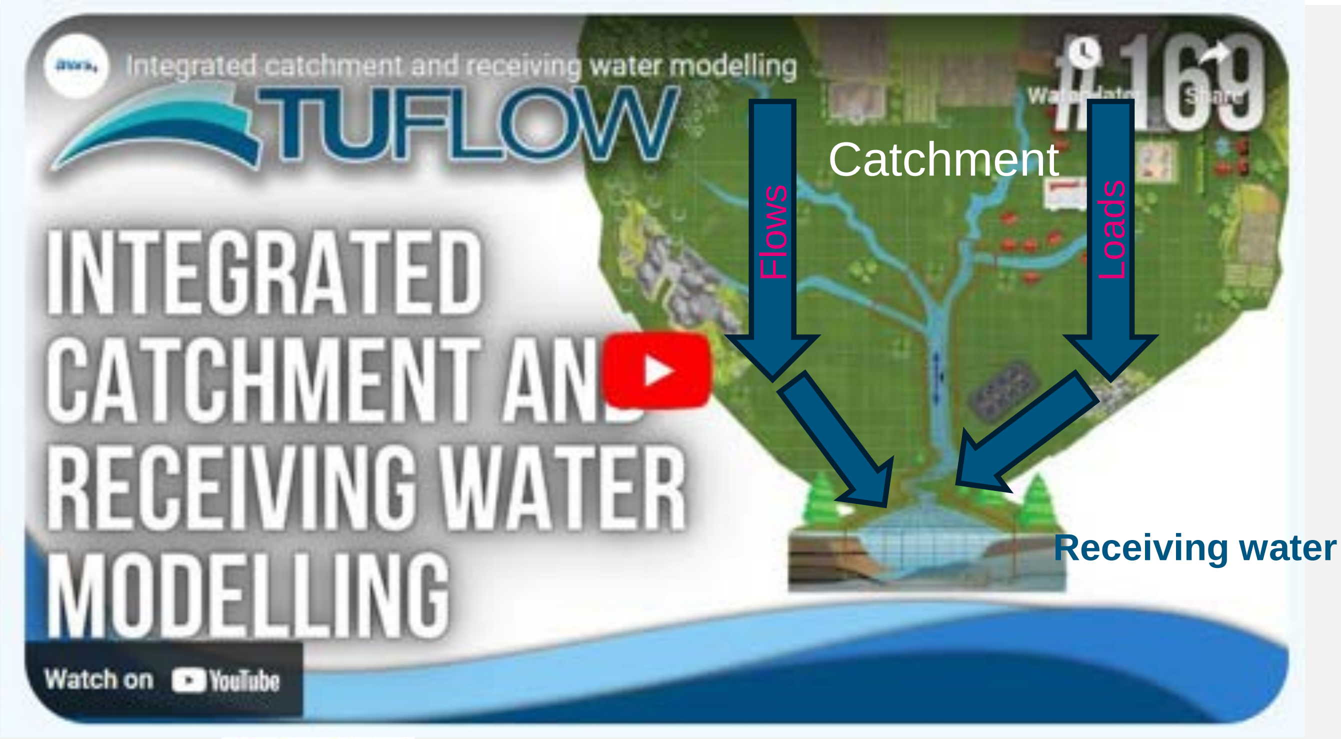
TUFLOW Subsurface Flow Modelling and its Applications

TUFLOW:
Greg Collecutt, Phillip Ryan, Shuang Gao

Water Technology:
Tony McAlister

Queensland University of Technology:
Lucy Reading

Background
Catchment Runoff and Subsurface Flow



https://www.tuflow.com/library/webinars/#oct2023_integrated_water_modelling

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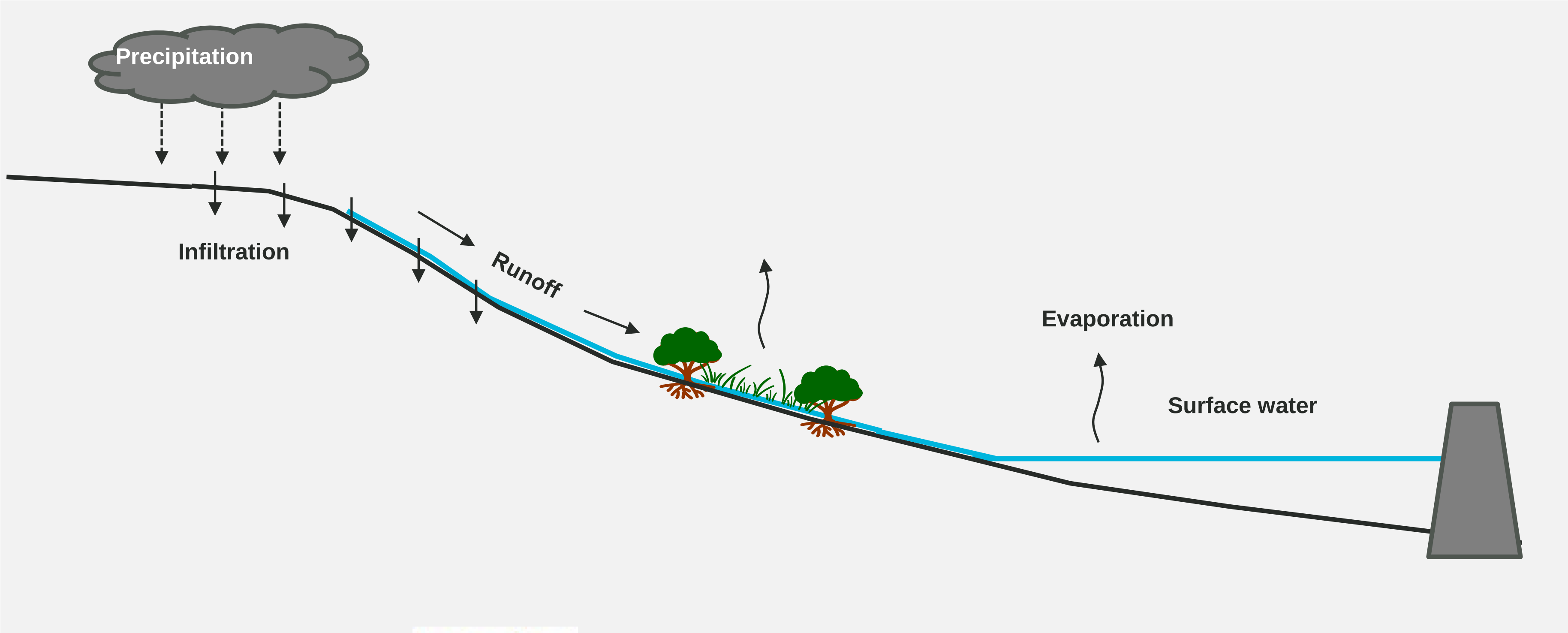
Catchment Runoff and Subsurface Flow



