Groundwater - Surface Water Interaction Workshop, 31 August – 1 September 2015, Te Papa Tongarewa Museum, Wellington – Presentations

A.P. Lovett (ed.)

GNS Science Miscellaneous Series 92
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CONTENTS

FIGURES

ABSTRACT

A two day workshop on groundwater - surface water (GW-SW) interaction was held at Museum of New Zealand Te Papa Tongarewa, Wellington from 31 August – 1 September, 2015. The workshop was convened by GNS Science and was an output of the GNS Science-led Smart Aquifer Characterisation (SAC) MBIE funded contestable research programme. The workshop was delivered on behalf of the Groundwater Alliance and included contributions from Aqualinc Research, Auckland Council, Environment Southland, Environmental and Scientific Research, Horizons, Lincoln Agritech, Ministry for the Environment, National Institute for Water and Atmospheric Research, Pattle Delamore Partners, and University of Waikato. The workshop was attended by 64 participants studying or working in the areas of freshwater science and policy at the national and regional scales.

The aim of the workshop was to increase knowledge base, and stimulate exchange of ideas between research organisations and policy staff via dissemination of research results in an interactive environment. A workshop environment was selected as it provided the best opportunities for sharing of knowledge, and because stakeholders had identified workshops as the preferred method for dissemination of research results during the New Zealand Hydrological Society annual conference in Wellington, 2012. Session topics covered important aspects of GW-SW interaction in New Zealand including: field methods; modelling; uncertainty; water budgets; and policy. The intent was for the workshop to follow an Interactive Skills Workshop format; however some sessions were given in a conference format at the preference of individual session facilitators. Sessions involved: discussions and reporting in revolving sub-groups; sub-group interactive sessions with opportunities for feedback and questions; and conference-style presentations with question and answer opportunities. The topics of modelling, water budget and uncertainty included technical overview and modelling exercises of stream depletion. The policy sessions involved interactive role-play to elicit community values, district and national policy in an imaginary catchment, including an Environment Court hearing.

The primary objectives of the workshop were to:

1. provide an overview of the state of characterisation of GW-SW interaction in New Zealand; and
2. inform as to how improved knowledge and new research on characterisation of GW-SW interaction should proceed.

All of the session presentations from the workshop have been collated into this report, and where possible, worked examples of the interactive sessions have been included.

KEYWORDS

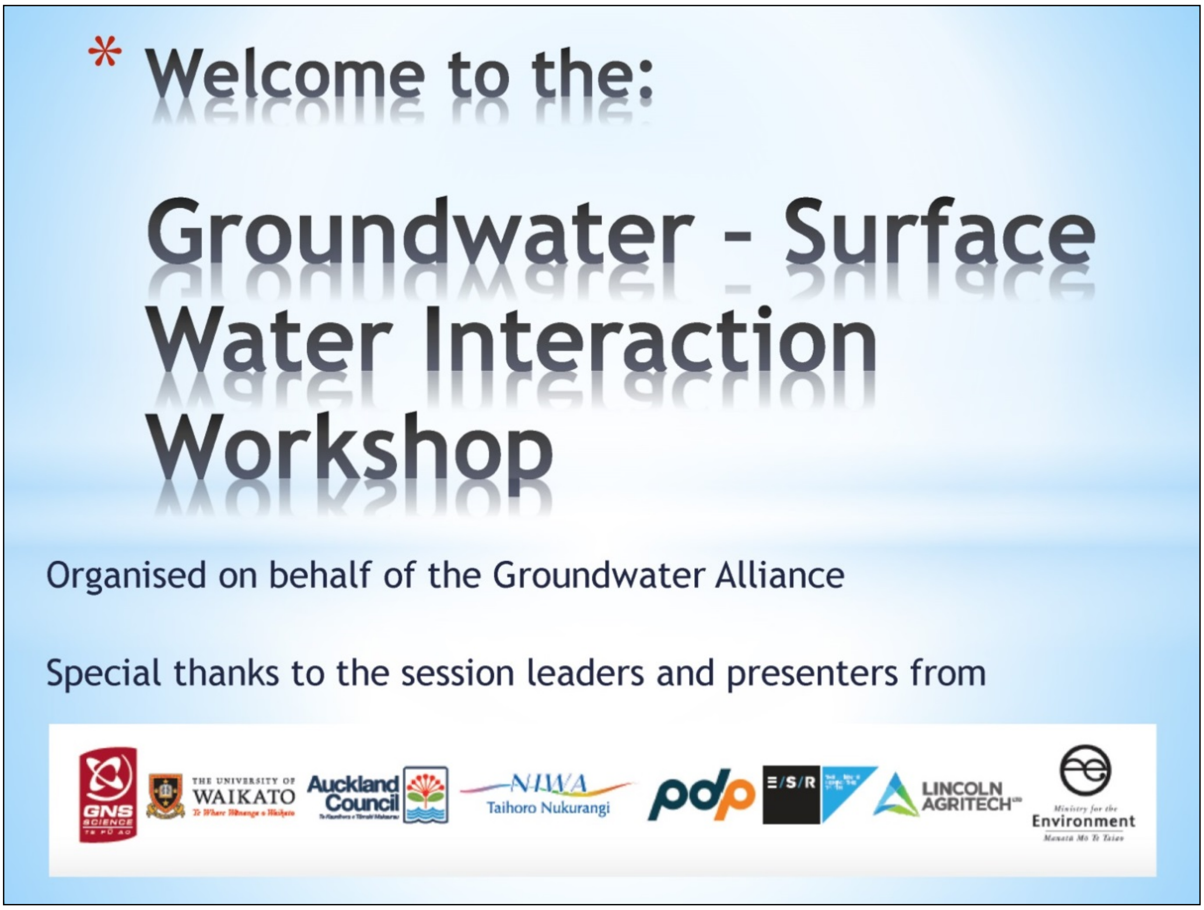
Groundwater - surface water interaction, policy, science, collaboration.

SESSION 1: GW-SW INTERACTION OVERVIEW FACILITATOR: STEWART CAMERON, GNS SCIENCE

1.1 INTRODUCTION

The aim of the groundwater - surface water overview session was to understand why it is important to characterise GW-SW interaction in the New Zealand context. The objectives for the session were:

- to understand why improved characterisation of GW-SW interaction is important; and
- to understand primary knowledge gaps in characterisation of GW-SW interaction.



* Health and safety
* House keeping
* Workshop format
    * It is participatory (60:40 rule)
    * But we have a time table
    * So the rules of engagement are ……..
    * Puka Glen catchment and workshop output
    * Feedback and questions
* Spectrum of knowledge in the room

SWGWSWGWSWGWSWGWSGWSWGWSWGV

* Workshop Introduction and conclusions

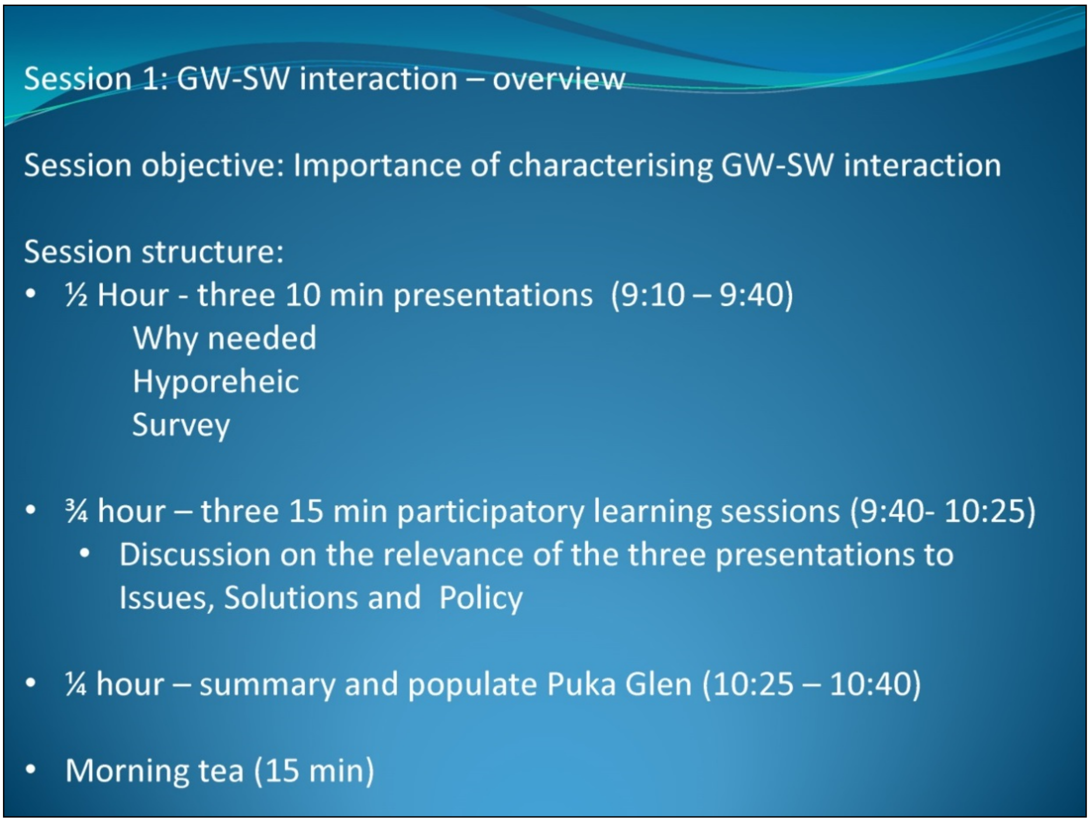
Sit down if you don't know:

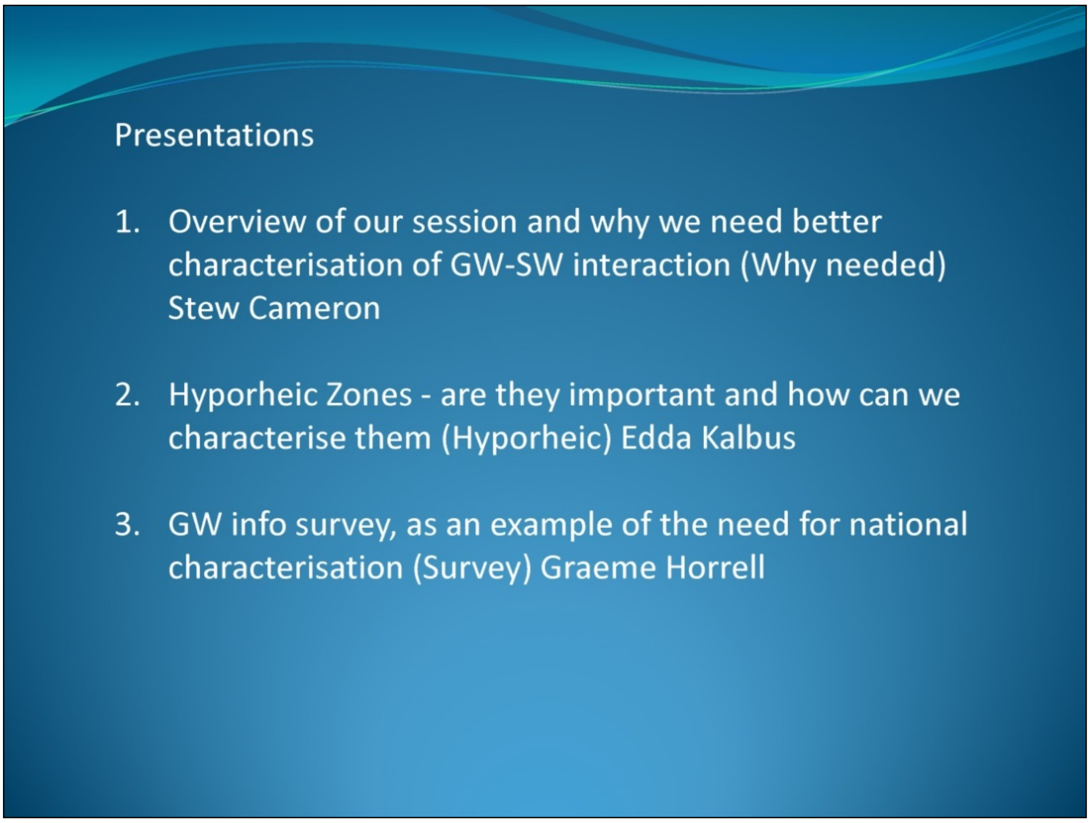
1. what GW-SW stands for
2. what causes GW to flow to SW, and SW to flow to GW
3. one reason why it is important to improve characterisation of GW-SW interaction
4. one traditional and recent technique used to characterise GW-SW interaction
5. modelling techniques used to characterise GW-SW interaction
6. how to quantify the reliability of the above methods
7. how outputs of the above might be translated into policy
8. the square root of 15,241,383,936

*Pre-assessment questions

1.2 PRESENTATIONS

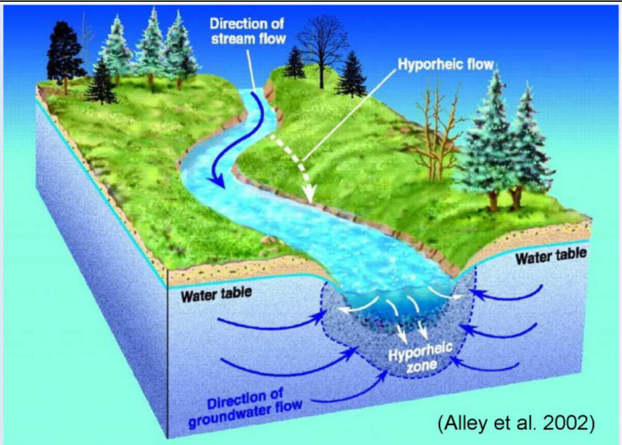
1.2.1 Why we need better characterisation of GW-SW interaction
Facilitator: Stewart Cameron, GNS Science





1.2.2 Hyporheic Zones – Are they important? How can we characterise them? Facilitator: Edda Kalbus, Auckland Council

Hyporheic Zones



(Alley et al. 2002)

- What are hyporheic zones?
- What is their role in stream functions?
- Are HZ processes significant for water management?

Edda Kalbus, Research and Evaluation Unit, Auckland Council

Auckland Council

What are hyporheic zones?

"hypo" (under) and "rheos" (flow) – a subsurface stream under the surface stream (Orghidan 1959/2010)

A zone where stream water locally recharges into shallow groundwater flow paths that return to the stream (Harvey et al. 1996, Storey et al. 2003)

A zone beneath the stream bed, and into the stream banks where stream water mixes with subsurface water (Triska et al. 1989, White 1993)

A groundwater zone penetrated by surface water organisms (Stanford & Ward 1993)

What are hyporheic zones?

"hypo" (under) and "rheos" (flow) – a subsurface stream under the surface stream (Orghidan 1959/2010)

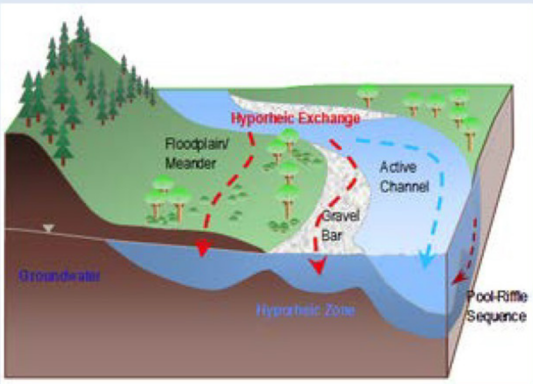
Hydrological approach

Geochemical approach

Ecological approach

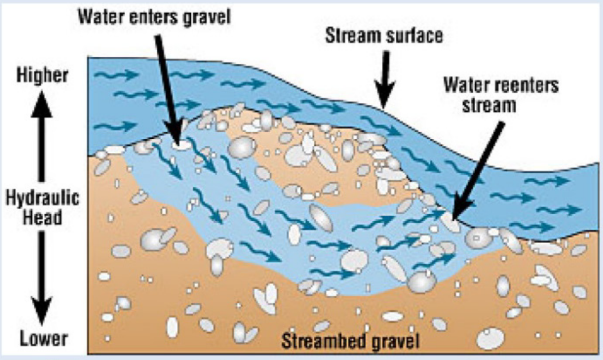
HZ Hydrology

Lateral



(http://www.wess.info/typo3/index.php?id=60)

Vertical



(http://naturemappingfoundation.org/natmap/water/field/hyporheic_zones.html)

"pumping"

→ Wide range of residence times
→ No net gain or loss by hyporheic exchange!

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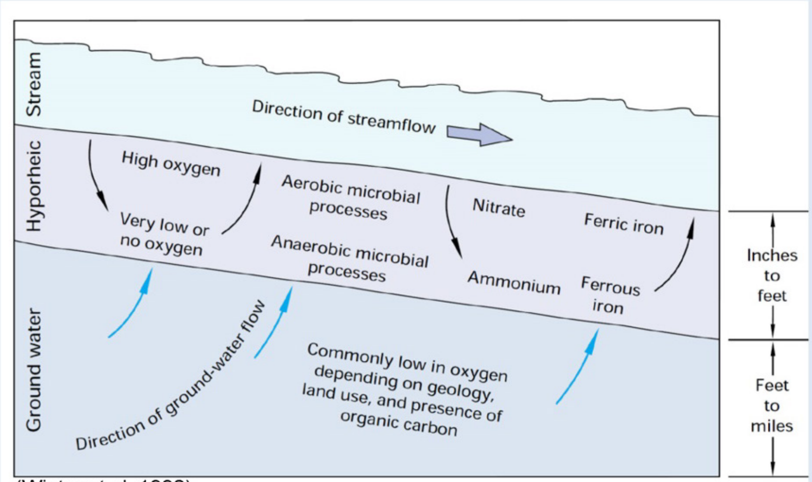
HZ Geochemistry

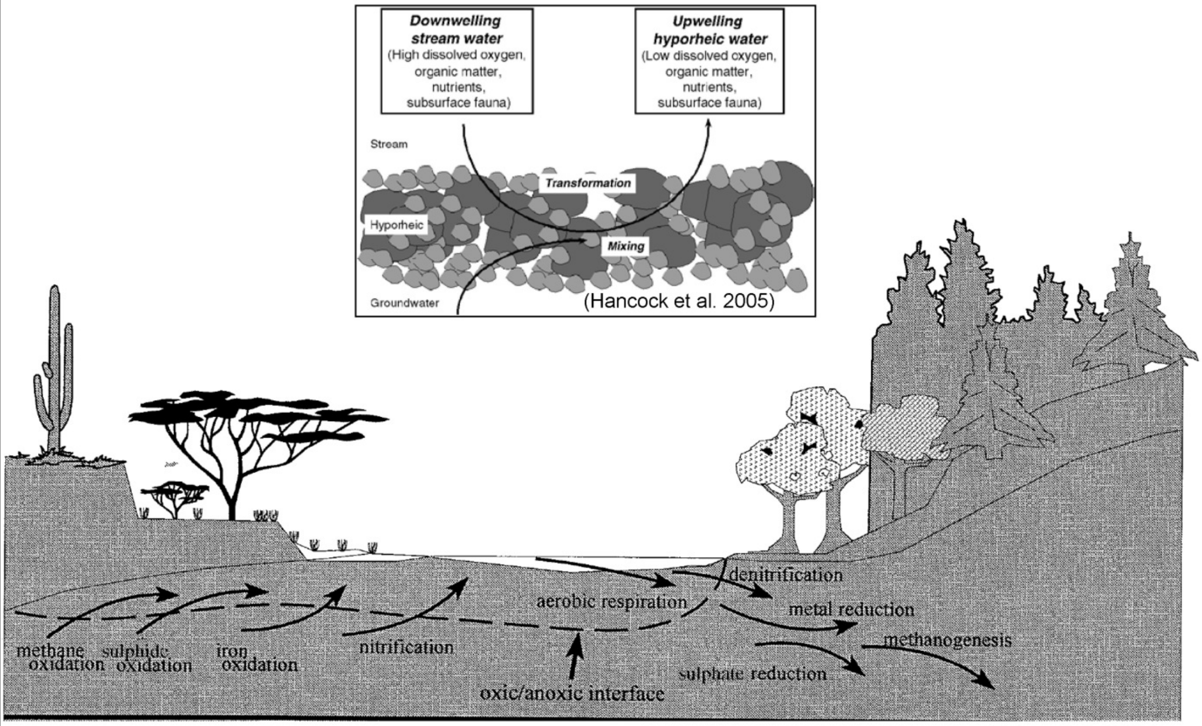


(Winter et al. 1998)

DO	EC	T
high	low	high/ low
?	?	?
low	high	const.

→Mixture of two general end member water types
→Strong geochemical gradients

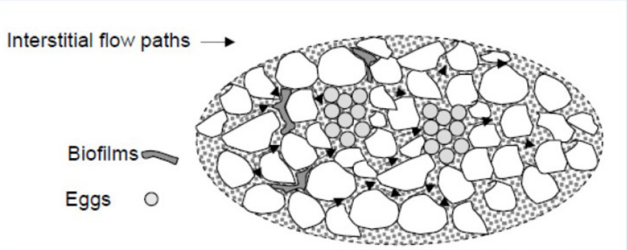
HZ Geochemistry



(Dahm et al. 1998)

HZ Ecology

- Permanent and temporal hyporheos (mainly invertebrates)
- Microbial community
  - Bacteria
  - Fungi
  - Protozoa
- Fish and other vertebrates
- Aquatic plants



(Environment Agency 2009)

HZ Ecology

Contribution of the HZ to community respiration

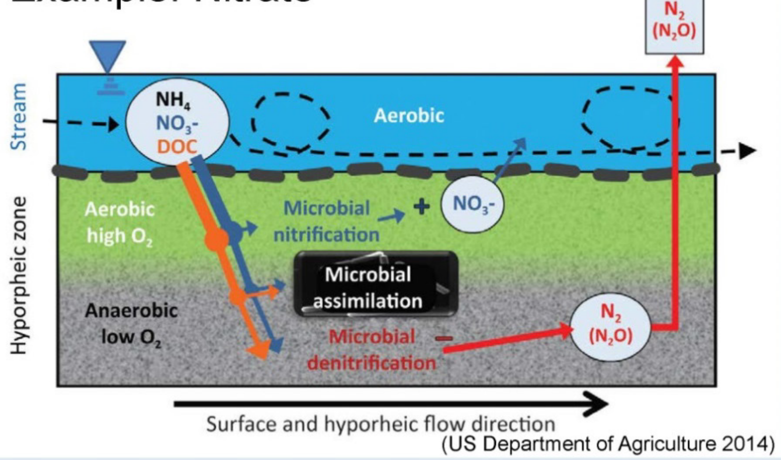
HZ contribution	Streambed sediments	Reference
40-50%	sand	Grimm & Fisher (1984)
70%	sand	Fuss & Smock (1996)
76-96%	gravel	Naegli & Uehlinger (1997)
40-93%	stony	Fellows et al. (2001)
52-56%	gravel	Burrell (2001)

Hyporheic zone functions

Hydrology	Geochemistry	Ecology
Flux and location of water exchange between stream and subsurface	Cycling of carbon, energy and nutrients	Habitat for macroinvertebrates
Moderating river water temperature	Natural attenuation of certain pollutants by biodegradation, sorption and mixing	Spawning ground and refuge for certain fish species
Sink/source of sediment within a river channel	Surface for microbial colonisation	Rooting zone for aquatic plants

Significance of the HZ for water management

Example: Nitrate



(US Department of Agriculture 2014)

Source or sink?

Depends on:

- Residence time of water in the HZ
- Uptake rates of oxygen in the HZ
- Anaerobic: denitrification limited by DOC

Significance of the HZ for water management

- Contributes to 'self-cleansing' of streams
- But: processes are complex and variable in space and time
- Potential for interventions to improve HZ functions

Auckland Council

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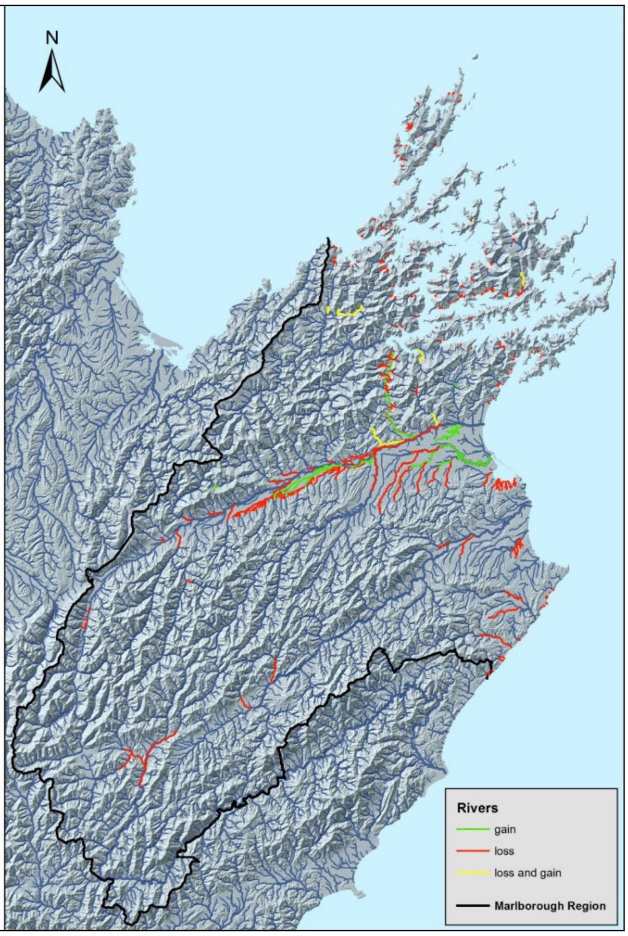
1.2.3 Example of the need for a national characterisation survey
Facilitators: Graeme Horrell and Christian Zammit, NIWA

Groundwater – surface water interaction identified by gaining and losing reaches survey of some South Island Rivers

