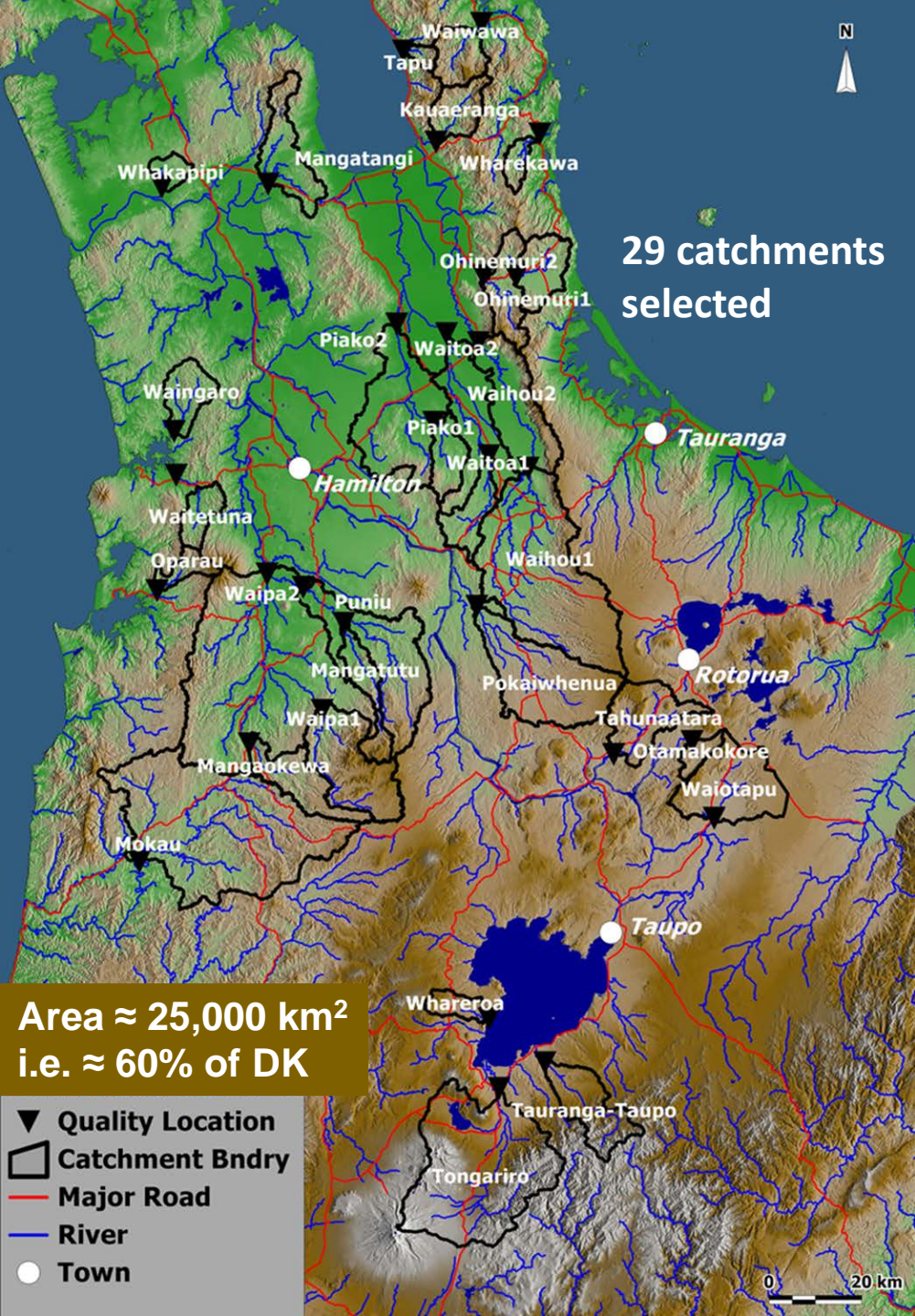
MEASURE. MODEL. MANAGE.

Aotearoa New Zealand



16 Regional Authorities:

- *How similar are our catchments regarding their contaminant transfer pathways?*
- *Does policy need to take spatial differences into account, or can it be applied uniformly?*
- *Does river water quality reflect current or former land use?*
- *How long will it take for new policy to show an effect on river water quality?*



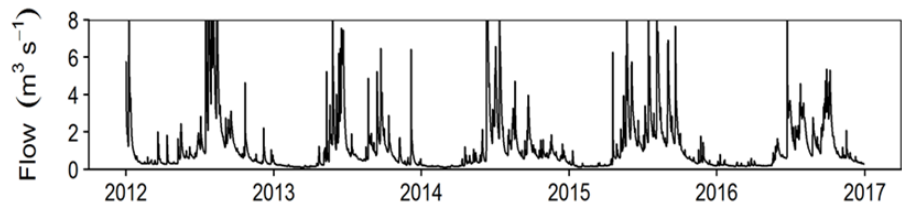
Waikato region

- Mean annual rainfall: 1143 – 2176 mm
- Climate: warm-wet, cold-wet, warm-dry
- Mean elevation: 75 – 808 m amsl
- Mean slope: 0 – 18°
- Geology: volcanic rocks, sedimentary rocks, alluvia
- Land use: 3 – 96% agricultural use