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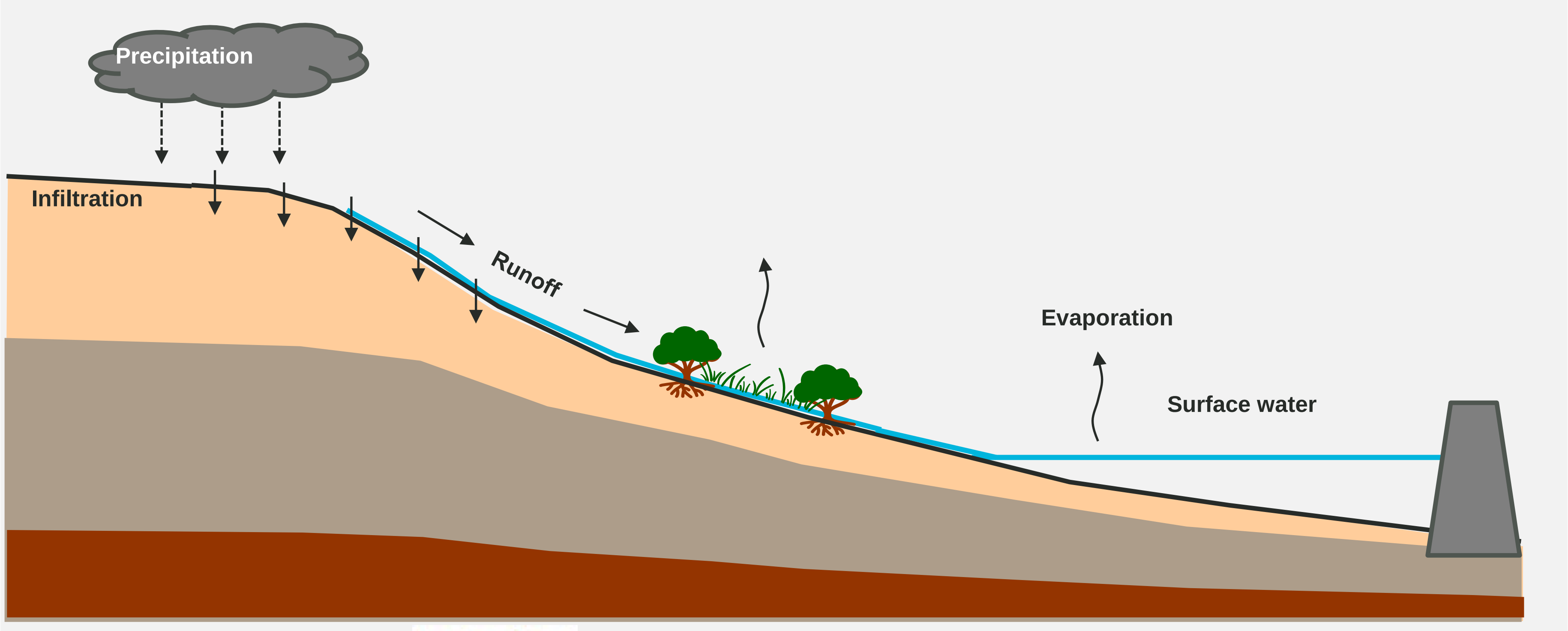

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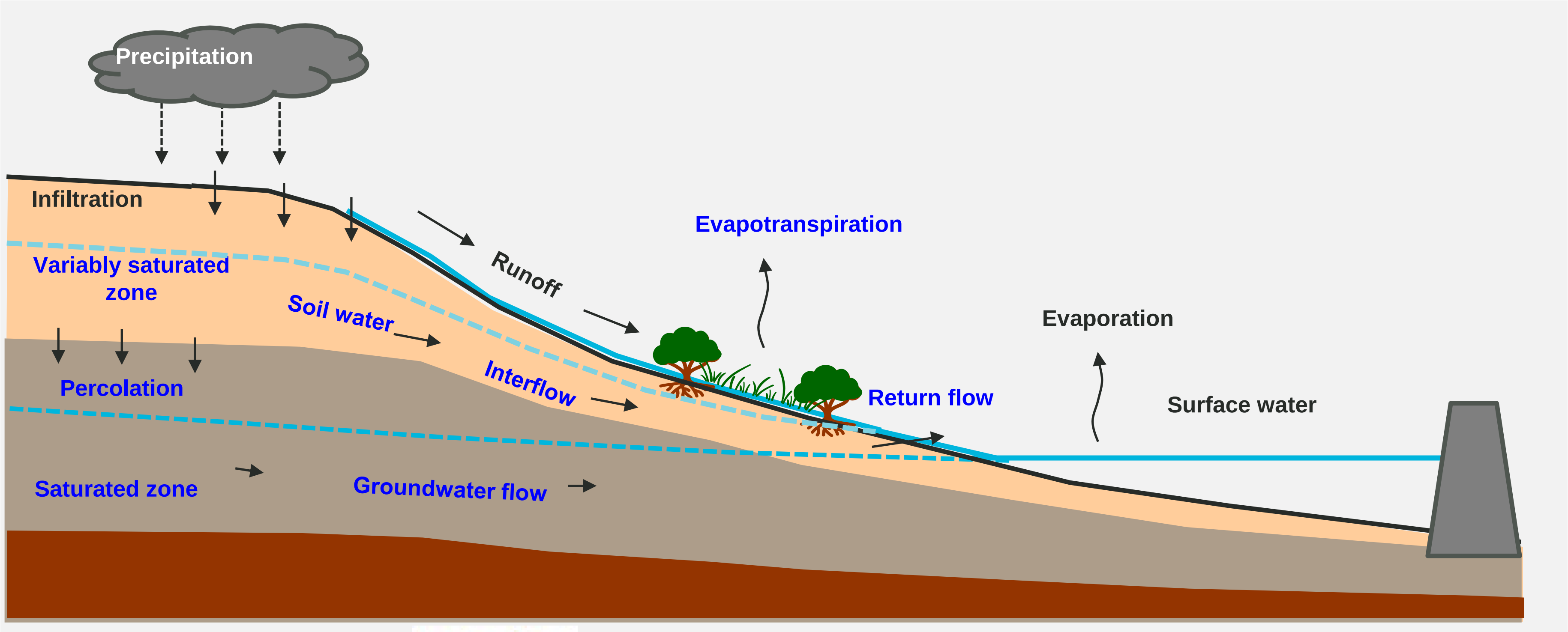

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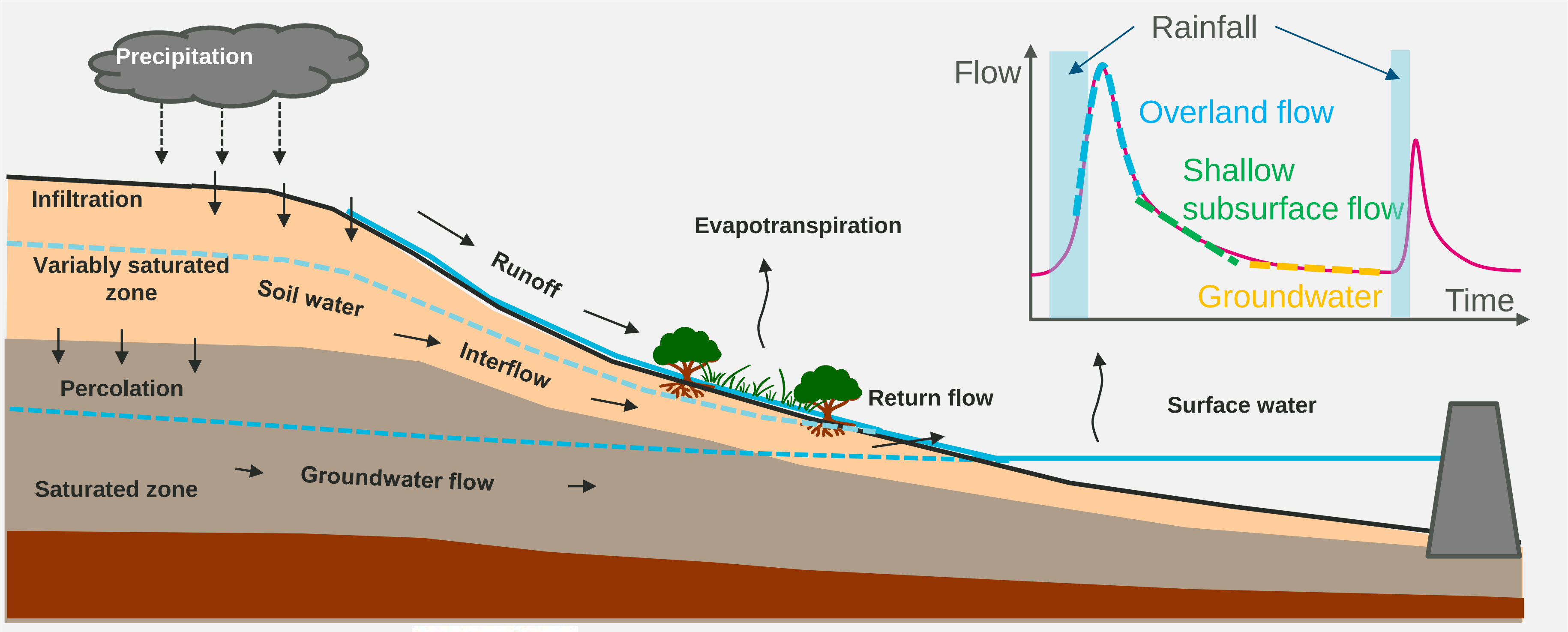