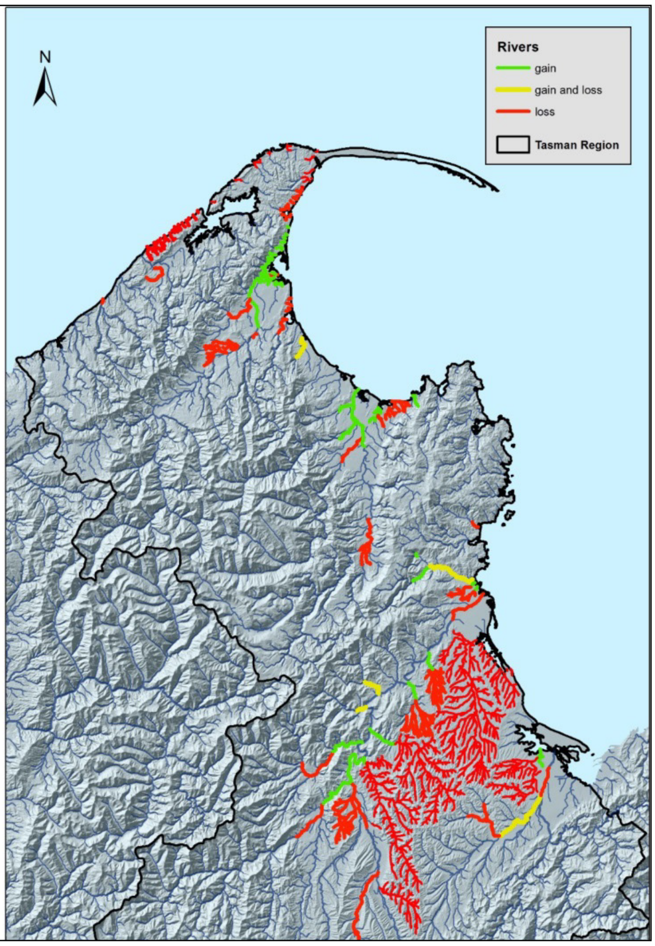
Graeme Horrell

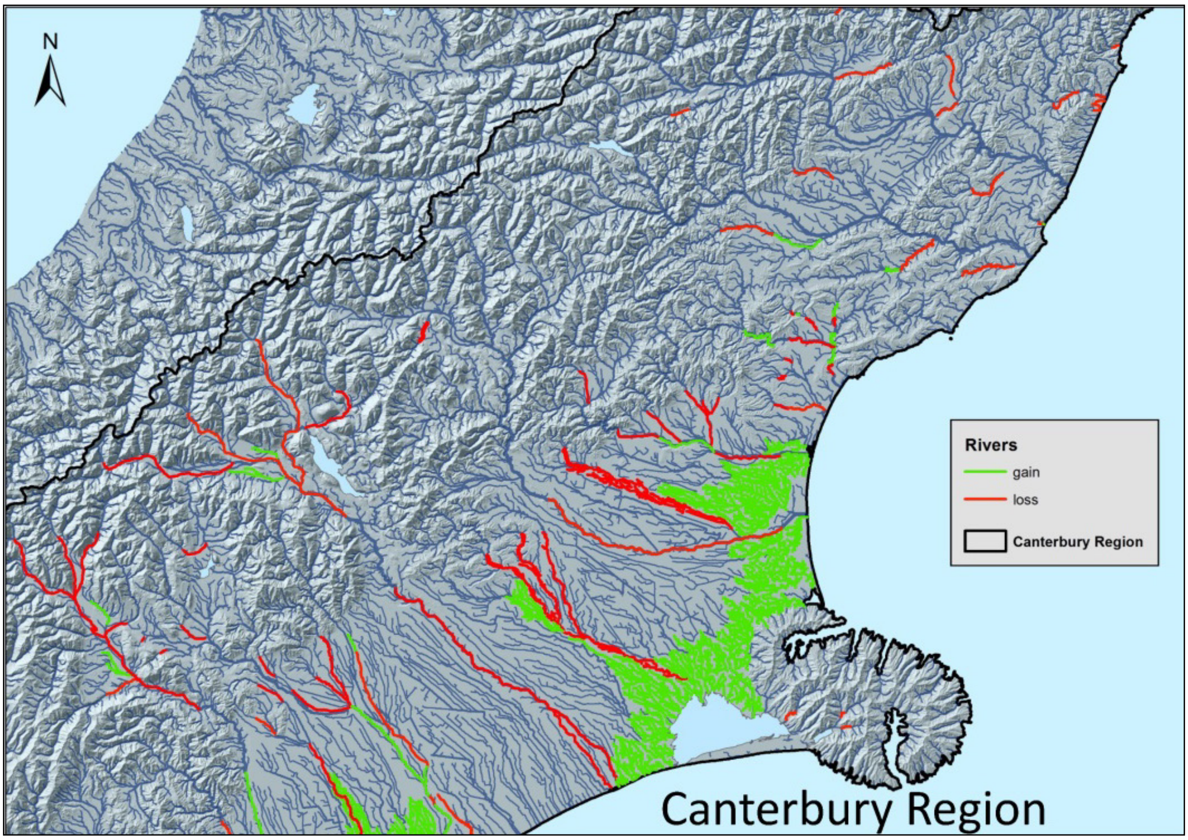
NIWA
Taihoro Nukurangi

Marlborough Region



Tasman Region





1.3 PARTICIPATORY EXERCISE

The aim of the following Participatory Learning exercise was to promote discussion on the relevance of the three presentations to Issues, Solutions and Policy. The workshop was broken into three groups of about 20 people each, with 10 min to:

Discuss, list and be prepared to report **issues** regarding:

- Group 1: Why needed CS to facilitate
- Group 2: Hyporheic EK to facilitate
- Group 3: Survey GH to facilitate

Discuss, list and be prepared to report **solutions** regarding:

- Group 1: Survey GH to facilitate
- Group 2: Why needed CS to facilitate
- Group 3: Hyporheic EK to facilitate

Discuss, list and be prepared to report **policy** regarding:

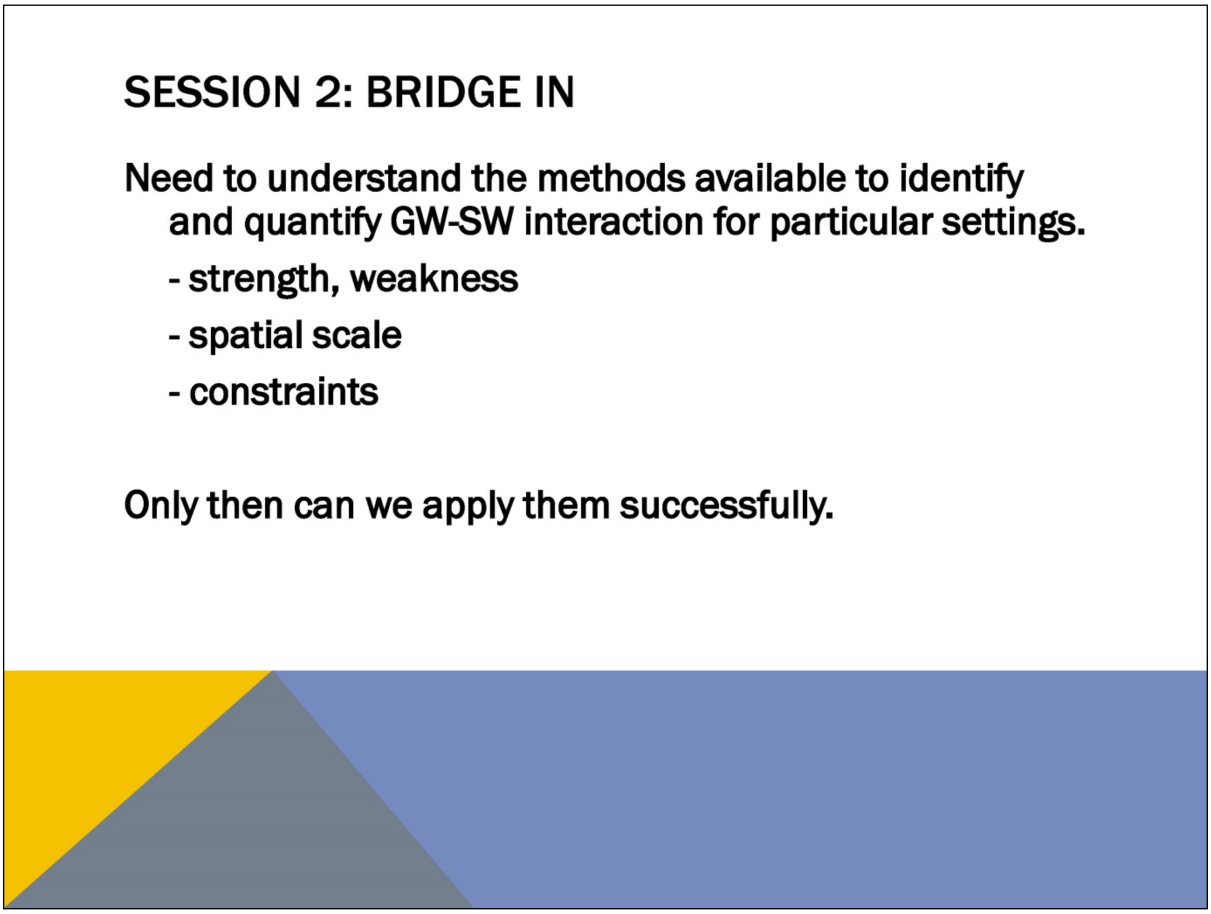
- Group 1: Hyporheic EK to facilitate
- Group 2: Survey GH to facilitate
- Group 3: Why needed CS to facilitate

SESSION 2: METHODS FOR DETECTING AND MEASURING GW-SW INTERACTION FACILITATORS: ABIGAIL LOVETT AND ROGIER WESTERHOFF, GNS SCIENCE

2.1 INTRODUCTION

The aim of the methods session was to understand methods available to identify and quantify GW-SW interaction for particular settings, so that they can be applied. The following objectives were defined:

- Objective 1: To identify what methods can be used for characterising GW-SW interaction, with a focus on NZ settings and examples;
- Objective 2: For each method, to identify strengths, limitations, and scale of application; and
- Objective 3: Identify regional polices and their impact on choosing suitable methods.



SESSION 2: OBJECTIVES

What methods can be used for characterising GW-SW interaction, with focus on NZ settings and examples

Methods strengths, limitations and their scale of application

Regional polices and their impact on choosing the suitable GW-SW interaction method

SESSION2: PRE-ASSESSMENT

With reference to your current knowledge and experience with GW-SW interaction methods, identify yourself as one of the following:

Group 1: I am unfamiliar or have little experience

Group 2: I understand or have worked with some methods

Group 3: I have expertise in one or more methods

SESSION 2: PARTICIPATORY LEARNING

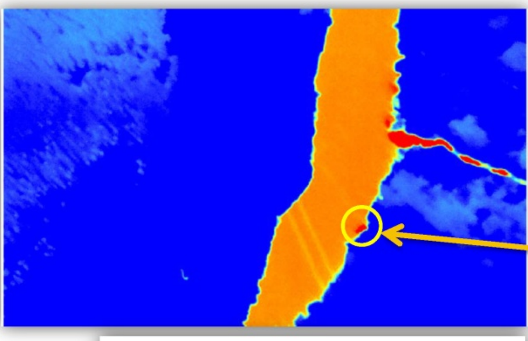
STAGE 1:

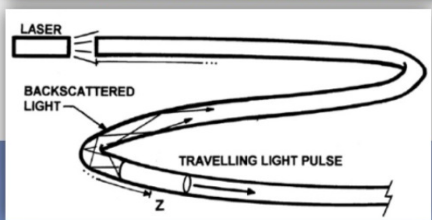
Edda Kalbus: GW-SW methods overview

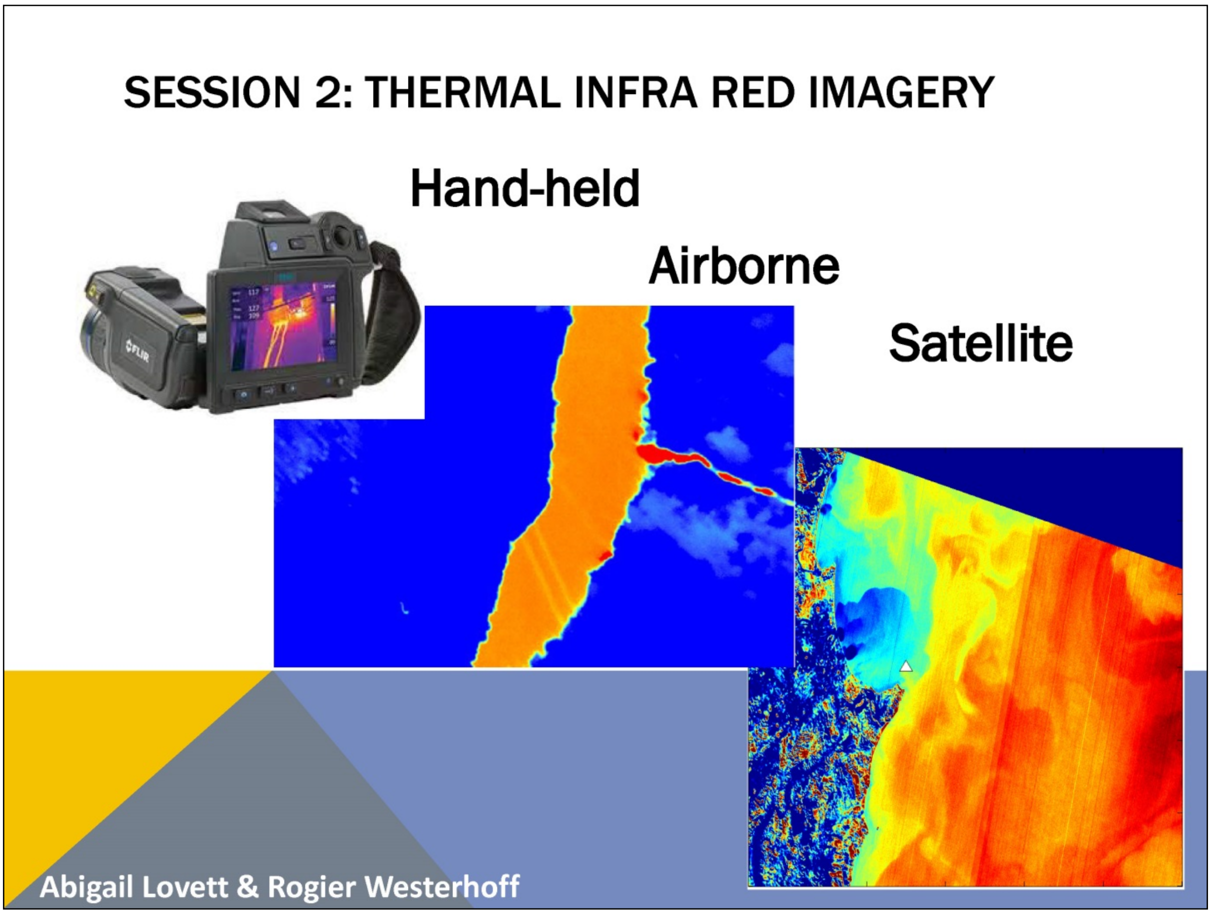
Group Presentations:

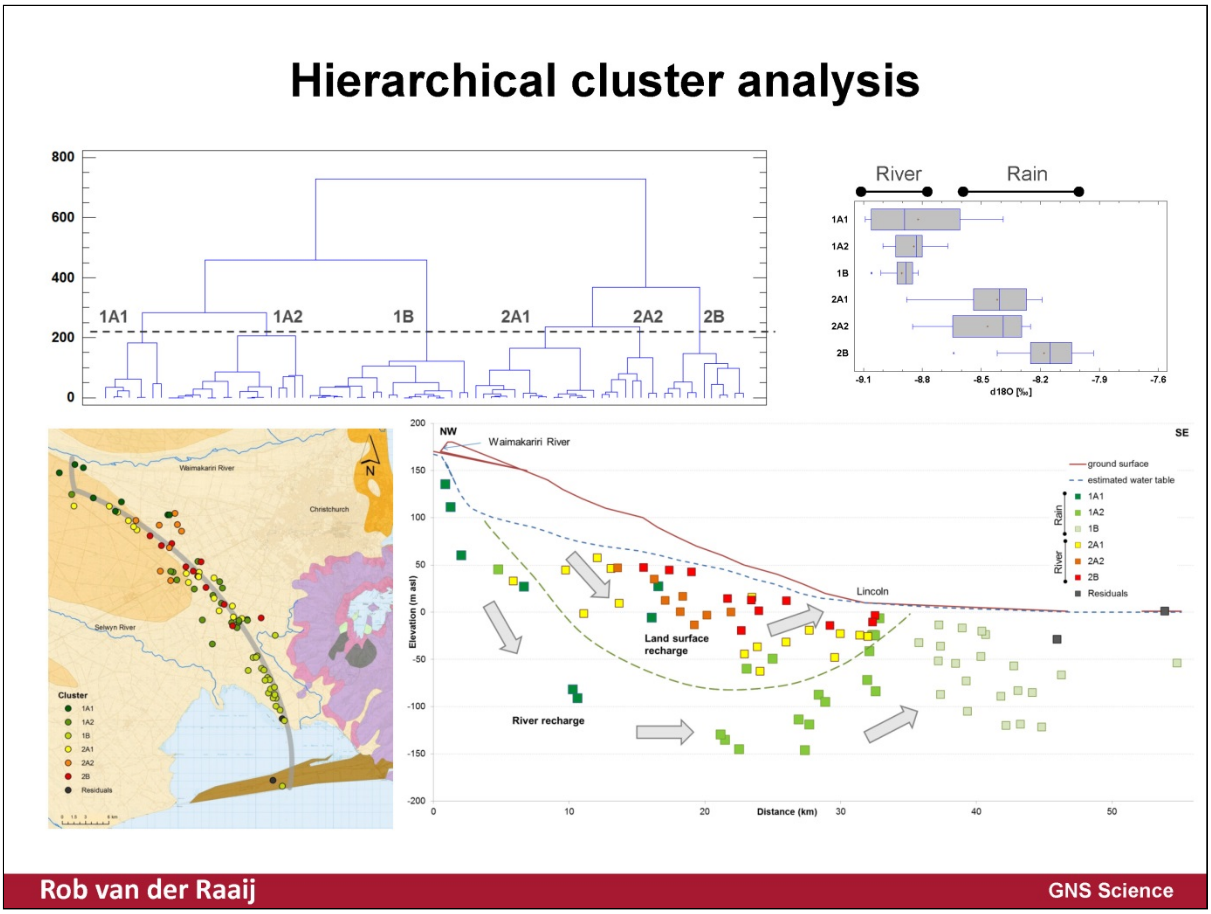
- Maryam Moridnejad: Fibre Optic Distributed Temperature Sensing
- Abigail Lovett / Rogier Westerhoff: Thermal Infra Red
- Rob van der Raaij: Hierarchical Cluster Analysis

SESSION 2: FODTS INTRODUCTION






SESSION 2: THERMAL INFRA RED IMAGERY
Hand-held
Airborne
Satellite
Abigail Lovett & Rogier Westerhoff


Hierarchical cluster analysis
800
600
400
200
0
1A1
1A2
1B
2A1
2A2
2B
River
Rain
d18O [‰]
NW
SE
Waimakariri River
Lincoln
Land surface recharge
River recharge
Elevation (m asl)
Distance (km)
ground surface
estimated water table
Residuals
Cluster
Christchurch
Selwyn River
Rob van der Raaij
GNS Science

SESSION 2: POSTER QUESTIONS

For each interactive session, please fill post-it notes with whatever comment you have for each question. One-liners, questions, yes/no, anything.

Q1. Do you understand this method (yes, partially, no)?

Q2. Identify an environment/context where this method can be used

Q3. Identify a weakness/limitation of this method.

Q4. Identify a strength of this method.

Q5. Would you be interested in applying this method to your work/research?

SESSION 2: PARTICIPATORY LEARNING

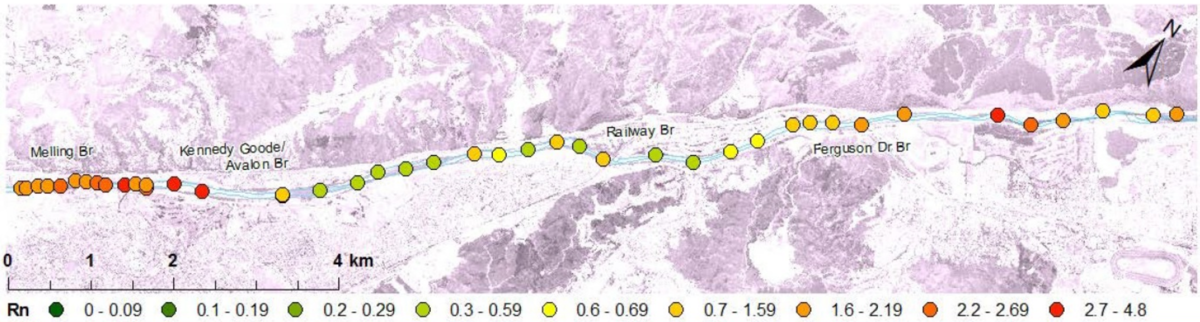
STAGE 2:

Group presentations:

- **Heather Martindale: Radon in SW gaining reaches**
- **Rogier Westerhoff: Rainfall recharge and water tables**
- **Murray Close: Radon in SW losing reaches**

Session 2: Radon Gaining
Mapping groundwater discharge into surface waters

- **Rn present in almost all rocks and soils.**
- **Dissolved in groundwaters but degasses quickly in surface waters.**
- **High Rn (>0.5 BqL^{-1}) in surface waters indicates area of groundwater discharge.**
- **Best results achieved in low flow conditions.**
- **Cost effective, simple method for mapping groundwater discharge over large areas.**



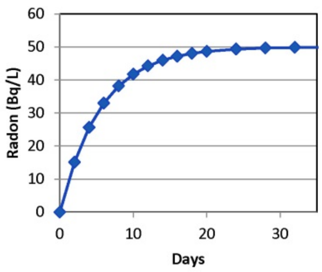
Heather Martindale

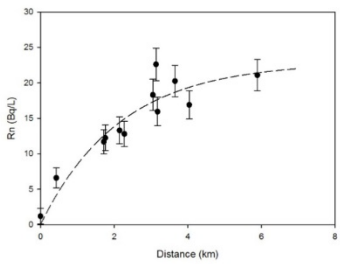
Use of Radon to characterise surface water recharge to groundwater

Radon: natural tracer from U decay: half-life = 3.8 days

Degasses from rivers => low levels; increase in groundwater can be used to provide information about recharge processes

Rn reaches equilibrium after 3 weeks so timeframe for useful information is 2-3 weeks; calculate equivalent distance.





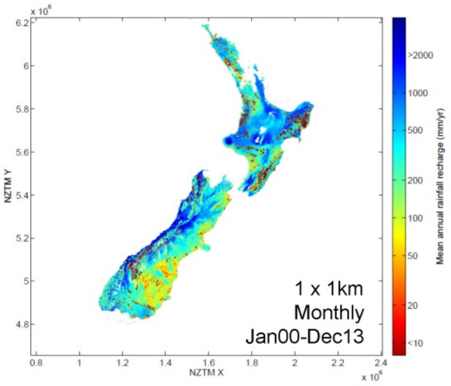
In-growth: $A_t = A_e(1-e^{-\lambda t})$

$A_d = A_e(1-e^{-\lambda d/V})$

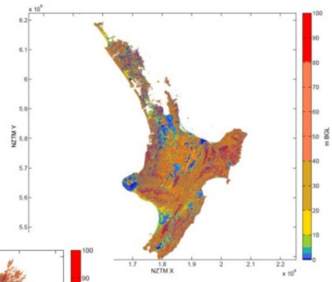
Murray Close

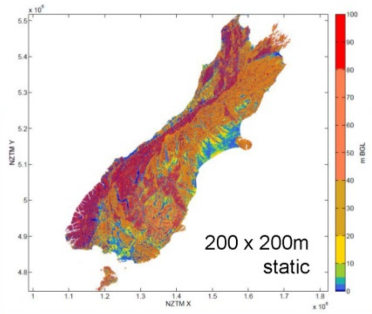
SESSION2:
RAINFALL RECHARGE AND WATER TABLES

Rainfall recharge to groundwater



Natural water table





Rogier Westerhoff

SESSION 2: POSTER QUESTIONS

For each interactive session, please fill post-it notes with whatever comment you have for each question. One-liners, questions, yes/no, anything.

Q1. Do you understand this method (yes, partially, no)?

Q2. Identify an environment/context where this method can be used

Q3. Identify a weakness/limitation of this method.

Q4. Identify a strength of this method.

Q5. Would you be interested in applying this method to your work/research?

POST ASSESSMENT

In this stage all of the A0 papers from the 6 methods will be distributed around the room (with each presenter), and everyone gets to review their understanding of the method.

Q1. Do you understand this method (yes, partially, no)?

Q2. Identify an environment/context where this method can be used

Q3. Identify a weakness/limitation of this method.

Q4. Identify a strength of this method.

Q5. Would you be interested in applying this method to your work/research?

SUMMARY

Overview and interactive session of GW-SW interaction methods.

Are they covering the state-of-the-art and innovation?

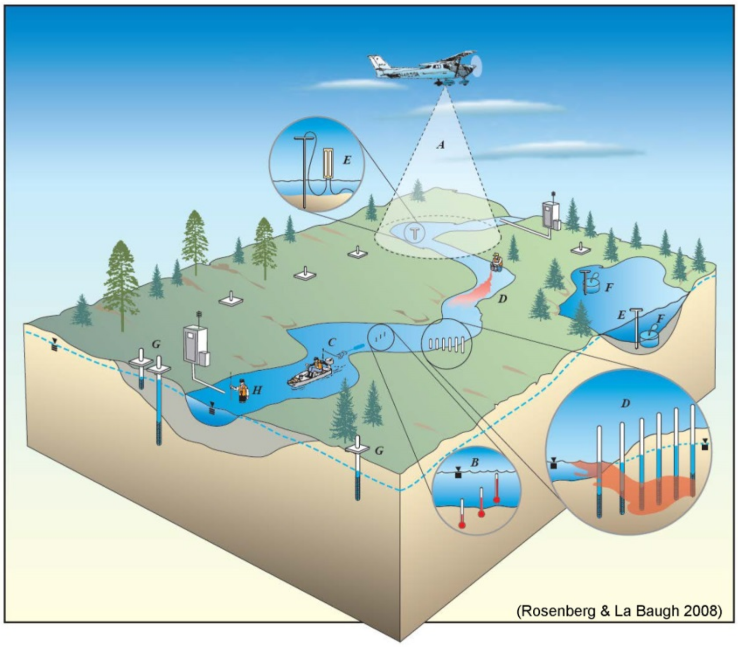
This information will be summarised and sent out to all participants as part of a report.

2.2 PRESENTATIONS AND INTERACTIVE SESSIONS

2.2.1 Overview of GW-SW interaction methods
Facilitator: Edda Kalbus, Auckland Council

Methods for characterising groundwater – surface water interactions

Edda Kalbus, Research & Evaluation Unit, Auckland Council



(A) Aerial infrared photography and imagery
(B) Thermal profiling
(C) The use of temperature and conductance probes
(D) Dyes and tracers
(E) Hydraulic potentiomanometers
(F) Seepage meters
(G) Well networks
(H) Streamflow measurements

What do we want to know?

- Locations of groundwater discharge/recharge?
- Rates of groundwater discharge/recharge at specific locations?
- Regional average net gain/loss?
- Rates of hyporheic exchange?
- Detect or quantify?
- Spatial or temporal?