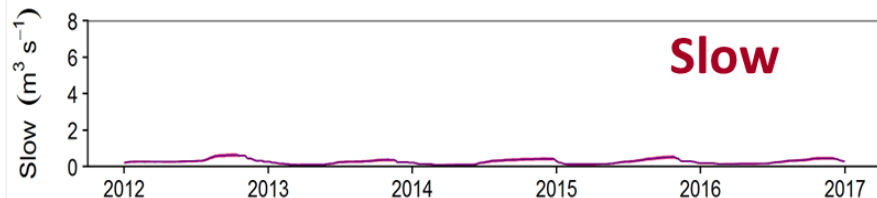
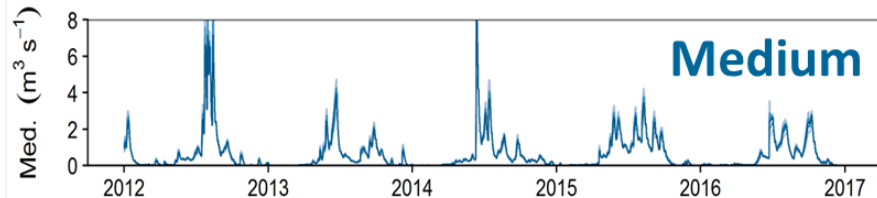
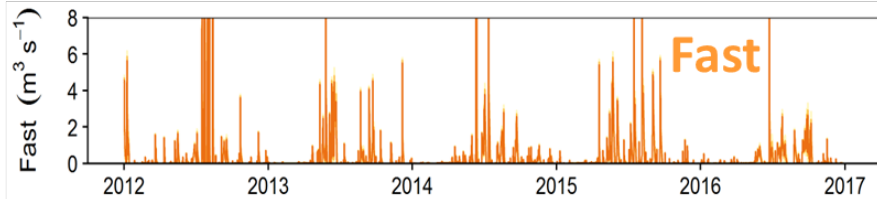
Two investigation methods

- I. BACH-modelling to estimate contributions to river flow by three hydrological pathways (n=29)
- II. Tritium-sampling to gain an empirical measure of the river water's mean age (n=19)

I. Bayesian chemistry-assisted hydrograph separation (BACH)

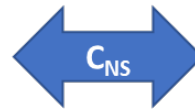


Three **flow components** estimated by applying a **recursive digital filter (RDF)** twice



Chemistry mixing model:
estimates characteristic concentrations of two tracers in each pathway

Pathways:



Near-surface (NS)

Surface runoff, interflow, artificial drainage
(episodic, very young: minutes - days)



Shallow groundwater (SGW)

(seasonal, local, young: weeks - years)

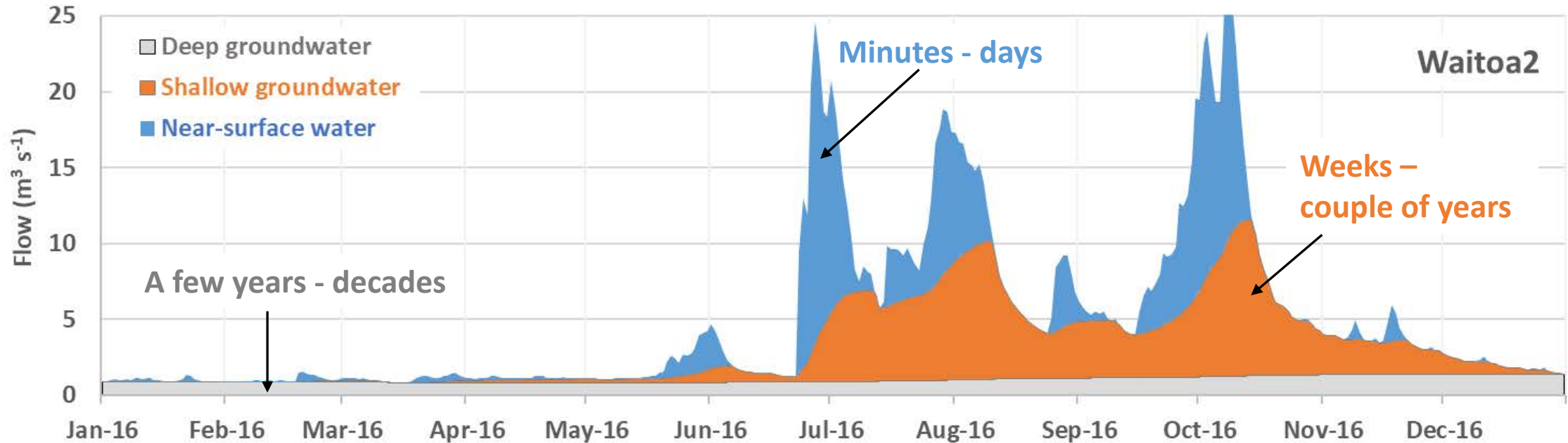


Deep groundwater (DGW)

(perennial, regional, old: years - decades)

Woodward, S. J. R. and Stenger, R. (2018) Bayesian chemistry-assisted hydrograph separation (BACH) and nutrient load partitioning from monthly stream phosphorus and nitrogen concentrations. *Stochastic Environmental Research and Risk Assessment*, 32(12): 3475-3501.