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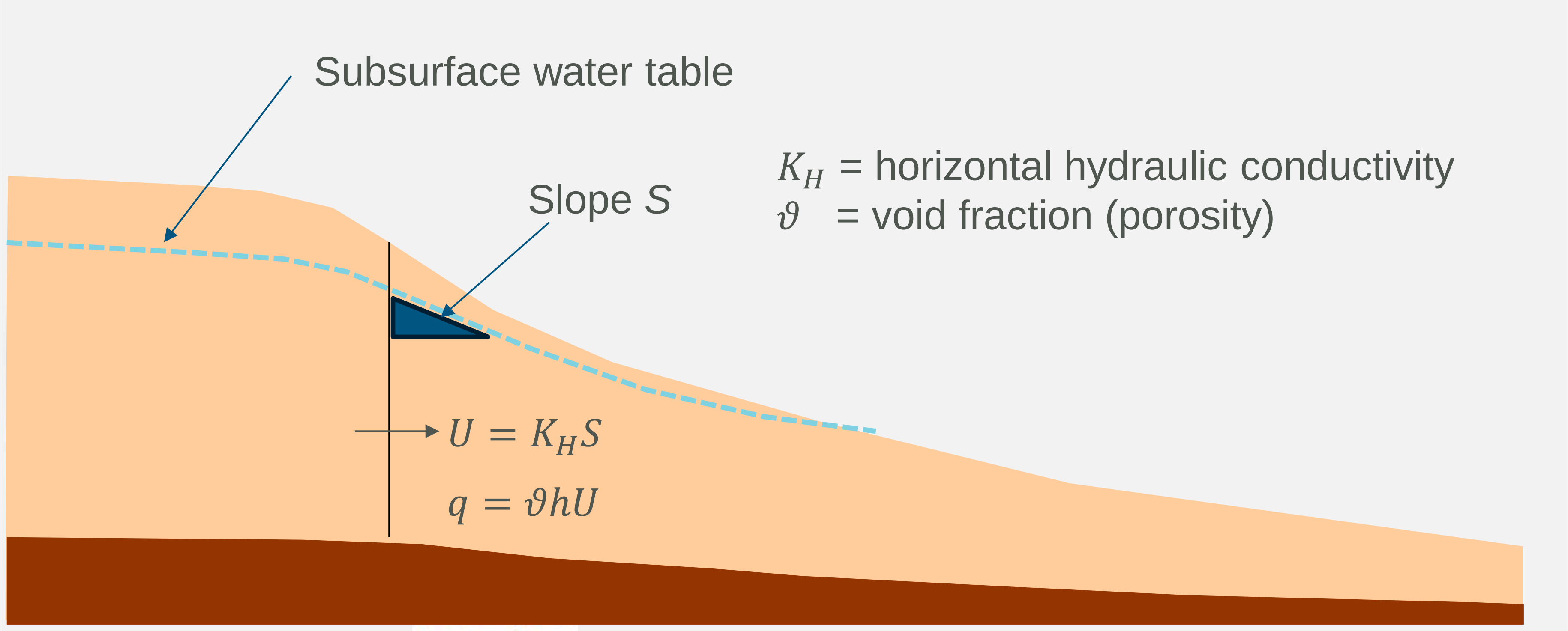
Catchment Runoff and Subsurface Flow



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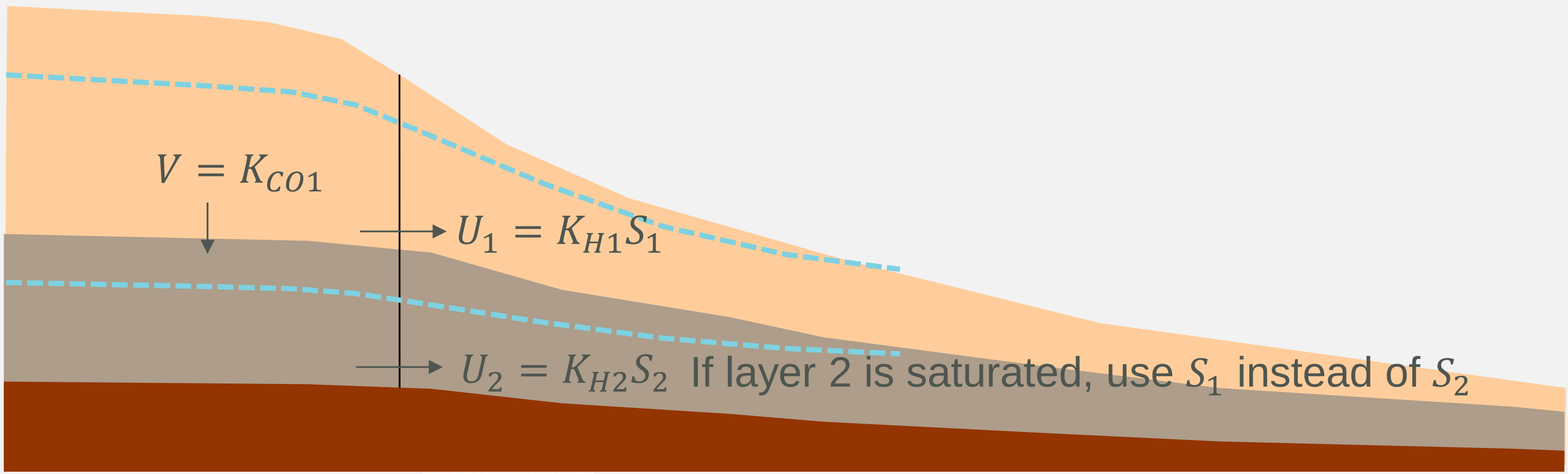

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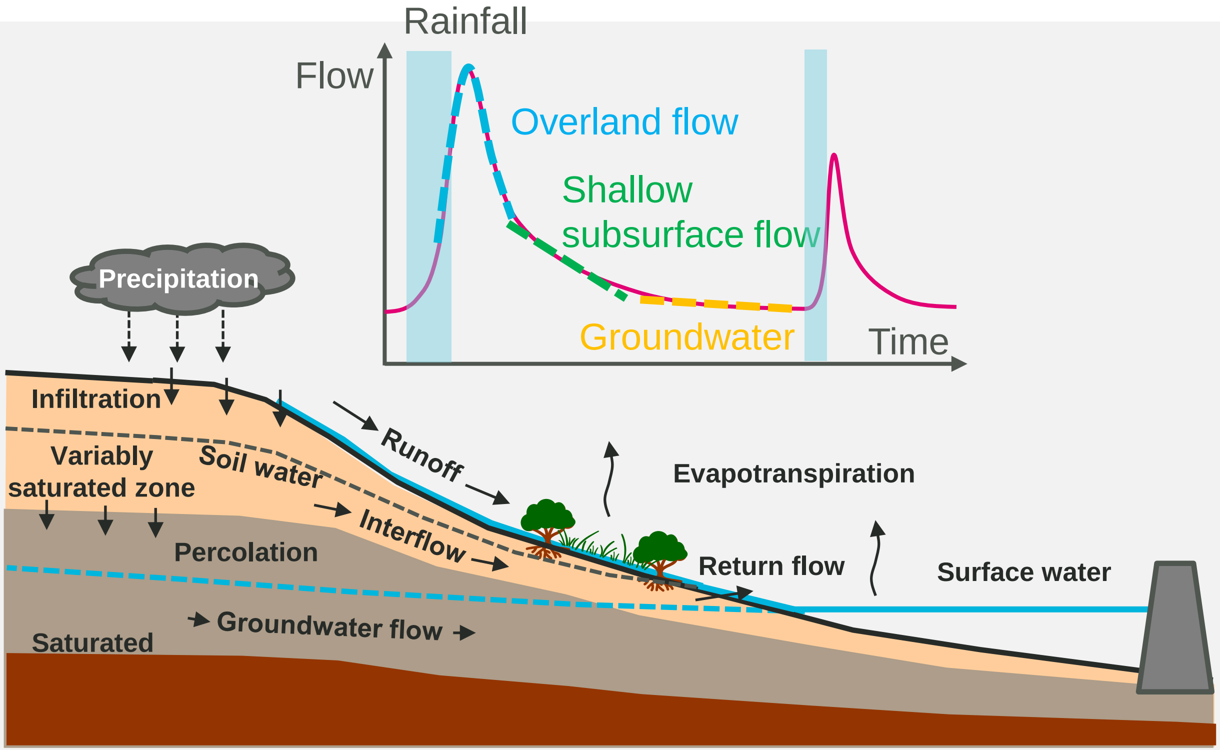
Saturated vs Unsaturated Soil Water Movement