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Overview

Point scale	Reach scale	Regional scale
Seepage meters	**Distributed temperature sensing**	**Hydraulic head/gradients**
Streambed piezometers	**Radon sampling**	Differential flow gauging
Temperature profiles		Hydrograph separation
		Solute tracers
		Thermal imagery
		River chemistry
		GW chemistry
		SW + GW chemistry

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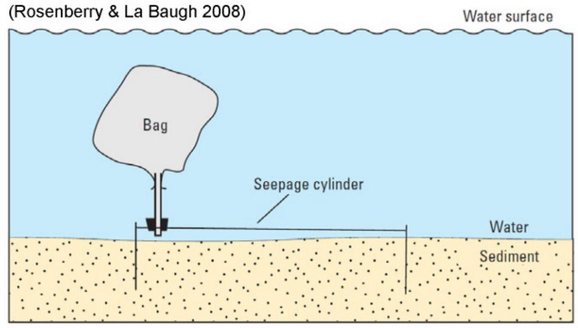
Seepage Meters

Point scale

(Rosenberry & La Baugh 2008)



(Brodie et al. 2007)

- ➢ Device may trigger advective pumping (streams)
- ➢ Stream flow may effect collection bag
- ➢ Fine-grained sediments only

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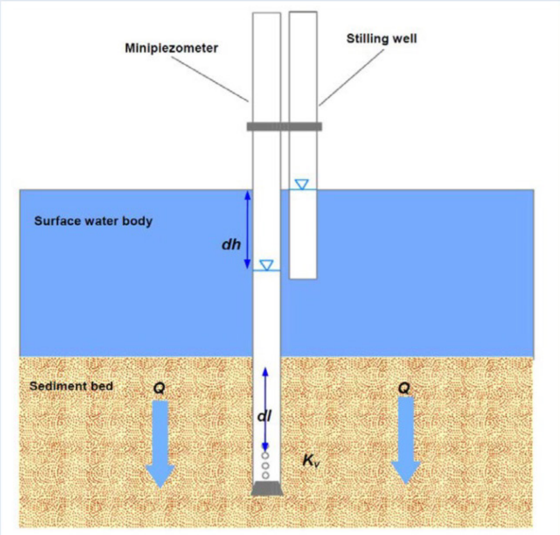
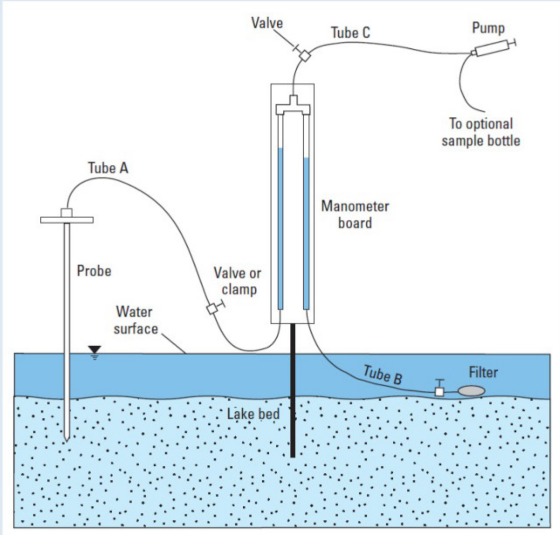
Streambed piezometers

Point scale





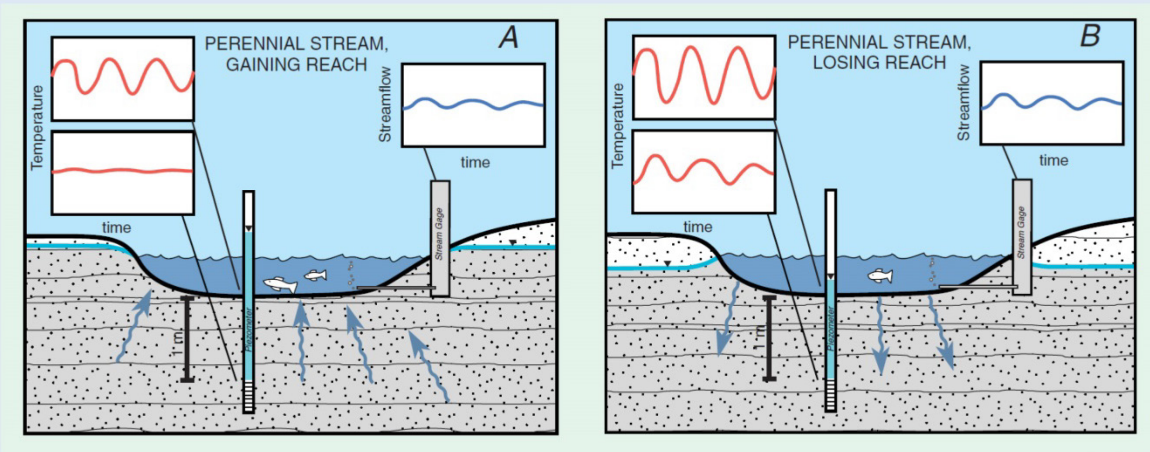
(Brodie et al. 2007) (Rosenberry & La Baugh 2008)

$$Q = A\frac{dh}{dl}K_v$$

- Based on head difference between streambed and stream
- Quantification requires estimation of K_v

Temperature profiles

Point scale



(Constantz and Stonestrom 2003)

- Based on temperature difference between GW and SW

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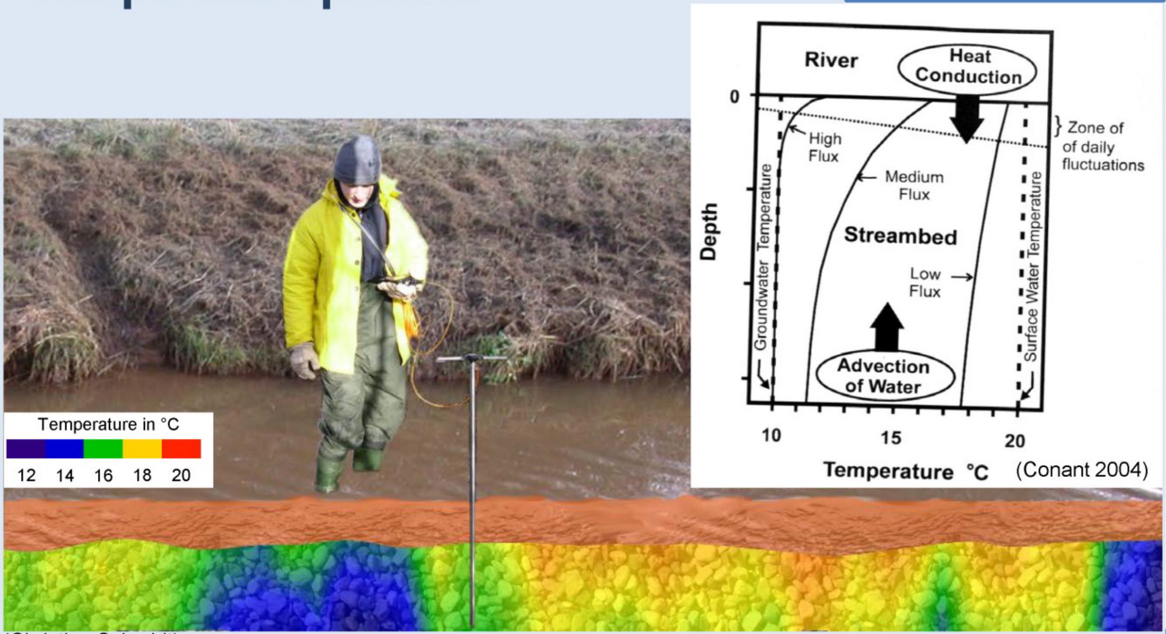
Temperature profiles

Point scale



(Conant 2004)

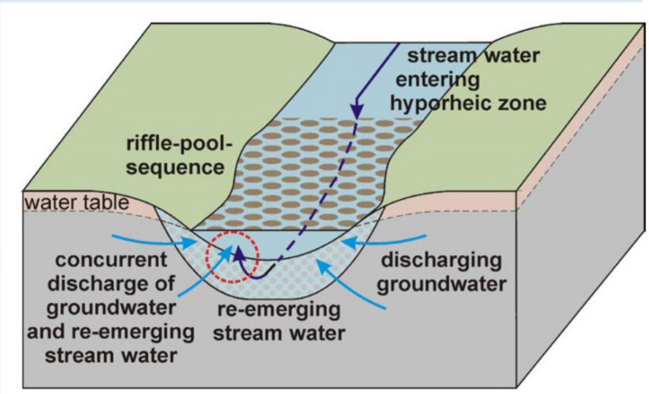
(Christian Schmidt)

➢ Quantification requires thermal parameters

Issues with upscaling

Point scale

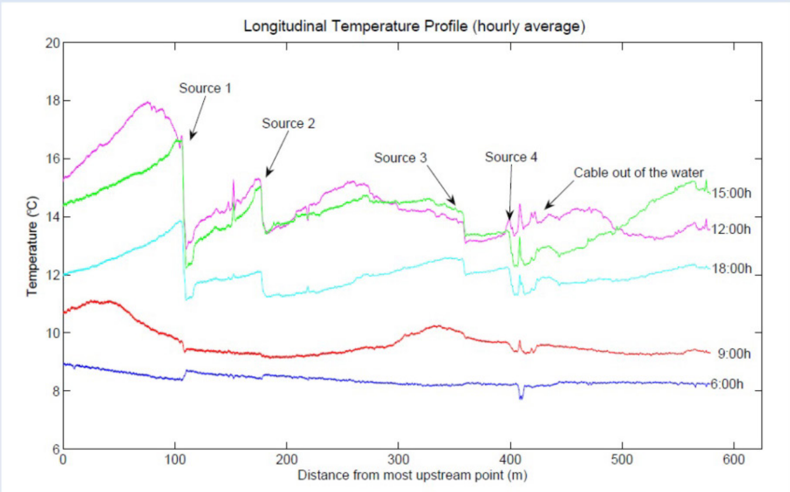
- Many closely spaced measurements necessary
- Not suitable for large rivers
- Challenge to distinguish between regional groundwater discharge and hyporheic flow



(Kalbus et al. 2006)

Reach scale

Distributed temperature sensing



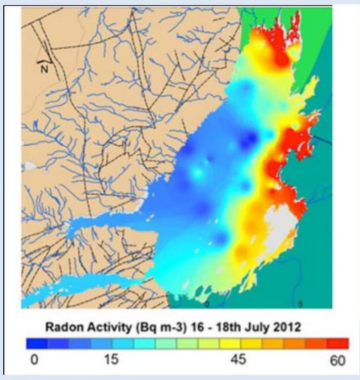
(Westhoff et al. 2007)

Maryam Moridnejad

Auckland Council

Reach scale

Radon sampling



(Wilson 2013)

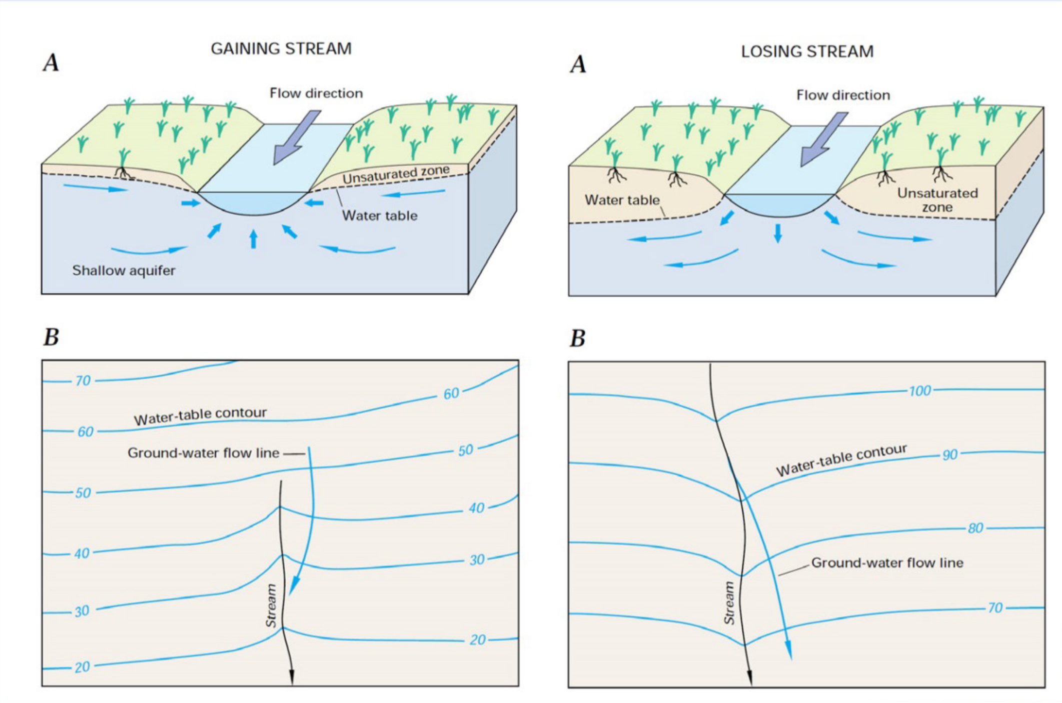
- GW: high radon; concentrations decrease rapidly when discharged to SW
- may be difficult to distinguish between GW discharge and hyporheic exchange

Heather Martindale

Auckland Council

Regional scale

Hydraulic heads

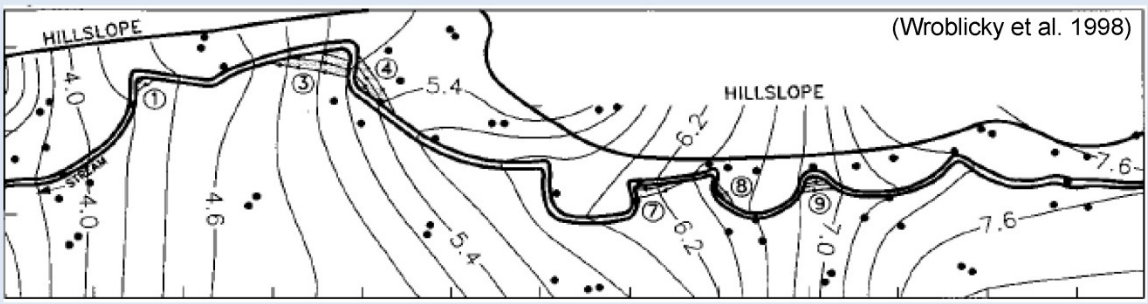


(Winter et al. 1998) 11

Regional scale

Example

Stream flow direction

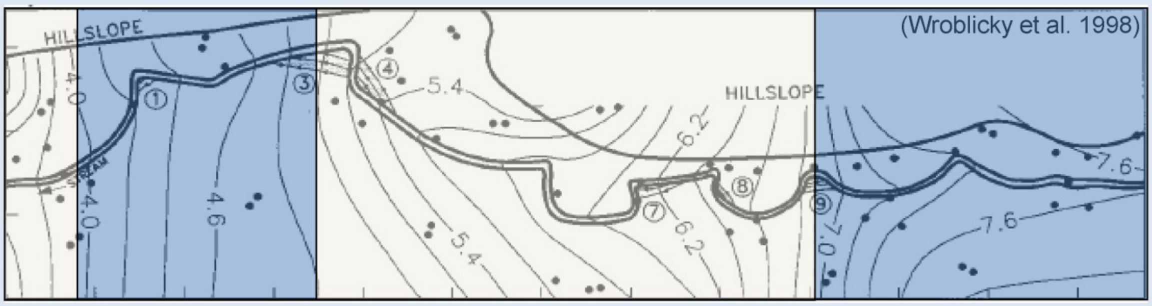


12

Example

Regional scale

Stream flow direction ←



(Wroblicky et al. 1998)

losing gaining losing gaining

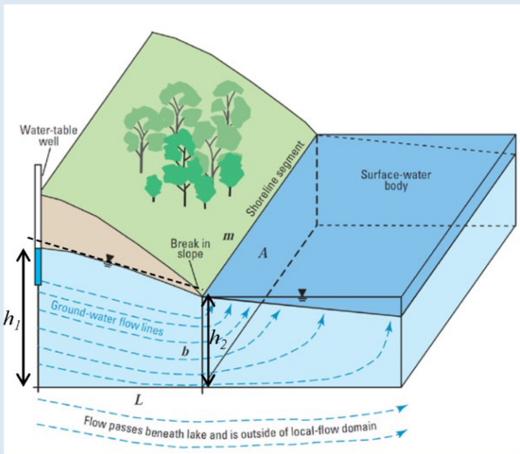
➔ Rogier Westerhoff

Auckland Council

13

Hydraulic gradient

Regional scale



(Rosenberry & La Baugh 2008)

$$Q = Km\frac{{h_1}^2 - {h_2}^2}{2L}$$

➢ Requires estimates of K

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Regional scale

Differential flow gauging

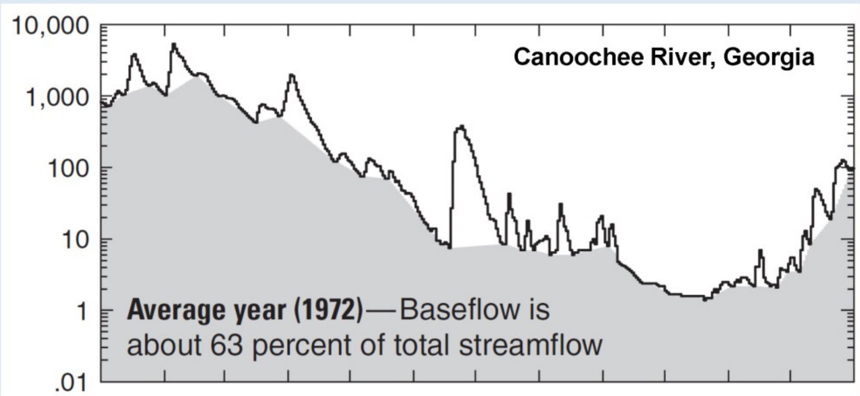
Difference between streamflow at successive cross-sections

- Inflow and outflow should be significantly greater that uncertainties in flow measurements
- May require considerable distance between gauging sites (km range)

Auckland Council

Regional scale

Hydrograph separation



(Priest 2004)

- Assumes baseflow = groundwater discharge

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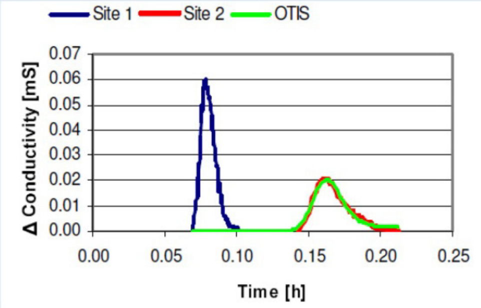
Regional scale

Solute tracers

Transient storage concept



(Rosenberry & La Baugh 2008)

➢ Assumes transient storage = subsurface storage

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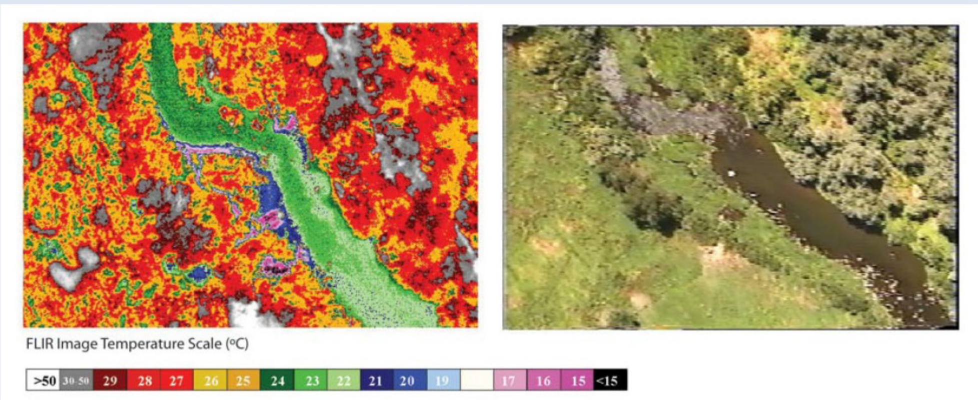
Regional scale

Thermal imagery



(http://pubs.usgs.gov/circ/circ1293/circ1293.html)

Abigail Lovett / Rogier Westerhoff

Regional scale

River chemistry

- Mass balance / mixing of two end-members
- 'Tracer-based hydrograph separation'
- Typical tracers: ion concentrations, hydrogen and oxygen isotopes, EC, helium, radon, CFCs

➢ Requires sufficient difference between river and GW
➢ Assumes evenly distributed GW discharge between sampling locations
➢ Assumes complete mixing

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Regional scale

Groundwater chemistry

- Groundwater recharge from river → losing rivers
- Groundwater velocity away from river represents loss rate
- Groundwater age allows calculation of groundwater velocity
- Typical tracers: Radon, tritium, ^{14}C, CFCs

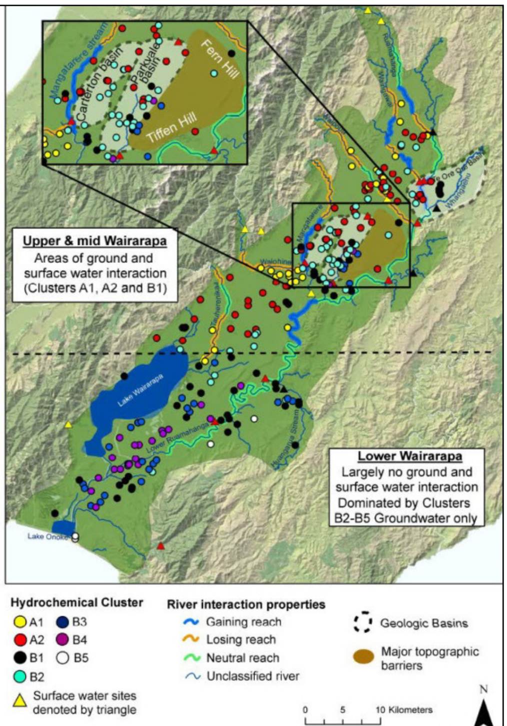
Murray Close

Auckland Council

Groundwater & Surface water chemistry

Hierarchical cluster analysis

- Groups sites into clusters based on hydrochemical similarity
- Assumes that similarity between GW and SW indicates interaction



(Guggenmos et al. 2011)

Rob van der Raaij

Auckland Council

Overview

Stage 1 **Stage 2**

Point scale	Reach scale	Regional scale
Seepage meters	**Distributed temperature sensing**	**Hydraulic head /gradients (water table)**
Streambed piezometers	**Radon sampling**	Differential flow gauging
Temperature profiles		Hydrograph separation
		Solute tracers
		Thermal imagery
		River chemistry
		GW chemistry (Radon)
		SW + GW chemistry (HCA)

Auckland Council

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Conant, B., 2004. Delineating and quantifying ground water discharge zones using streambed temperatures. *Ground Water*, 42(2), pp.243–257.

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Harvey, J.W. & Wagner, B.J., 2000. Quantifying hydrologic interactions between streams and their subsurface hyporheic zones. In J. B. Jones & P. J. Mulholland, eds. *Streams and Groundwaters*. Academic Press, San Diego.

Kalbus, E., Reinstorf, F. & Schirmer, M., 2006. Measuring methods for groundwatersurface water interactions: a review. *Hydrology and Earth System Sciences*, 10(6), pp.873–887.

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Westhoff, M.C. et al., 2007. A distributed stream temperature model using high resolution temperature observations. *Hydrology and Earth System Sciences*, 11(4), pp.1469–1480.

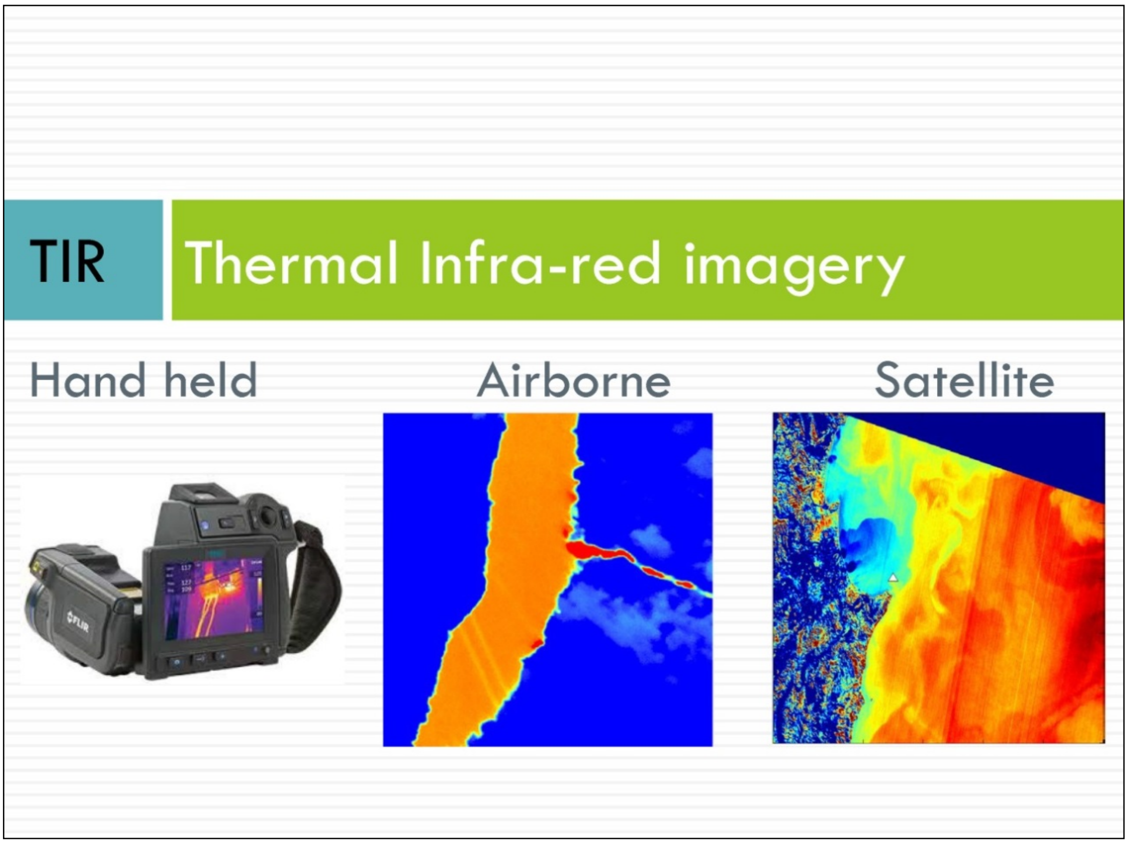
Wilson, J. (2013): What lies beneath…? Thermal remote sensing unveils the Mask. PlanetGeog@TCD (https://planetgeogblog.wordpress.com/2013/11/27/what-lies-beneath-thermal-remote-sensing-unveils-the-mask/)

Winter, T.C. et al., 1998. *Ground Water and Surface Water : A Single Resource*, U. S. Geological Survey.

Wroblicky, G.J. et al., 1998. Seasonal variation in surface-subsurface water exchange and lateral hyporheic area of two stream-aquifer systems. *Water Resources Research*, 34(3), pp.317–328.

2.2.2 Application of satellite, airborne and handheld thermal infrared imaging to characterise GW-SW interaction

Facilitators: Abigail Lovett and Rogier Westerhoff, GNS Science



TIR images show the behavior of the earth and water to the thermal wave band (~10 micrometer, larger than optical).

A TIR image is not just a straightforward temperature image, it contains information on:

(1) material composition,
(2) temperature, and
(3) reflections on the illuminated area.

Activity 1: Using the hand held imager

Activity 2: Interpreting TIR images

Airborne:
Upper Waikato River catchment

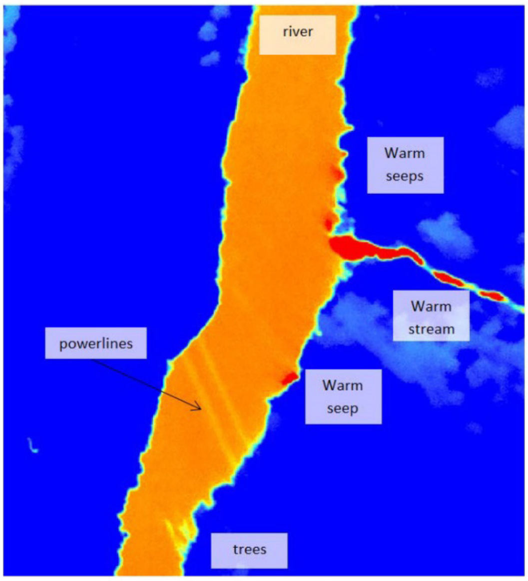
- FLIR mounted to a fixed wing aircraft
- Manual processing
- Look at the TIR images and the aerial image and try to interpret the processes that are occurring. Then compare with the guided answer sheet.

Satellite:
Heretaunga Plains coastal region

- Landsat 8 thermal band (band 10)
- Quick processing (automated)

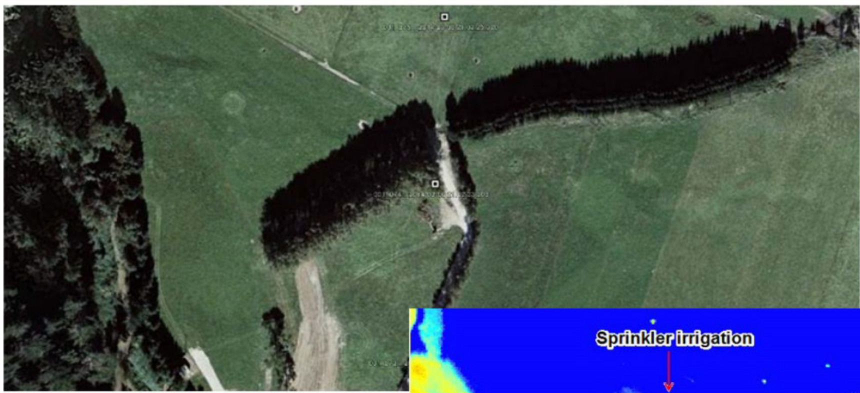
Airborne: Upper Waikato River catchment

Aerial image of the case study site.