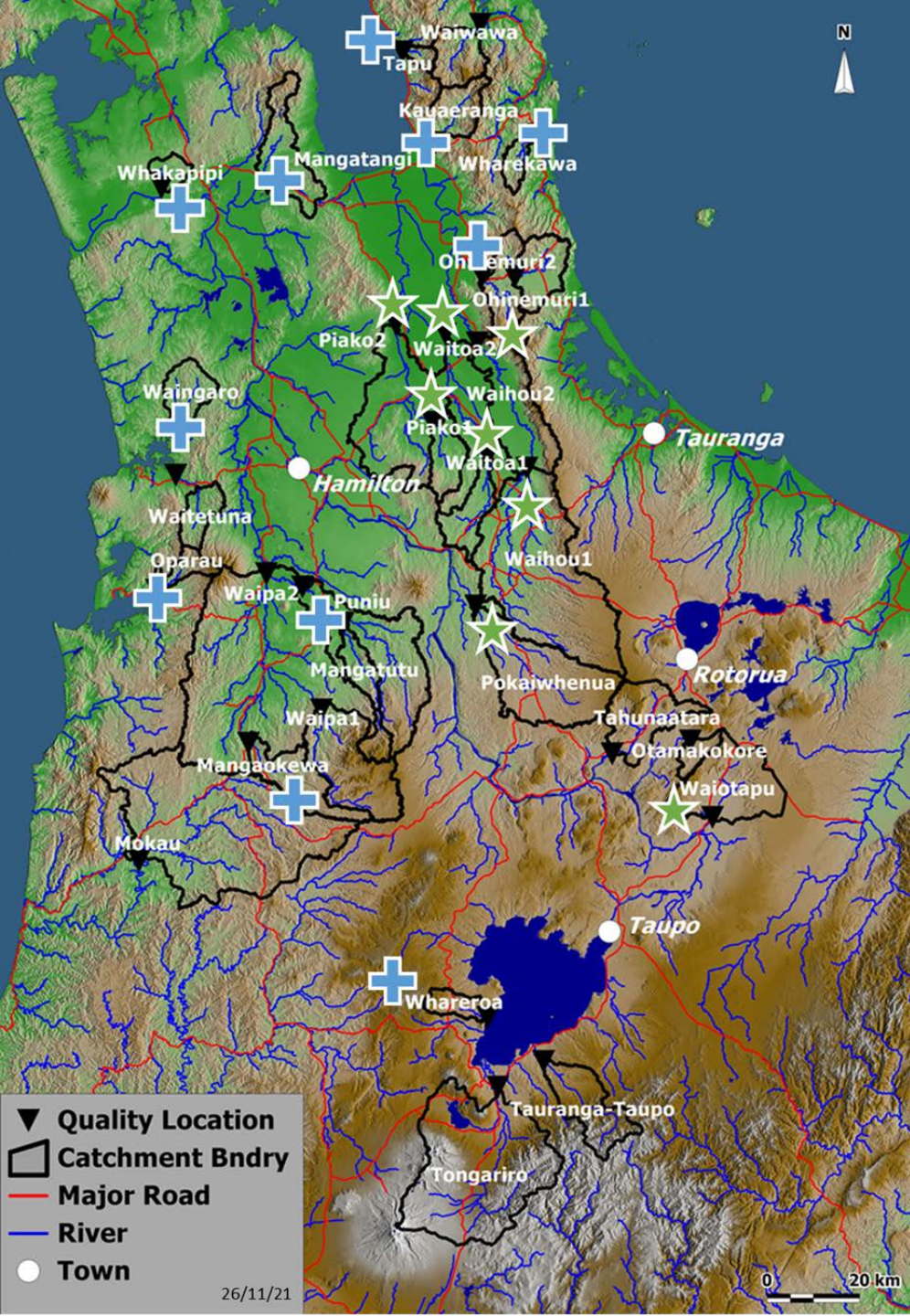
I. Variation of pathway contributions with flow



- Changing pathway contributions result in corresponding changes in the water's mean age.
- Question: Are the estimated pathway dynamics in agreement with water ages determined empirically?