Flood peak:

- Excess runoff
- Infiltration

Receding Limb / Baseflow:

- Subsurface flow
- Recharge of surface water
- Soil moisture store during dry period



Springbrook Groundwater Investigation

Dr Lucy Reading and Grant Periott

QUT team: Jim Stanley, Juliana Albano Reis, Laura Bellis, Wade Somerville, Callan Howell, Jakob Lowry, Chloe Rynne, Kylie van Duyn, Rif'at Bachmid

Queensland University of Technology

CITY OF GOLDCOAST.

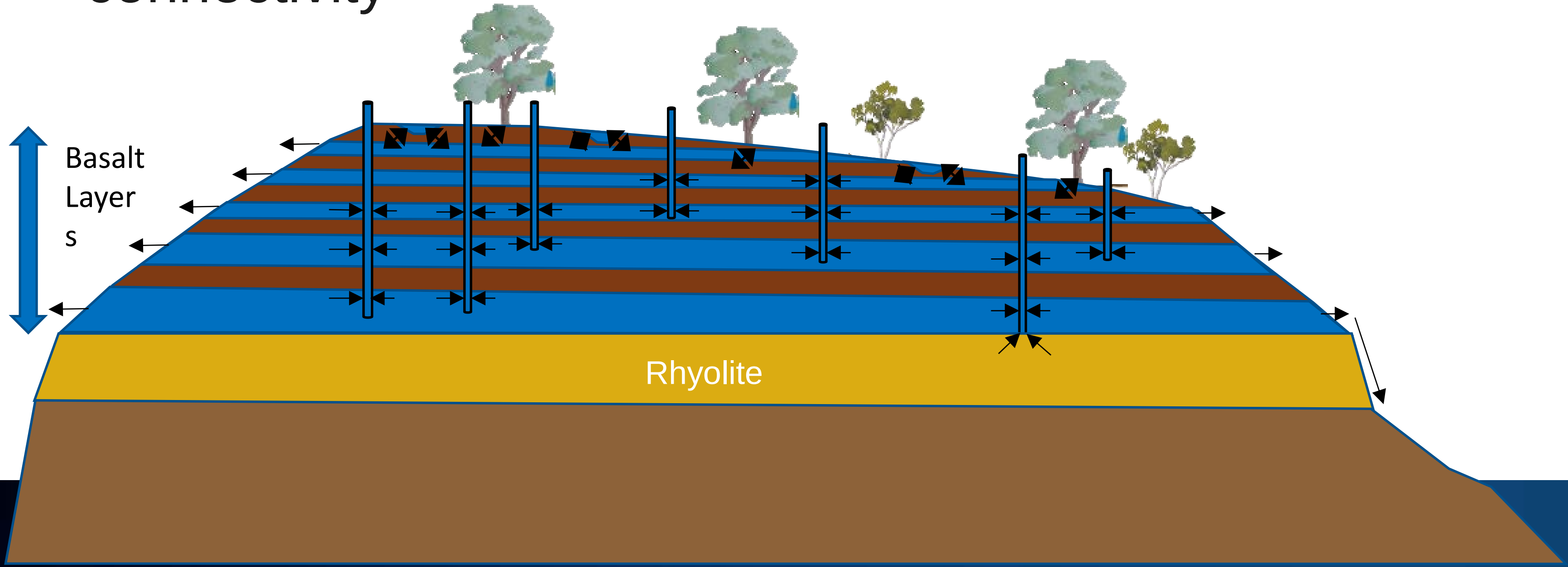
seqwater WATER FOR LIFE

Queensland Government

QUT visualisation platform

Springbrook monitoring – research questions

1) Interactions between different aquifers
2) Groundwater dependence of deep-rooted vegetation
3) Temporal and spatial extent of groundwater-surface water connectivity



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Catchment Runoff and Subsurface Flow

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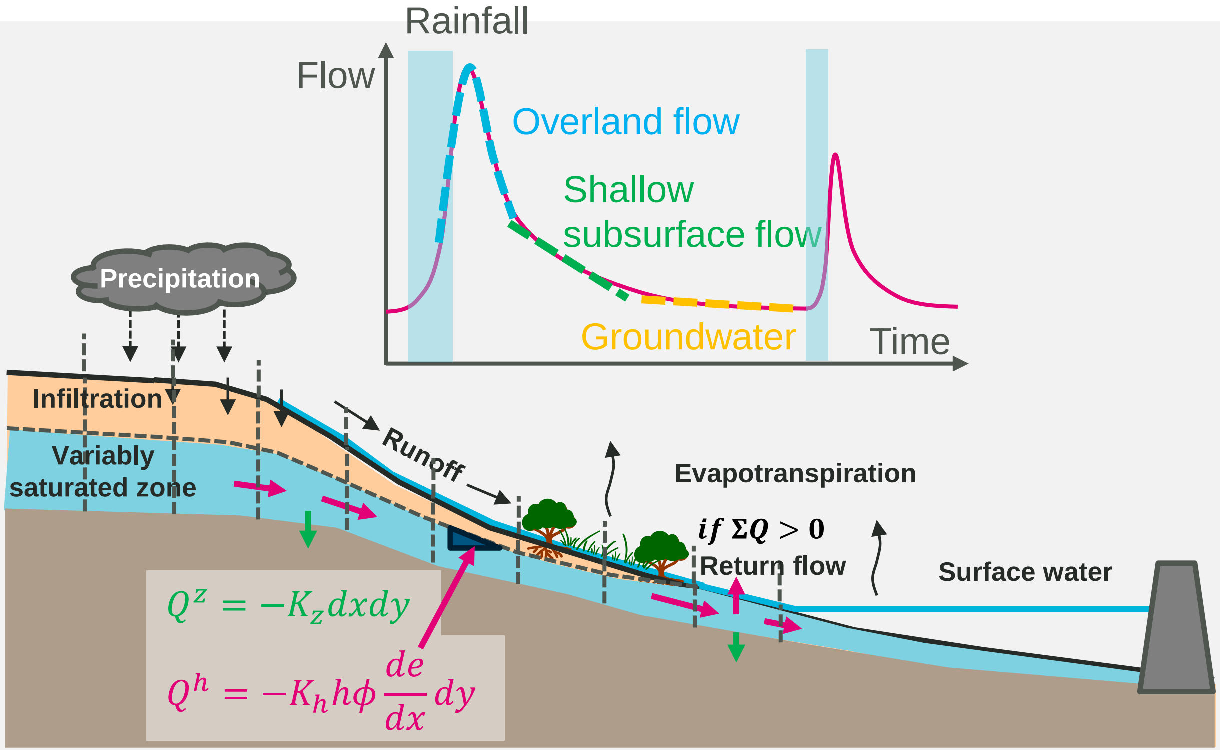
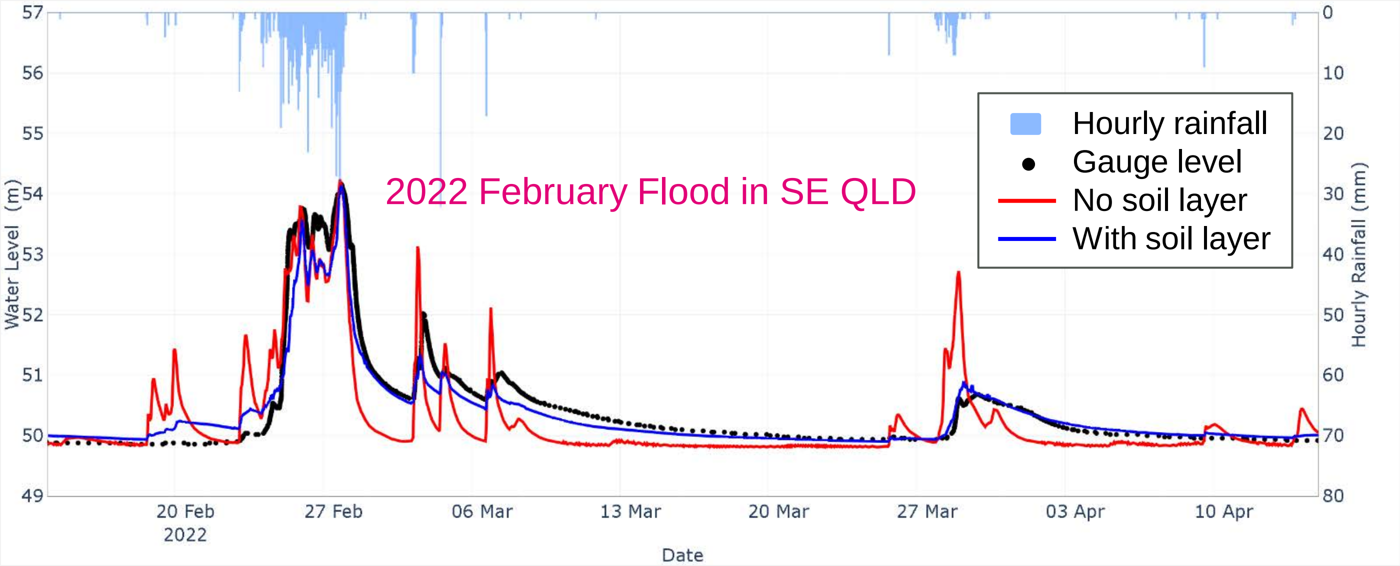


