# Impact of different soil databases on flow prediction uncertainty in SWAT+gwflow for a forested catchment

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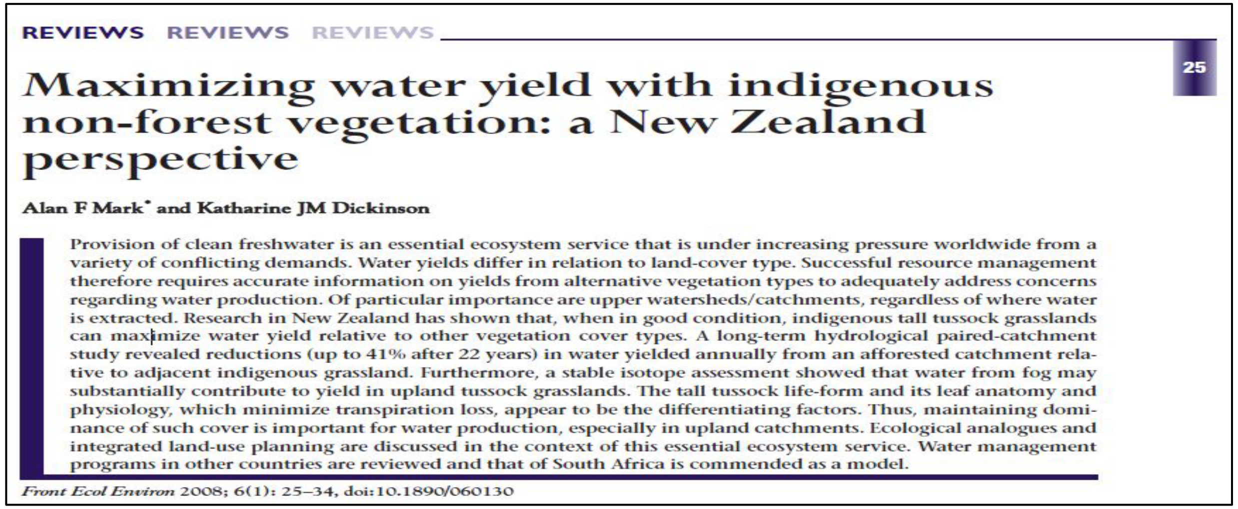
# Tree Plantation Impacts