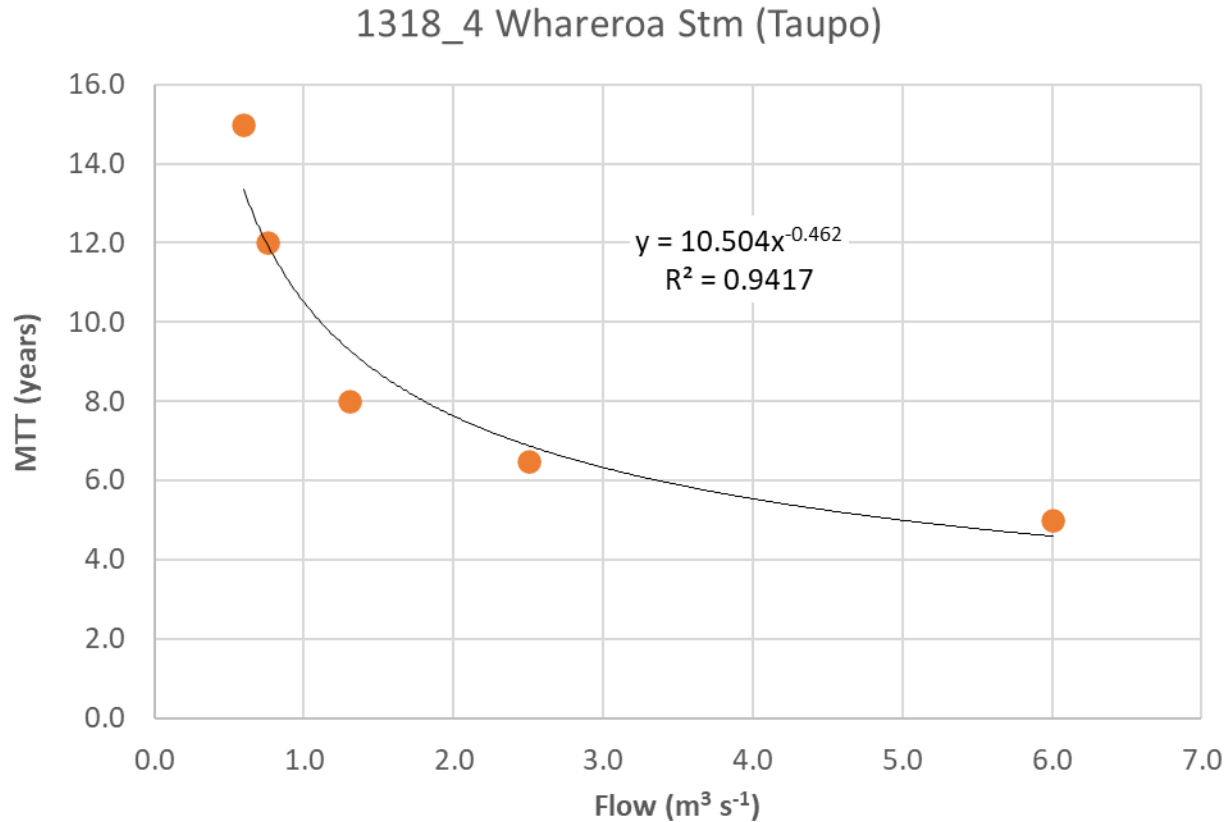
Stenger et al. (2024). Routine stream monitoring data enables the unravelling of hydrological pathways and transfers of agricultural contaminants through catchments. *Science of the Total Environment*, 912, 169370.

II. Tritium-derived Mean Transit Times (MTTs)



- Samples for tritium analysis taken at 12 monthly routine water quality samplings
- 19 sites sampled
- Four to nine samples per site analysed to capture the flow variation observed in a year
- MTTs estimated using exponential-piston flow model (EPM) with 70% mixing fraction