Gao et al (2023)

Background
Catchment Runoff and Subsurface Flow

Oxley Creek Catchment modelling (Gao et al, HWRS 2023): New Beith water level gauge



Hydraulic conductivity calibrated during a wet year didn't apply to dry years !!

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Modelling Approach Update
"Unsaturated" Subsurface Flow

Unsaturated soil water movement:

- Reduction of Hydraulic conductivity → This study
- Suction head → Future study (Richard's equation)

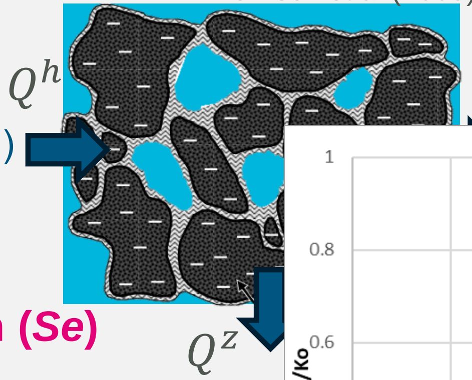
$$Q^z = -\boldsymbol{K_z(Se)}dxdy$$

$$Q^h = -\boldsymbol{K_h(Se)}h\phi\frac{de}{dx}dy$$

K as function of relative saturation (Se)

$$S_e = (\theta - \theta_r)/(\theta_s - \theta_r)$$

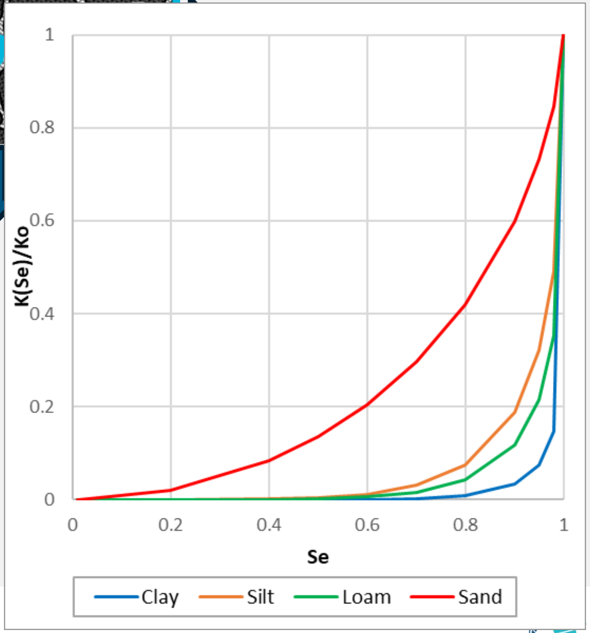
Lehrsch et al (2009)



Unsaturated hydraulic conductivity (van Genuchten, 1980):

$$K(S_e) = K_o S_e^L \left\{1 - \left[1 - S_e^{n/(n-1)}\right]^{1-1/n}\right\}^2$$

Curves from ROSETTA Model:
https://cales.arizona.edu/research/rosetta/rosetta.html



Springbrook Catchment Overview

Springbrook Catchment, Australia

- 36 km^2 Catchment in Southeast Queensland
- All runoff captured by Little Nerang Dam / release from spillway
- Lower half: **dense forest**, steep slope
- Upper half: Springbrook Plateau, **dense forest** / cleared grassland (QUT study area)

Modelling approach:

- TUFLOW HPC Direct Rainfall model + Subsurface flow
- Green-Ampt infiltration
- 2023 dry year → 2024 January flood: (09/11/2023 ~ 14/01/2024)
- Cell size 20m (40m ~ 5m tested)

Seqwater Facebook

Springbrook Catchment
Model Input

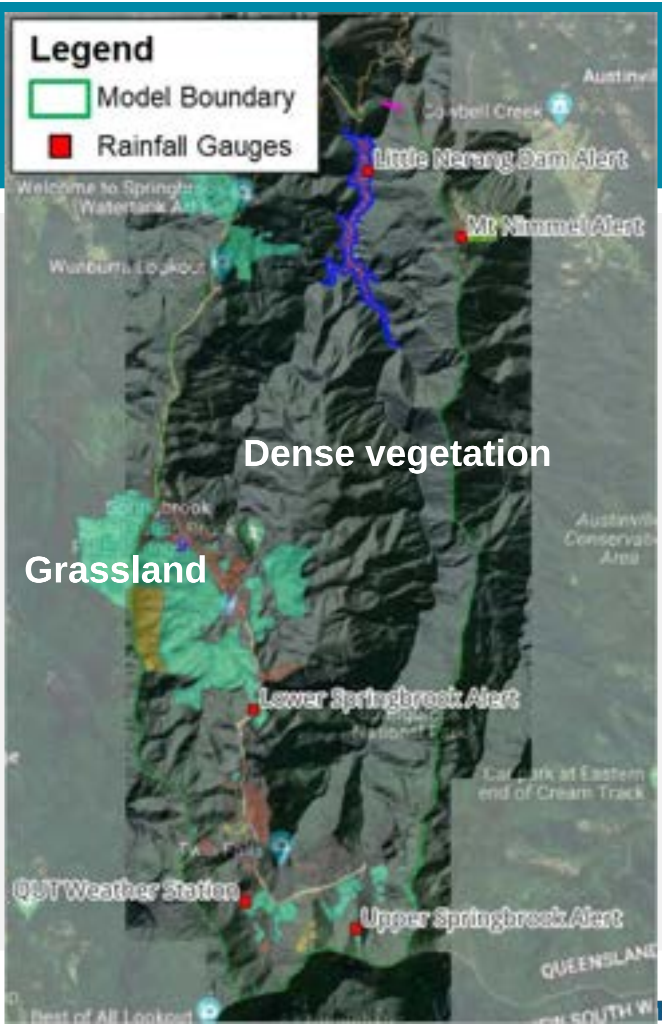
Surface data

- 1 m resolution DEM data was collected from Elvis
  https://elevation.fsdf.org.au/
- 2D cell elevations updated at the dam based on the Storage vs Elevation curve from "Emergency Action Plan of Little Nerang Dam" (SeqWater, 2023)
- "Queensland, Australia Land Use Queensland"
  https://koordinates.com/layer/114191-queensland-australia-land-use/
  → land use / bed friction