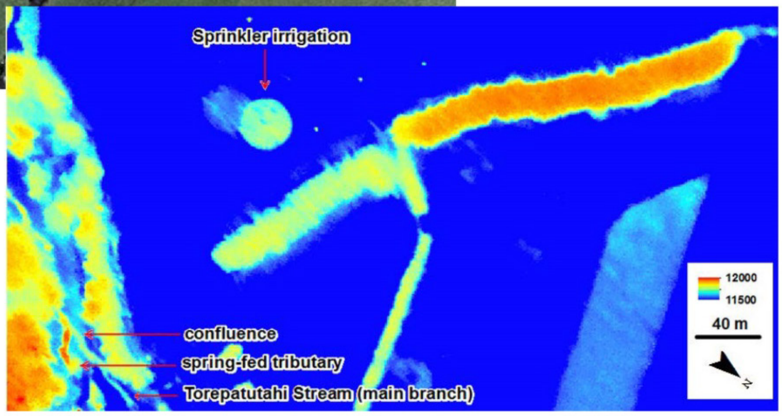


TIR image and suggested features.

Airborne: Upper Waikato River catchment



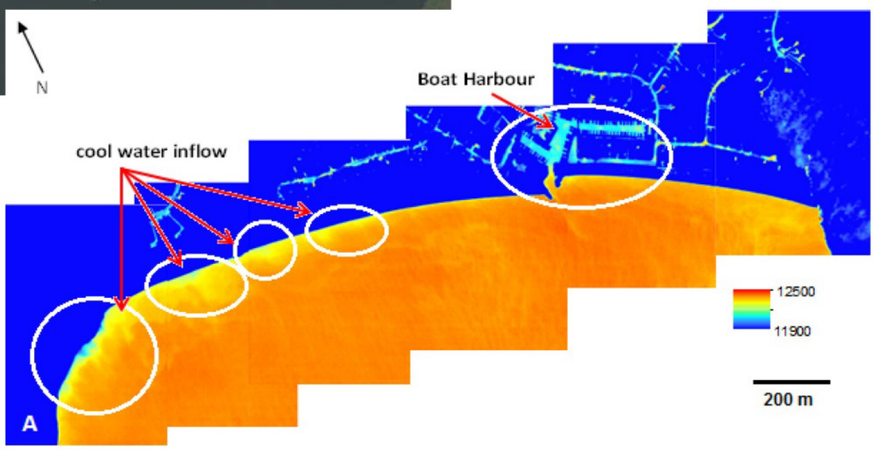
Aerial image of the case study site.



TIR image and suggested features.

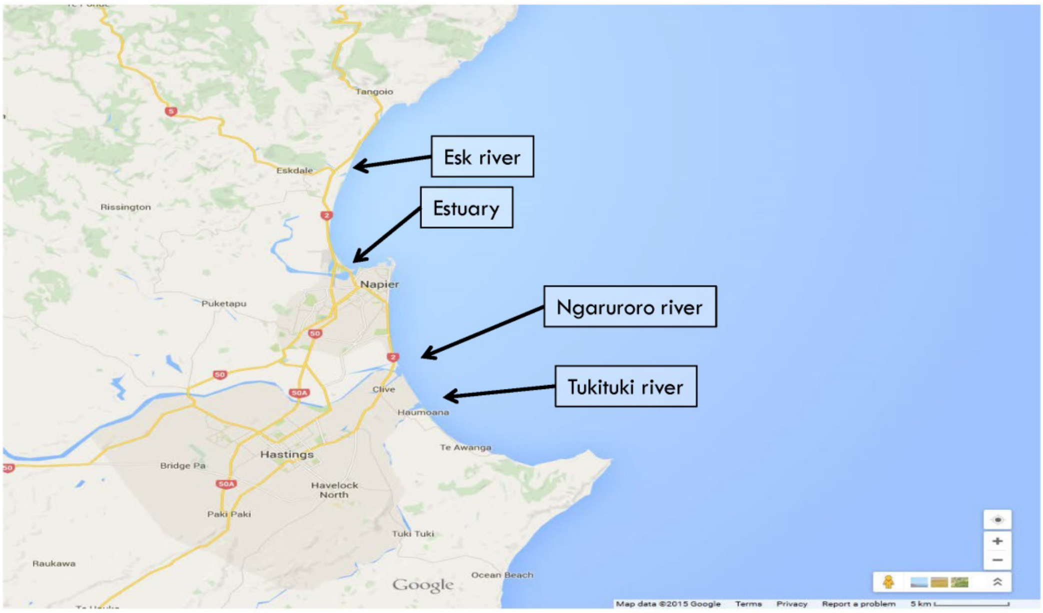
Airborne: Upper Waikato River catchment

Aerial image of the case study site.

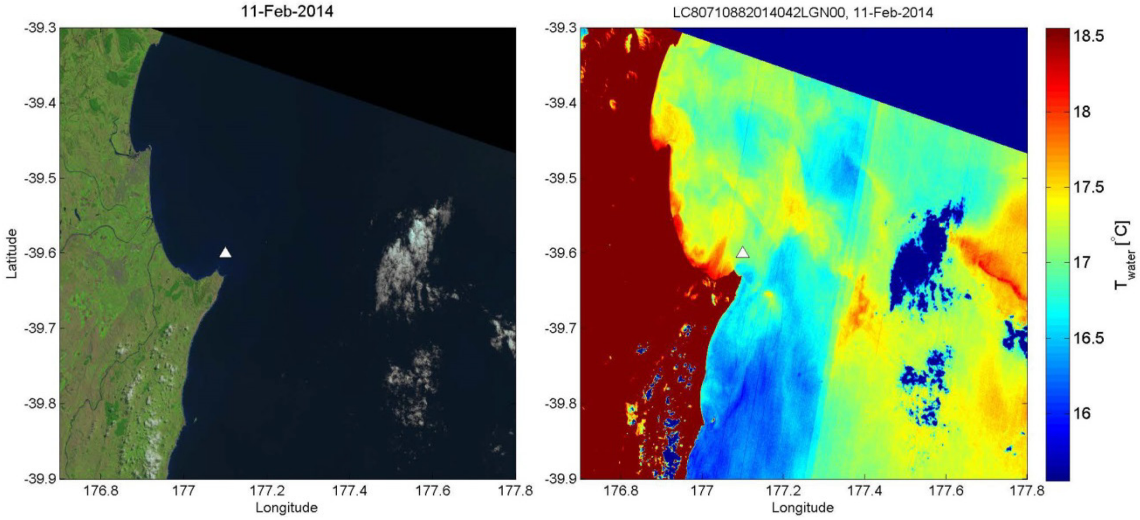


TIR image and suggested features.

Satellite: Heretaunga Plains coastal region

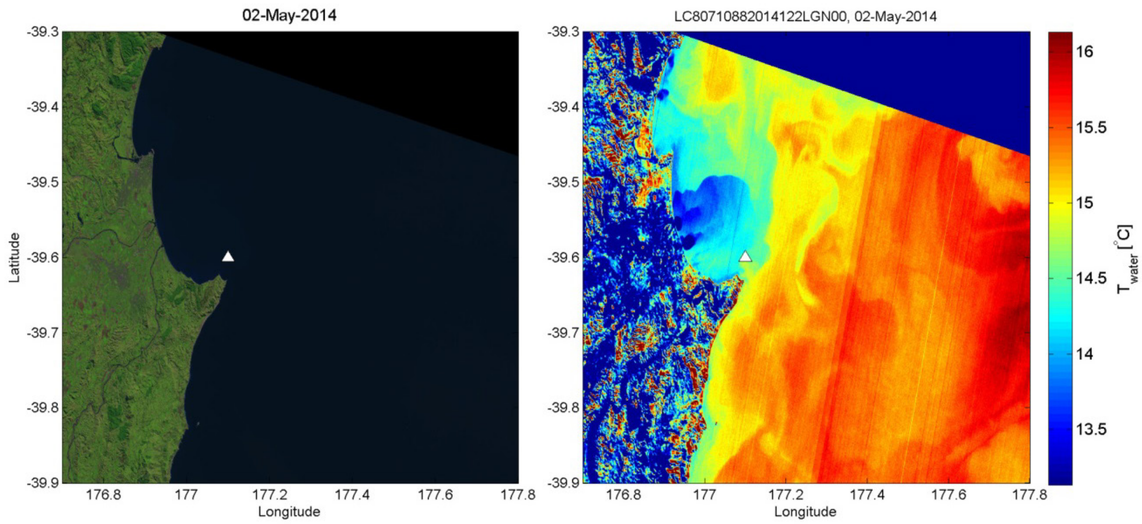


Satellite: Heretaunga Plains coastal region



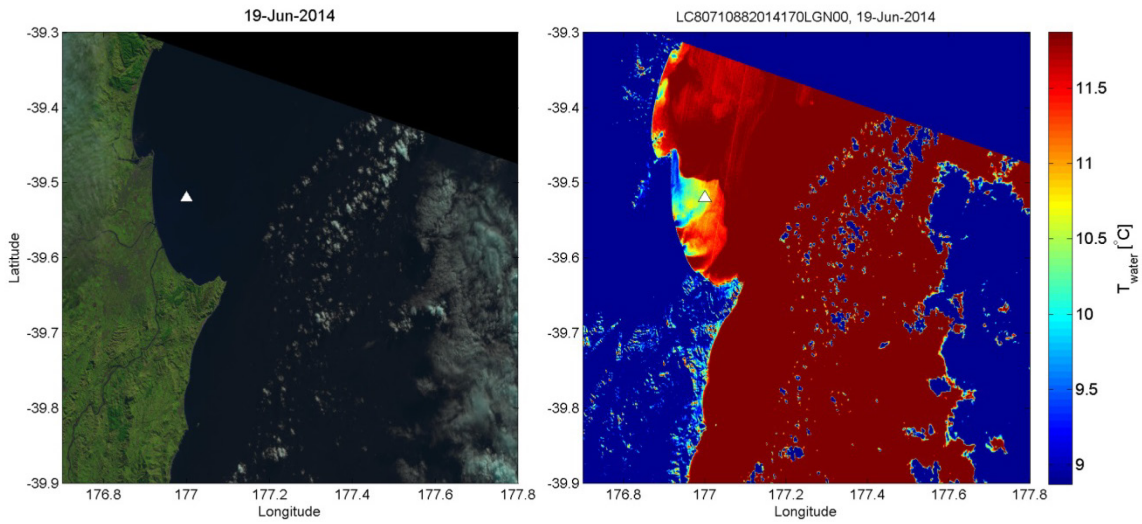
White triangle = calibration point

Satellite: Heretaunga Plains coastal region



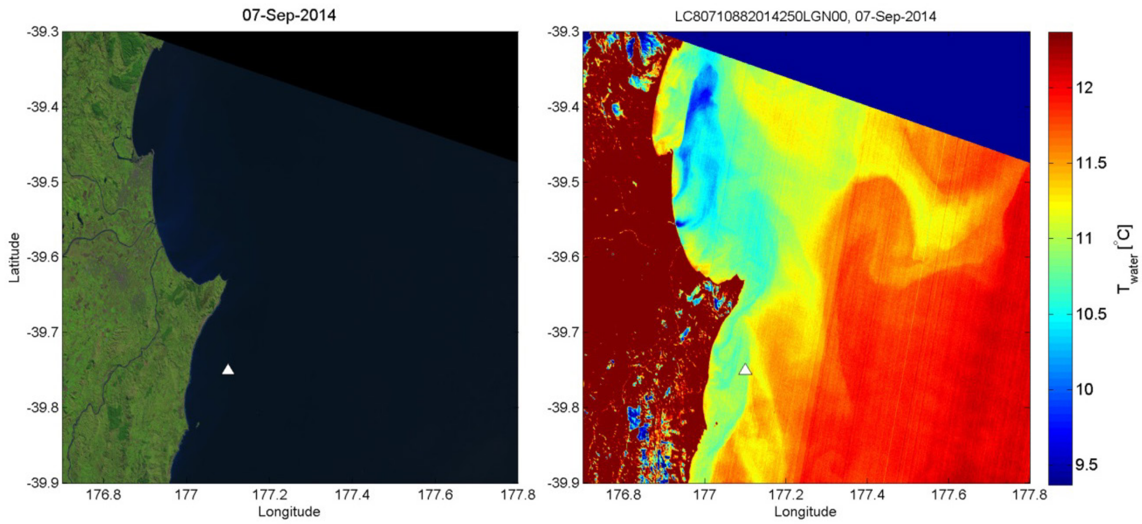
White triangle = calibration point

Satellite: Heretaunga Plains coastal region



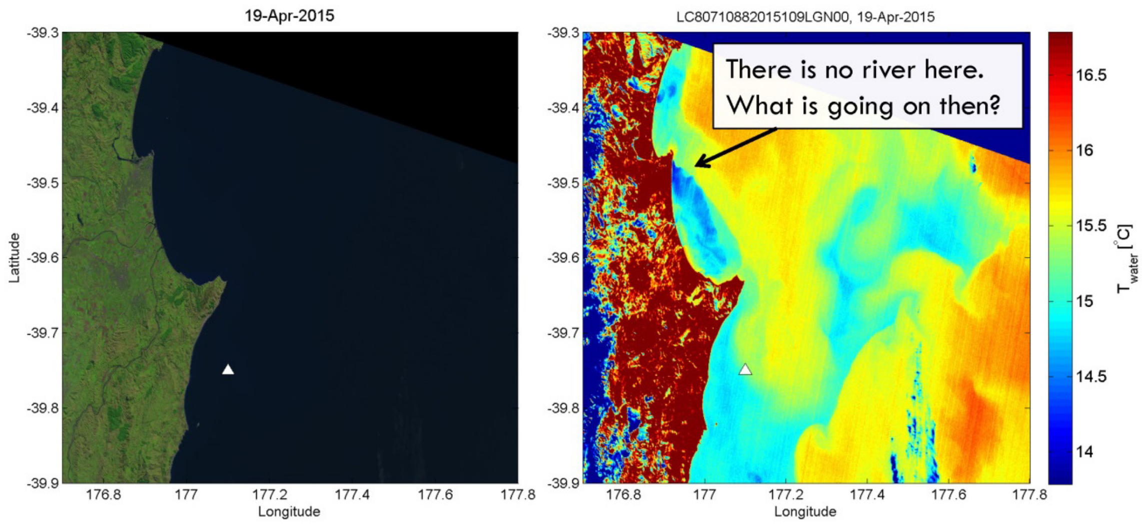
White triangle = calibration point

Satellite: Heretaunga Plains coastal region



White triangle = calibration point

Satellite: Heretaunga Plains coastal region

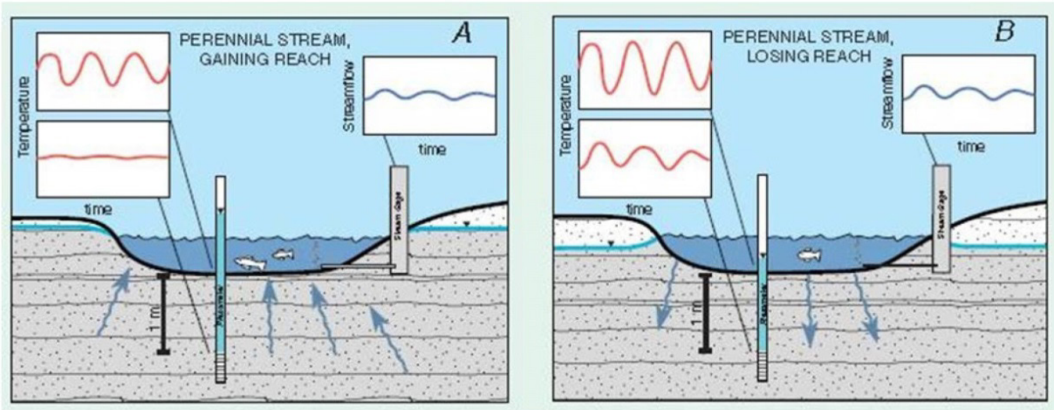


White triangle = calibration point

2.2.3 Fibre optic distributed temperature sensing to characterise GW-SW interaction

Facilitator: Maryam Moridnejad, GNS Science

Why use temperature as a tracer?



Why Fibre Optic Distributed Temperature Sensing (FODTS)?

Since 2006 FODTS technique has been used for hydrological applications.

Very high spatial and temporal resolution **(~ 1 m and < 1 minute)**

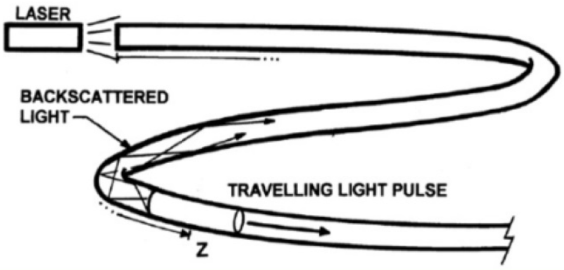
Excellent temperature precision **(0.01° C)**

Over large distances **(up to 30 km)**

Theory of fibre optic distributed temperature sensing (FODTS)

A portion of the transmitted energy is scattered back at shorter (Anti-Stokes) and longer (Stokes) wavelengths.

The Stokes/Anti-Stokes ratio provides temperature along the cable.



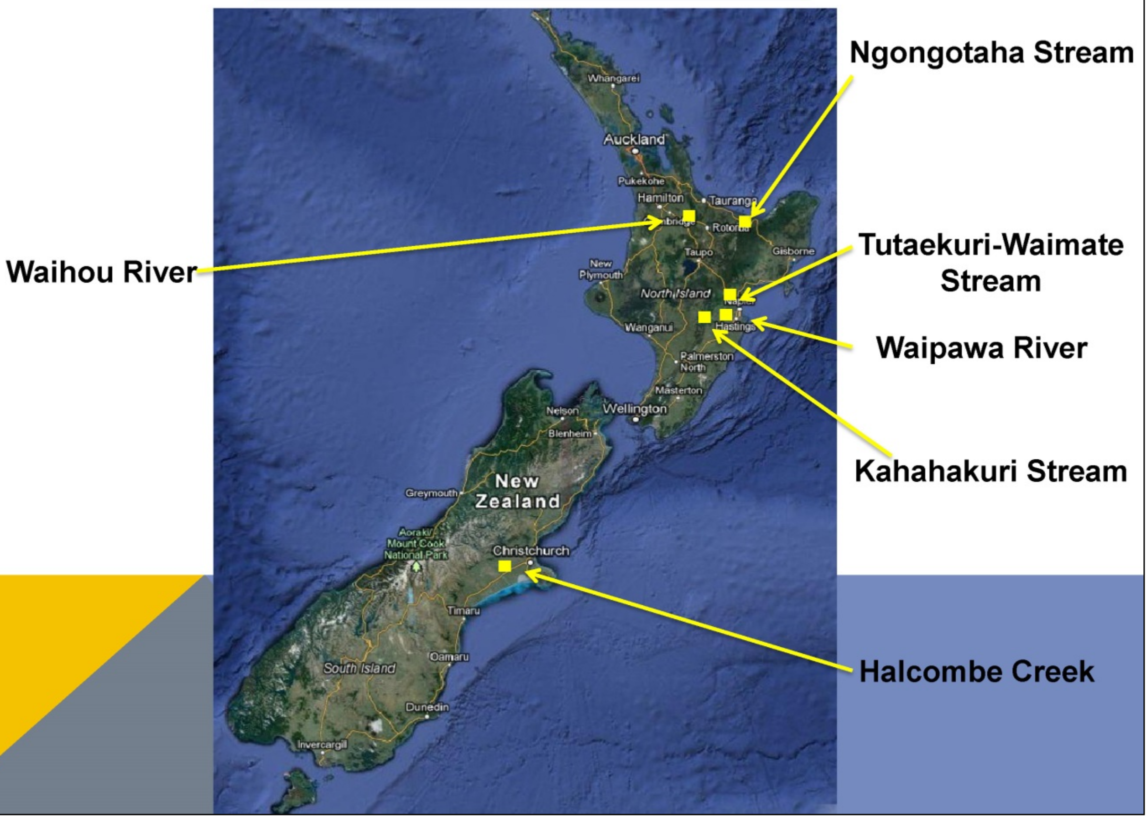
Calibration

How FODTS help us for better characterization of groundwater-surface water interaction

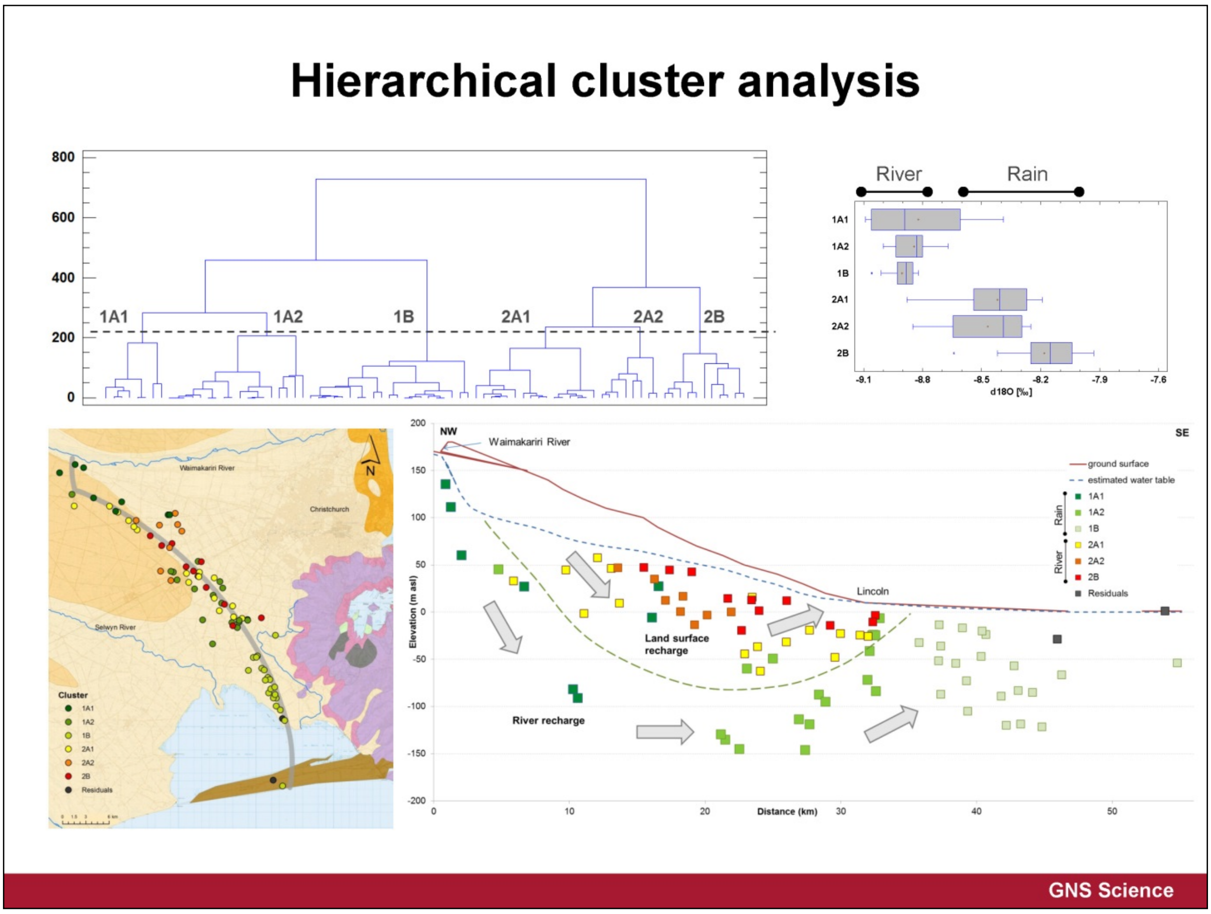
To identify the location of springs and/or diffuse discharge in stream/river reaches

Quantify groundwater discharge

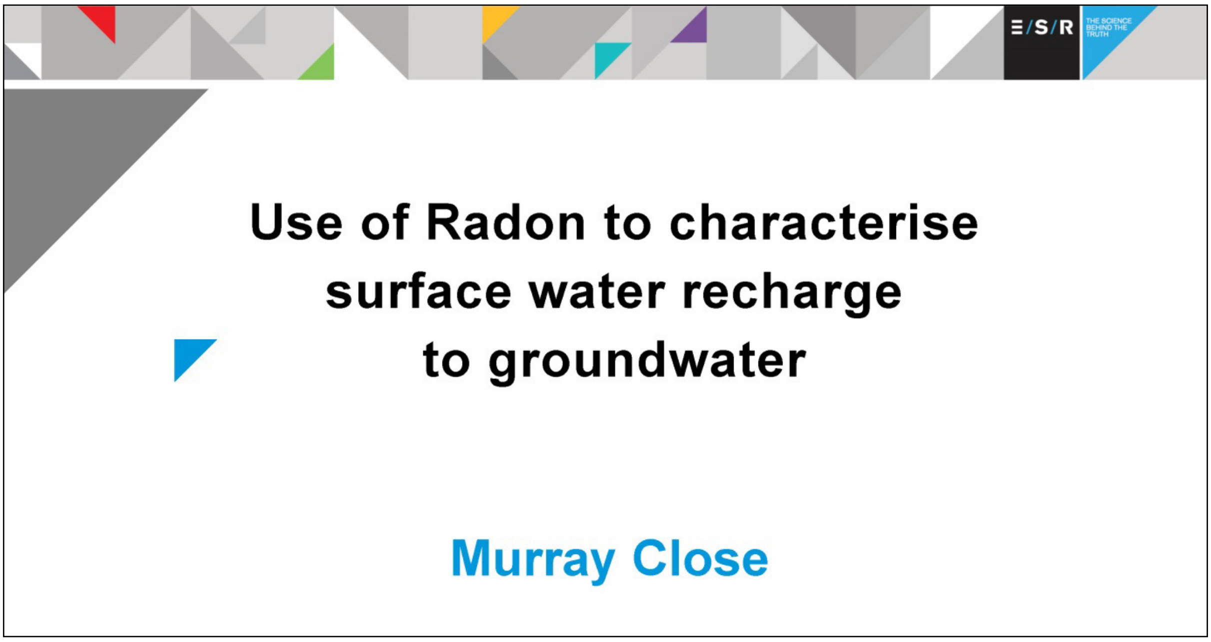
Case study areas

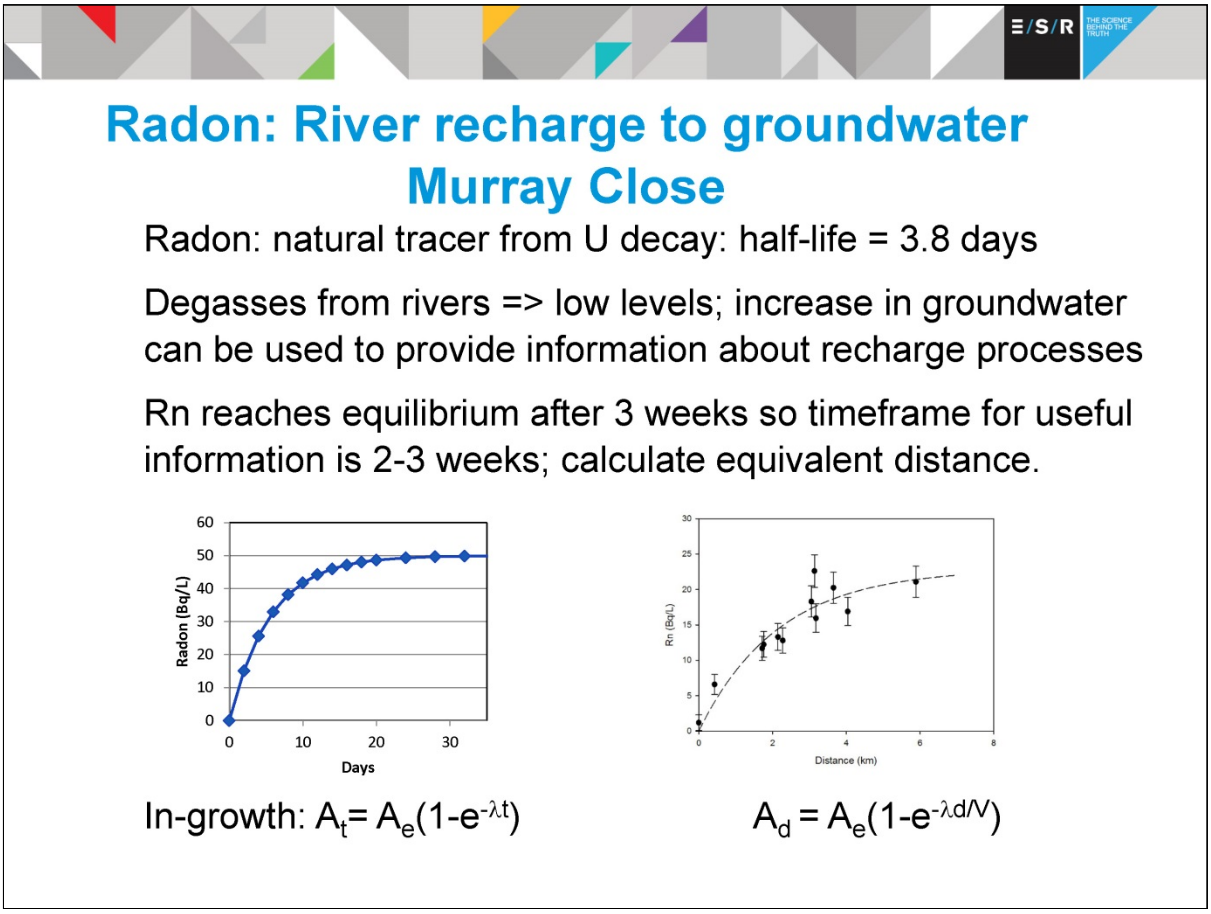


2.2.4 Using Hierarchical Cluster Analysis (HCA) to identify river water signature in groundwater, and groundwater signature in rivers
Facilitator: Rob van der Raaij, GNS Science



2.2.5 Use of radon for indication of river recharge to groundwater
Facilitator: Murray Close, ESR





Outline

- Go through methodology
- Apply to two sites
  - Waimakiriri River near Christchurch
  - Wairau River near Blenheim
- Look at other potential applications
- Reference: Close, M.; Matthews, M.; Burbery, L.; Abraham, P.; Scott, D. (2014). Use of Radon to characterise surface water recharge to groundwater. Journal of Hydrology (New Zealand) 53(2): 97-111.