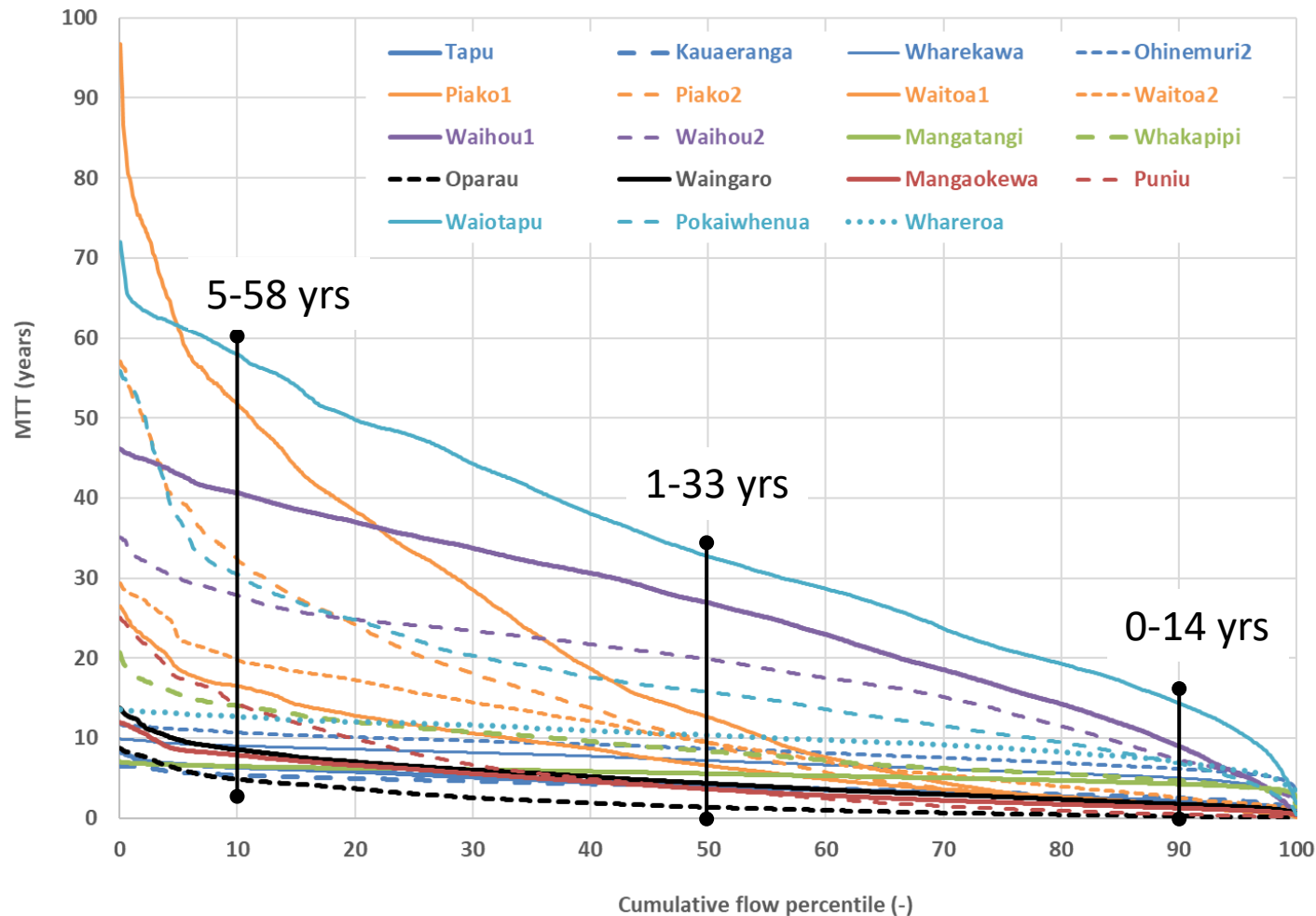
II. MTT variation with flow



- Simple power functions suitable:
 $\text{MTT} = a \cdot Q^b$
- $R^2 \geq 0.90$ in 12 of 19 catchments

Morgenstern, U., Stewart, M.K., Stenger, R. (2010) Dating of streamwater using tritium in a post nuclear bomb pulse world: continuous variation of mean transit time with streamflow. *Hydrol. & Earth Syst. Sci.*, 14, 2289-2301.

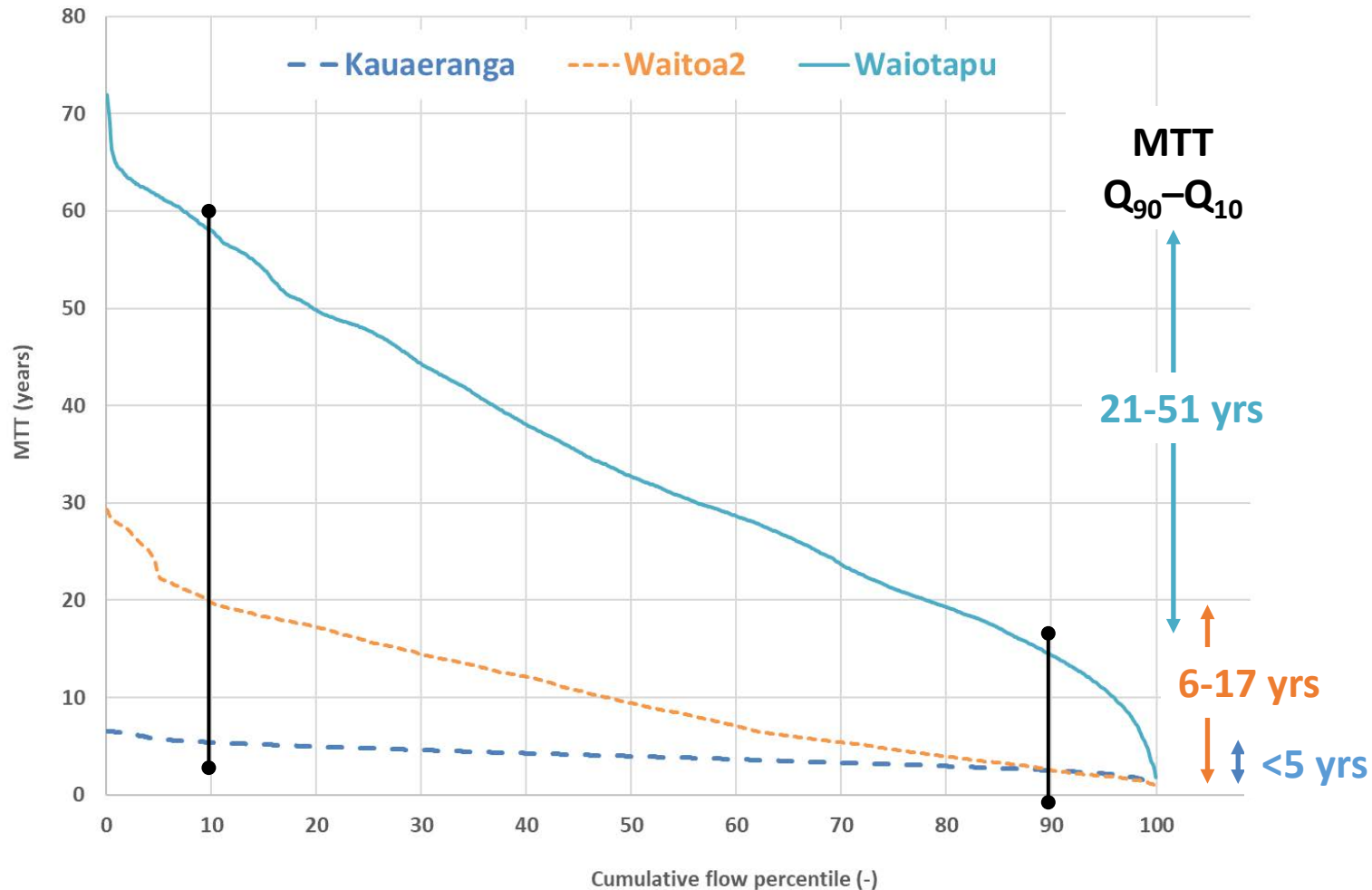
II. Variation of MTT dynamics between catchments