REVIEWS REVIEWS REVIEWS

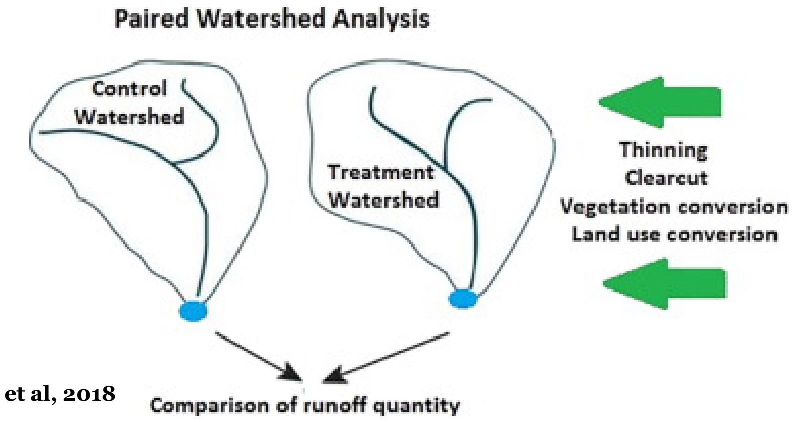
25

**Maximizing water yield with indigenous non-forest vegetation: a New Zealand perspective**

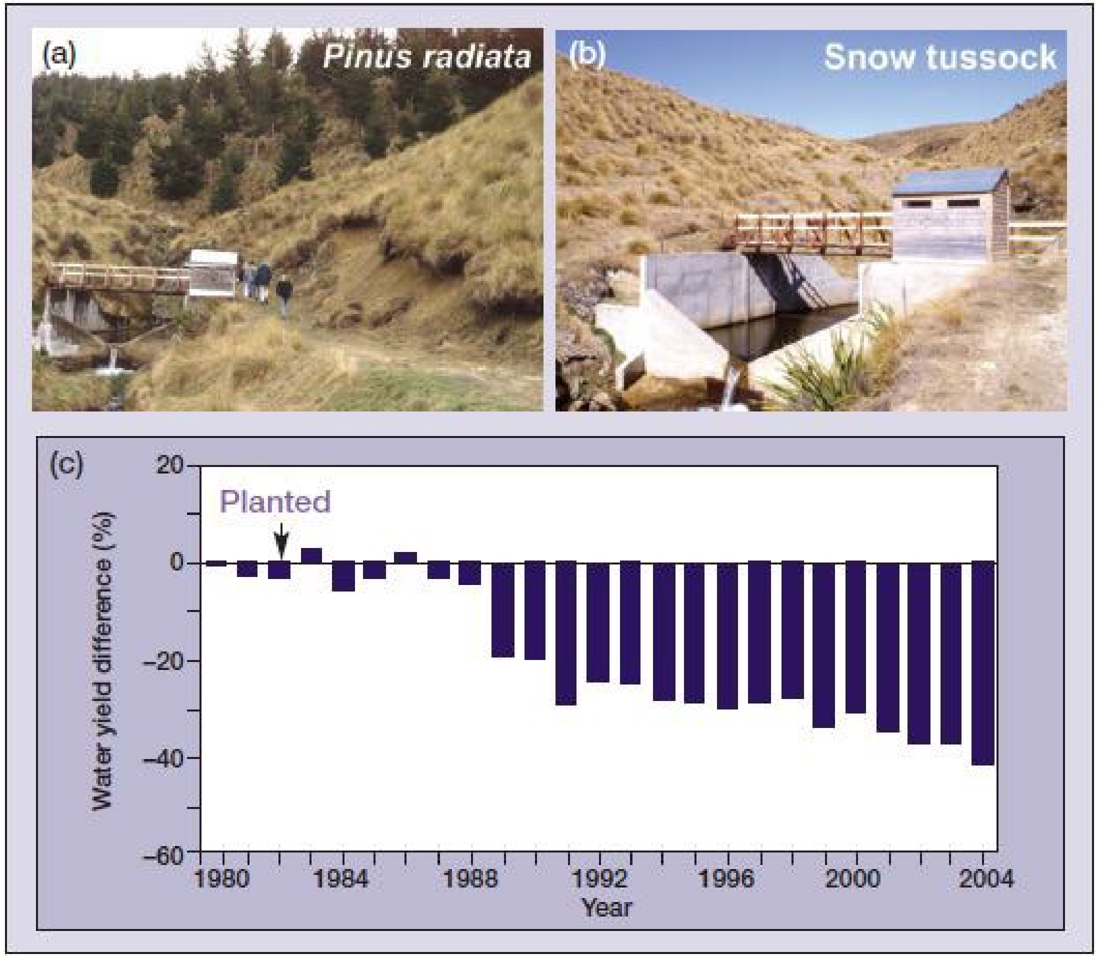
Alan F Mark* and Katharine JM Dickinson

Provision of clean freshwater is an essential ecosystem service that is under increasing pressure worldwide from a variety of conflicting demands. Water yields differ in relation to land-cover type. Successful resource management therefore requires accurate information on yields from alternative vegetation types to adequately address concerns regarding water production. Of particular importance are upper watersheds/catchments, regardless of where water is extracted. Research in New Zealand has shown that, when in good condition, indigenous tall tussock grasslands can maximize water yield relative to other vegetation cover types. A long-term hydrological paired-catchment study revealed reductions (up to 41% after 22 years) in water yielded annually from an afforested catchment relative to adjacent indigenous grassland. Furthermore, a stable isotope assessment showed that water from fog may substantially contribute to yield in upland tussock grasslands. The tall tussock life-form and its leaf anatomy and physiology, which minimize transpiration loss, appear to be the differentiating factors. Thus, maintaining dominance of such cover is important for water production, especially in upland catchments. Ecological analogues and integrated land-use planning are discussed in the context of this essential ecosystem service. Water management programs in other countries are reviewed and that of South Africa is commended as a model.

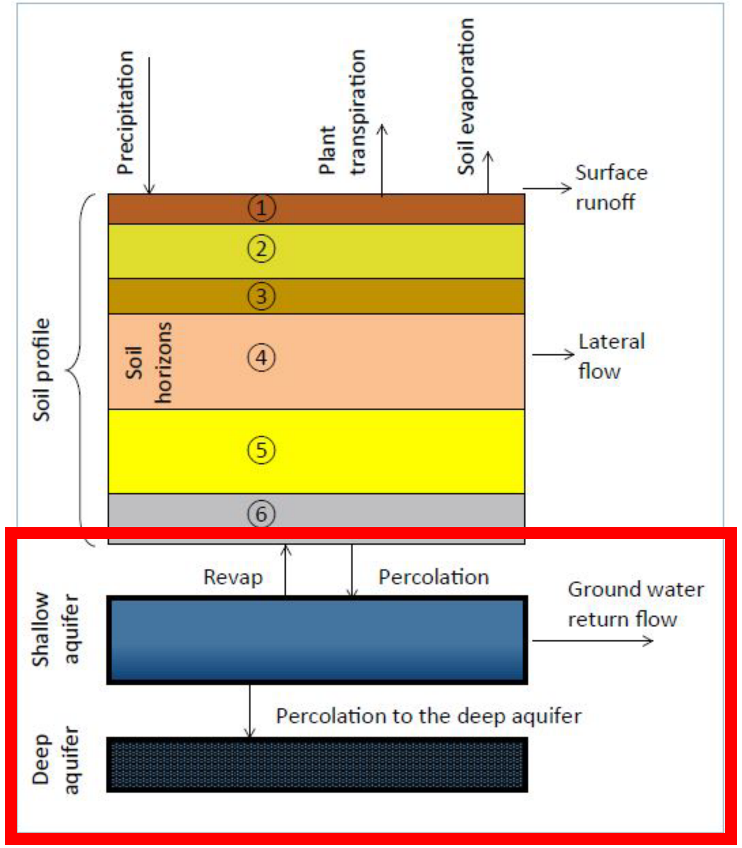
*Front Ecol Environ* 2008; 6(1): 25–34, doi:10.1890/060130