Canterbury Plains

New Zealand

Background

- In 2011 National Radiation Laboratory (NRL) became part of ESR
- Routinely measure Radon (Rn)
- Opportunity to explore some hydrological applications
- Surface water – groundwater interaction

Radon-222

- Part of the U-238 decay series
- Ra-226 decays to Rn-222 $T_{1/2}$ = 1620 yr
- Rn-222 decays to Po-218 $T_{1/2}$ = 3.8 days

- Eventually ends up as Pb-210 ($T_{1/2}$ = 22.3 yr) and Pb-206 (stable)
- Present in minerals like greywacke

- Rn gas reasonably soluble in water but will degas to the atmosphere
  - Hence rivers will have low Radon levels

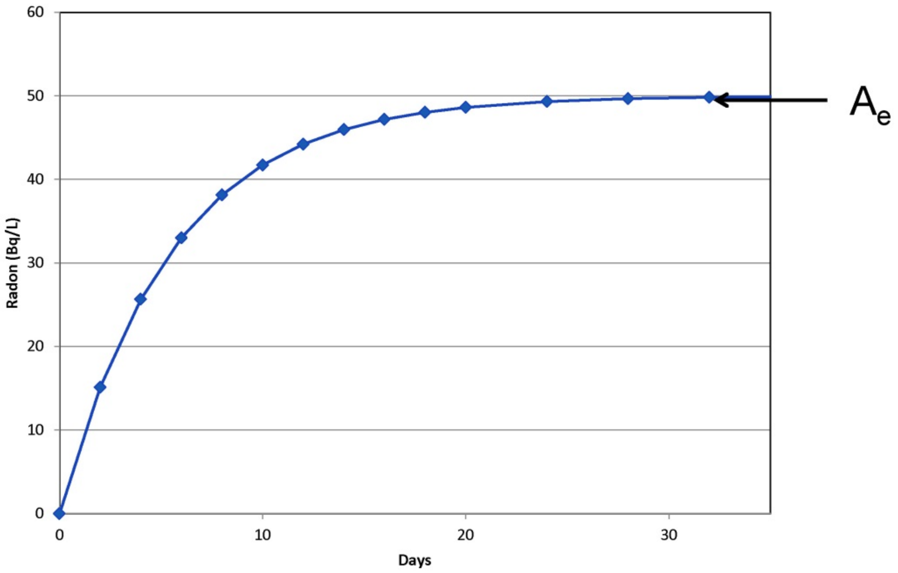
Radon-222

- Ra-226 is distributed in rocks and sediments
- If it decays near the surface of a mineral grain under water, then Rn may be transferred to the water.
- At equilibrium, rate of production (entry into water) = rate of decay
- In-growth: $A_t = A_e(1-e^{-\lambda t})$

where $A_{t,e}$ = Rn activity at times t and equilibrium;

λ = decay constant (0.18 day^{-1})

Increase of Radon in groundwater with time



Assumptions for GW-surface water interaction

- Distribution of Rn precursors is homogeneous
- A_e measured away from the river is representative of the water flow path
- Losses of Rn to VZ and atmosphere are constant
- Infiltrating water does not mix with older groundwater
- No additional recharge through surface features such as streams or stock water races

Assumptions for GW-surface water interaction

- Distribution of Rn precursors is homogeneous
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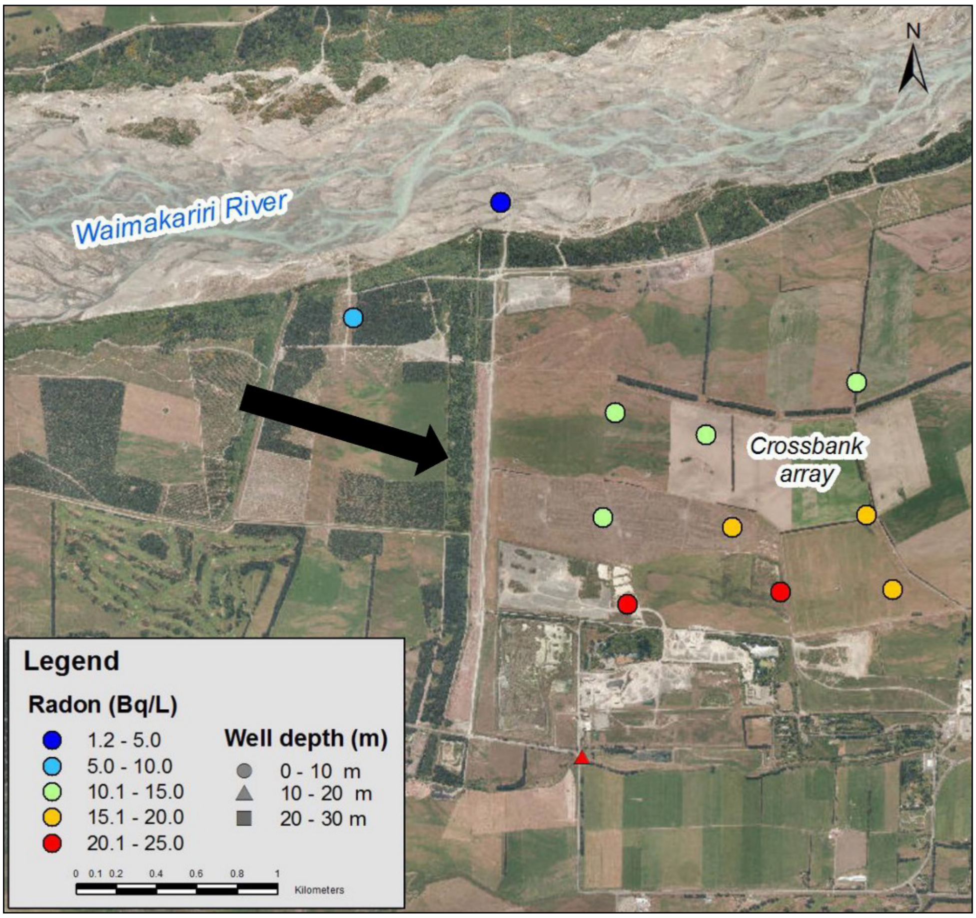
- Infiltrating water does not mix with older groundwater
- No additional recharge through surface features such as streams or stock water races

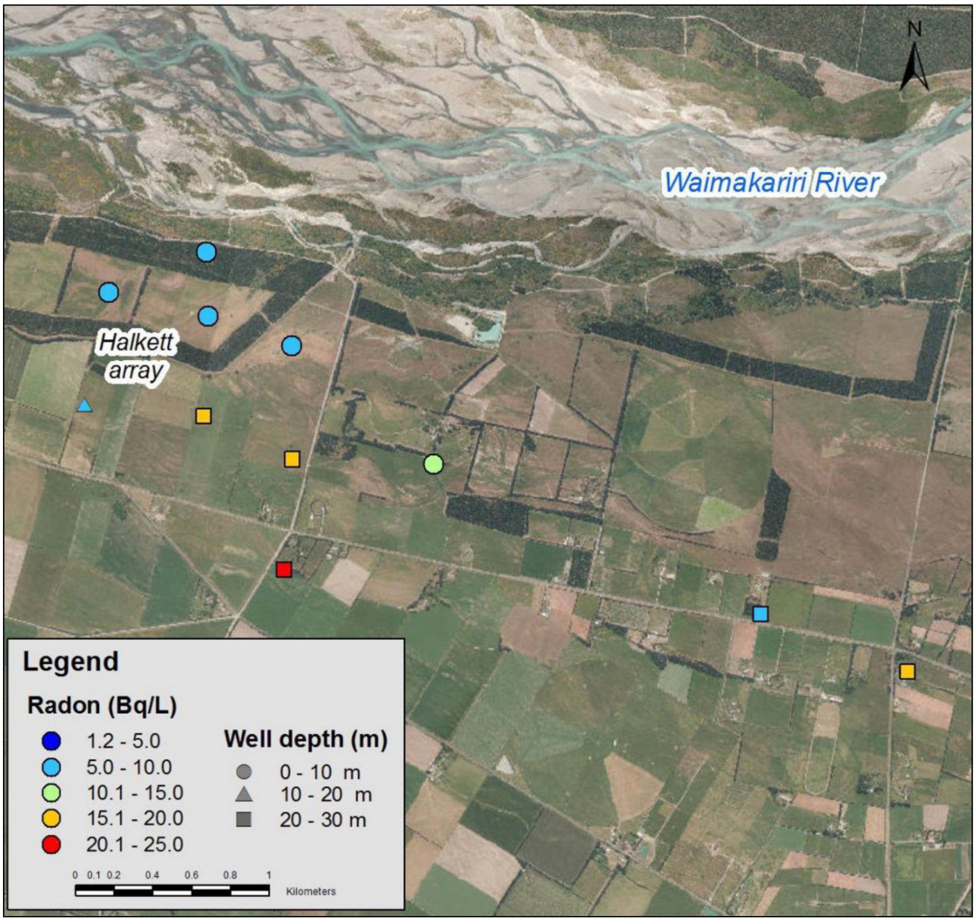
Historical data for Rn

- NRL carried out a survey of Rn in potable water supplies in 1980
- High levels (12- 50 Bq/L) in alluvial gravel aquifers
  - Canterbury, Napier
- Significantly below health thresholds but easily detectable

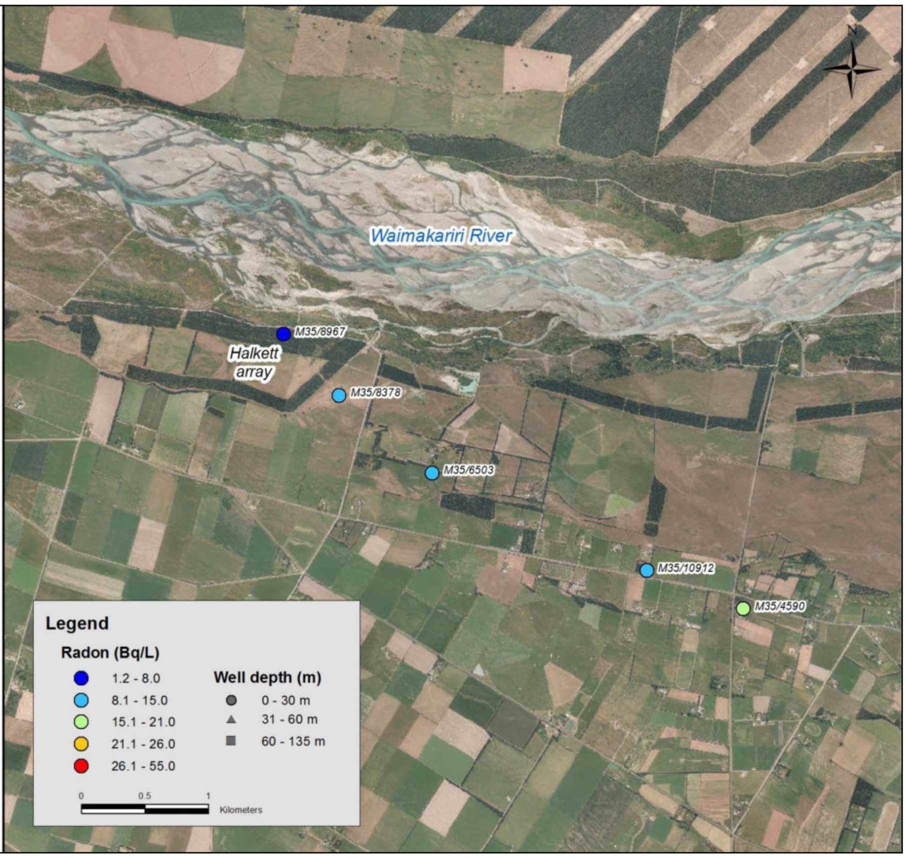
Site selection

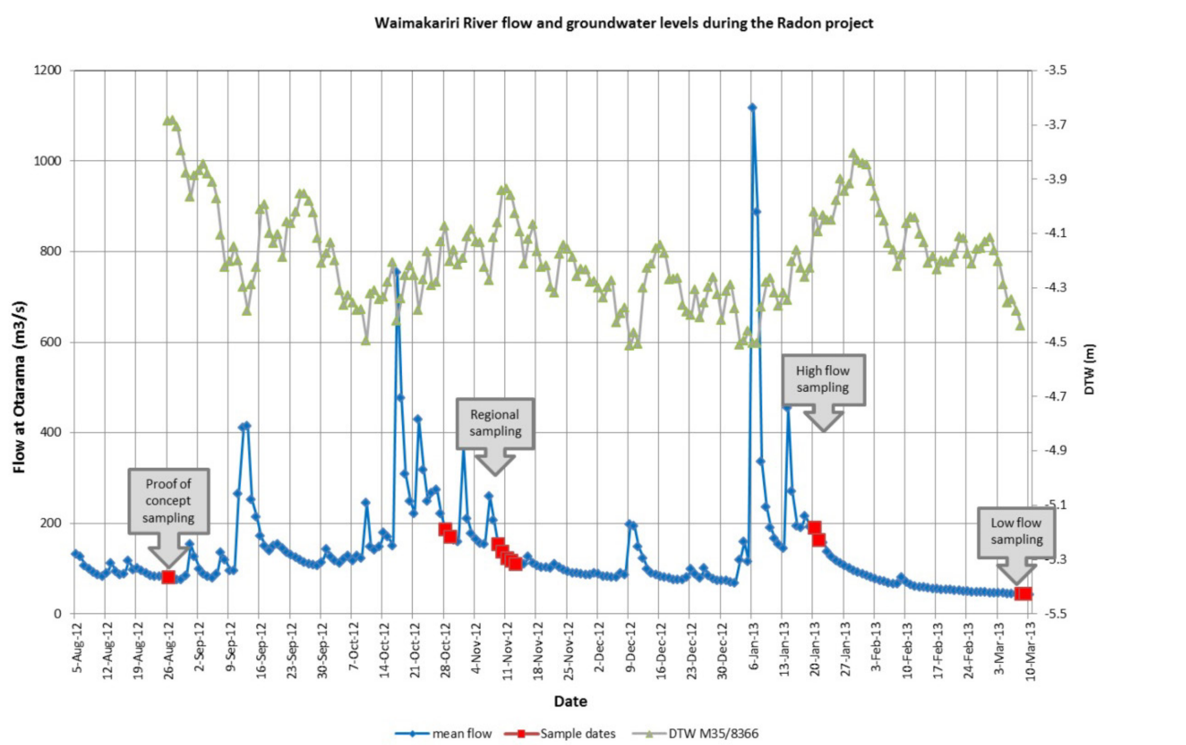
- River that was known to lose water & recharge groundwater
- Shallow wells close to the river
- Waimakariri River
  - Two sites with arrays of wells close to river
- Wairau River near Blenheim


N
Waimakariri River
Crossbank
array
Legend
Radon (Bq/L)
1.2 - 5.0
5.0 - 10.0
10.1 - 15.0
15.1 - 20.0
20.1 - 25.0
Well depth (m)
0 - 10 m
10 - 20 m
20 - 30 m
0 0.1 0.2 0.4 0.6 0.8 1
Kilometers


N
Waimakariri River
Halkett
array
Legend
Radon (Bq/L)
1.2 - 5.0
5.0 - 10.0
10.1 - 15.0
15.1 - 20.0
20.1 - 25.0
Well depth (m)
0 - 10 m
10 - 20 m
20 - 30 m
0 0.1 0.2 0.4 0.6 0.8 1
Kilometers

Issues with estimation of distance





Flow conditions

Date	7 day mean (m^3/s)	14 day mean (m^3/s)	21 day mean (m^3/s)	Sampling
16/01/2013	244	273	264	Crossbank
17/01/2013	202	221	268	Halkett
4/03/2013	45	47	49	Crossbank
5/03/2013	44	46	48	Halkett

- Factor of 4.5 to 6 between low and high flows

Variation of Radon with Flow

Well_No	Sample	Radon	Difference
M35/8372	Halkett-High	22.5	-0.8
	Halkett-Low	21.7	
M35/8375	Halkett-High	14.4	2
	Halkett-Low	16.4	
M35/8376	Halkett-High	20.1	-2.1
	Halkett-Low	18	
M35/8377	Halkett-High	10.5	-1
	Halkett-Low	9.5	
M35/8378	Halkett-High	8.7	-0.8
	Halkett-Low	7.9	
M35/8379	Halkett-High	9	-1.4
	Halkett-Low	7.6	
M35/8380	Halkett-High	8.2	0.7
	Halkett-Low	8.9	
M35/8967	Halkett-High	5.5	-1.5
	Halkett-Low	4	
		Mean Diff =	-0.6

Variation of Radon with Flow

Well_No	Purpose	Radon	Difference
M35/8363	Crossbank-H	16.6	0.6
	Crossbank-L	17.2	
M35/8364	Crossbank-H	19	2.5
	Crossbank-L	21.5	
M35/8365	Crossbank-H	20.1	5
	Crossbank-L	25.1	
M35/8366	Crossbank-H	15.1	1.7
	Crossbank-L	16.8	
M35/8367	Crossbank-H	17.8	1
	Crossbank-L	18.8	
M35/8368	Crossbank-H	12.5	0.6
	Crossbank-L	13.1	
M35/8369	Crossbank-H	10.8	1.8
	Crossbank-L	12.6	
M35/8370	Crossbank-H	14	-1.4
	Crossbank-L	12.6	
M35/8371	Crossbank-H	13.1	-1.7
	Crossbank-L	11.4	
M35/8968	Crossbank-H	6.3	0.6
	Crossbank-L	6.9	
	Mean Diff =		1.07

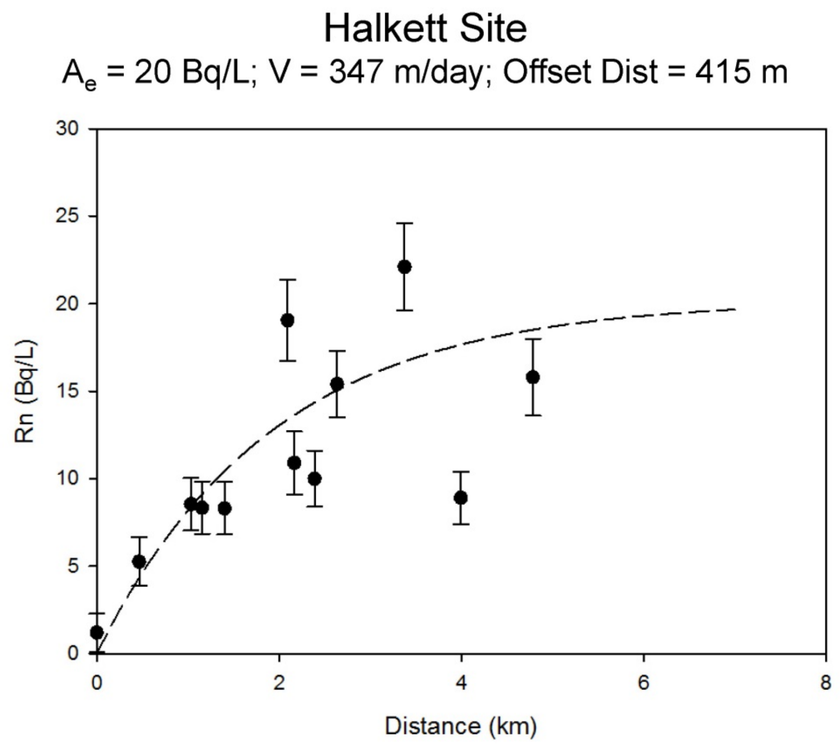
E/S/R THE SCIENCE BEHIND THE TRUTH

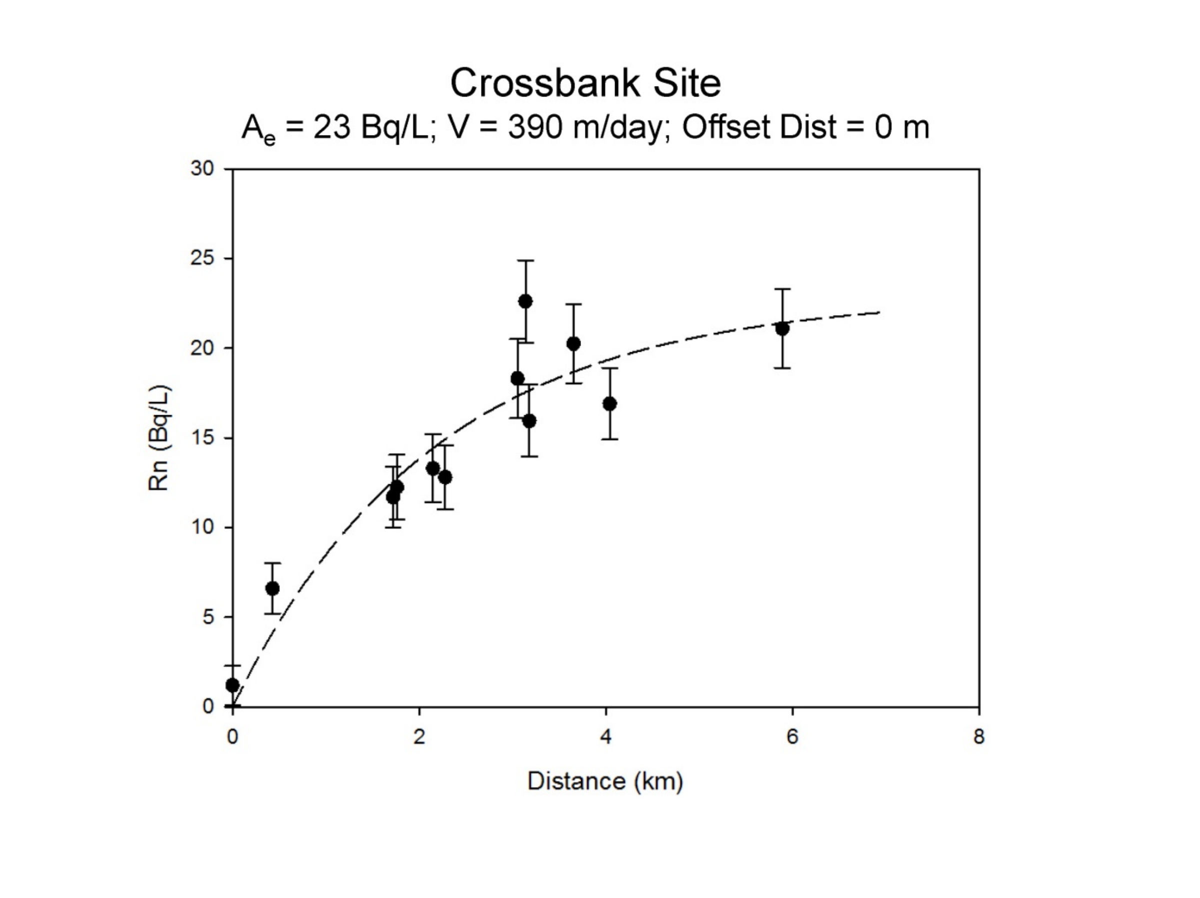
Variation of Radon with Flow

- Analytical errors in Radon measurement are between 1.1 and 2.5 Bq/L
- Increase with increase in concentration
- Little variation in Radon with flow
- Consistent with previous work
- Therefore we averaged the observed Radon data before model fitting

