# Nation-wide estimates of rainfall recharge, groundwater flow and baseflow

Rogier Westerhoff – GNS Science, Deltares

Paul White – GNS Science

# Acknowledgements


- Smart Aquifer Characterisation (SAC) Programme, funded by Ministry of Business, Innovation and Employment (MBIE), 2011-2017
- Co-funding from European Union Project ‘eartH2Observe’
- In collaboration with Andrew Tait (NIWA) (VCS data)
- Case study co-funded by Waikato Regional Council

# Why national scale?

- Currently, no consistent national approach
- Required for national inventory / stocktake
- As a means to fill in the gaps between observed data points in national, regional and sub-regional studies

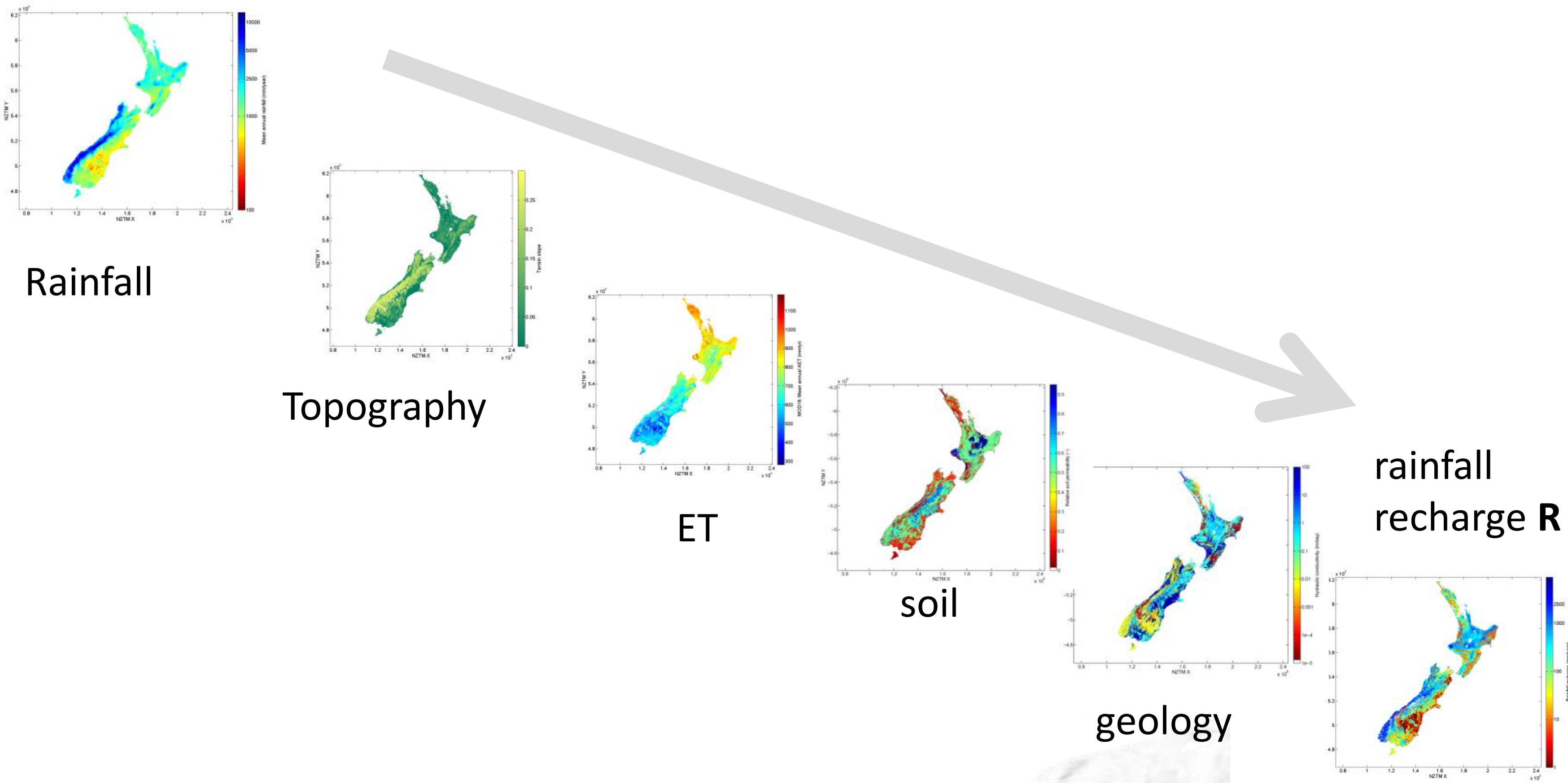

r.westerhoff@gns.cri.nz

# Rainfall recharge

# Rainfall recharge: method

- **National Groundwater Recharge Model (NGRM)**
  - remotely sensed components
  - soil water balance (SWB) approach
  - monthly time step
  - 1km x 1km resolution
  - includes:
  - includes geology
  - and surface runoff estimate
- Other SWB models:
  - SOILMOD (Scott, 2004)
  - SOILMOD/DRAIN (White et al., 2014)
  - SMB-SMC (Hong and White, 2014)
  - USGS-SWB (Westenbroek et al., 2012)
  - WaterGAP, WGHM (Döll and Fiedler, 2008)