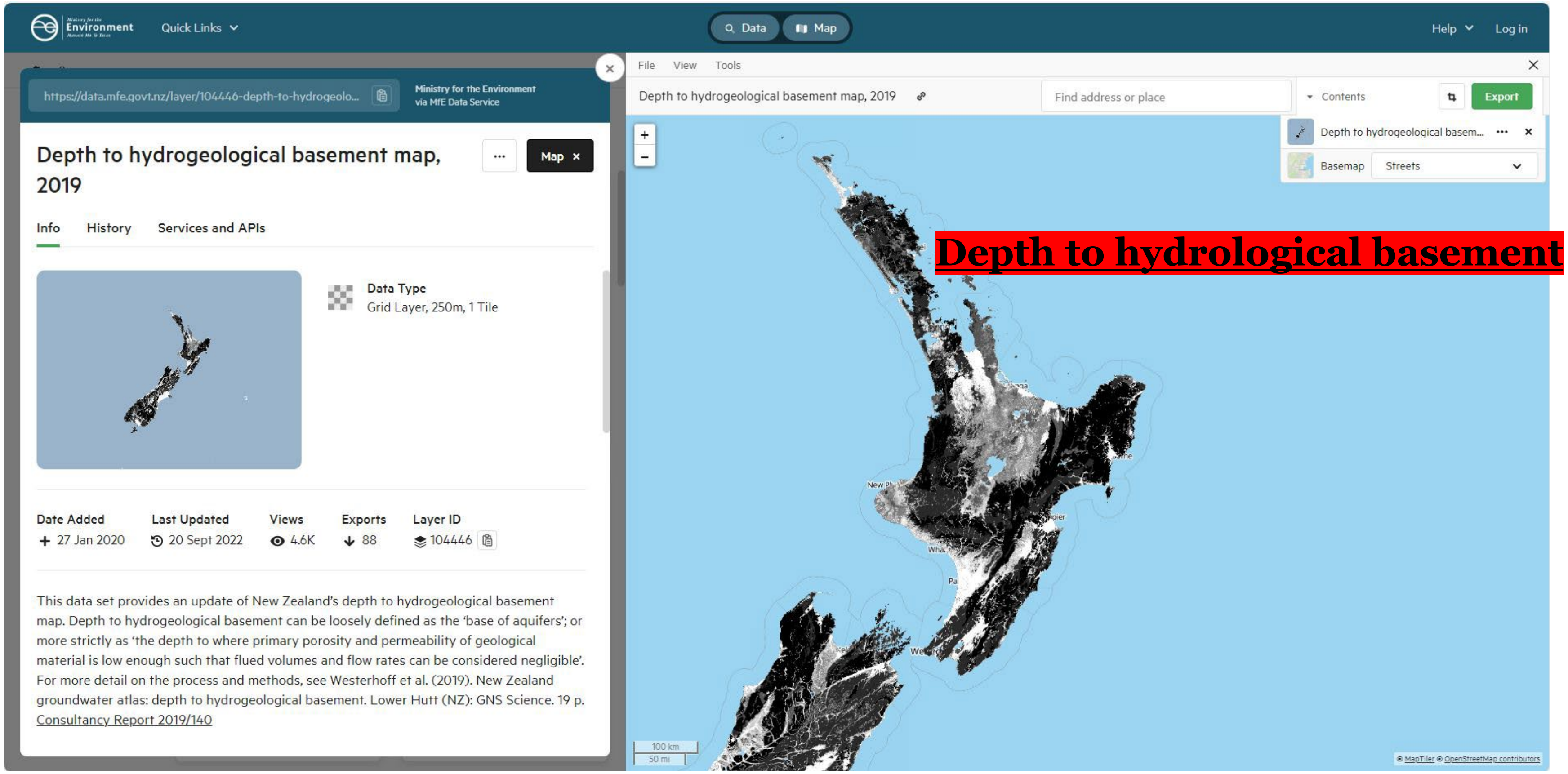



Yurtseven et al, 2018



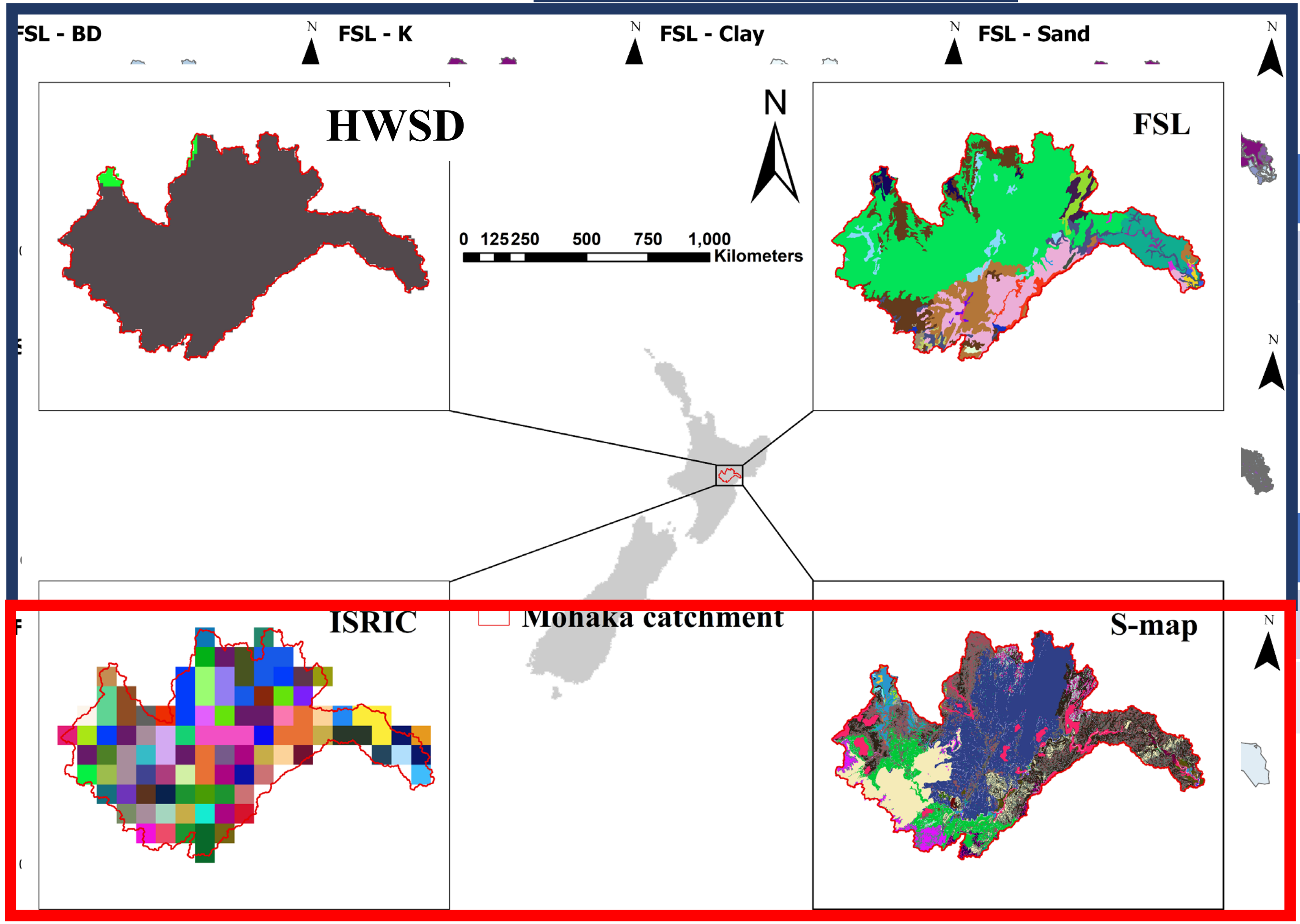
# Soil maps


Precipitation
Plant transpiration
Soil evaporation
Surface runoff
Soil profile
Soil horizons
1
2
3
4
5
6
Lateral flow
Revap
Percolation
Ground water return flow
Shallow aquifer
Percolation to the deep aquifer
Deep aquifer


Environment
Quick Links
Data
Map
Help
Log in
https://data.mfe.govt.nz/layer/104446-depth-to-hydrogeolo...
Ministry for the Environment via MfE Data Service
Depth to hydrogeological basement map, 2019
Map
Info
History
Services and APIs
Data Type
Grid Layer, 250m, 1 Tile
Date Added
27 Jan 2020
Last Updated
20 Sept 2022
Views
4.6K
Exports
88
Layer ID
104446
This data set provides an update of New Zealand's depth to hydrogeological basement map. Depth to hydrogeological basement can be loosely defined as the 'base of aquifers'; or more strictly as 'the depth to where primary porosity and permeability of geological material is low enough such that flued volumes and flow rates can be considered negligible'. For more detail on the process and methods, see Westerhoff et al. (2019). New Zealand groundwater atlas: depth to hydrogeological basement. Lower Hutt (NZ): GNS Science. 19 p. Consultancy Report 2019/140
File
View
Tools
Depth to hydrogeological basement map, 2019
Find address or place
Contents
Export
Depth to hydrogeological basem...
Basemap
Streets
Depth to hydrological basement
100 km
50 mi

# Variations in soil data sets

## Local Soil Databases




## Global Soil Databases

FSL - Depth [mm]

## Global Soil Databases

| Name | Resolution | Soil units |
|---|---|---|
| HWSD | 806 m | 2 |
| ISRIC | 4838 m | 83 |