Fitting the model

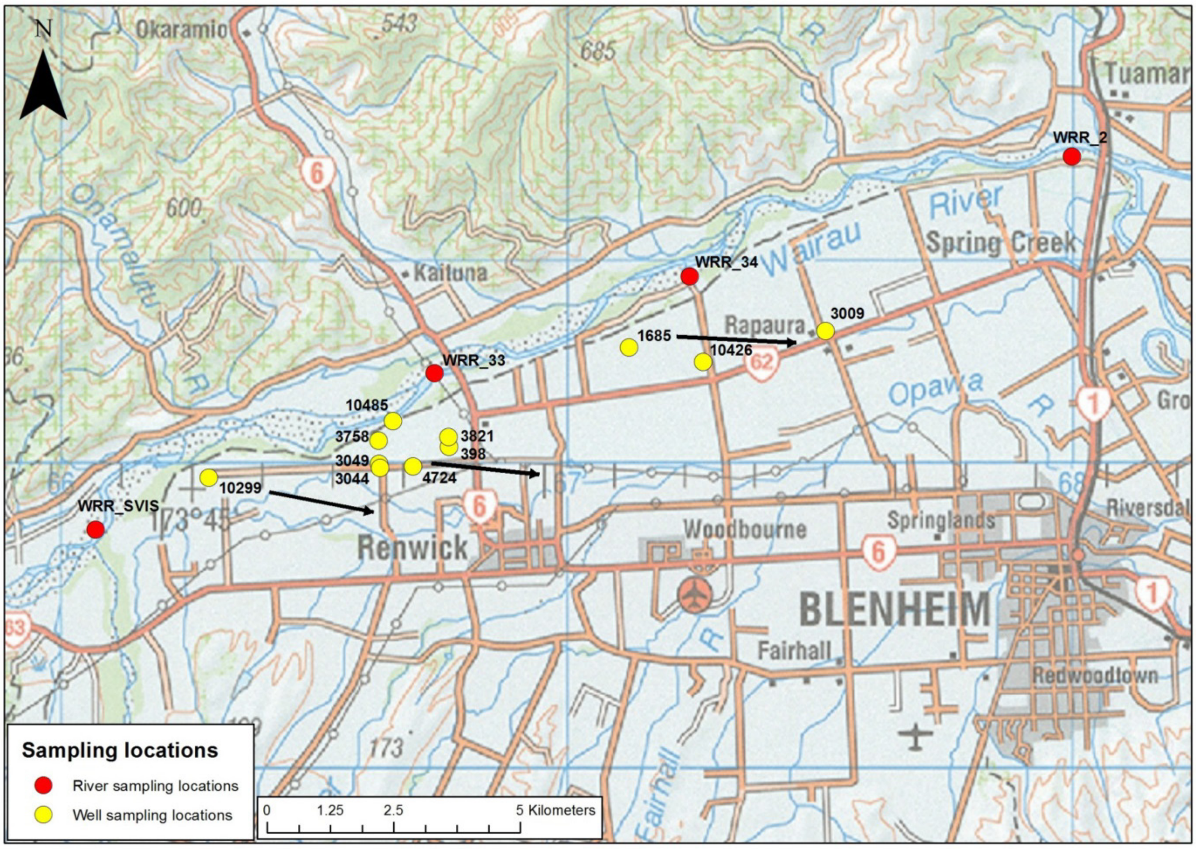
- $A_t = A_e(1-e^{-\lambda t})$
- $A_d = A_e(1-e^{-\lambda d/V})$
- d = estimated distance to river edge plus offset distance
- Optimise for A_e; V; offset distance
- Used Excel solver



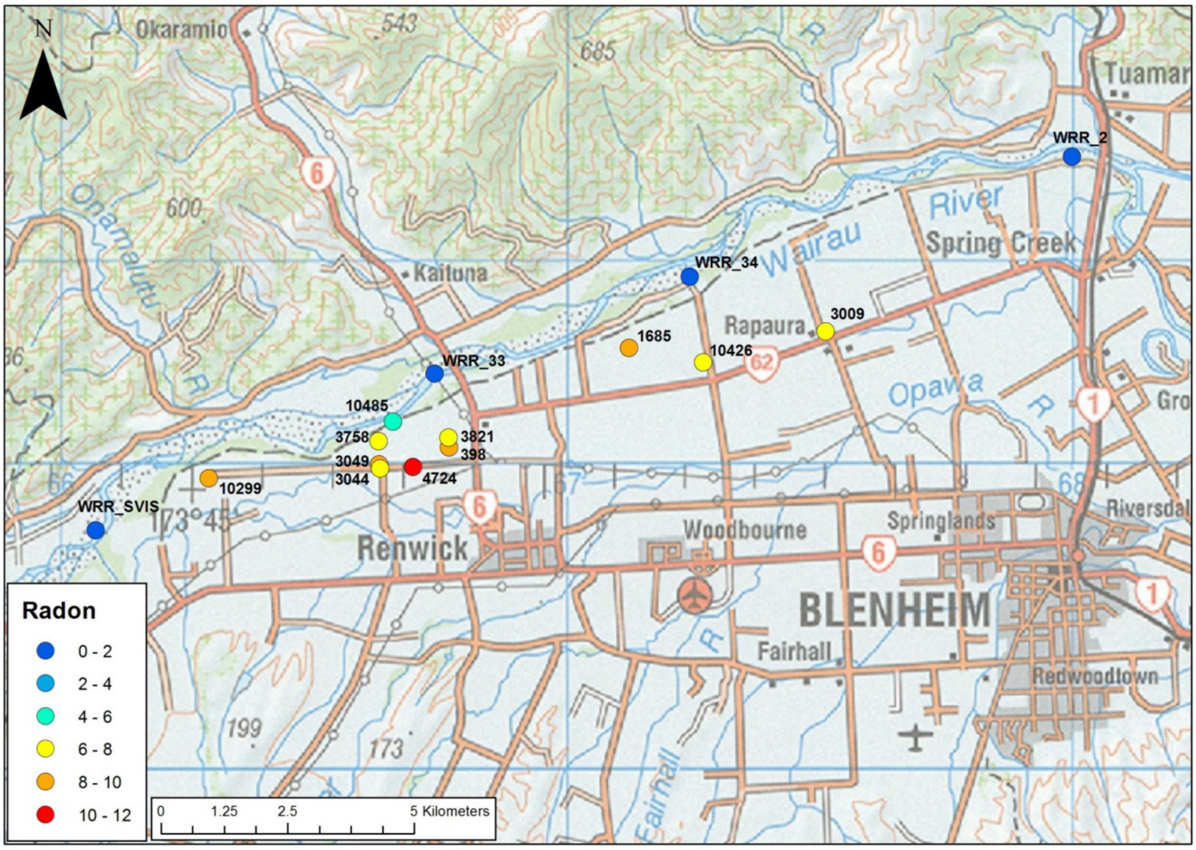


Variation in A_e

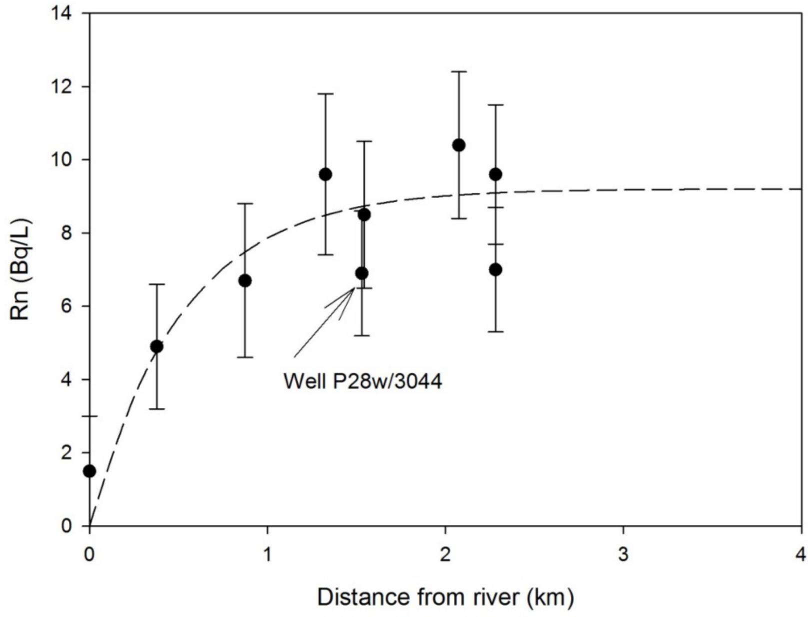
- Both arrays close to the river, A_e = 20 – 23 Bq/L
- Further away and deeper, A_e could be higher
- A_e varies with rock type
  - Greywacke is reasonably high in NZ context
- A_e varies with particle size
  - Smaller particles have higher surface area
- A_e varies with amount of organic material
  - Peat & other organic matter have lower Rn levels

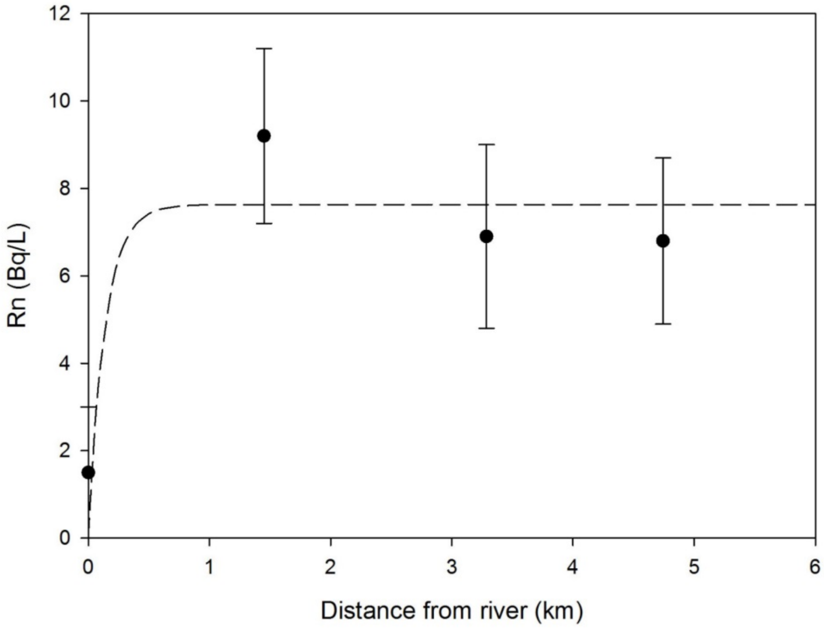


Sampling locations
River sampling locations
Well sampling locations
WRR_2
WRR_34
WRR_33
WRR_SVIS
1685
3009
10426
10485
3758
3821
398
3049
3044
4724
10299
0 1.25 2.5 5 Kilometers



Radon
0 - 2
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
WRR_2
WRR_34
WRR_33
WRR_SVIS
1685
3009
10426
10485
3758
3821
398
3049
3044
4724
10299
0 1.25 2.5 5 Kilometers


14
12
10
8
6
4
2
0
Rn (Bq/L)
0
1
2
3
4
Distance from river (km)
Well P28w/3044


12
10
8
6
4
2
0
Rn (Bq/L)
0
1
2
3
4
5
6
Distance from river (km)

Summary of Wairau results

Zone 1: A_e = 9.2 Bq/L; GW velocity = 94 m/day

Zone 2: A_e = 7.6 Bq/L; already at equilibrium
GW velocity < 25 m/day

Lower A_e values than for Waimakiriri study

Currently collecting temperature data and will analyse temperature and radon data together

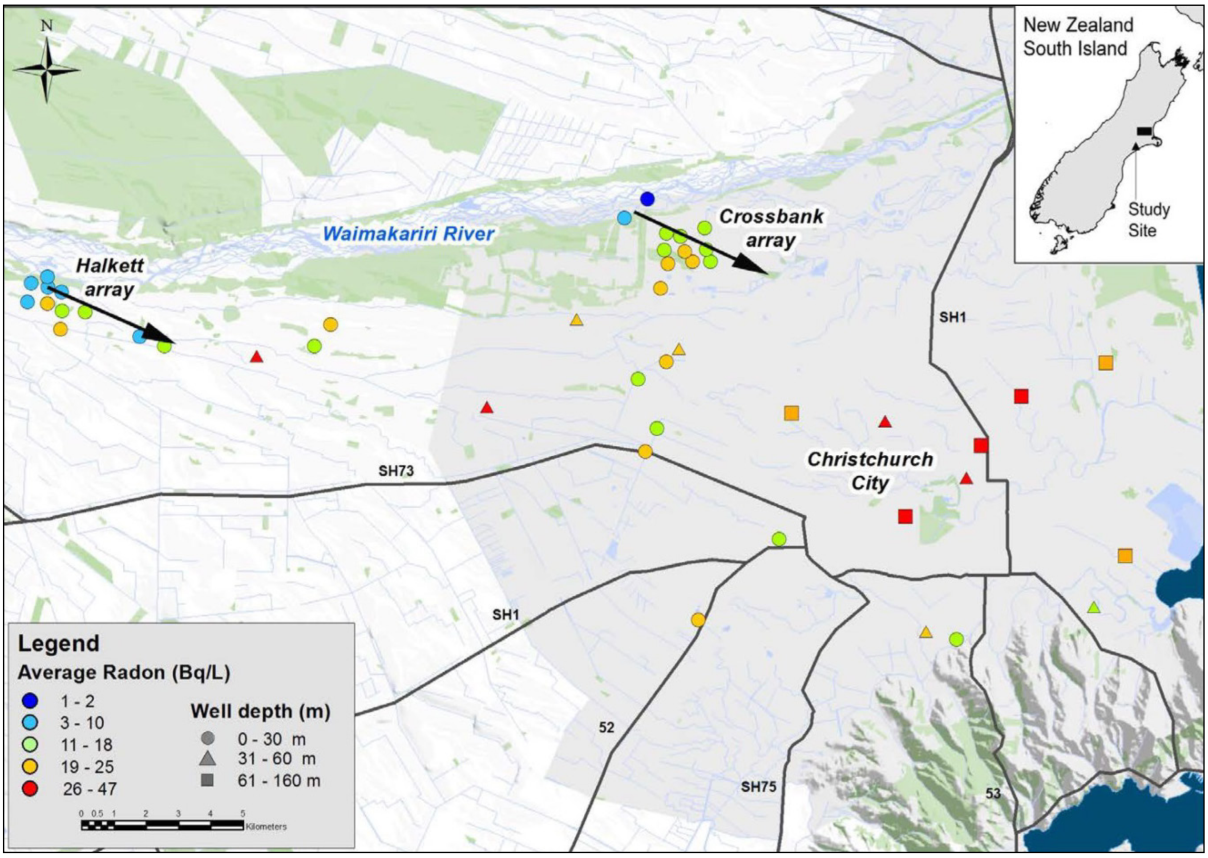
Potential applications

- Survey of wells near a river can provide information where groundwater is being recharged
- Can provide relative recharge information
- Quantitative recharge information is limited by knowledge of porosity values and cross-sectional areas
- Limited to where wells are located

Acknowledgements

- ESR & MDC for funding this work
- Murray Matthews, Lee Burbery & Phil Abraham for assistance with projects
- ECan & well owners for access to wells

Questions?


New Zealand
South Island
Study Site
N
Waimakariri River
Crossbank array
Halkett array
SH1
SH73
Christchurch City
SH1
52
SH75
53
Legend
Average Radon (Bq/L)
1 - 2
3 - 10
11 - 18
19 - 25
26 - 47
Well depth (m)
0 - 30 m
31 - 60 m
61 - 160 m
0 0.5 1 2 3 4 5
Kilometers

2.2.6 Use of radon for indication of groundwater discharge to river
Facilitator: Heather Martindale, GNS Science

Radon - Mapping groundwater discharge into surface waters

- Purpose – locate areas of groundwater discharge within a surface water body easily and cheaply
- How it works – Radon is a soluble colourless, gaseous, unstable isotope with a half-life of 3.8 days. It is generated as part of the uranium decay series. Uranium is ubiquitous in almost all rocks and soils, resulting in the release of radon from uranium bearing minerals in groundwater. Radon is abundant in groundwaters but has almost negligible concentrations in surface waters due to rapid radon loss to the atmosphere through degassing. This contrast in radon concentrations between groundwaters and surface waters enables radon to be an ideal tracer to measure groundwater-surface water interaction. Surface waters which have elevated concentrations of radon indicate a location where groundwater is discharging into the surface water. The concentration of radon can be calculated by measuring the alpha decay of radon.

Radon - Mapping groundwater discharge into surface waters

- Techniques – LSC and semiconductor detectors
- LSC – Measurement of the alpha decay from ^{222}Rn and its two daughter products, ^{218}Po and ^{214}Pb, are measured in a low level scintillation counter. LLD = 0.2 BqL^{-1}. Grab sample collected in 25 mL bottles without the presence of air.
- LSC is one of the fastest measurement techniques for processing large numbers of samples at once. Samples can be left unattended whilst the counting process is being carried out. Disadvantage that the lower limit of detection makes it hard to distinguish between waters with low conc. Of radon but enrichment methods have been developed to overcome this – requires taking a larger sample.
- Semiconductor detectors are used in continuous radon detectors– measures energy from radons positively charged polonium daughters. This positive energy is used to calculate radon concentration. Continuous – LLD 0.04BqL^{-1} – only one sample measured per every 30 minutes or longer so a slow process.

Radon - Mapping groundwater discharge into surface waters

- Recap
  - Radon is naturally occurring in almost all rocks and soils but degasses in surface waters
  - Radon in surface waters indicate groundwater discharge
  - LSC provides a fast and efficient method for measuring large numbers of samples.

Activity 1: mapping GW-SW interaction

Purpose: demonstrate how/why radon might be useful

- On Map 2: Indicate where the gaining and losing sections are.
- On Map 3: Indicate where the gaining and losing sections are.

Compare the maps, and in pairs discuss:

Q: What method (LSC or Radon detector is best) for this sampling.
A: LSC – because can collect multiple samples quickly.

Q: The advantages of using radon for this purpose.
A: Quick, cheap, not influenced by underflow beneath the gravels (commonly water flows underneath meanders and this is not captured by flow gauging).

Q: Disadvantages of using radon for this purpose.
A: Half life and how to distinguish between gain or residual radon.

Activity 1: mapping GW-SW interaction

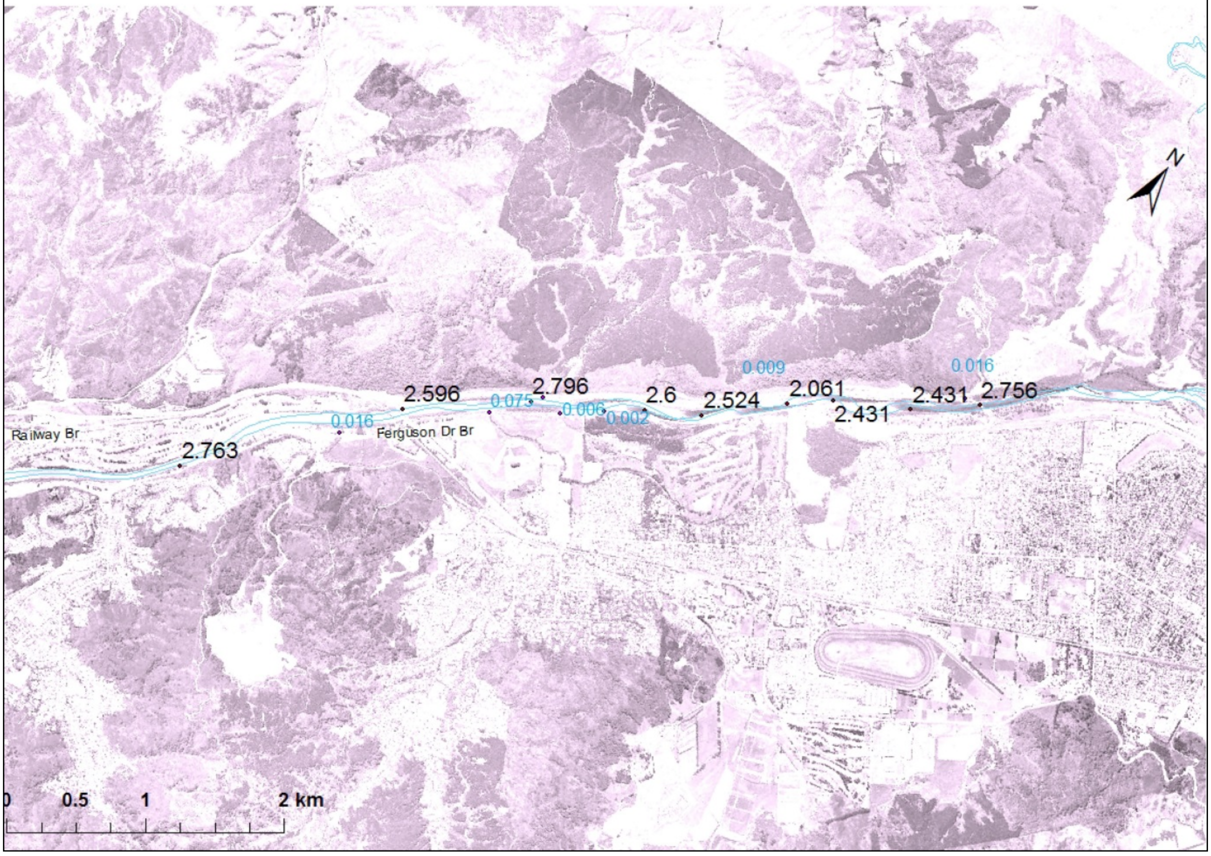
The last few radon concentrations on map 3 decrease.
Q: Is this residual radon or groundwater discharge?

Options:

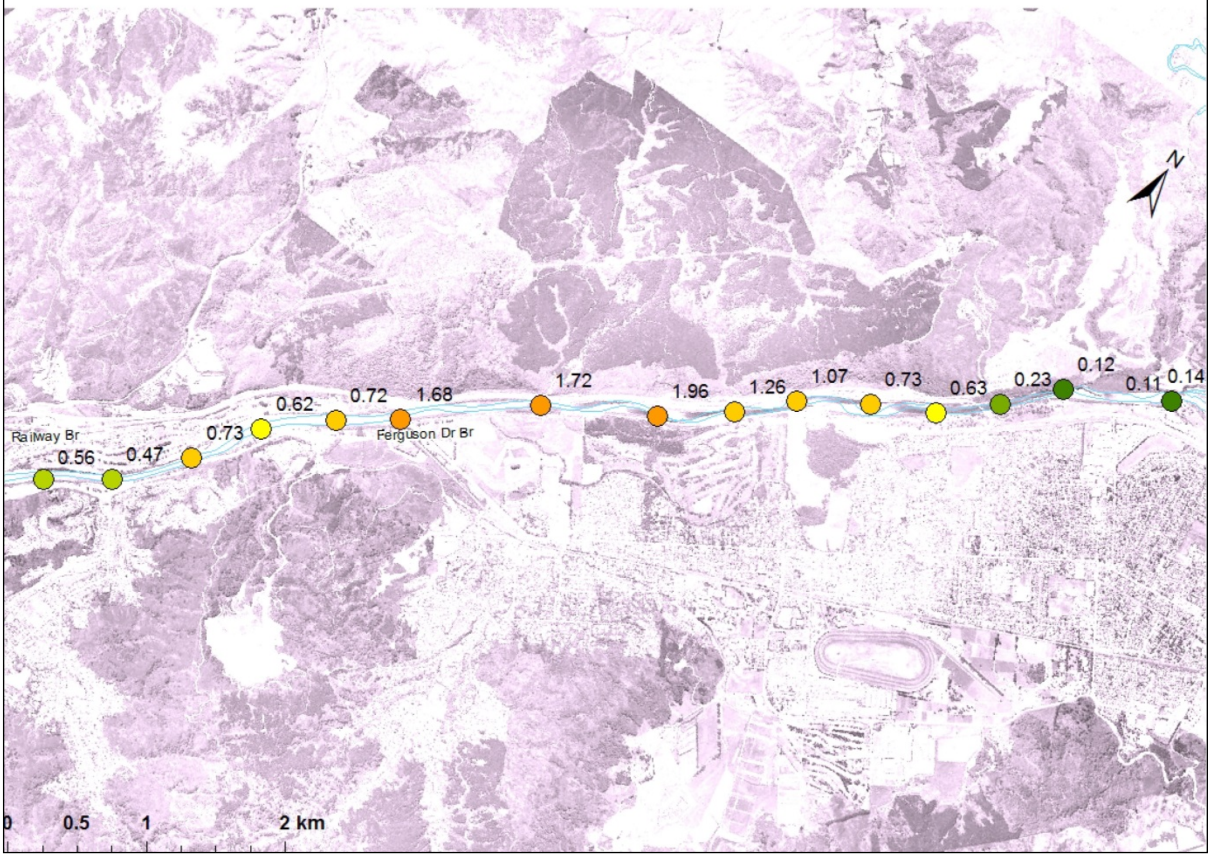
1. We can take a higher sensitivity measurement; OR
2. can complete activity #2.

Case study: Hutt River, Upper Hutt, Map 1

Case study: Hutt River, Upper Hutt, Map 2.



Case study: Hutt River, Upper Hutt, Map 3.

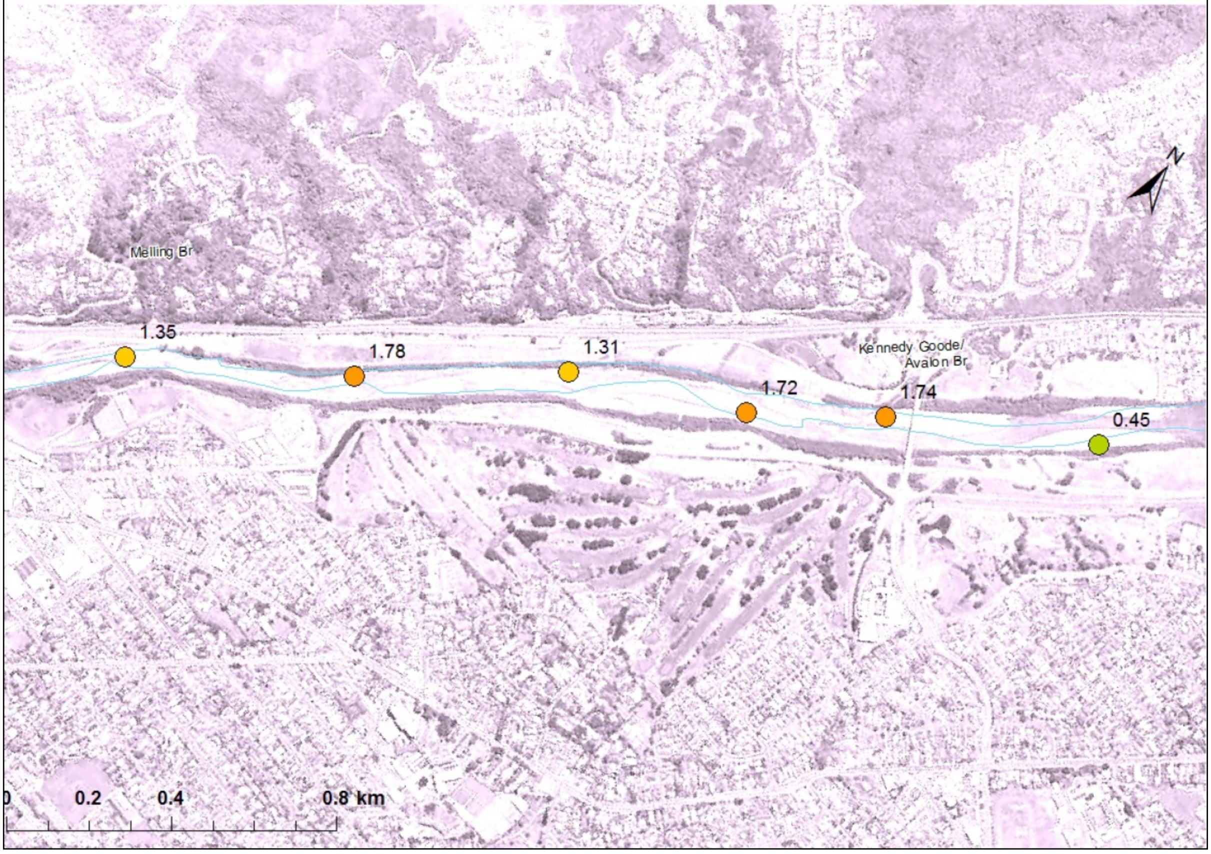


Activity 2:

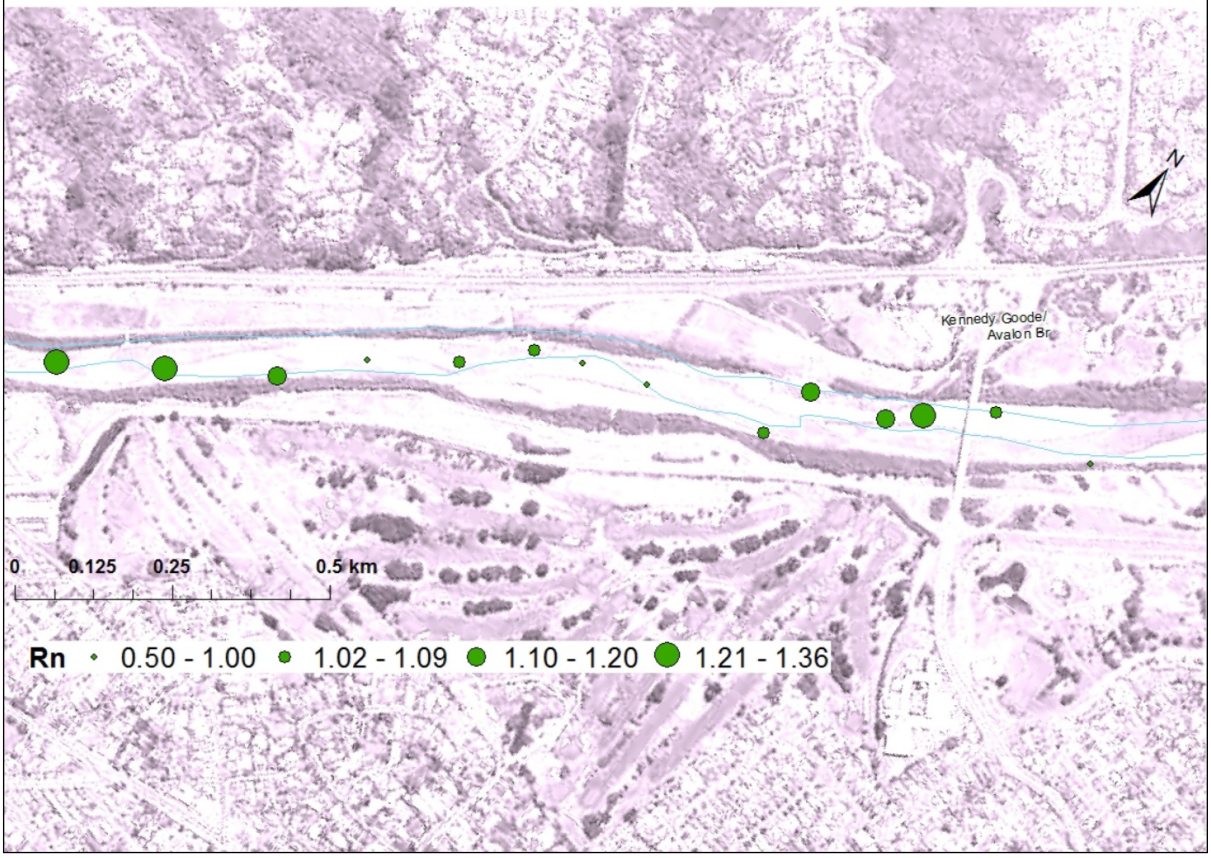
- Where are gains? Taken in low flow (Map 4)
- Now show winter survey (Map 5).
- Discuss the differences in sampling in different flow conditions.
- Radon measurements are quick cheap and not influenced by underflow in gravel bed rivers.
- Best measurements are taken in low flow.
- Measurements taken in higher flows need to be taken at a much higher resolution.
- Heather to ask group for their thoughts.