# Rainfall recharge: method



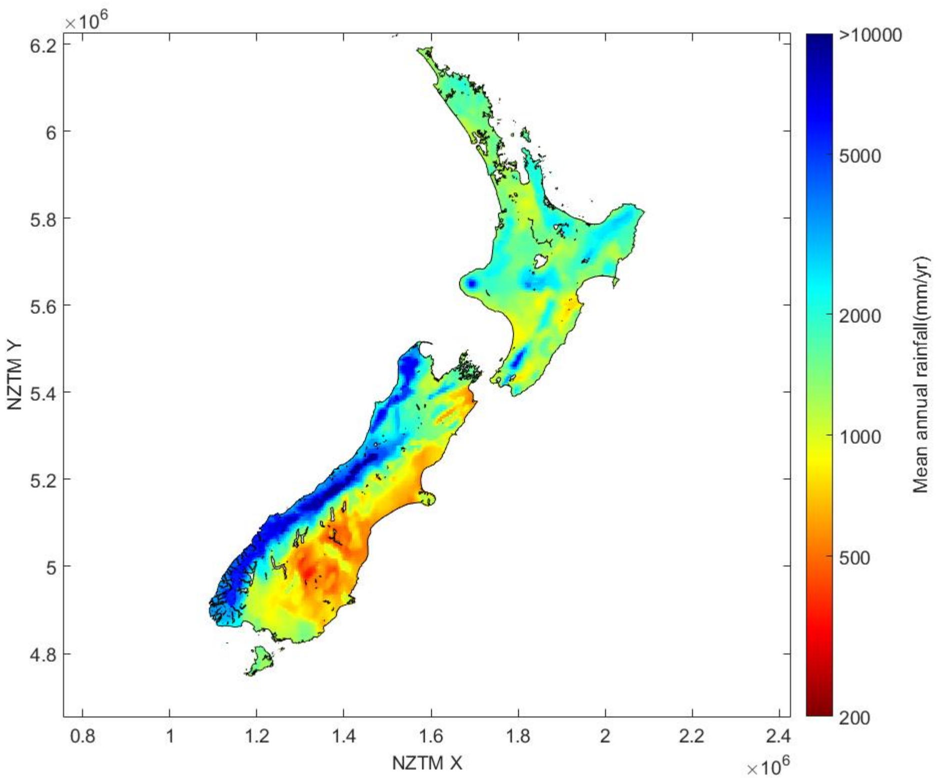

**In month i:** $$RECH_i = \{R_i\, f_{slope} - AET_i - S_{i-1}\}\, f_{soil} f_{geology}$$

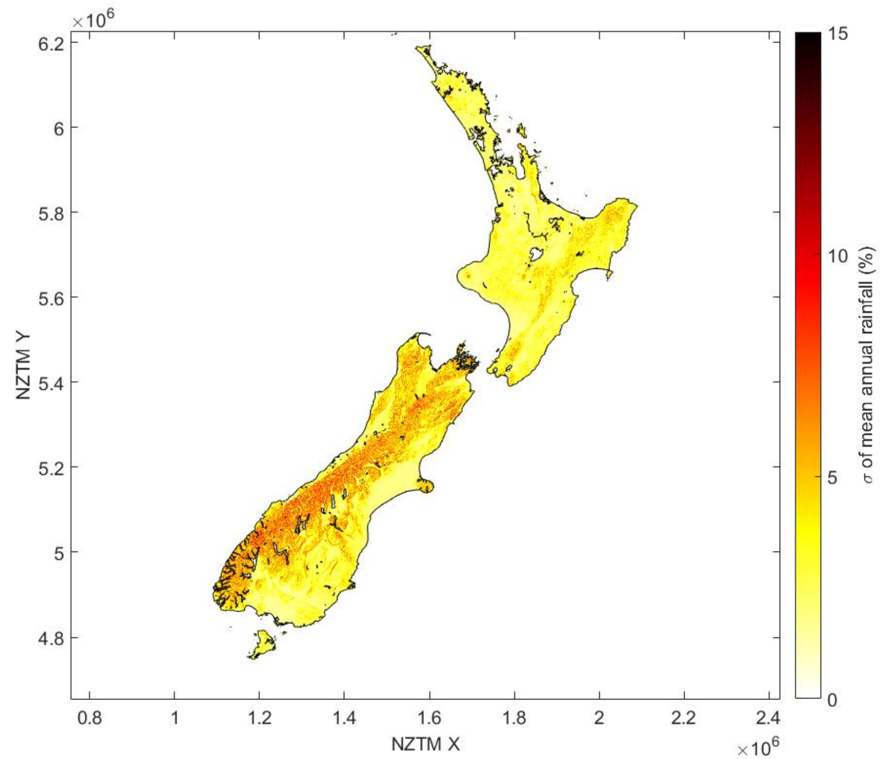
Westerhoff, R., White, P., and Rawlinson, Z.: Application of global models and satellite data for smaller-scale groundwater recharge studies, Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-410, in review, 2016.

# Rainfall recharge: method

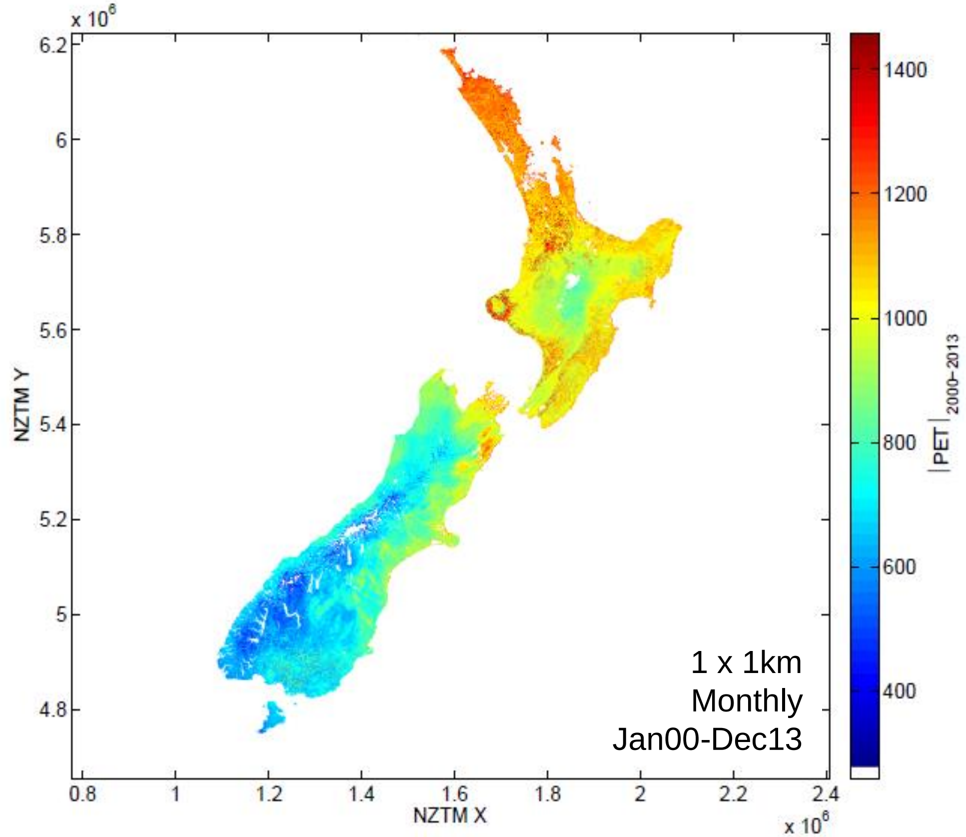
## Precipitation

- Estimates from NIWA Virtual Climate Station (VCS) data (Tait et al., 2006)
- Uncertainty estimated as standard deviation. It increases with terrain slope



## Evapotranspiration




Satellite sensor: MODIS
Products: PET, **AET** (Mu et al, 2011)

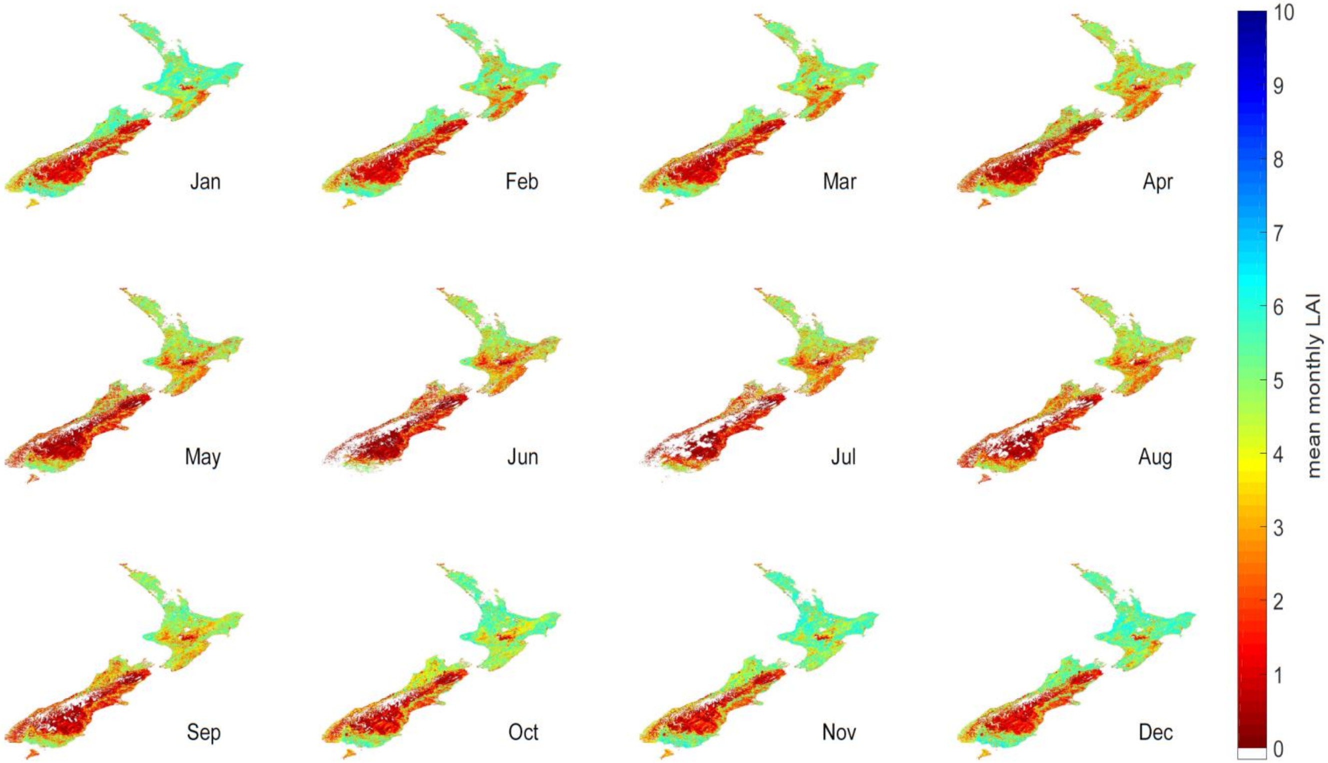
Penman-Monteith
Spatial res.: 1km x 1km
Temporal res.: monthly
Time: Jan 2000 – Dec 2013