701 - 1100
1101 - 1280
0 5 10 20 Kilometers

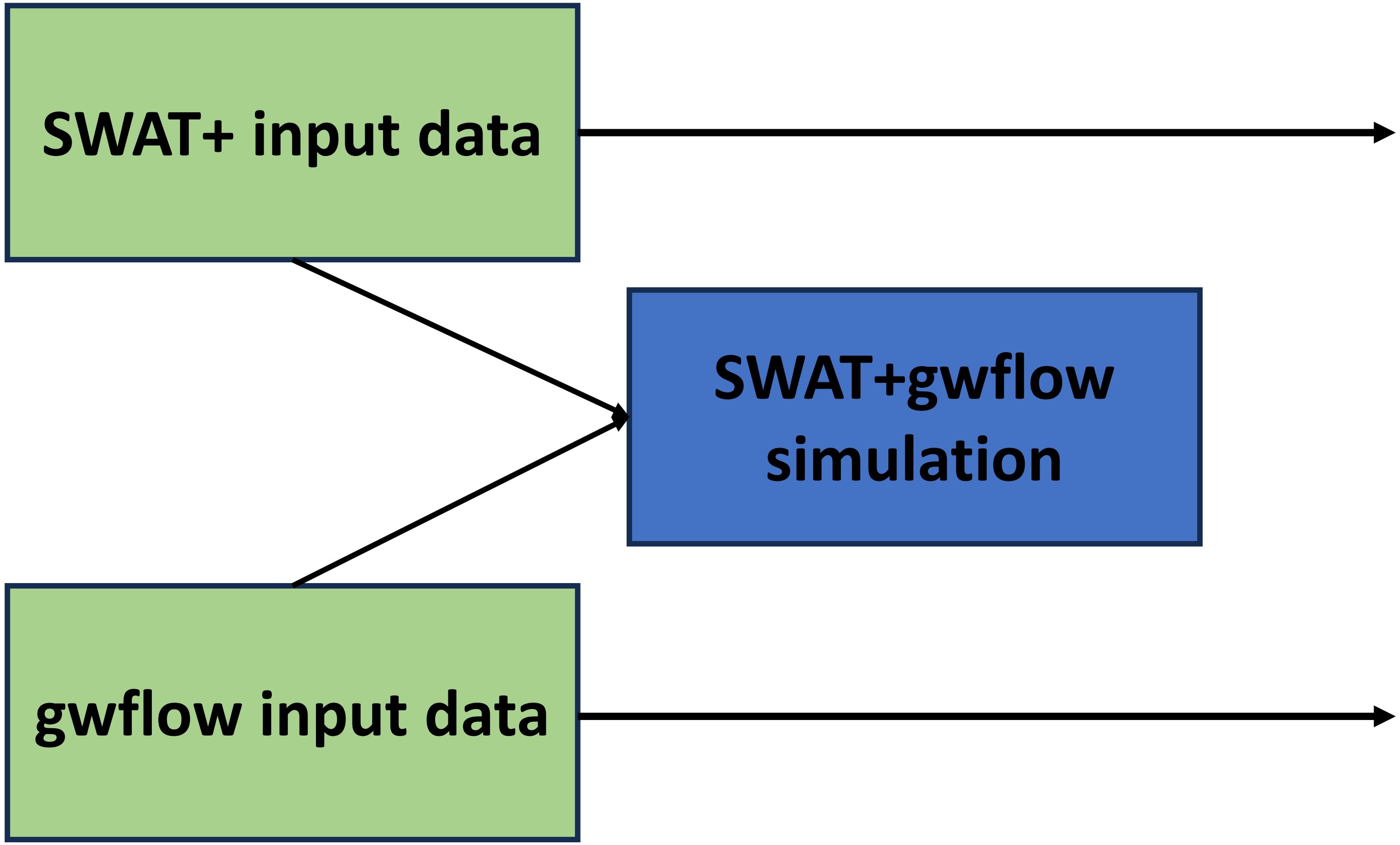
S-map - Depth [mm]

## Local Soil Databases

| Name | Resolution | Soil units |
|---|---|---|
| FSL | 15 m | 24 |
| S-map | 15 m | 36 |

121 - 350
351 - 990
991 - 1020
1021 - 1040
0 5 10 20 Kilometers

# Input data: SWAT+gwflow




| Data | Source |
|---|---|
| **Topography** | University of Otago |
| **Land use** | Landcare Research |
| **Soil** | Landcare Research<br>Global websites (FAO, ISRIC) |
| **Climate** | HBRC & NIWA |

| Data | Source |
|---|---|
| **Aquifer thickness** | GNS Science |
| **Geologic unit** | GNS Science |

# Soil in SWAT(+)

## Percolation

$$w_{perc,ly} = SW_{ly,excess} \cdot \left(1 - exp\left[\frac{-\Delta t}{TT_{perc}}\right]\right)$$

$$TT_{perc} = \frac{SAT_{ly} - FC_{ly}}{K_{sat}}$$

**W:** percolation (mm)
**SW:** soil water content
**TT:** travel time for percolation (hr)

Saturated hydraulic conductivity (mm/hr)

## Transpiration

$$AWC = FC - WP$$

$$WP_{ly} = 0.4 \frac{m_c . \rho_b}{100}$$

**AWC:** Available Water Capacity
**FC:** Water content at field Capacity
**WP:** Water content at wilting point
**$\rho_b$**: soil bulk density

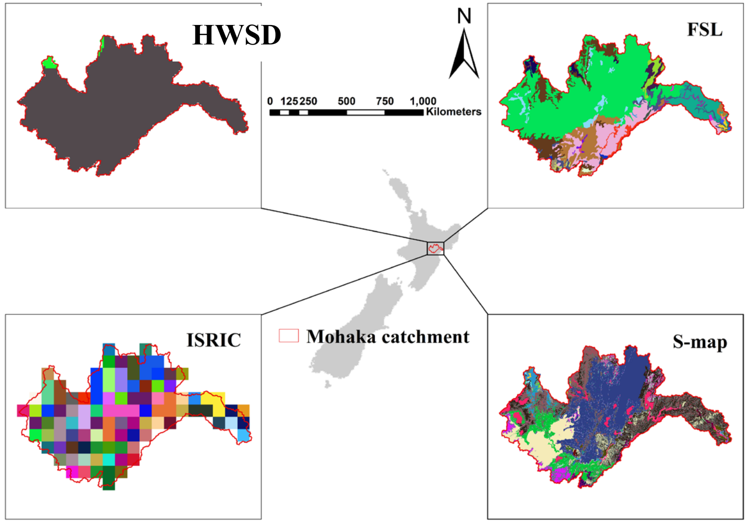
Clay content (%)

# Gaps/Questions: soil databases

1) Impact of different soil databases on streamflow estimation within a catchment, with identical input data except for the soil.

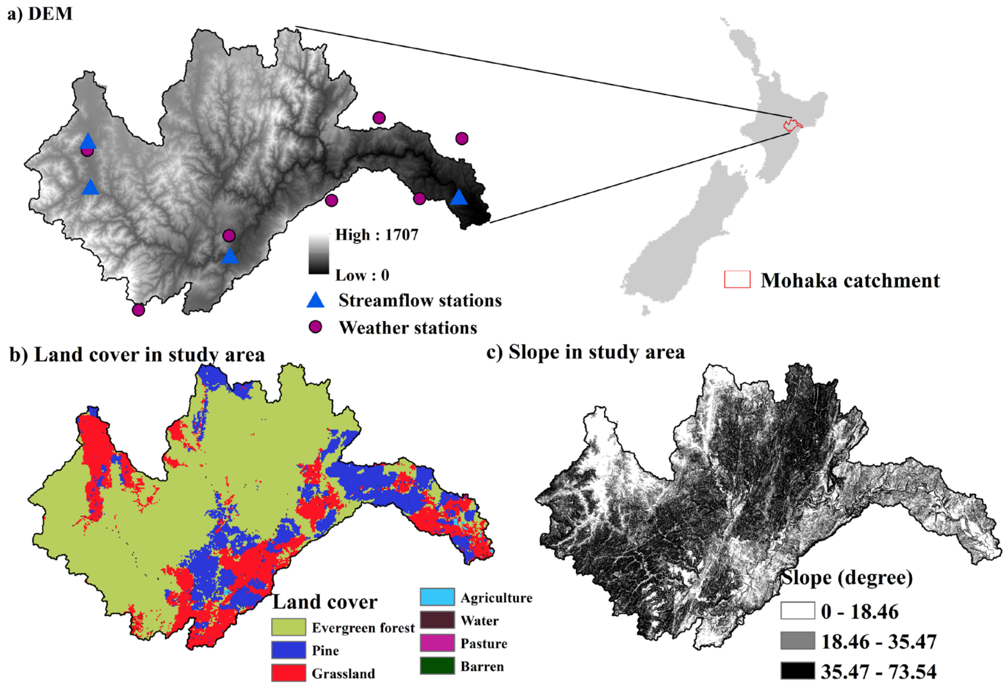
2) Key parameters or parameter groups contributing to prediction uncertainty reduction **[and by how much?]**.