- Greatest MTT variation between catchments at low flows (range 5-58 yrs)
- Still substantial variation at median flow (range 1-33 yrs)
- Little MTT variation at high flows (range 0-14 yrs)
- **Three groups of catchments distinguishable** based on their differing degree of MTT variation

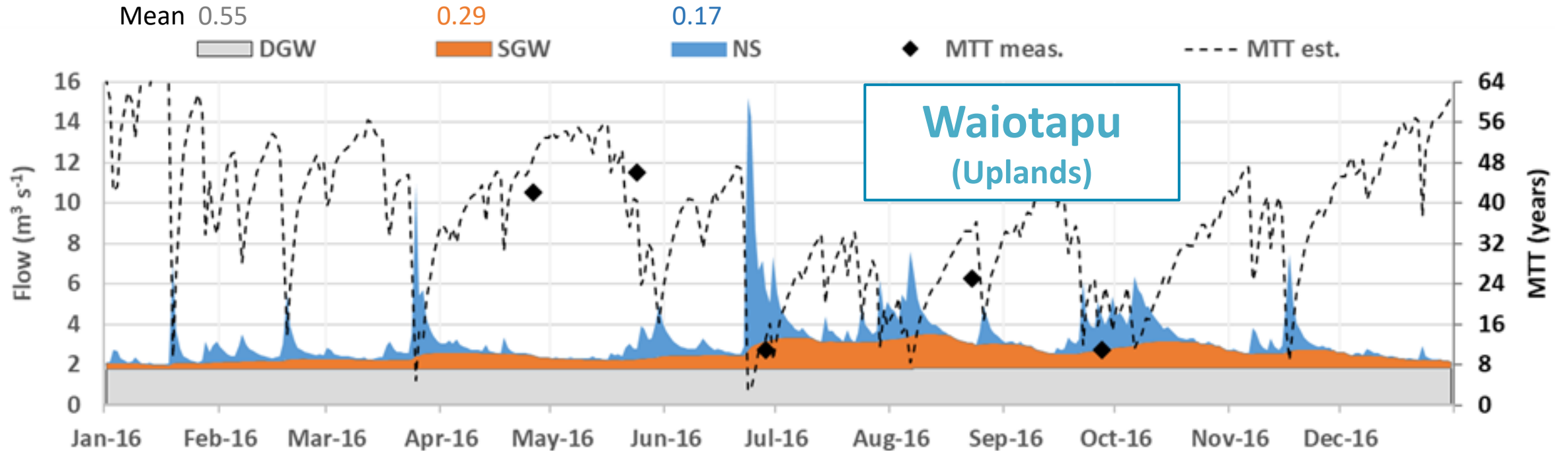
Berghuijs & Kirchner (2017) *'...most streamflow originates from a thin veneer of total groundwater storage.'*