**With uncertainty**
(Westerhoff, 2015)

# Rainfall recharge: method

- Interception *Ic* as function from precipitation and MODIS Leaf Area Index (LAI):

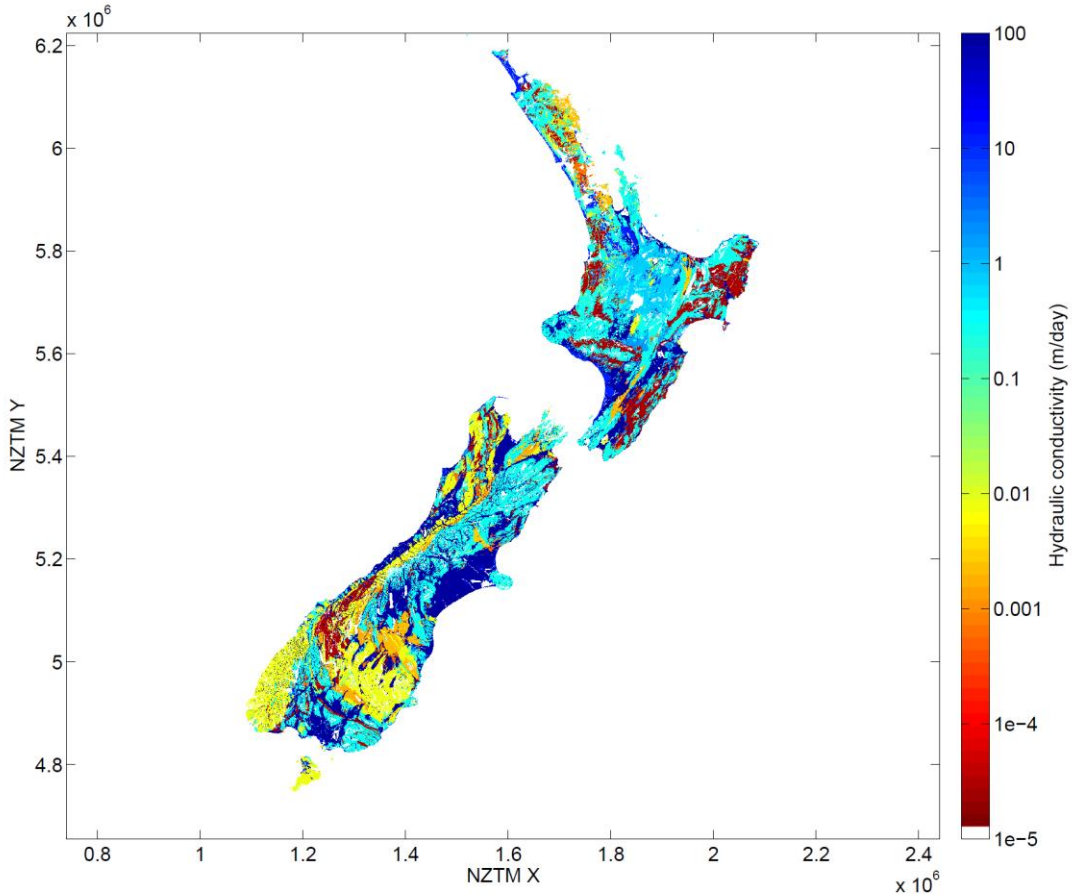
$$Ic = (P * LAI) / 3E+03$$





r.westerhoff@gns.cri.nz

## Geology: hydraulic conductivity K




- QMAP main rock type, secondary rock type and age are converted to K through look up table approach (183 members)
- Input from
  Gleeson et al. (2011)
  Tschritter et al. (2014)
- Rasterised to 1km x 1km
- Uncertainty ~ K

# Rainfall recharge method: uncertainty

$$\sigma_f^2 = g^T V g$$

where $\sigma_f^2$ is the variance of a function *f*, which has $n_i$ = 1 : N input components; $V$ is the variance-covariance matrix of all input components; $g$ is a vector of input component $\partial f / \partial n_i$ and $g^T$ is the transpose of $g$ (e.g., Tellinghuisen, 2001).

So, if $R_i = \{P_i f_{slope} - AET - S_{i-i}\} f_{soil,geol}$

Then: $g = \left( \frac{\partial R}{\partial P}, \frac{\partial R}{\partial f_{slope}}, \frac{\partial R}{\partial AET}, \frac{\partial R}{\partial S}, \frac{\partial R}{\partial f_{soil,geol}} \right)$ ,