  Manning's equation with fixed Manning's *n*

  vs

  "Log Law / Roughness Length" approach
- Multiple rainfall gauges (QUT and the Bureau of Meteorology)



Springbrook Catchment Model Input

Soil Thickness

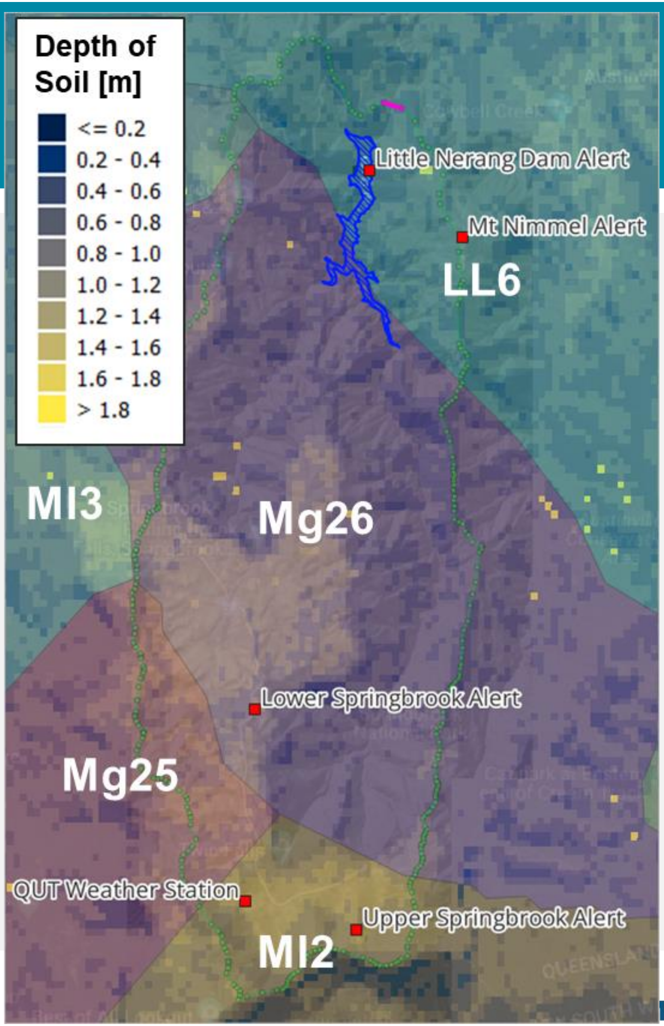
Field survey coming up!!

- 30 m resolution 'Depth of Soil' grid from Soil and Landscape Grid of Australia https://esoil.io/TERNLandscapes/Public/Pages/SLGA/
- "Depth to Regolith" also available (future study)

Soil Type (hydraulic conductivity / porosity)

- CSIRO "Digital Atlas of Australian Soils" https://data.gov.au/dataset/ds-dga-2d0809ec-34c8-4e66-8cef-e3de2416c144/details
  - Soil type: "Porous earths" (K_s = 30~300 mm/hr) with **high clay content**
  - Clay (K_s = 0.3 mm/hr), Clay Loam (K_s = 1.0 mm/hr) (Rawls et al, 1983).
  - Soil anisotropy: horizontal conductivity typically **two or more orders higher** than the vertical conductivity (Barwell and Lee 1981).

Parameter	Symbol	Tested Range
Horizontal hydraulic conductivity	K_h	1 ~ 1,000 mm/hr
Green-Ampt hydraulic conductivity	K_{GA}	0.3 ~ 100 mm/hr
Vertical hydraulic conductivity (for multiple layers model)	K_v	0.3 ~ 100 mm/hr



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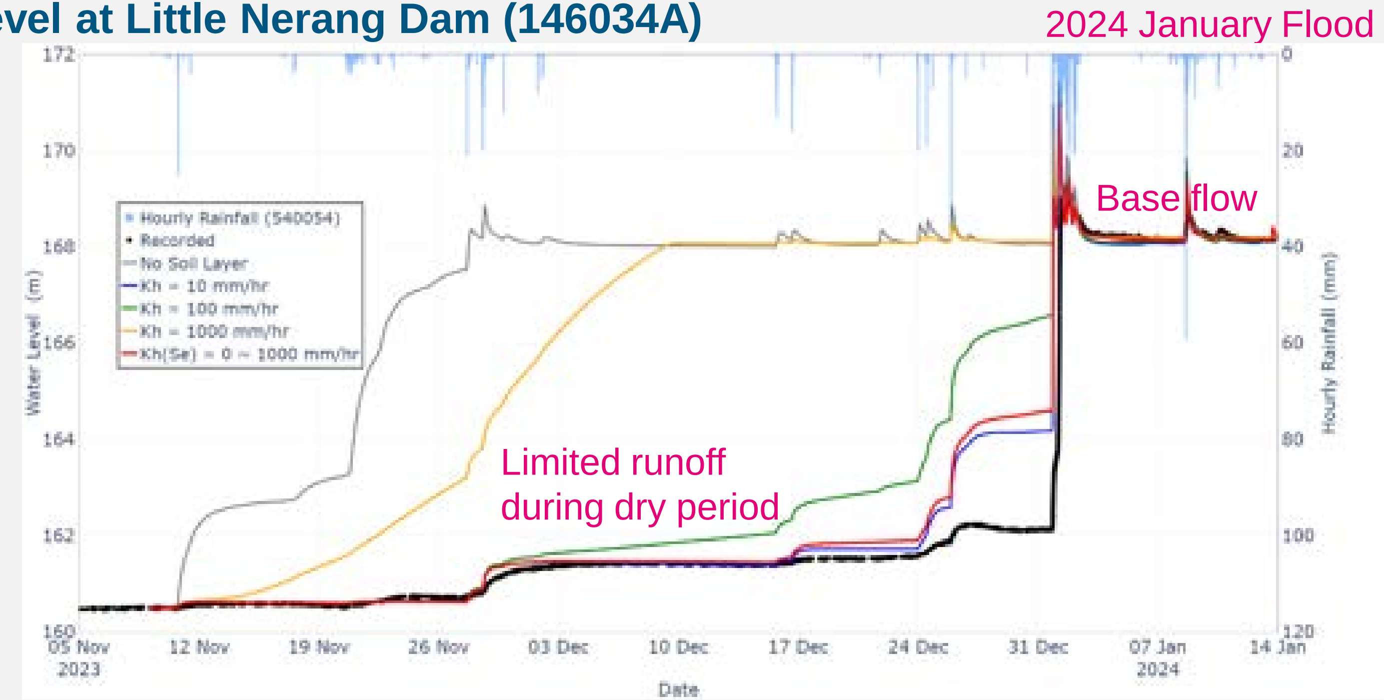
Modelling Results
Horizontal Hydraulic Conductivity

Water level at Little Nerang Dam (146034A)



Modelling Results
Horizontal Hydraulic Conductivity

Catchment wide Soil Moisture vs AWRA-L model

AWRA-L (Frost and Shokri, 2021): "Australian Water Outlook"
https://awo.bom.gov.au/products/historical/soilMoisture-rootZone

- Based on the historical near real-time climate data
- Daily timestep
- ~ 5 km grid (national wide)