# Methodology: Discretisation




| Soil Database | # Sub-basin | # HRU | # Soil units |
|---|---|---|---|
| FAO | 19 | **385** | 2 |
| HWSD | 19 | **680** | 24 |
| ISRIC | 19 | **761** | 83 |
| S-map | 19 | **822** | 27 |

## Mohaka catchment




**Area:** 2,400 km²

**Average rainfall:** 1620 mm

**Average slope:** 28 degree

# Methodology: Techniques/tools

**I.** Performance evaluation (in simulating streamflow)

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{oi} - Q_{si})^2}{\sum_{i=1}^{n}(Q_{oi} - \bar{Q})^2}$$

$$PBIAS = \frac{\sum_{i=1}^{n}(Q_{oi} - Q_{si})}{\sum_{i=1}^{n} Q_{oi}} \times 100$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Q_{oi} - \widehat{Q_{pi}})^2}{\sum_{i=1}^{n}(Q_{oi} - \bar{Q})^2}$$

**II.** Contribution of parameters (groups) to prediction uncertainty

**Linear Analysis:**

first-order-second moment (FOSM analysis)

# Performance evaluation: SWAT+gwflow

## Daily performance statistics

| Soil Database | NSE | PBIAS | $R^2$ |
|---|---|---|---|
| FAO | -0.58 | -86.4 | 0.34 |
| ISRIC | -0.54 | -92.9 | 0.31 |
| S-map | 0.35 | 17.6 | 0.61 |
| FSL | 0.45 | -6.9 | 0.67 |

## Monthly performance statistics

| Soil Database | NSE | PBIAS | $R^2$ |
|---|---|---|---|
| FAO | -1.26 | -86.3 | 0.71 |
| ISRIC | -1.62 | -92.8 | 0.63 |
| S-map | 0.46 | 17.6 | 0.82 |
| FSL | 0.56 | -6.8 | 0.81 |

# Water balance

Local soil databases

Global soil databases

| | Component | S-map | FSL | ISRIC | FAO |
|---|---|---|---|---|---|
| Catchment inputs | Precipitation | 1657 | 1667 | 1658 | 1616 |
| | GW boundary inflow | 146 | 169 | -400 | 122 |
| Catchment outputs | Surface ET | 473 | 373 | 486 | 514 |
| | Surface runoff | 137 | 320 | 176 | 456 |
| | Lateral soil flow | 935 | 831 | 689 | 96 |
| | GW discharge to streams | 206 | 0 | 0 | 0 |
| | Stream seepage to GW | -71495 | -268000 | -9632 | -30088 |
| | Saturation excess flow | 70580 | 266950 | 6244 | 25592 |
| | GW ET | 0.03 | 0.11 | 0.00 | 0.00 |
| Internal flows | Recharge | 2680 | 3640 | 31705 | 9783 |
| | Pumping irrigation | 0 | 0 | 0 | 0 |
| | Surface water irrigation | 0 | 0 | 0 | 0 |
| | GW transfer to soil | 3496 | 4883 | 36990 | 14394 |

# Linear analysis (FOSM analysis)

$$h = Zk + \varepsilon$$

**Z:** the action of a model on its parameters (Jacobian or sensitivity matrix)

**h:** observation of the system states and fluxes

**ε:** observation noise/errors

**Jacobian or sensitivity matrix**

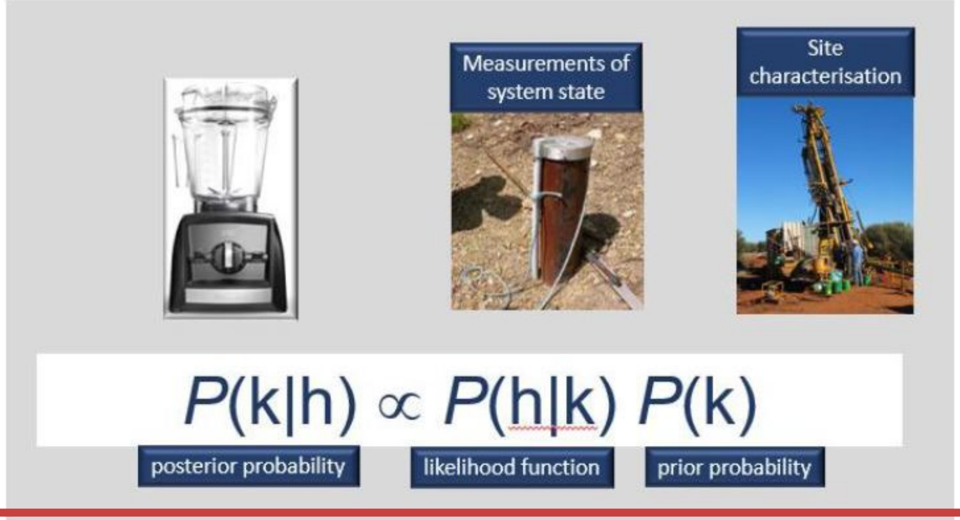
$$\begin{matrix} \frac{\partial o_1}{\partial p_1} & \frac{\partial o_1}{\partial p_2} & \frac{\partial o_1}{\partial p_3} & \frac{\partial o_1}{\partial p_4} & \text{etc} \\ \frac{\partial o_2}{\partial p_1} & \frac{\partial o_2}{\partial p_2} & \frac{\partial o_2}{\partial p_3} & \frac{\partial o_2}{\partial p_4} & \\ \frac{\partial o_3}{\partial p_1} & \frac{\partial o_3}{\partial p_2} & \frac{\partial o_3}{\partial p_3} & \frac{\partial o_3}{\partial p_4} & \\ \frac{\partial o_4}{\partial p_1} & \frac{\partial o_4}{\partial p_2} & \frac{\partial o_4}{\partial p_3} & \frac{\partial o_4}{\partial p_4} & \\ \frac{\partial o_5}{\partial p_1} & \frac{\partial o_5}{\partial p_2} & \frac{\partial o_5}{\partial p_3} & \frac{\partial o_5}{\partial p_4} & \\ \text{etc} & & & & \end{matrix}$$

$$s = y^t k$$

$$\sigma_s^2 = y^t C(k) y$$

$$\sigma_{s'}^2 = y^t C'(k) y$$

$$\begin{matrix} \frac{\partial s}{\partial k_1} & \frac{\partial s}{\partial k_2} & \frac{\partial s}{\partial k_3} & \frac{\partial s}{\partial k_4} & \text{etc} \end{matrix}$$