$$\frac{\partial R}{\partial P} = f_{slope} f_{soil,geol};$$

$$\frac{\partial R}{\partial f_{slope}} = P f_{soil,geol}$$

$$\frac{\partial R}{\partial AET} = -f_{soil,geol}$$

$$\frac{\partial R}{\partial S} = -f_{soil,geol}$$

$$\frac{\partial R}{\partial f_{soil,geol}} = P f_{slope} - AET - S$$

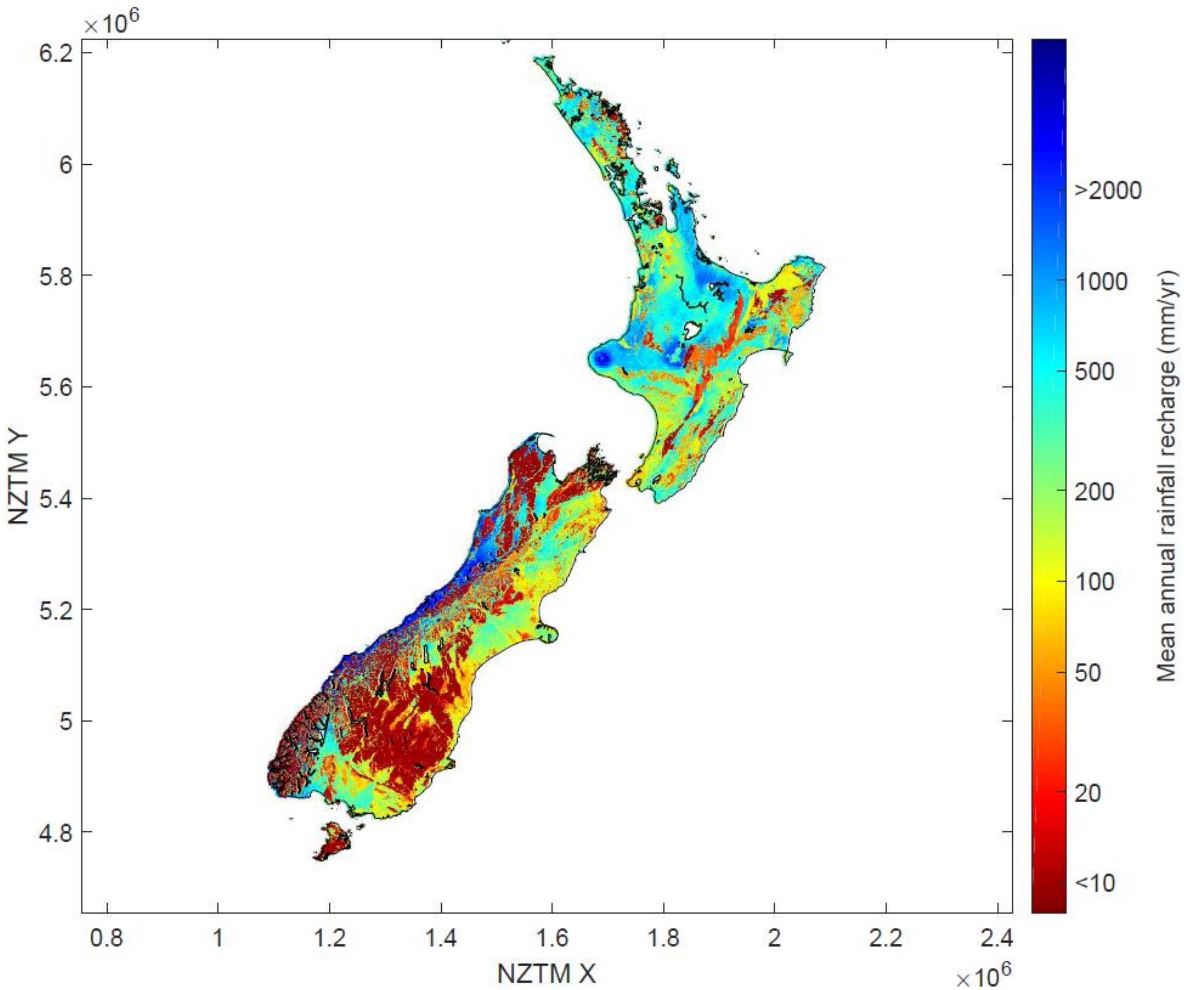
# Rainfall recharge method: uncertainty

$$V = \begin{bmatrix} \sigma_P^2 & .. & .. & .. & .. \\ .. & \sigma_{fslope}^2 & .. & .. & .. \\ .. & .. & \sigma_{AET}^2 & .. & .. \\ .. & .. & .. & \sigma_S^2 & .. \\ .. & .. & .. & .. & \sigma_{fsoil,geol}^2 \end{bmatrix}$$

- .. = covariance, which was calculated through a covariance analyses of 2 years of monthly compiled model input data.


r.westerhoff@gns.cri.nz

# Rainfall recharge: results




**Monthly rainfall recharge**

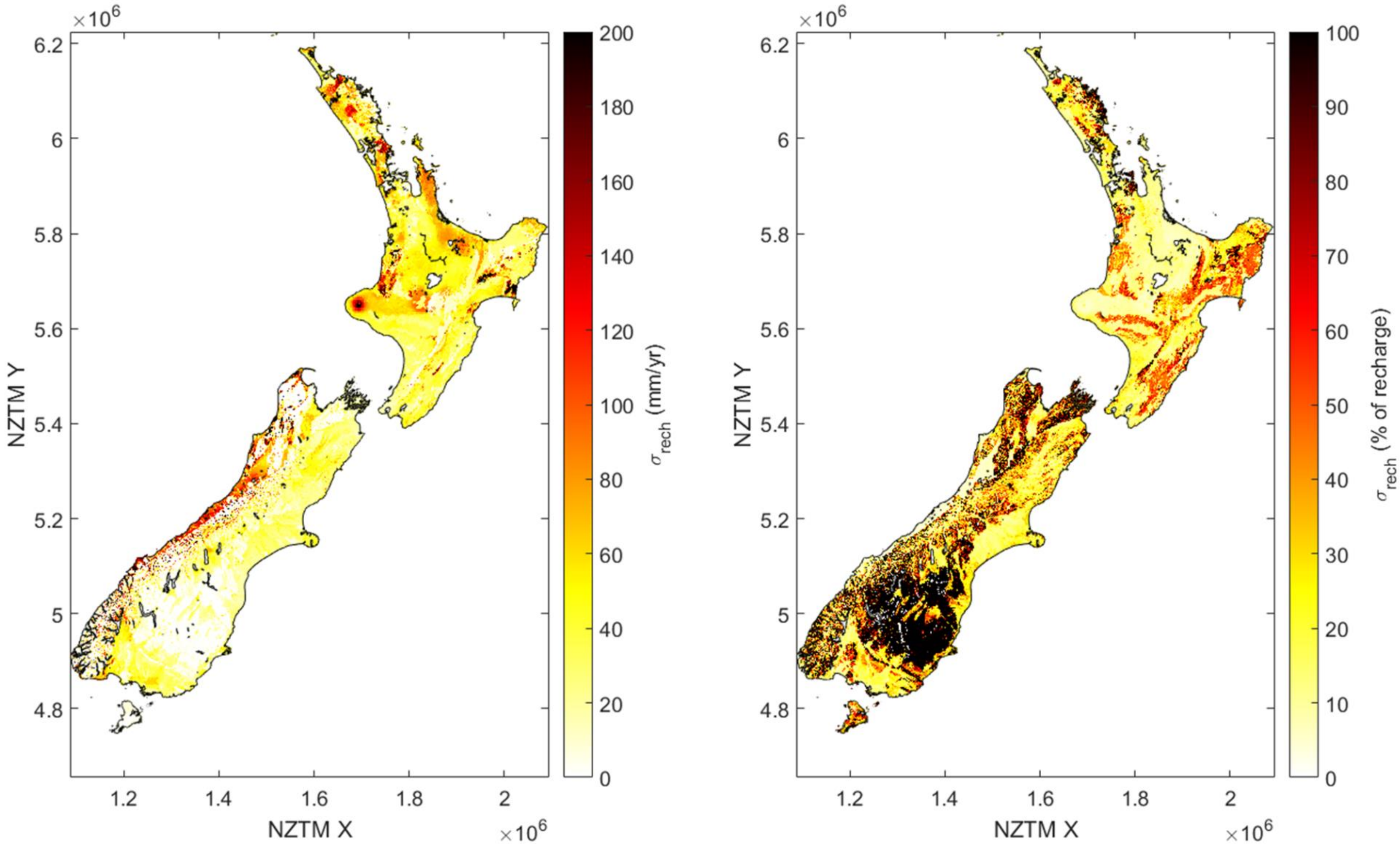
**1km x 1km**

**Jan 2000 – Dec 2013**

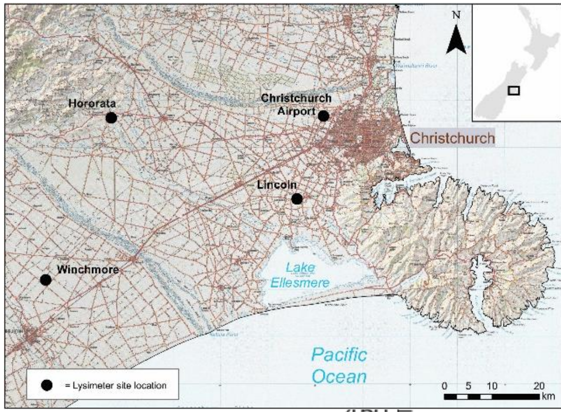
recharge high in some mountain and flank regions, mostly due to high rainfall and low ET. But that is not uncommon (e.g., Calmels *et al*, 2011)