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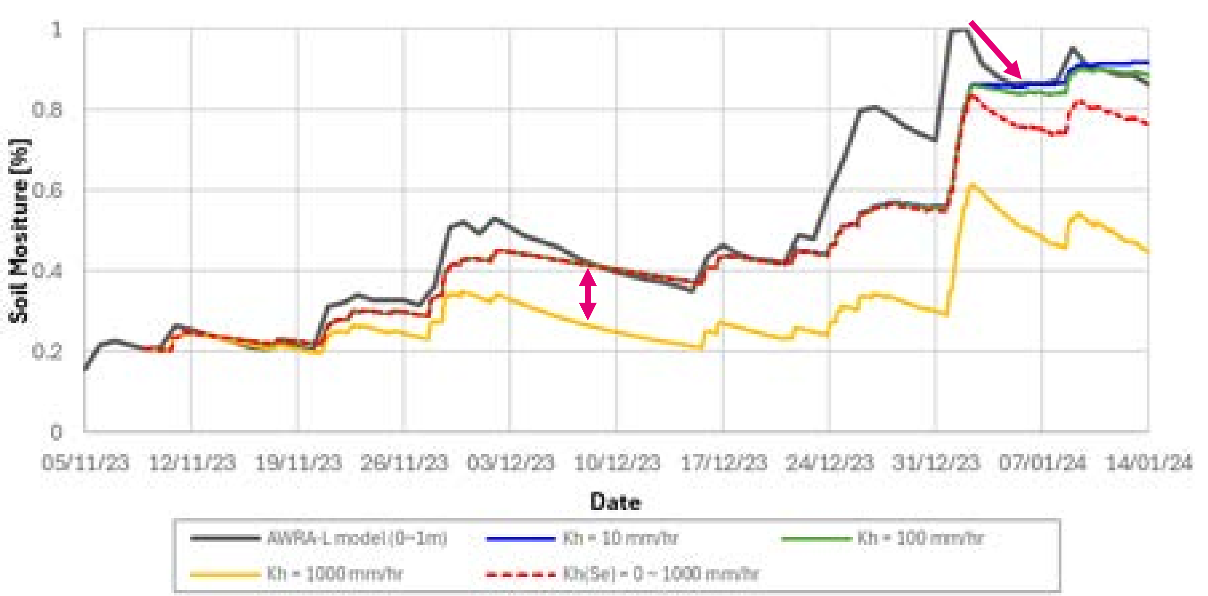
- 20m grid
- Total soil moisture / Total soil storage in the corresponding meshes



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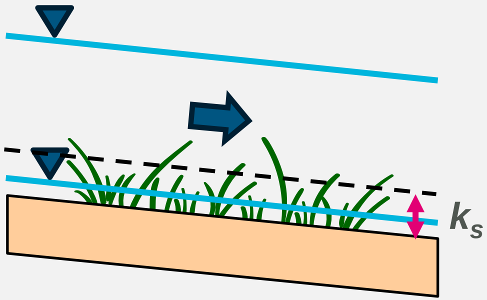
Modelling Results
Log Law vs Fixed Manning's n

Why Log Law?

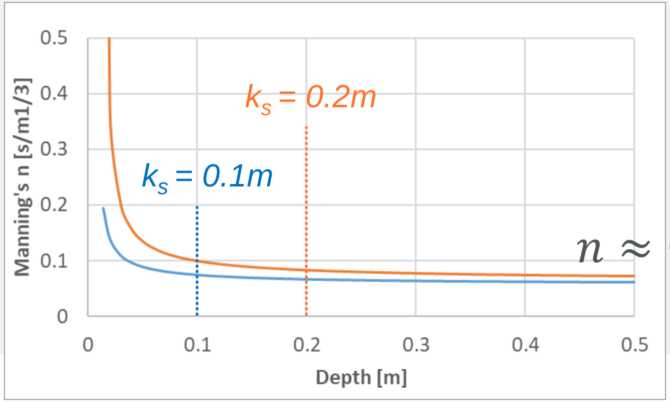
- Manning's equation: roughness as bed friction
  depth (***h***) > roughness length ($\boldsymbol{k_s}$)



- Sheet flow
  depth (***h***) <= roughness length ($\boldsymbol{k_s}$)

$$n \approx \frac{\kappa h^{1/6}}{\sqrt{g}}\left[ln\left(\frac{k_s}{15h}\right)\right]^{-1}$$

- k_s = 0.1m ~ 0.2m
  Grass ~ Dense vegetation



$n \approx 0.06$

Modelling Results
Log Law vs Fixed Manning's n

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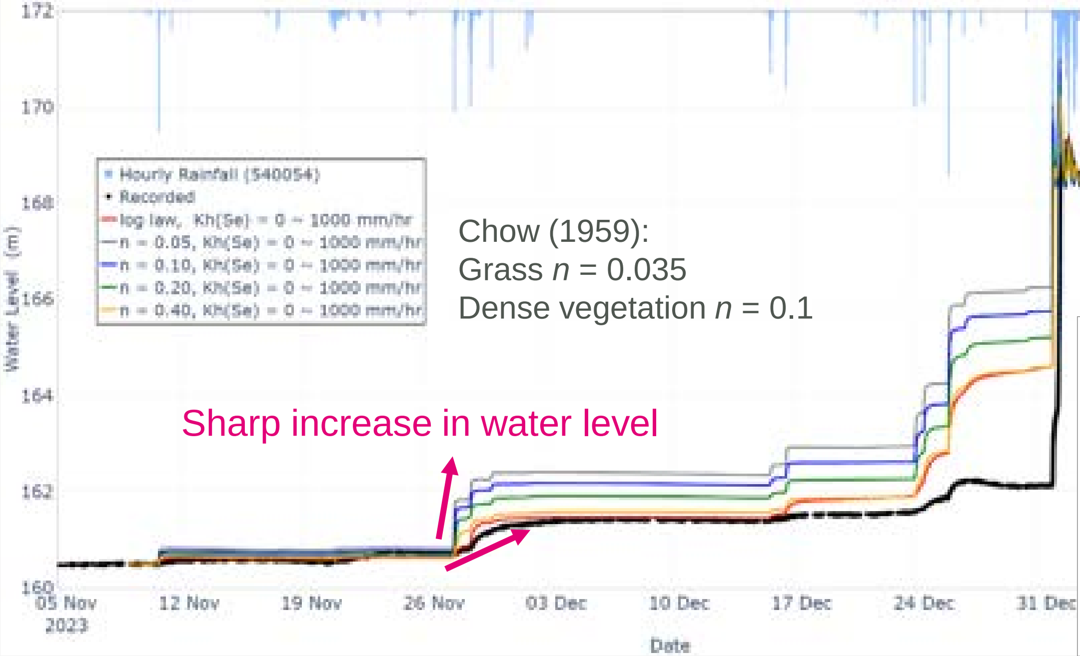