Case study: Hutt River, Avalon, Map 4.

Case study: Hutt River, Avalon, Map 5.

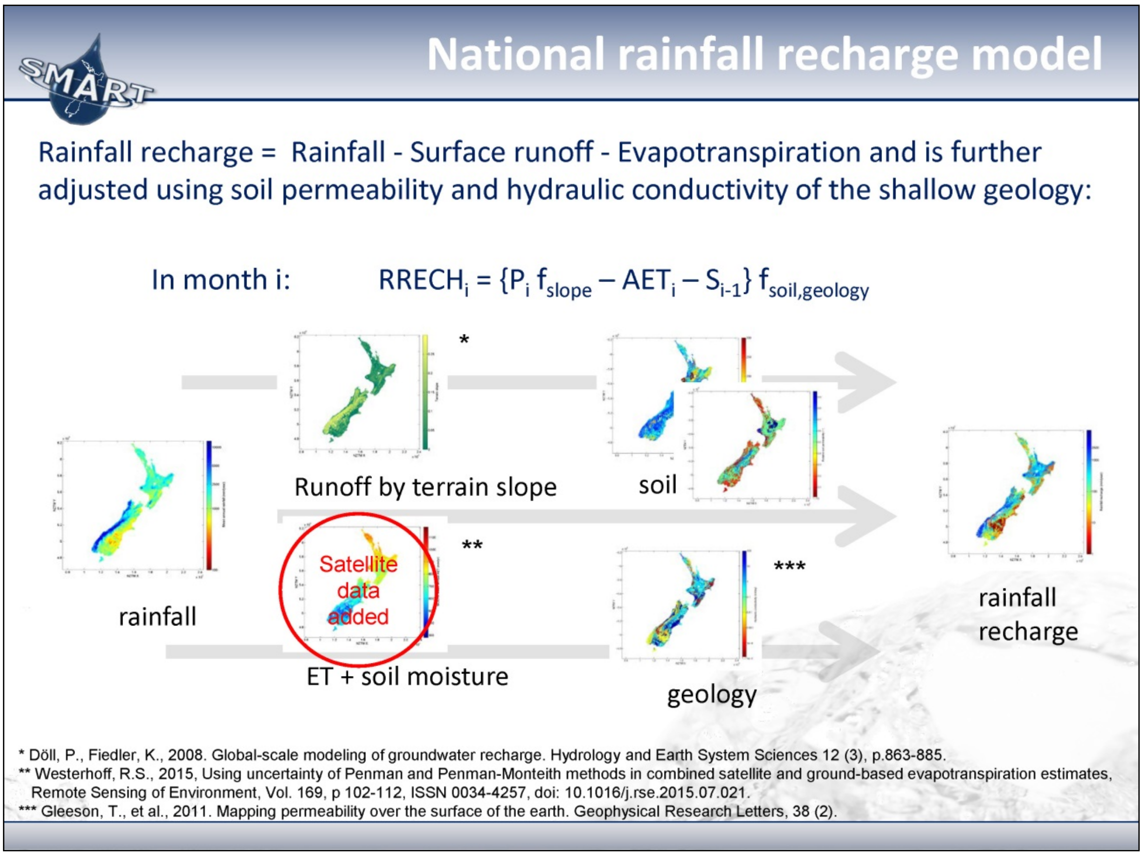


Case study: Hutt River, Avalon, Map 6.



2.2.7 National rainfall recharge model and equilibrium water table baseflow estimates

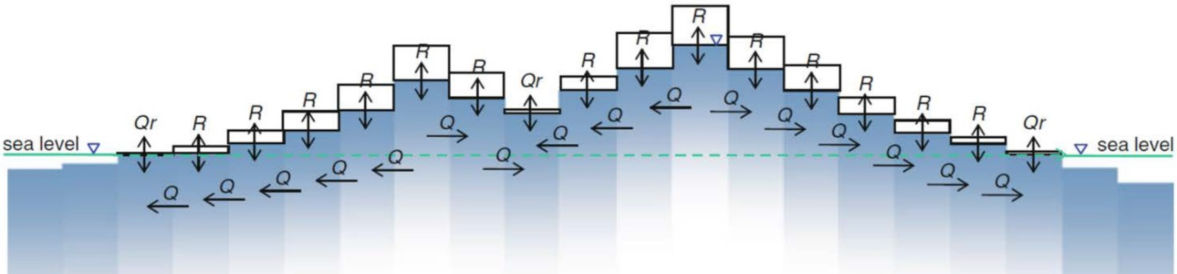
Facilitator: Rogier Westerhoff, GNS Science



EWT method

EWT method calculates the balance between annual recharge R and groundwater flow Q.

This is done iteratively in a transient model



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

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

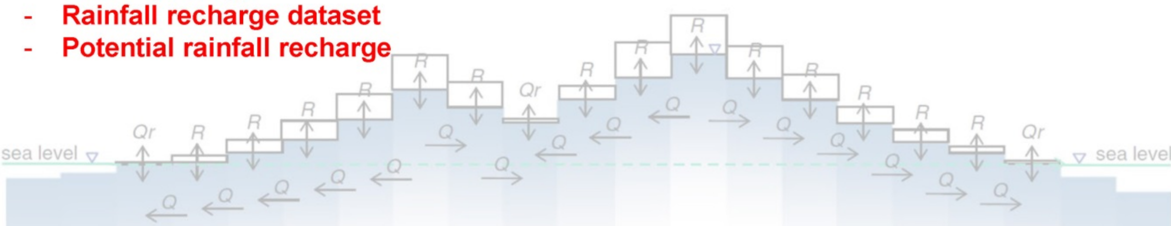
Source: Fan *et al*. (2013), Freeze and Cherry (1979)

3

EWT method

Input:

- **NZ DTM (200x200m)**
- **QMAP geology**
- **Rainfall recharge dataset**
- **Potential rainfall recharge**



Output:

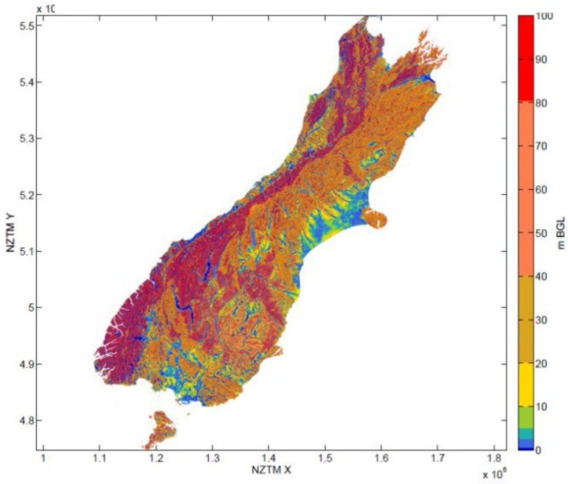
- **Water table**
- **Hydraulic conductivity**
- **Baseflow/interflow estimate**
- **Actual rainfall recharge**

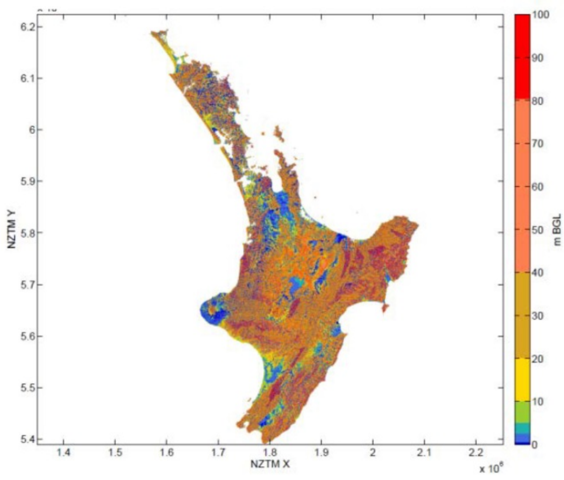
4

Nation-wide EWT

Long-term natural water table
- **Does not incorporate all human factors (e.g., water abstraction)**
- **Static file, but seasonality possible**
- **200m x 200m resolution**

- **EWT mostly points out where groundwater is most likely to come to the surface**





4 Case studies

5 people per group

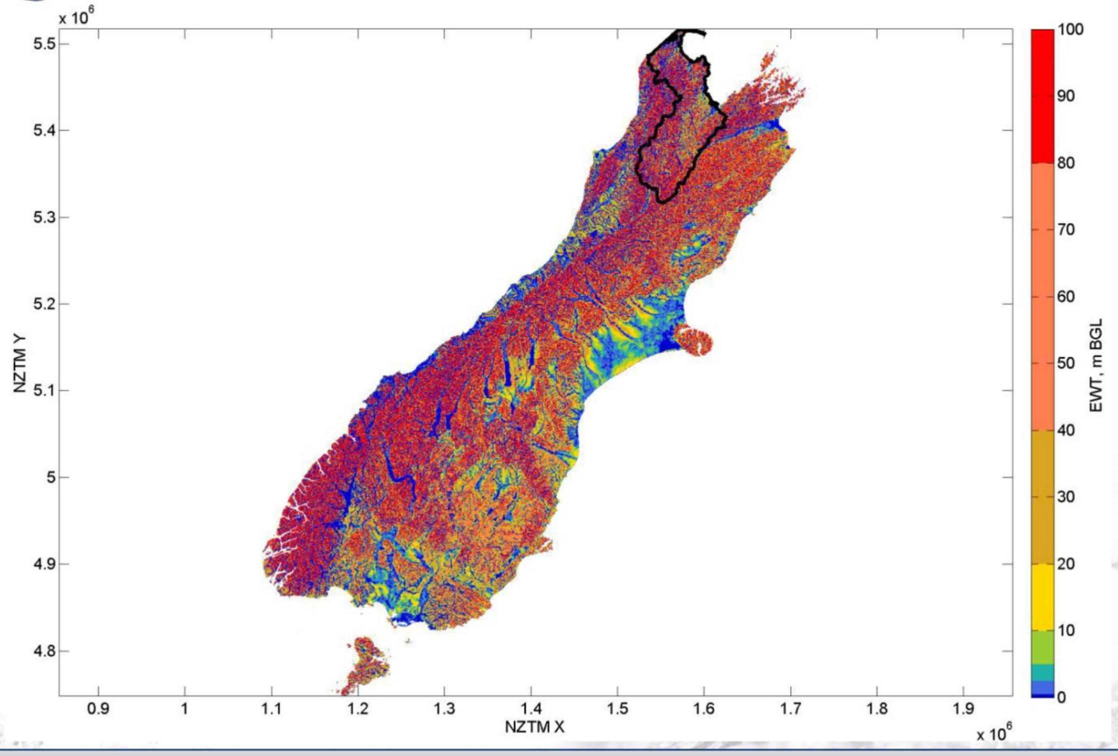
- North Island
- Hauraki Plains
- Southland
- Tasman

All have element mentioned of the mythical Puka Glen catchment

The assignment

- You will be given a print-out of:
  - Rainfall recharge;
  - Water table depth (after ~50 years of daily steps);
  - Baseflow;
  - Elevation;
- QUIZ (questions also on the sheets)
  - In what order would these outputs have been made?
  - What other data would have been used to estimate this?
  - I'll ask your opinion on what needs to be done to improve these nationally-based estimates.

Participatory exercise: Tasman region



Participatory exercise: Tasman region

- **Tasman region: QUIZ**

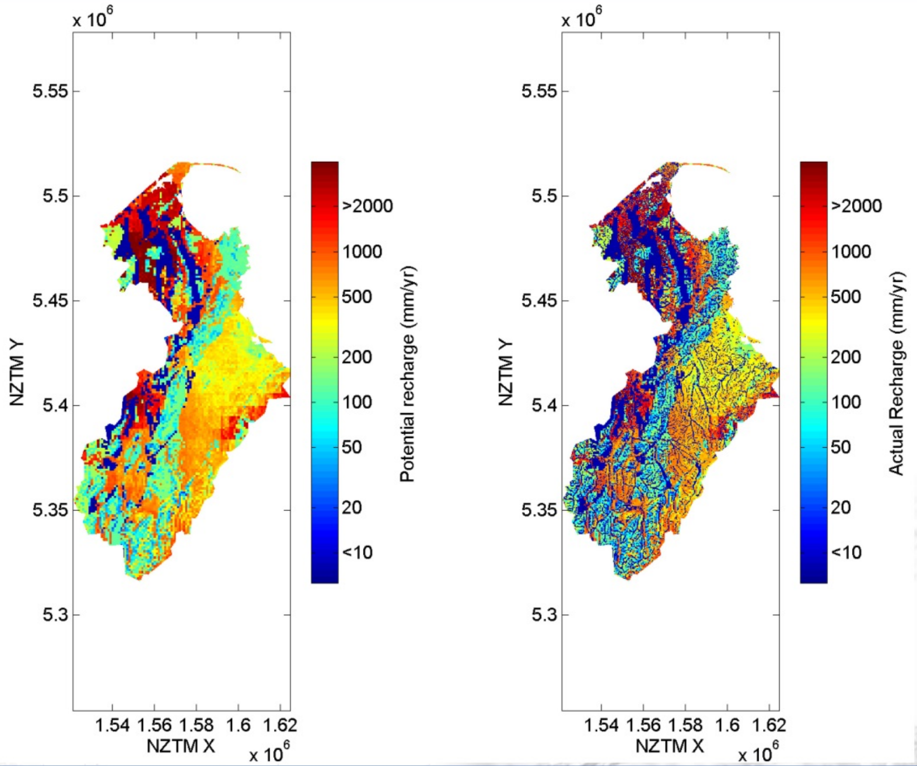
In what order were these outputs created?

What other data have been used to estimate this?

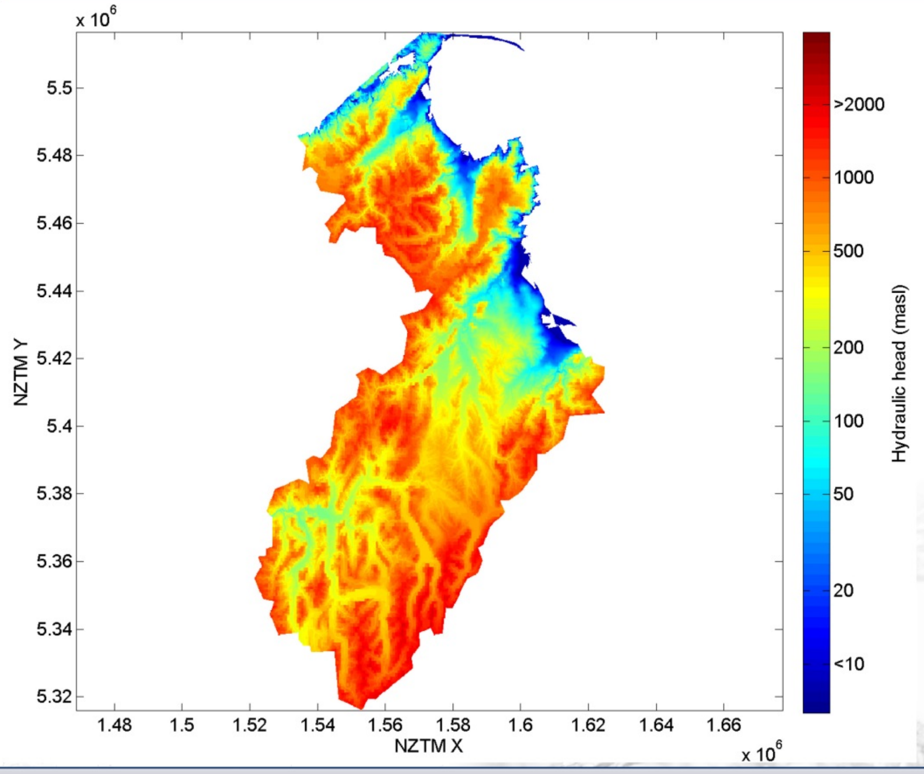
Are there overall trends or patterns between or in datasets?

What is your opinion on what needs to be done to improve these nation-wide estimates?

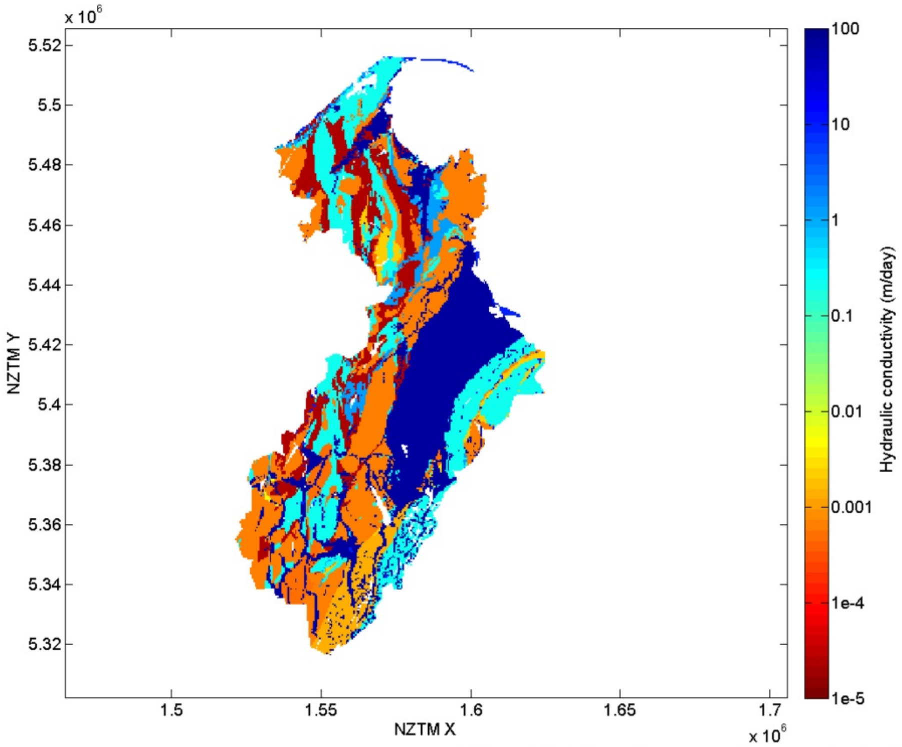
Participatory exercise: Tasman region

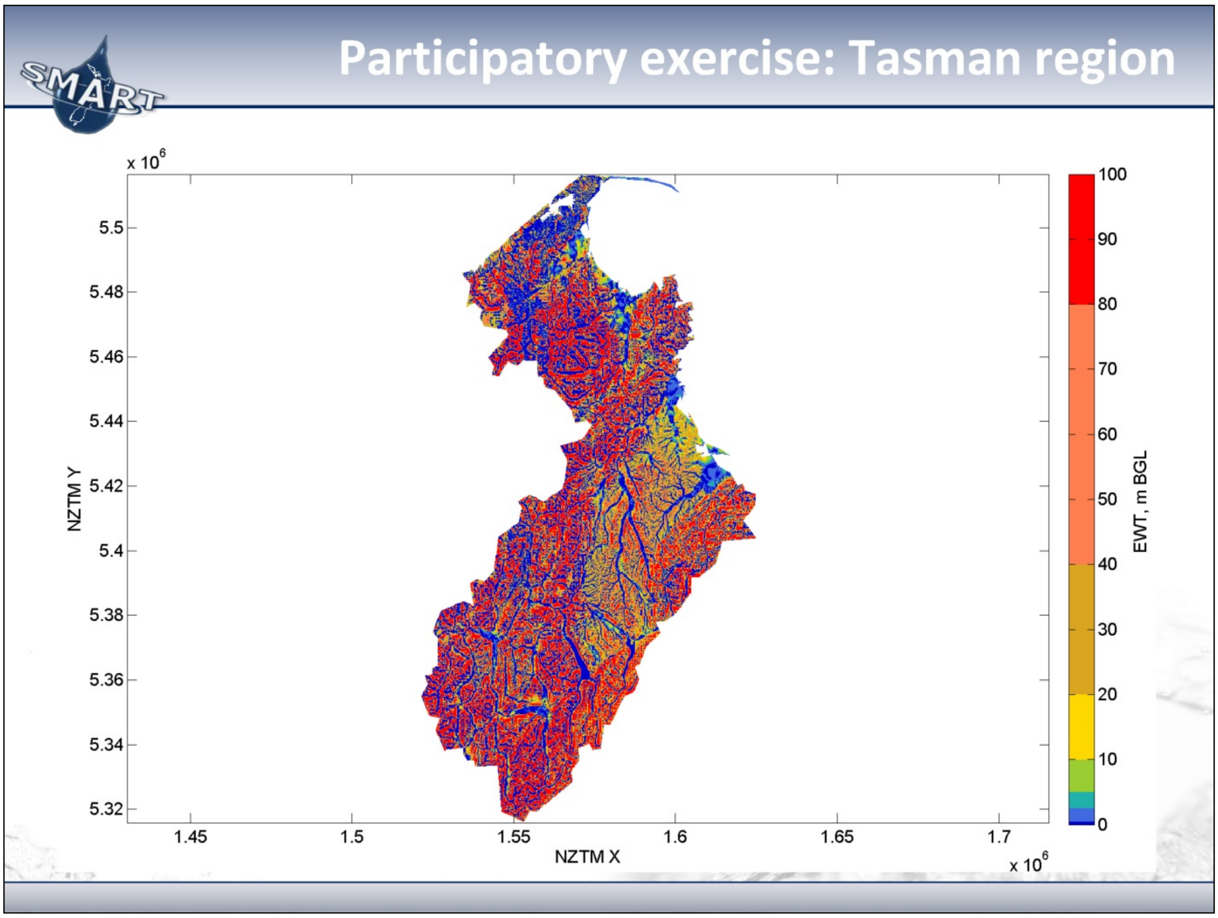


Participatory exercise: Tasman region

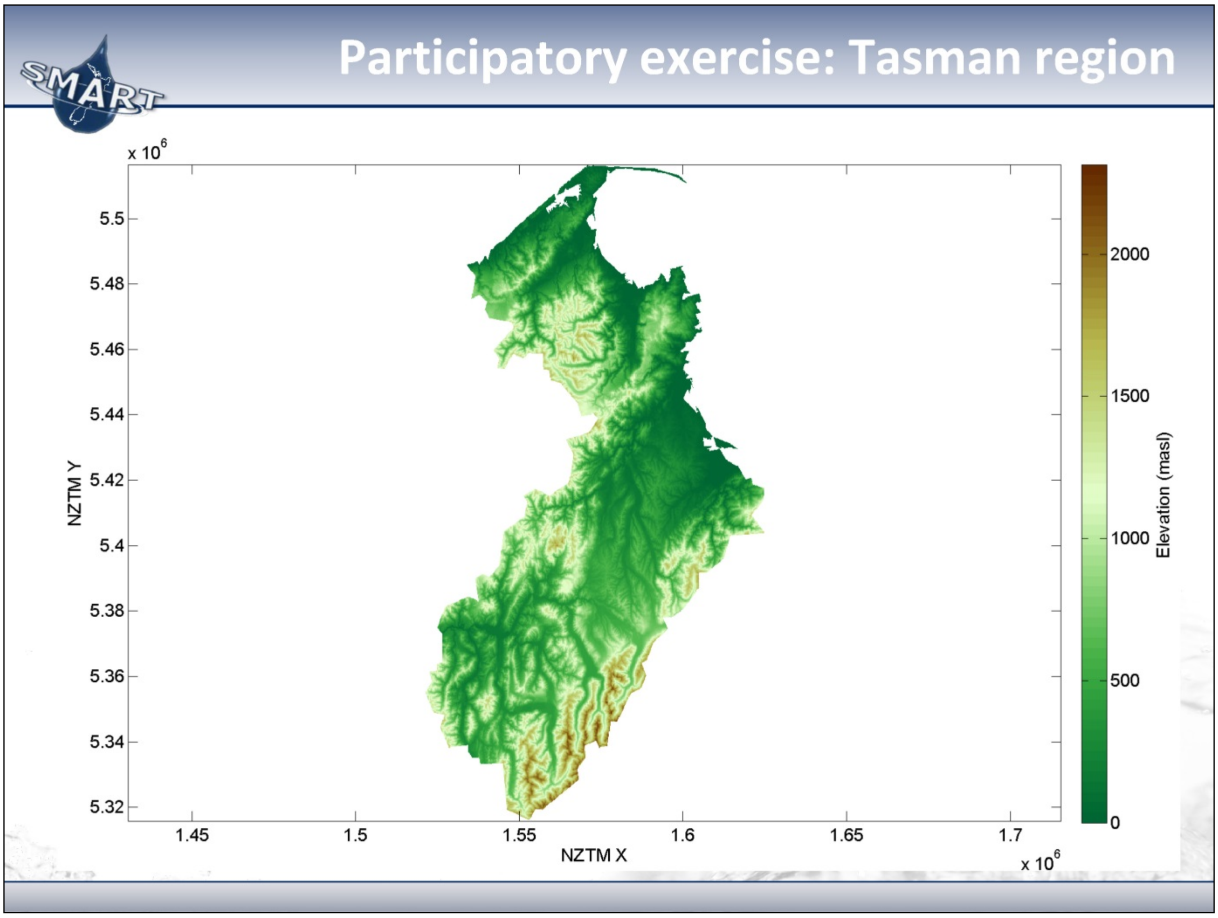


Participatory exercise: Tasman region



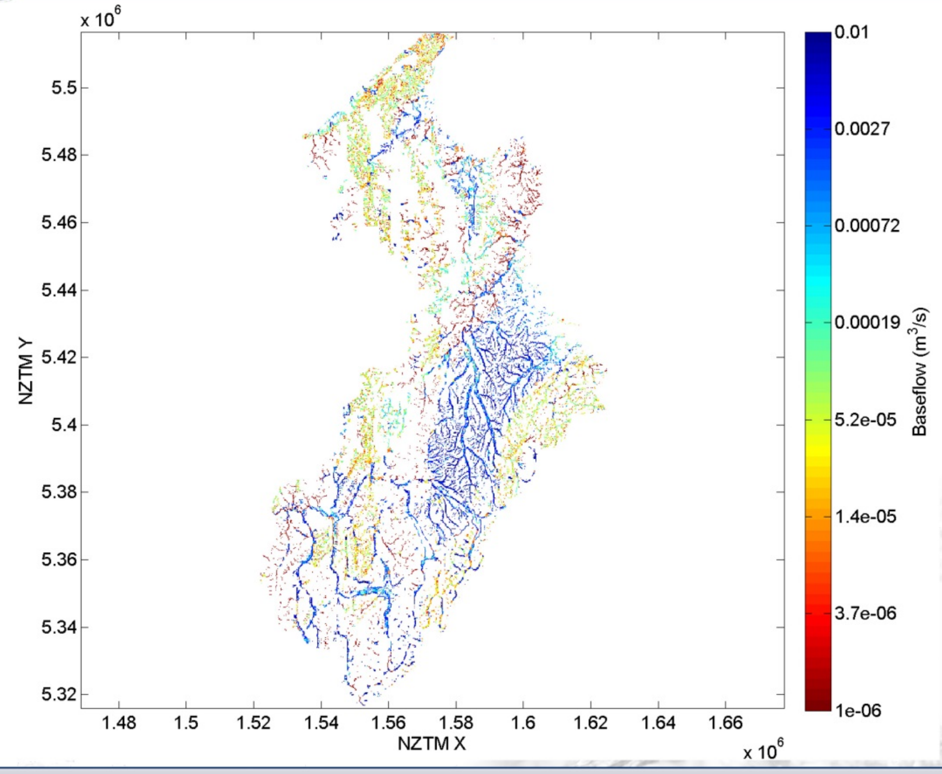


Participatory exercise: Tasman region
SMART
x 10^6
5.5
5.48
5.46
5.44
5.42
5.4
5.38
5.36
5.34
5.32
NZTM Y
1.45
1.5
1.55
1.6
1.65
1.7
NZTM X
x 10^6
100
90
80
70
60
50
40
30
20
10
0
EWT, m BGL