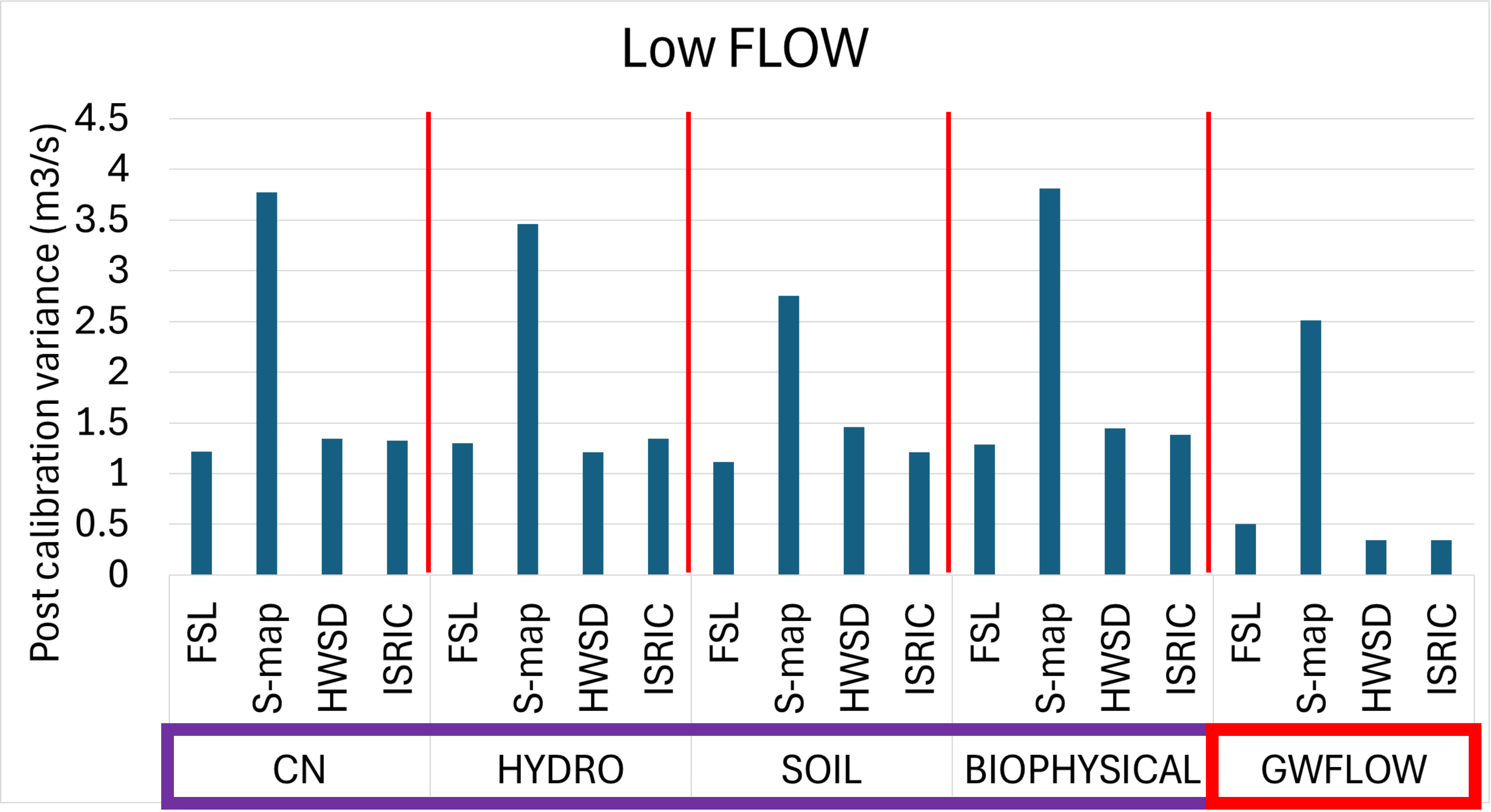



$\sigma_s^2$: prior variance of prediction s

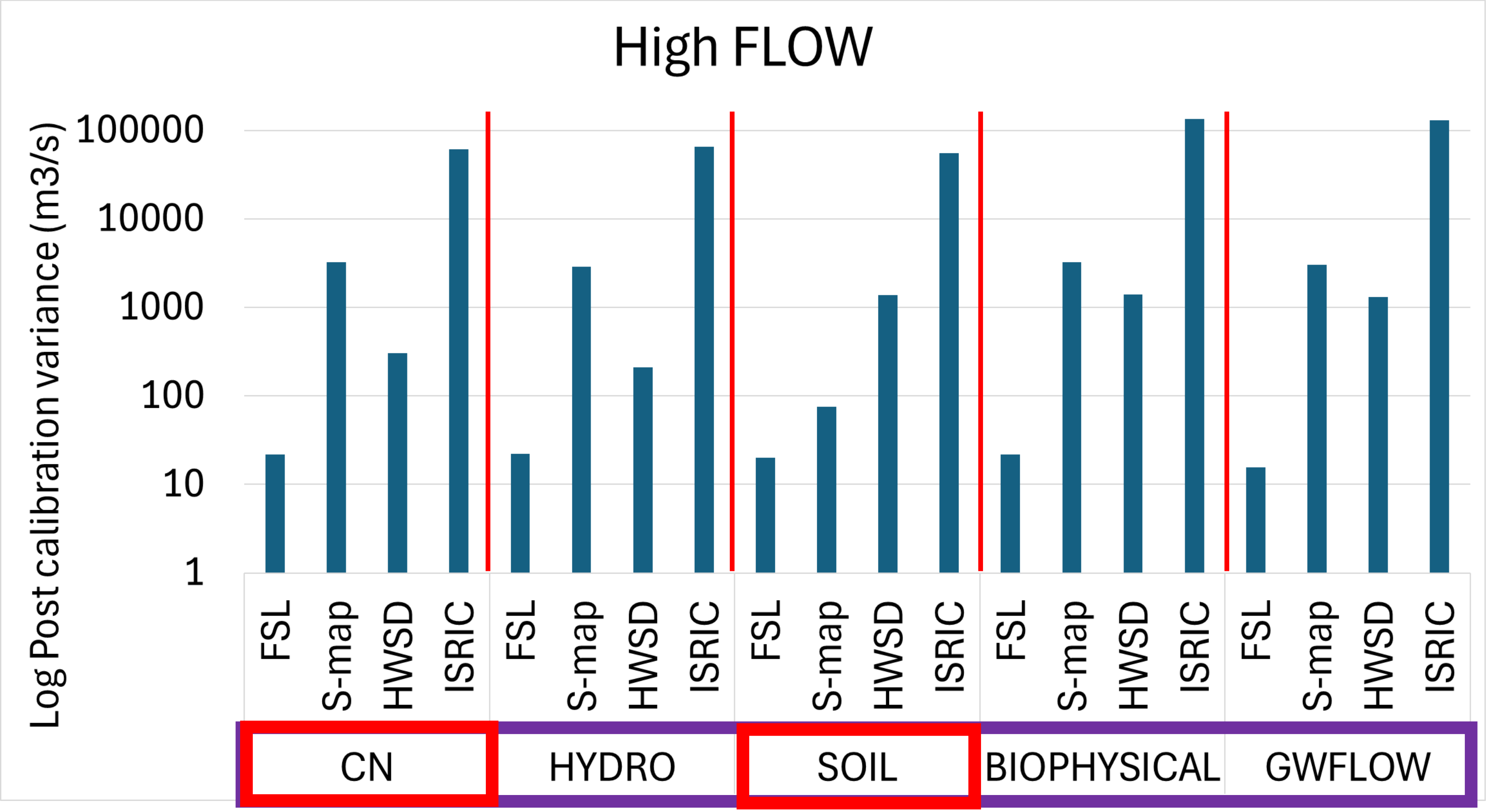
$\sigma_{s'}^2$: posterior variance of prediction s