II. Three patterns of MTT variation with flow



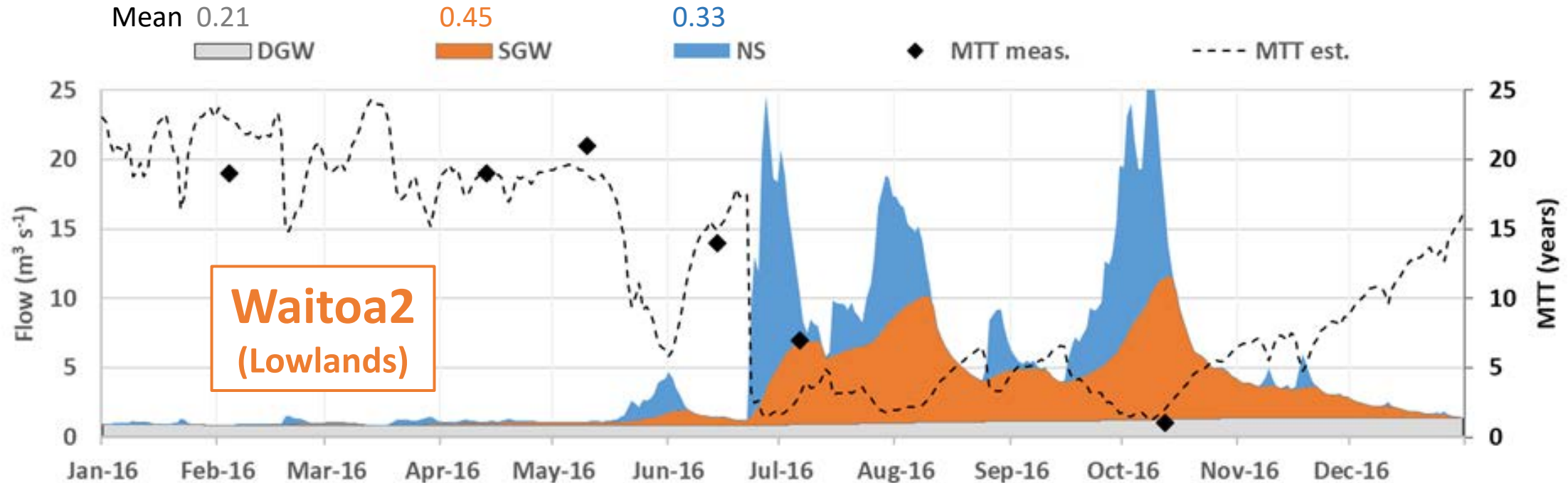
- **Waiotapu: six catchments with the greatest MTT variation:** mainly recharge areas in volcanic uplands
- **Waitoa2: seven catchments with modest MTT variation:** various lowland areas
- **Kauaeranga: six catchments with the smallest MTT variation:** steep hill country with high rainfall

Agreement between pathways and MTT dynamics?



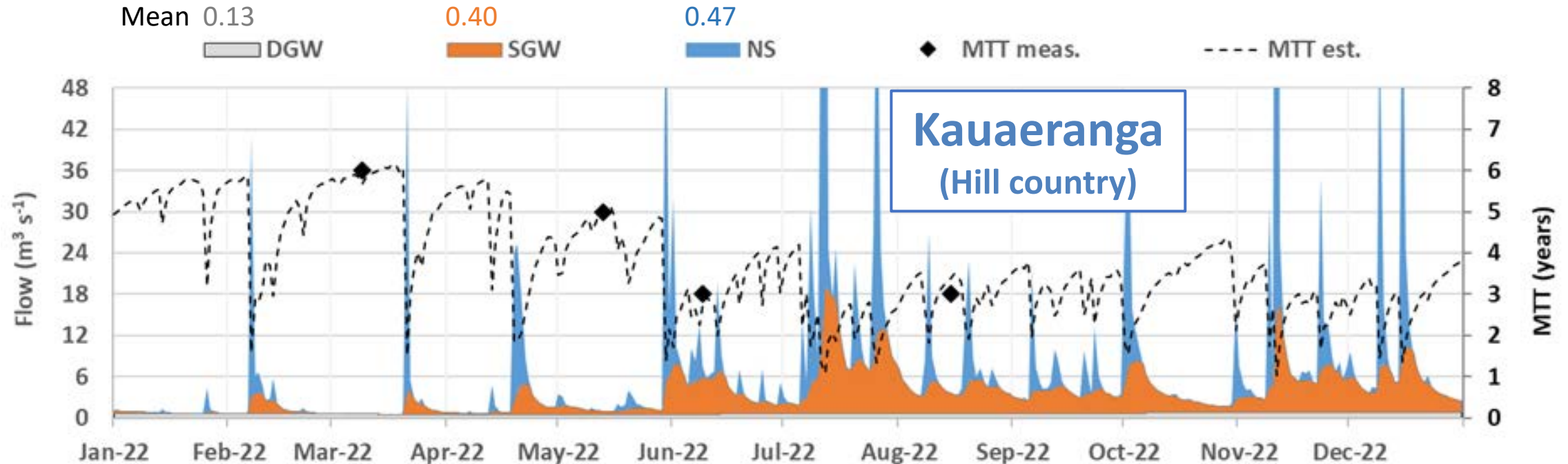
- MTTs >40 yrs in summer/autumn, when DGW discharge dominates flow
- MTTs dropping substantially when NS and SGW flows become more prevalent
- MTTs <20 yrs episodically at storm events and more prolonged during high-flow periods

Agreement between pathways and MTT dynamics?