**Uncertainty**

- Translated to standard deviation

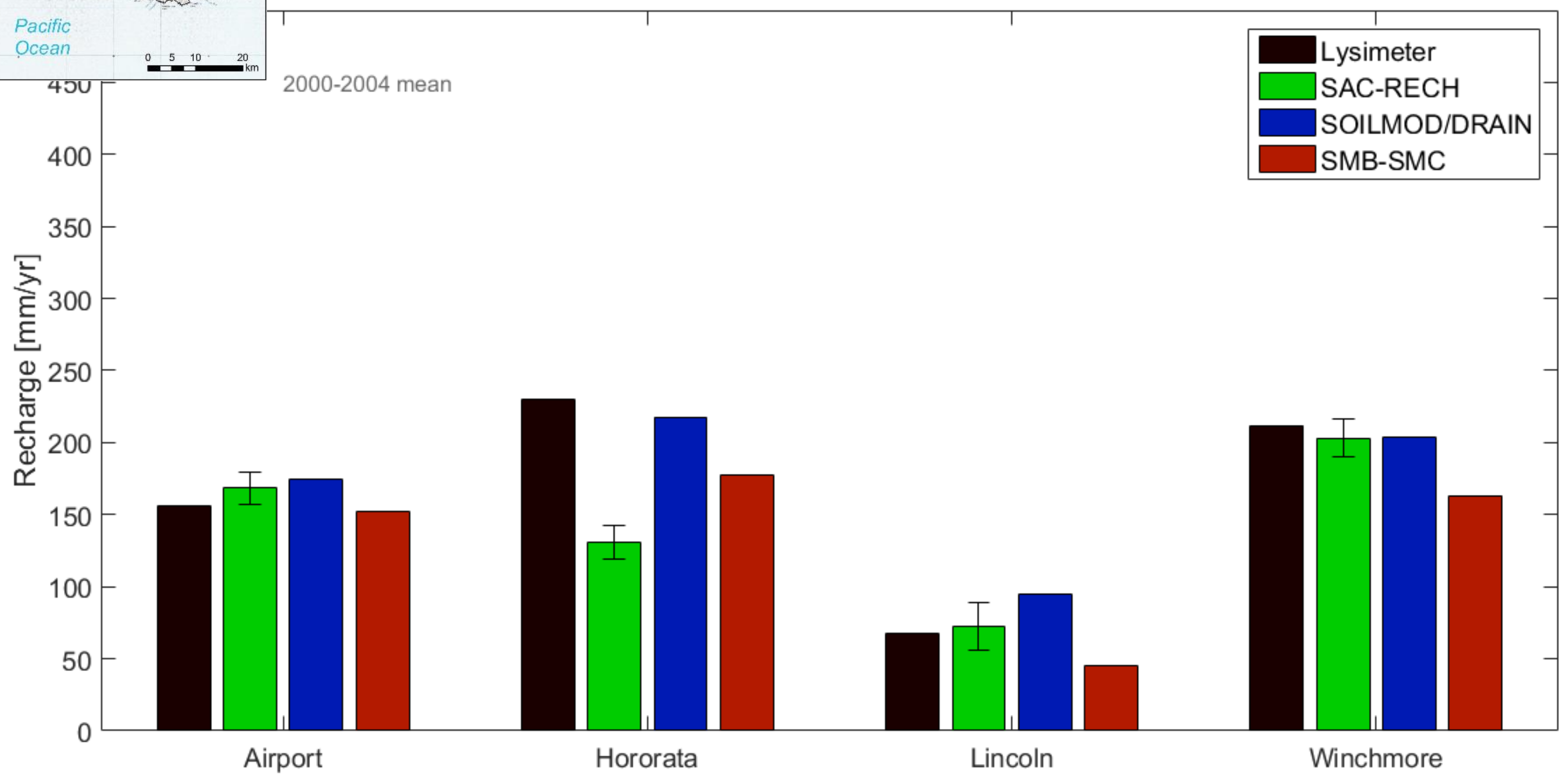


# Rainfall recharge: results




## Validation at lysimeters

- SAC-RECH matches lysimeters and two other local models well at 3 of 4 lysimeters in Canterbury



# Groundwater flow and water table

- The **Equilibrium Water Table (EWT)** approach was used to estimate a long-term average water table

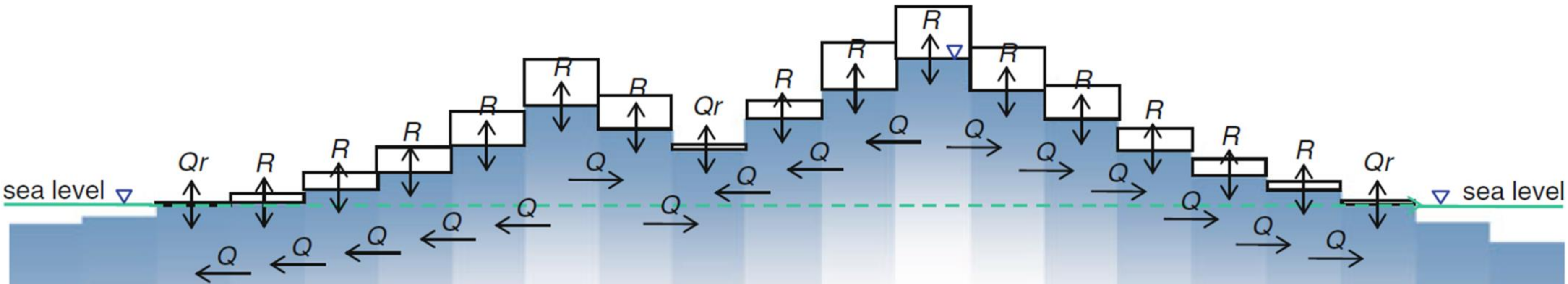
- EWT is a simple model: it calculates long-term balance between recharge R and groundwater flow Q. It is a ‘natural long-term water table’