**s:** prediction of interest

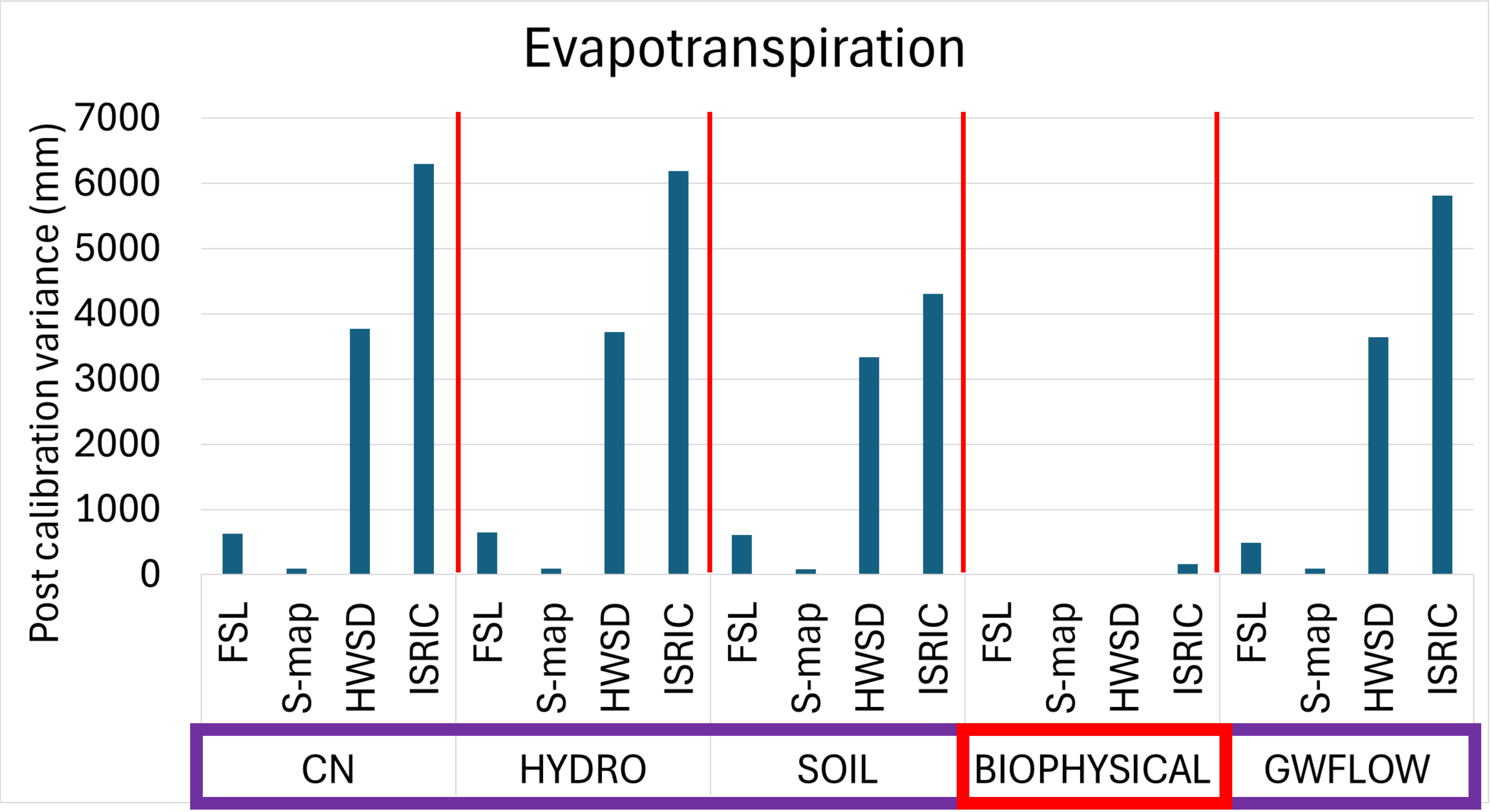
# Linear uncertainty analysis (Low flows)



# Linear uncertainty analysis (High flows)



# Linear uncertainty analysis (ET)



# Conclusion

**Thank you!**

1) Local soil databases outperformed global soil databases in estimating the streamflow at the outlet of the catchment.

2) **Contribution to prediction uncertainty reduction:**

**Low flow simulation → groundwater-related parameters (maintaining the baseflow during low flow conditions)**

**High flow simulation → Soil parameters and CN (critical parameters in runoff and infiltration rates)**

**Evapotranspiration → Biophysical parameters (vegetation dynamics)**

# Global sensitivity analysis

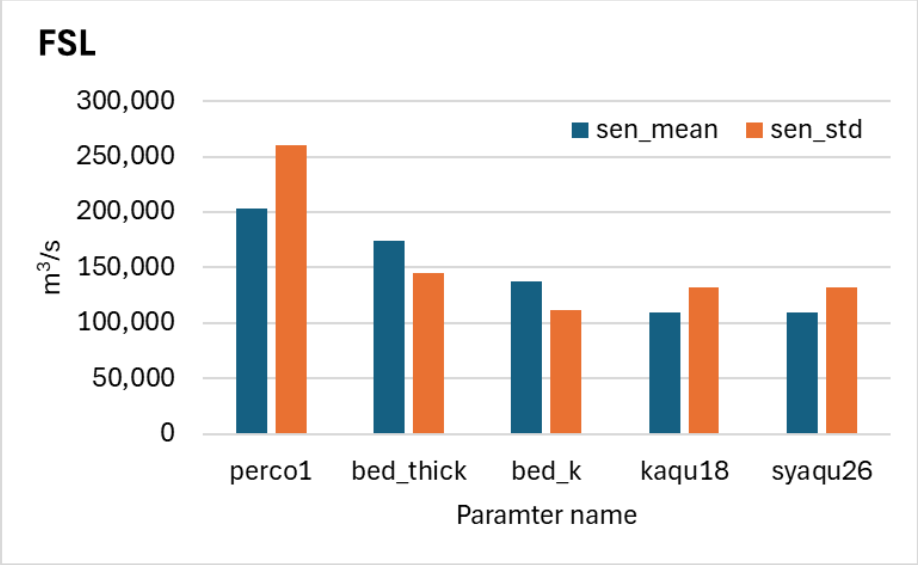
## Morris Screening (Elementary Effects)