- Pattern similar to Waio tapu, but MTTs substantially lower (<25 yrs)
- DGW reservoir sustaining flow in summer/autumn is younger and smaller than at Waio tapu
- MTTs <5 yrs for most of high-flow period caused by NS and SGW flows in winter/spring

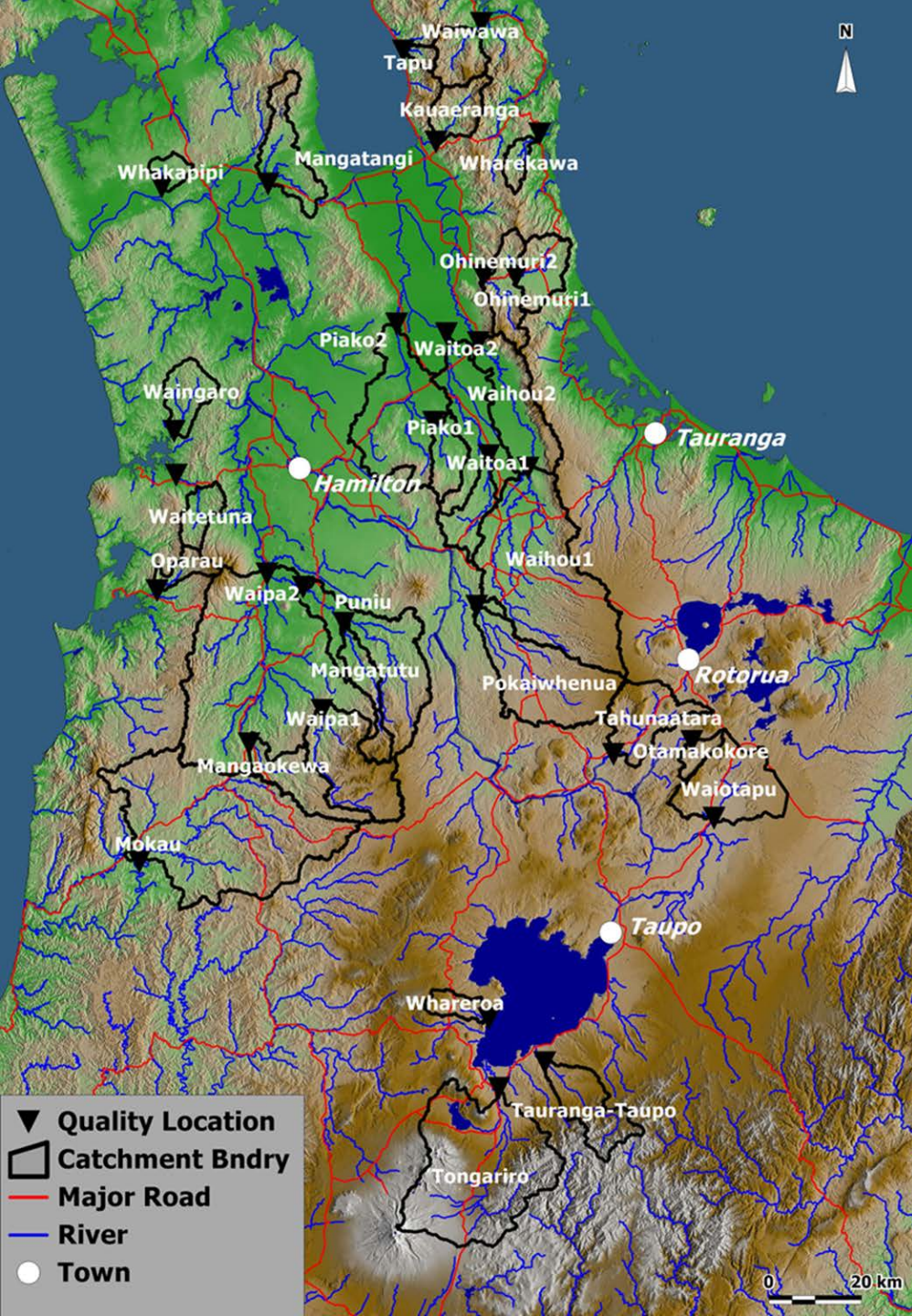
Agreement between pathways and MTT dynamics?



- Very little flow contribution by DGW (long-term mean 13%)
- Very young NS and young SGW flows dominate stream flow almost all year around
- MTTs very low (≤ 6 yrs) and showing little variation with flow

Agreement between pathways and MTT dynamics?

- **Broad agreement** between BACH-estimated pathway contributions and tritium-derived MTTs
- **Systematic discrepancy:** EPMs cannot describe the very wide MTT distributions with substantial young water fractions that are inherent in the BACH approach
- **Binary Mixing Models (BMM)** would be coherent with BACH, but cannot be reliably fitted due to insufficient length and quality of existing tritium time series
- **Outlook:** Could BACH be used to enable alternative approaches to the fitting of BMMs, e.g. by constraining the young water fraction?



Regional Council:

Does environmental regulation need to take spatial differences into account, or can policy be applied uniformly across the region?

Broadly three types of catchments:

- *Significant recharge areas in volcanic uplands: high DGW contribution, elevated MTTs even above Q_{50}
➔ long hydrologic lags*
- *Lowlands: SGW dominant, low MTTs above Q_{50}
➔ short hydrologic lags*
- *Hill country: NS + SGW dominant, low MTTs throughout
➔ very short hydrologic lags*

Thank you for your attention!



Questions?

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