r.westerhoff@gns.cri.nz

# Groundwater flow

**Transient model. Runs are typically ~100 year at daily time step.**

**K decays over depth, as aq function of terrain slope**




$$Q = wT\left(\frac{h - h_n}{l}\right)$$

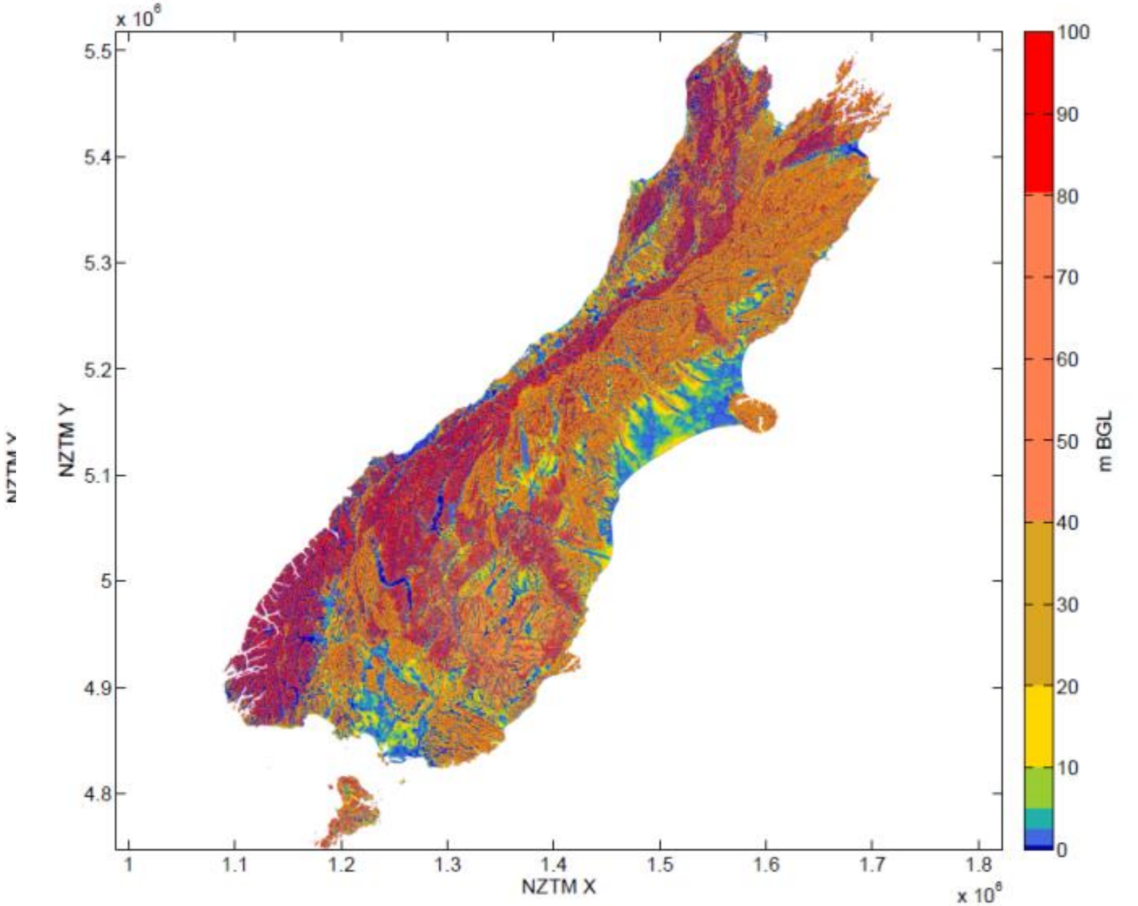
Q = groundwater flow ($m^3/s$)
T = transmissivity = hydraulic conductivity K over depth
h = head
$h_n$ = head at neighbouring cell
w = width of cell
l = distance between cells

$Q_r$ = seepage

Source: Fan *et al*. (2013), Freeze and Cherry (1979)


r.westerhoff@gns.cri.nz

**The EWT covers the known shallow aquifers systems and can thus be used as an estimate of depth to water table in data sparse areas (Westerhoff and White, 2014) and provides an indication of pre-European water table**



# Baseflow

# Waipa River catchment study

- Flow recorder site data in a conceptual water budget
- SAC-RECH recharge model
- USGS-SWB recharge model

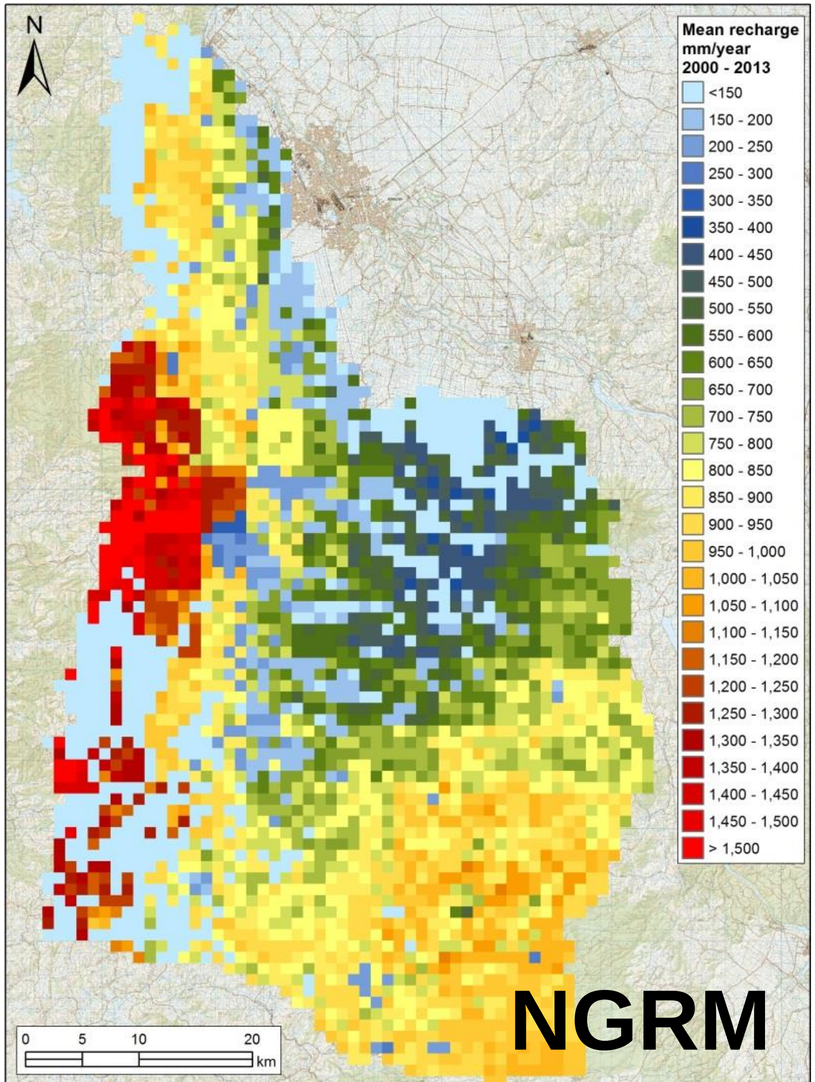
were used in a comparative study in the Waipa River catchment