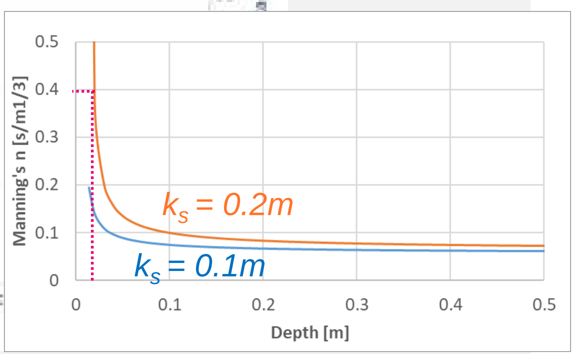

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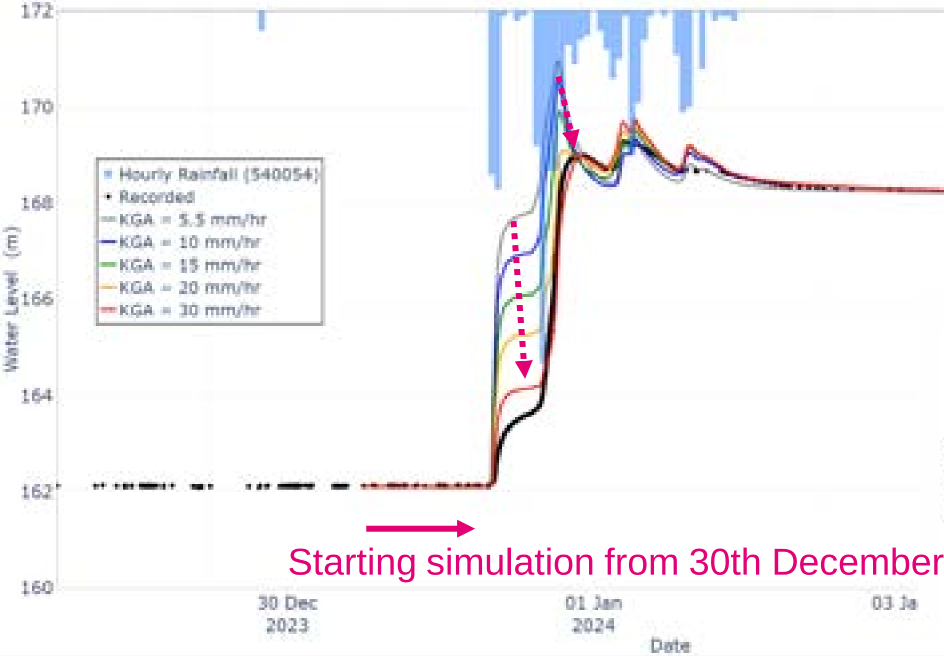
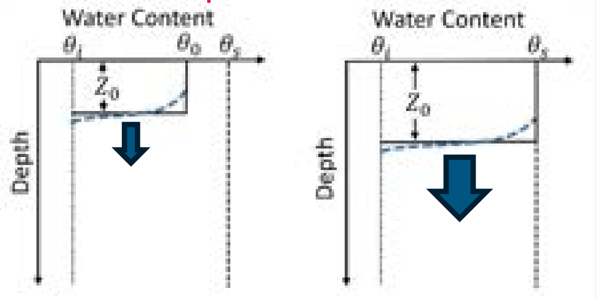
Modelling Results
Green-Ampt Infiltration Rate at Flood Peak

Water level at Little Nerang Dam (146034A)



Starting simulation from 30th December

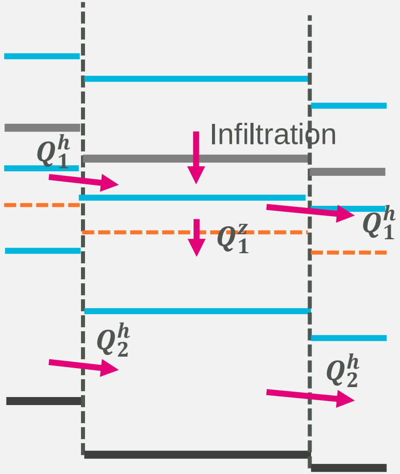
Saturated vs unsaturated
Green-Ampt Infiltration Rate??

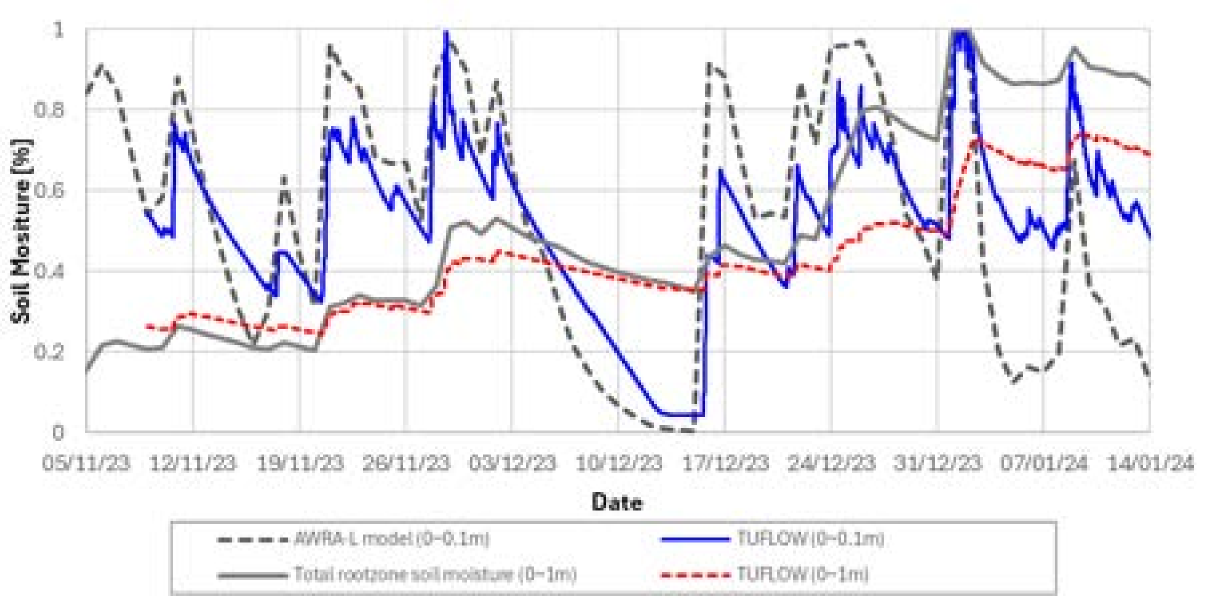


(Smith et al, 1993)

Modelling Results
2-Layer Model

Top 10cm + Rest of ‘Depth of Soil’

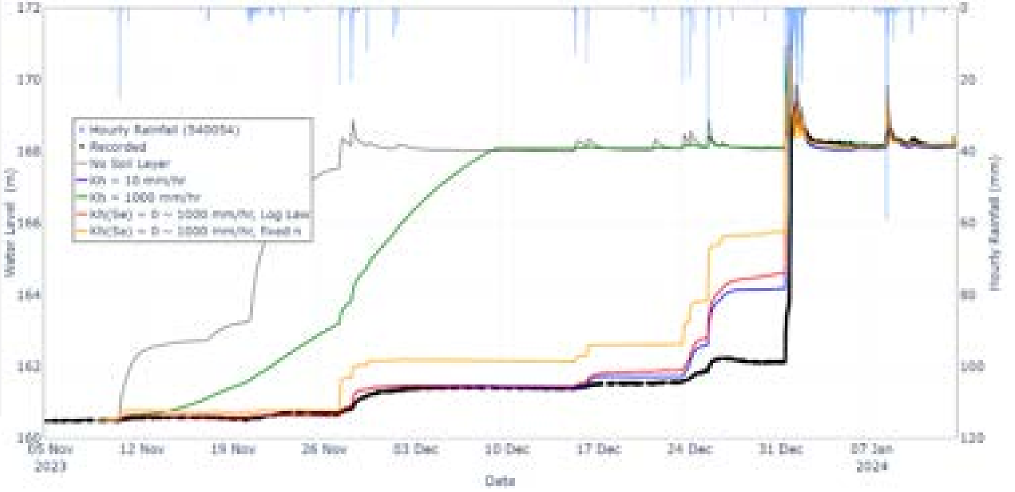




Conclusions

The good:

- Soil moisture dependent hydraulic conductivity significantly improves the runoff prediction for both wet and dry periods
- Reasonable agreement for soil moisture with AWRA-L model
- “Log Law / Roughness Length” bed friction approach produces superior hydrology response by applying higher bed friction at small depth



Challenges:

- Unsaturated surface infiltration rate
- Deep groundwater flow
- Richard’s equation

Hydrology and Water Resources Symposium 2024

In conjunction with Hydraulics in Water Engineering 2024

Arinex

ENGINEERS AUSTRALIA

Title:
Enhancing Catchment Runoff Simulations using Soil Moisture Dependent Hydraulic Conductivity

18–21 November 2024
Sofitel Melbourne on Collins
25 Collins Street, Melbourne, VIC 3000

engineersaustralia.org.au/hwrs

Presenter Name: Shuang Gao
Date: 19 November 2024

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Questions