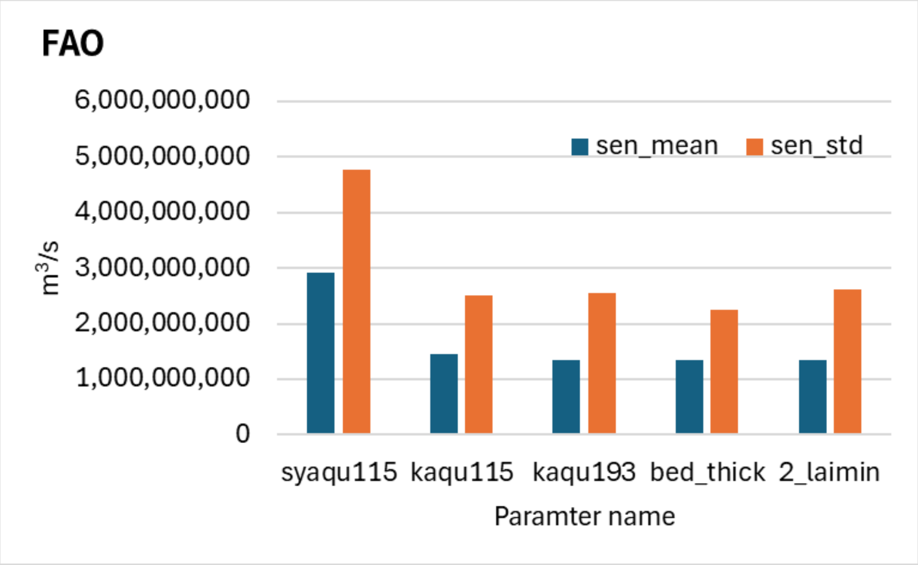
$$EE_i = \frac{f(x_1, \dots, x_i + \Delta_i, \dots, x_p) - f(x)}{\Delta_i}$$ Elementary Effect

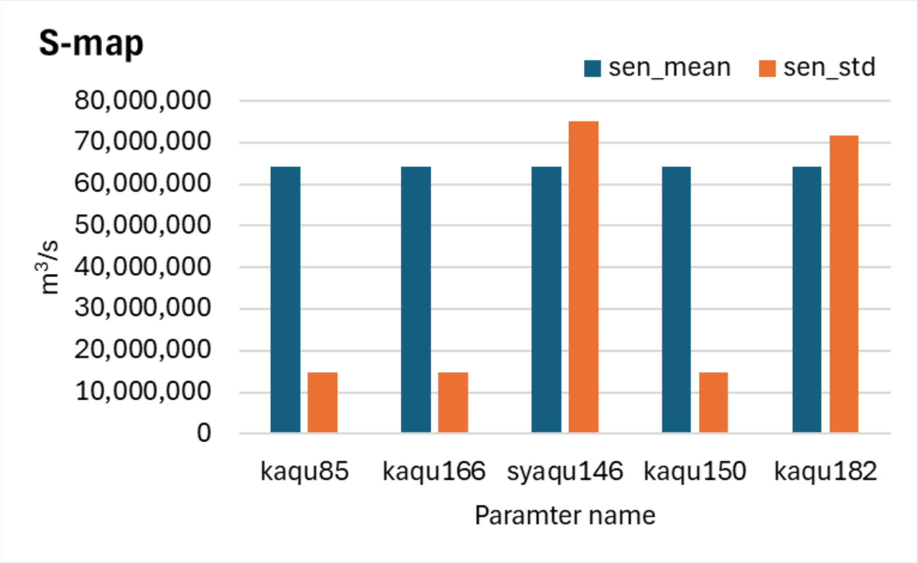
$$\mu_i^* = \frac{1}{n}\sum_{j=1}^{n} |EE_i(j)|$$ $\boxed{\textbf{Sensitivity index}}$

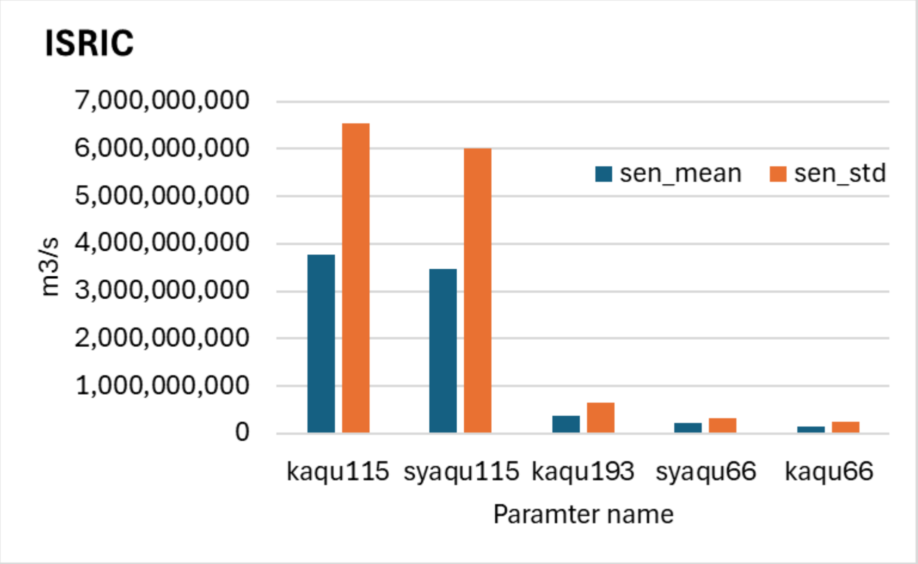
$$\sigma_i = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}\left[EE_i(j) - \frac{1}{n}\sum_{j=1}^{n} EE_i(j)\right]^2}$$ $\boxed{\textbf{Non-linearity/interaction index}}$

# Global sensitivity results



# Global sensitivity results

1) Groundwater flow/properties/processes (GWFLOW) control the streamflow ➔ improving the GW algorithm will be beneficial
2) Model outputs in GLOBAL soil databases showed MUCH higher sensitivities to parameter changes (sen_mean)
3) Parameters in global soil databases showed MUCH higher non-linearity and/or interactions with each other (sen_std)

**Large differences in sensitivity indices ➔ higher uncertainty in model predictions ➔➔ <u>importance of choosing the right soil database</u>**

**Ultimate goal of a model:**

**Make a <u>prediction</u>!**

**Parameter contribution to prediction uncertainty???**