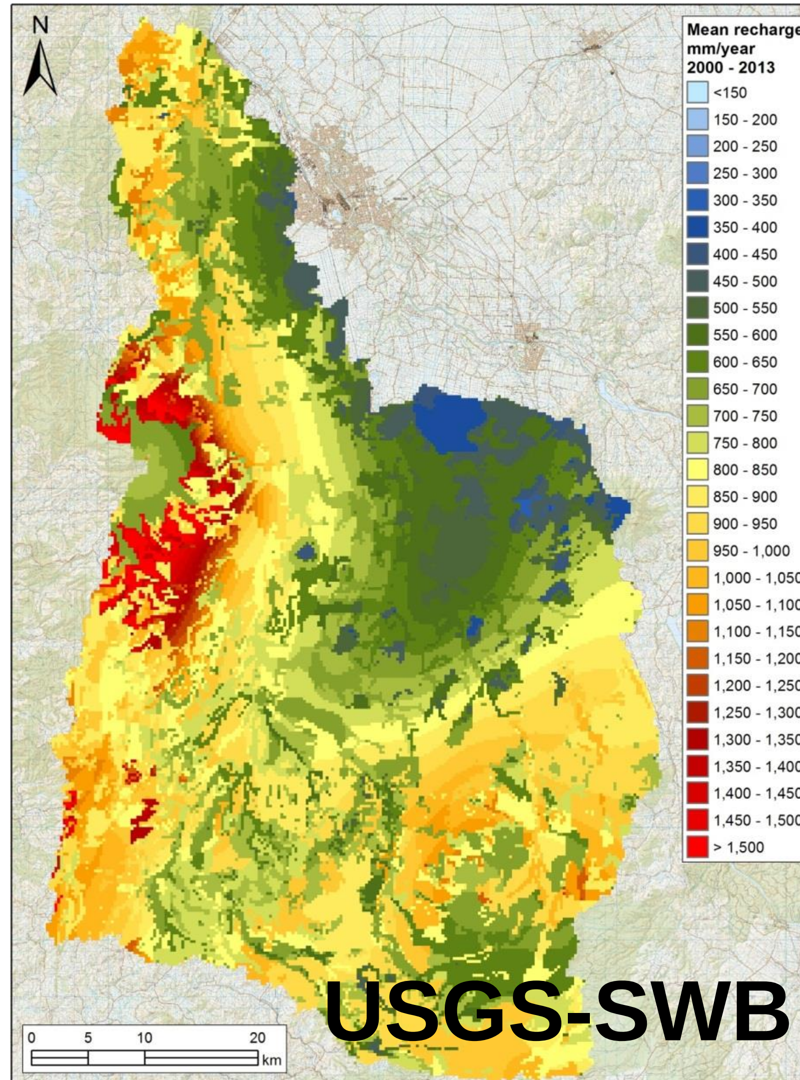
Source: *White *et al*. (2015); **Rawlinson et al. (2015)

# Case study: Waipa River catchment

Source: *White *et al*. (2015); **Rawlinson et al. (2015)

# Case study: Waipa



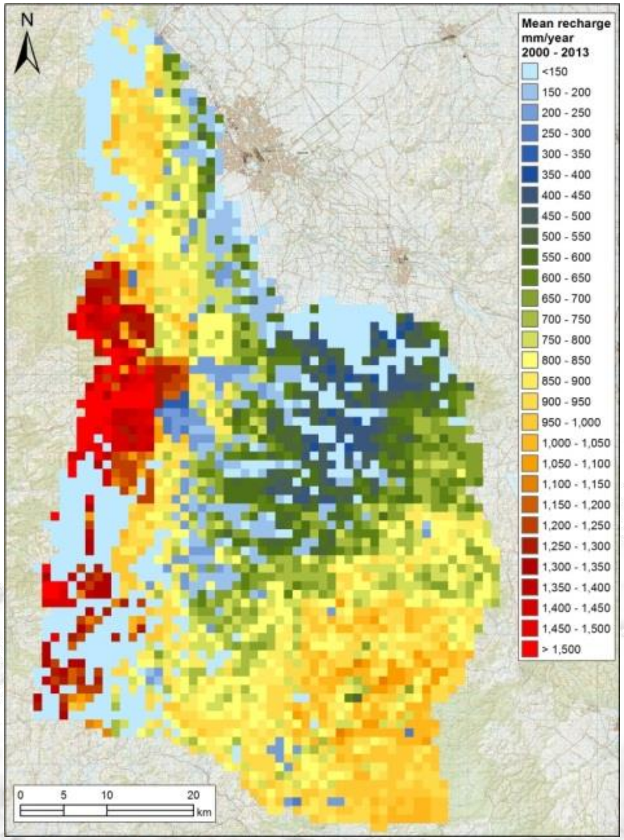




Similar results. NGRM fits the total measured base flow out of catchment best.

- Assuming negligible groundwater in- and out-flow:

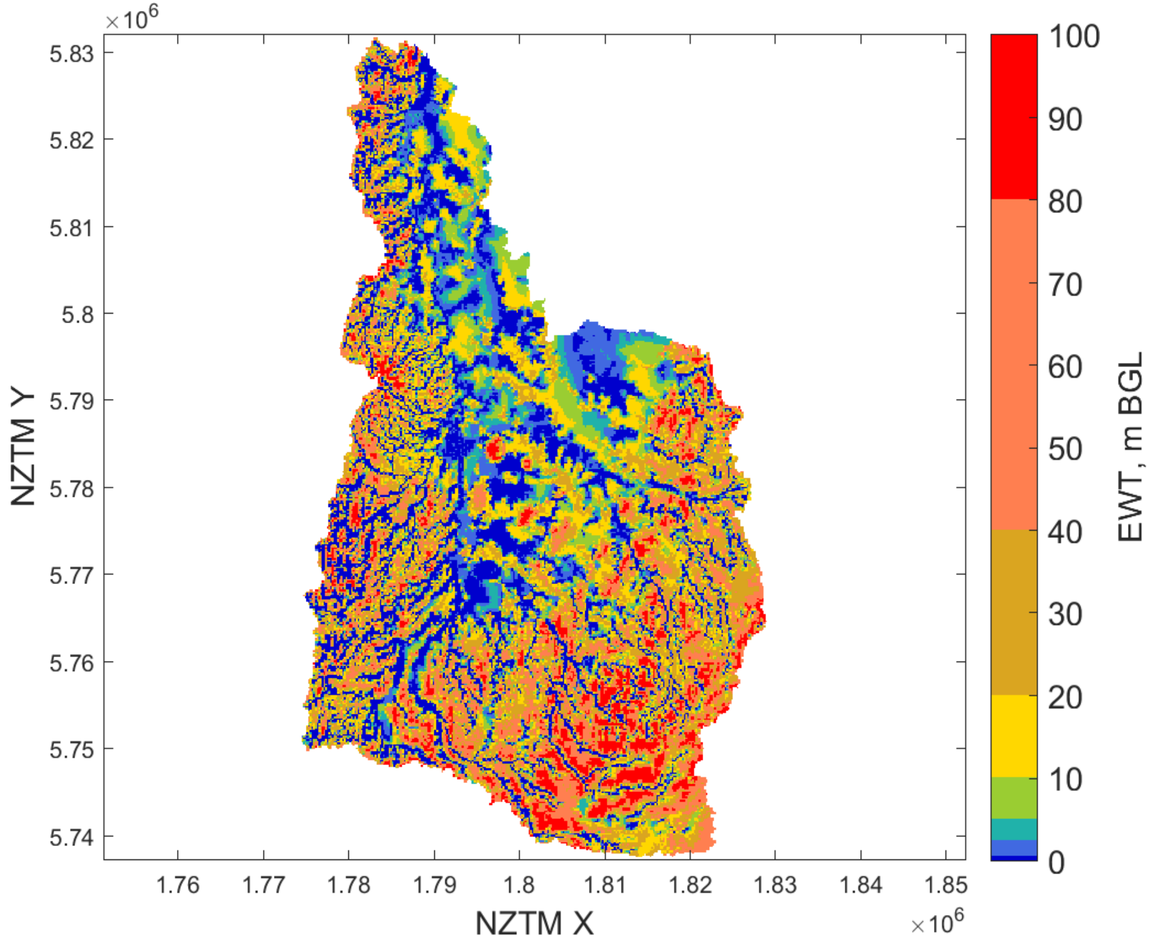
after calibration

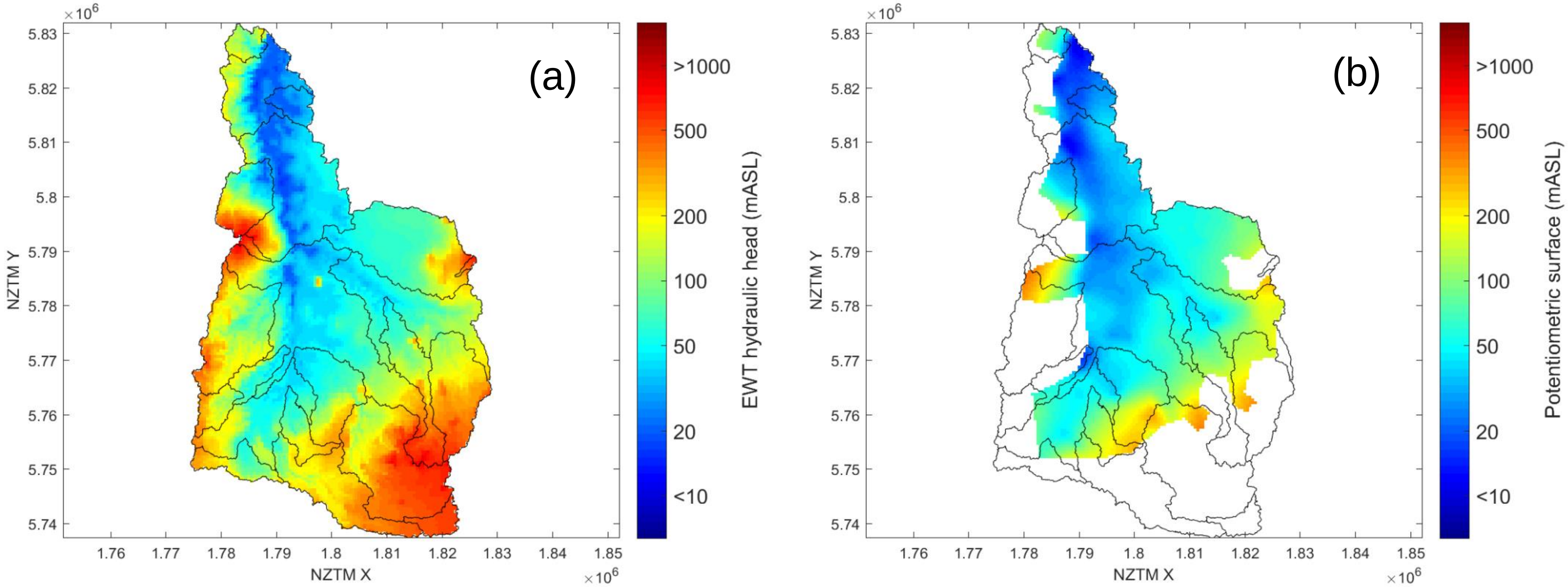
- Baseflow 68.5 $m^3/s$ (BFI ~ 0.7)



## EWT for Waipa River catchment

- Result after 100 years of daily model runs using SAC-RECH recharge as input



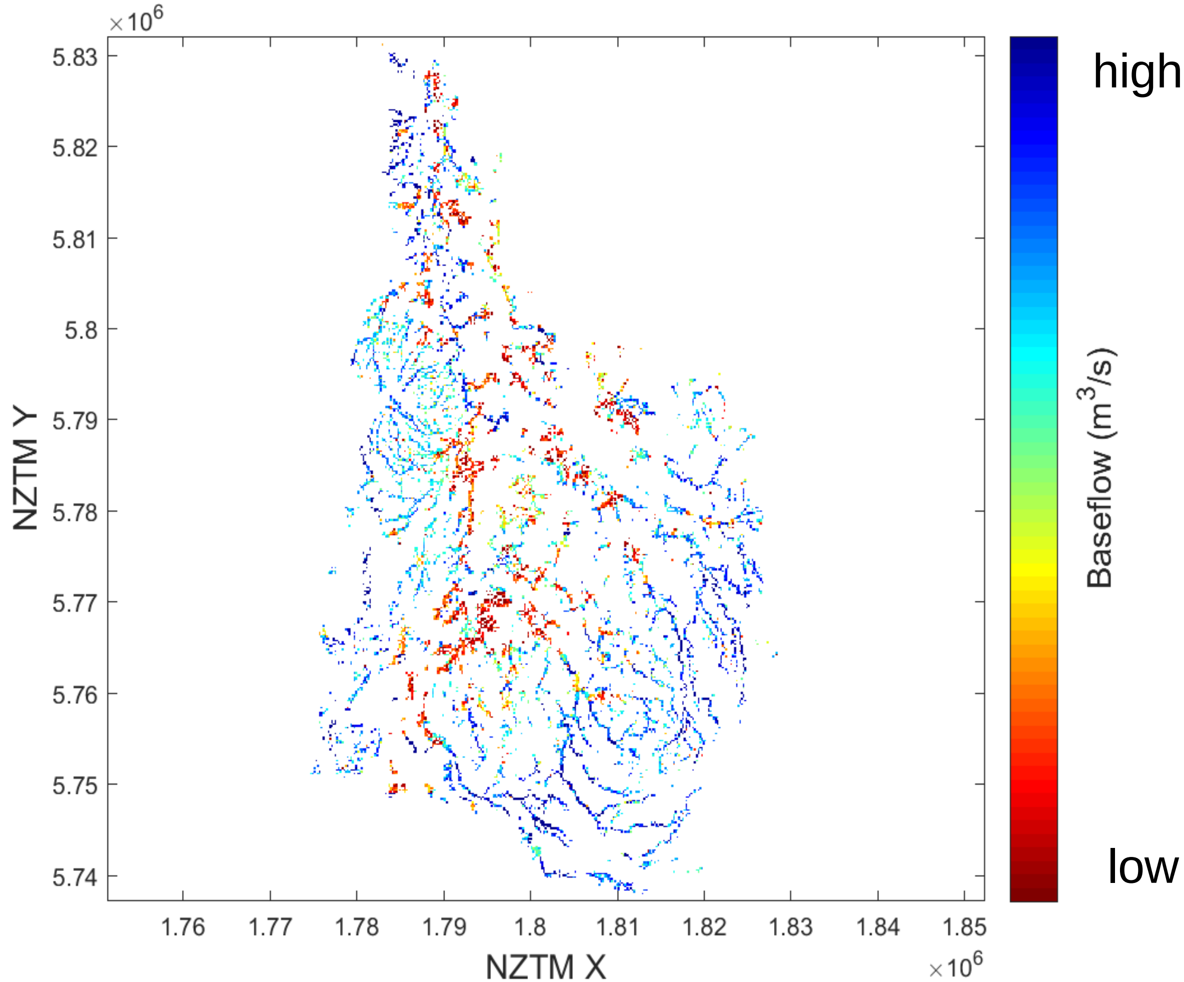



Hydraulic head (EWT)

Water level measurements

# Case study: Waipa

- Model runs  100 years in daily time steps
- From 50-100 years, all groundwater discharging to surface is summed
- Then, it is averaged and scaled to recharge



# Discussion

- Requires comparison with an gw-flow models
- Uncertainty of rainfall and AET are still a topic of research
- River recharge is not implemented
- Land use: Water Holding Capacity, interception – not accounted for
- More comparison to measured flow required

# Take home points

- Nation-wide rainfall recharge (monthly, 1km x 1km) that compares well to lysimeters and other models
- National scale groundwater flow model
- Baseflow estimates: conceptual and gridded estimates

# Thank you!

Rogier Westerhoff

Paul White

Deltares, GNS Science, Waikato University, eartH2Observe

rogier.westerhoff@deltares.nl

r.westerhoff@gns.cri.nz

p.white@gns.cri.nz