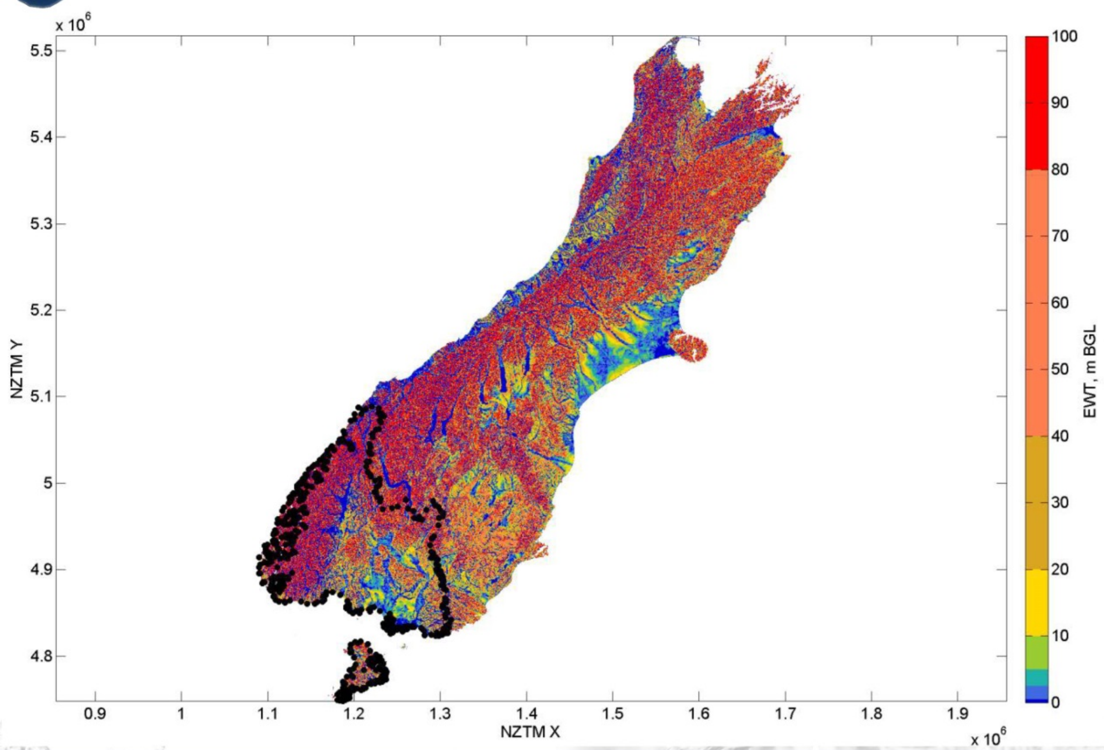


Participatory exercise: Tasman region
SMART
x 10^6
5.5
5.48
5.46
5.44
5.42
5.4
5.38
5.36
5.34
5.32
NZTM Y
1.45
1.5
1.55
1.6
1.65
1.7
NZTM X
x 10^6
2000
1500
1000
500
0
Elevation (masl)

Participatory exercise: Tasman region



Participatory exercise: Southland region



Participatory exercise: Southland region

- **Southland region: QUIZ**

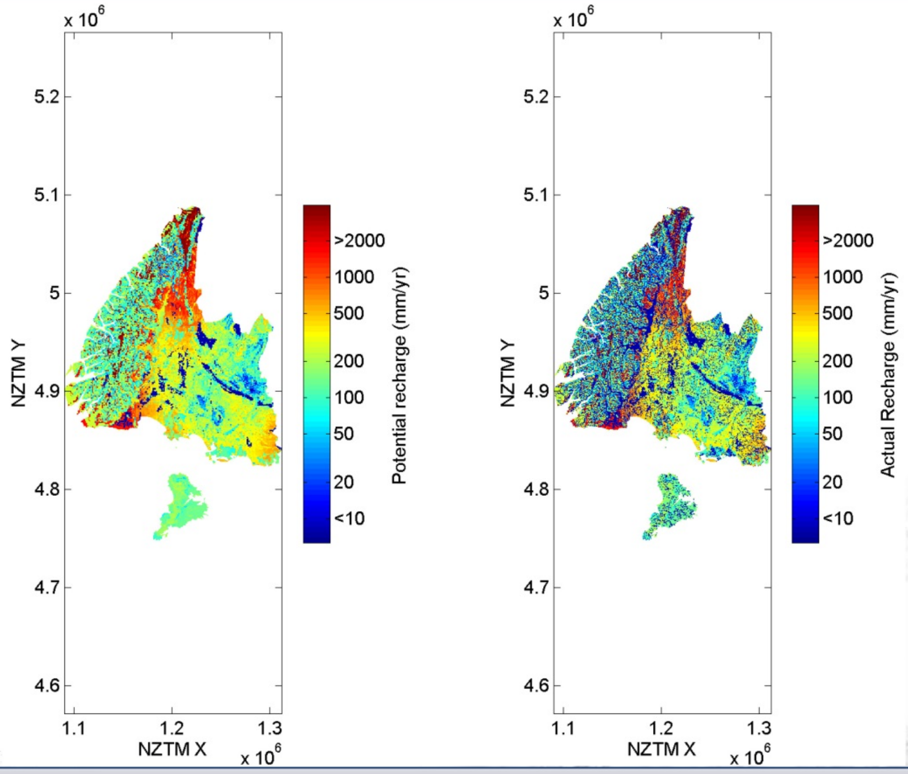
In what order were these outputs created?

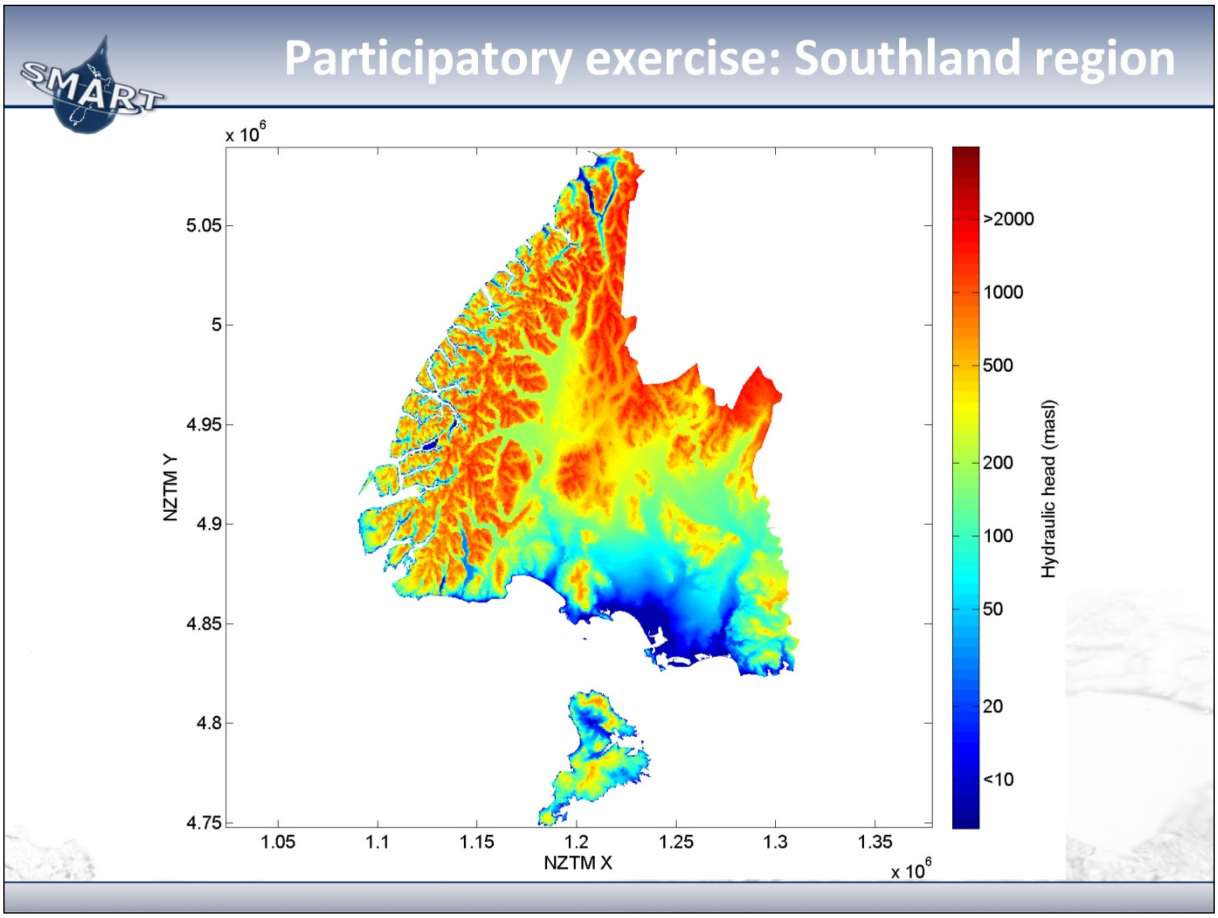
What other data have been used to estimate this?

Are there overall trends or patterns between or in datasets?

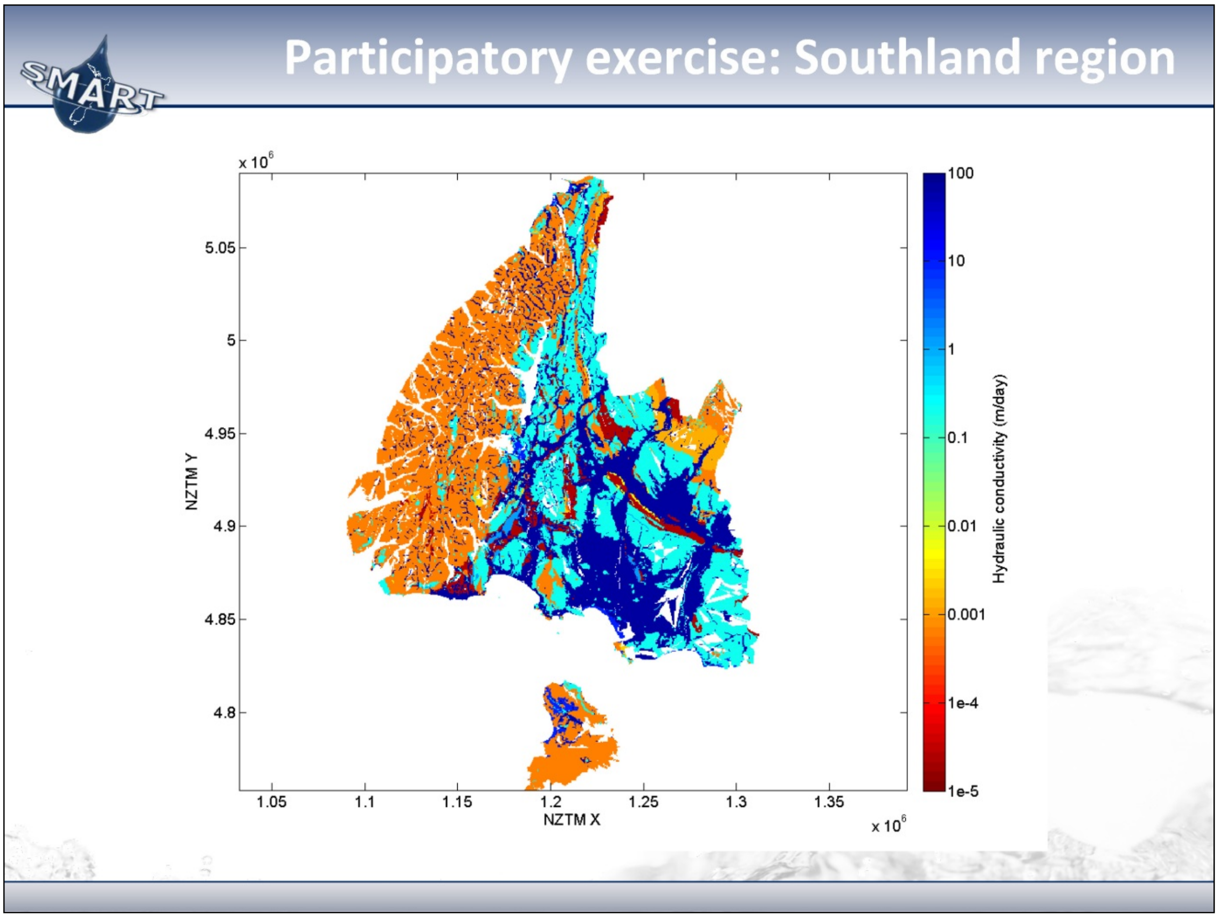
What is your opinion on what needs to be done to improve these nation-wide estimates?

Participatory exercise: Southland region



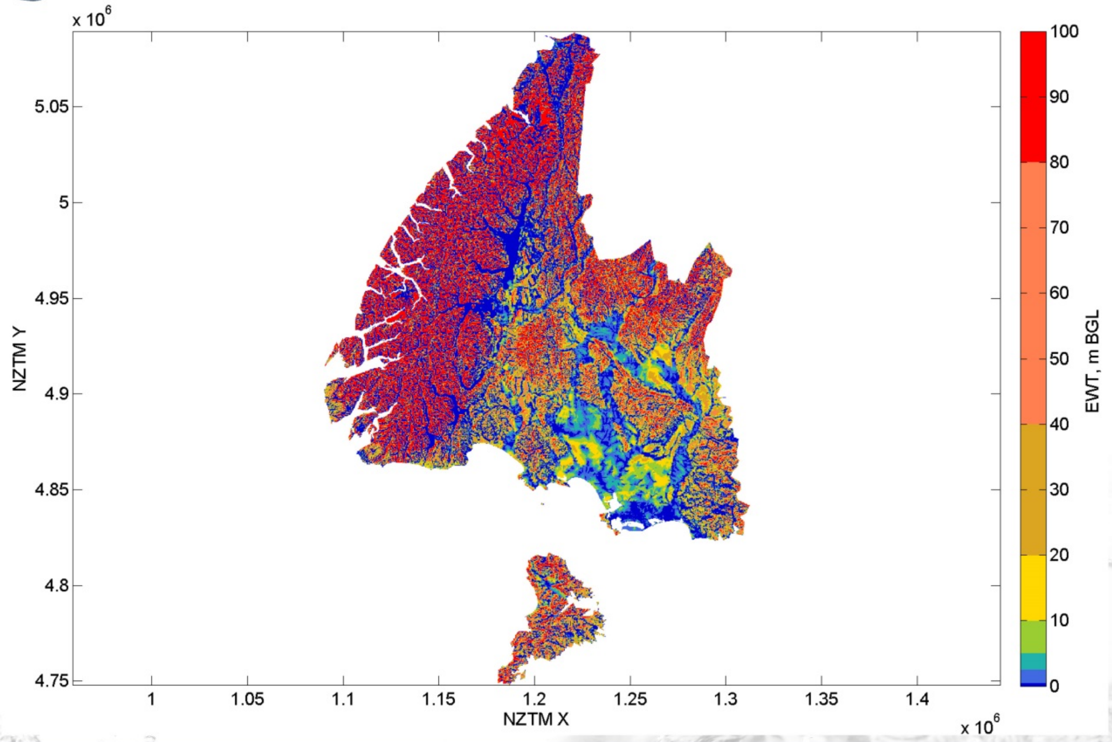


SMART
Participatory exercise: Southland region
x 10^6
5.05
5
4.95
4.9
4.85
4.8
4.75
NZTM Y
1.05
1.1
1.15
1.2
1.25
1.3
1.35
NZTM X
x 10^6
>2000
1000
500
200
100
50
20
<10
Hydraulic head (masl)

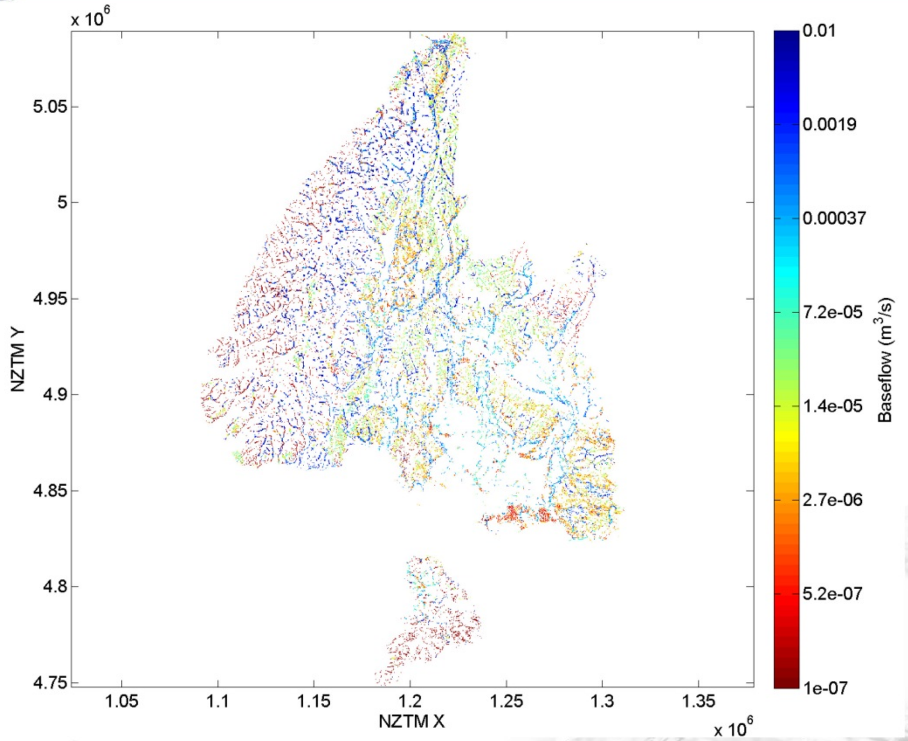


SMART
Participatory exercise: Southland region
x 10^6
5.05
5
4.95
4.9
4.85
4.8
NZTM Y
1.05
1.1
1.15
1.2
1.25
1.3
1.35
NZTM X
x 10^6
100
10
1
0.1
0.01
0.001
1e-4
1e-5
Hydraulic conductivity (m/day)

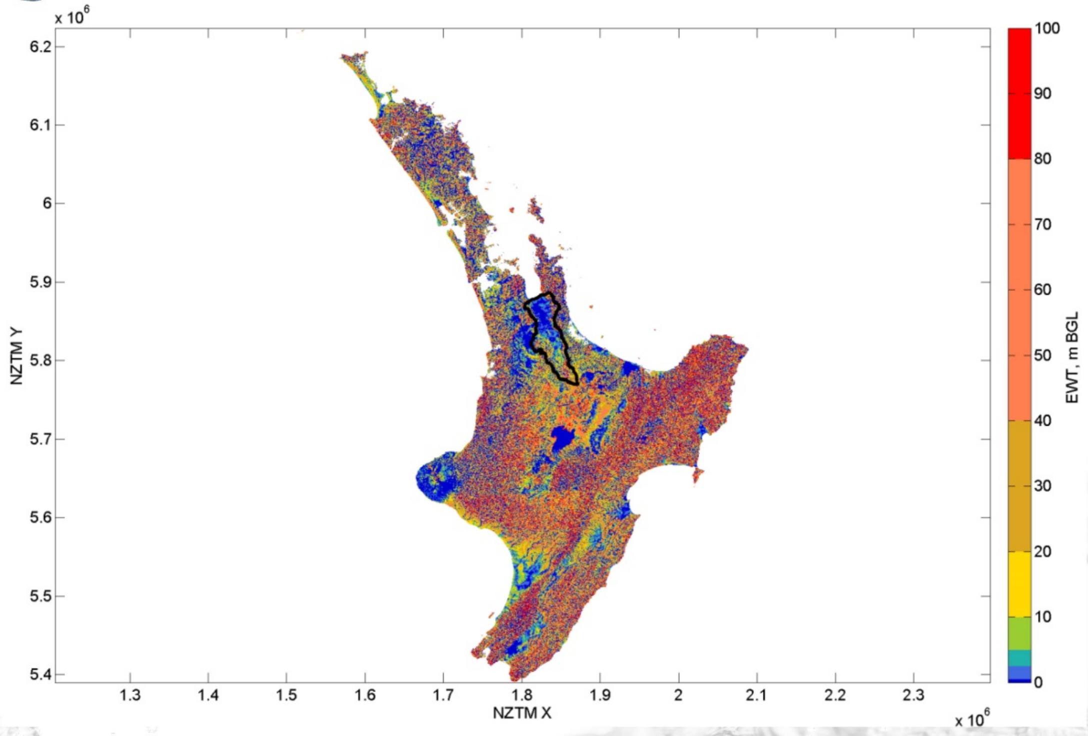
Participatory exercise: Southland region



Participatory exercise: Southland region



Participatory exercise: Hauraki Plains



Participatory exercise: Hauraki Plains

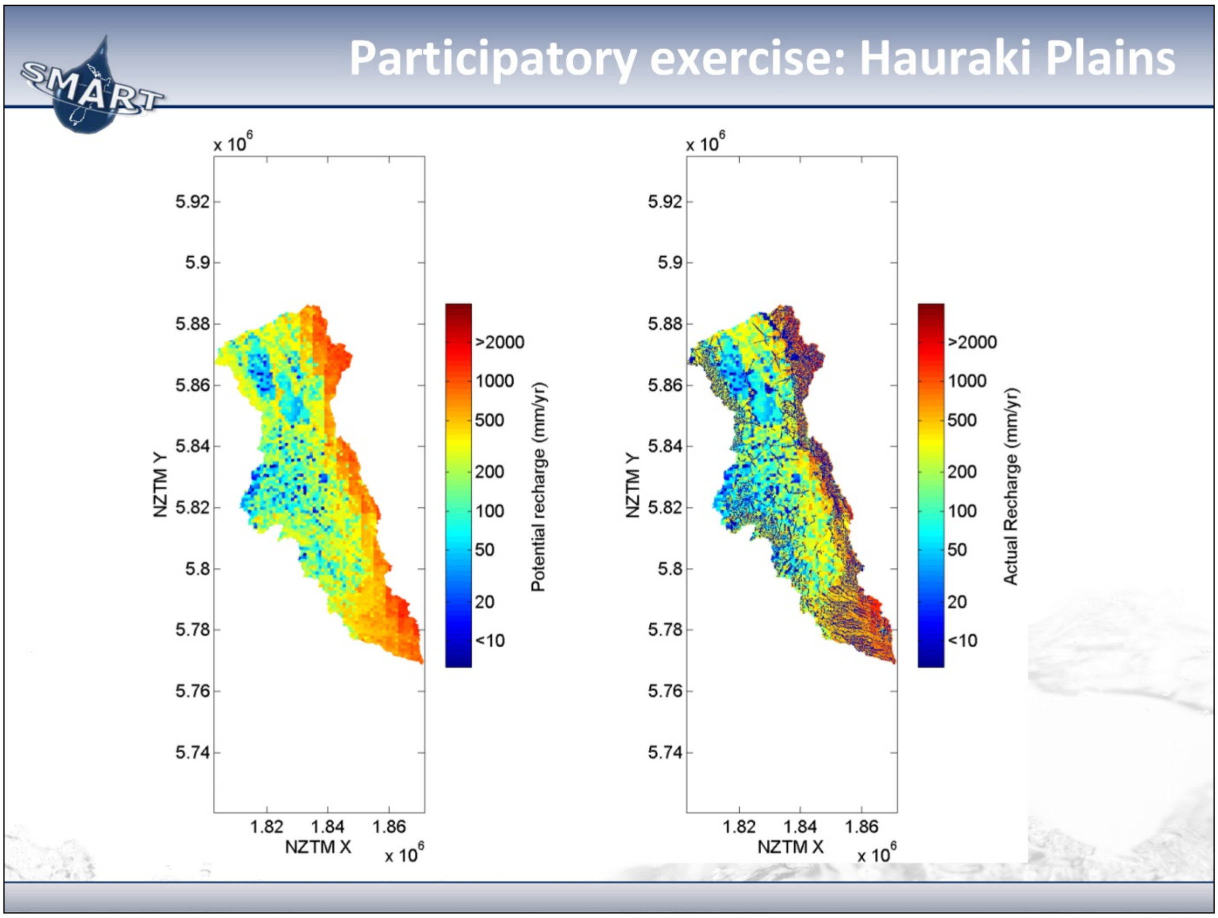
- **Hauraki Plains: QUIZ**

In what order were these outputs created?

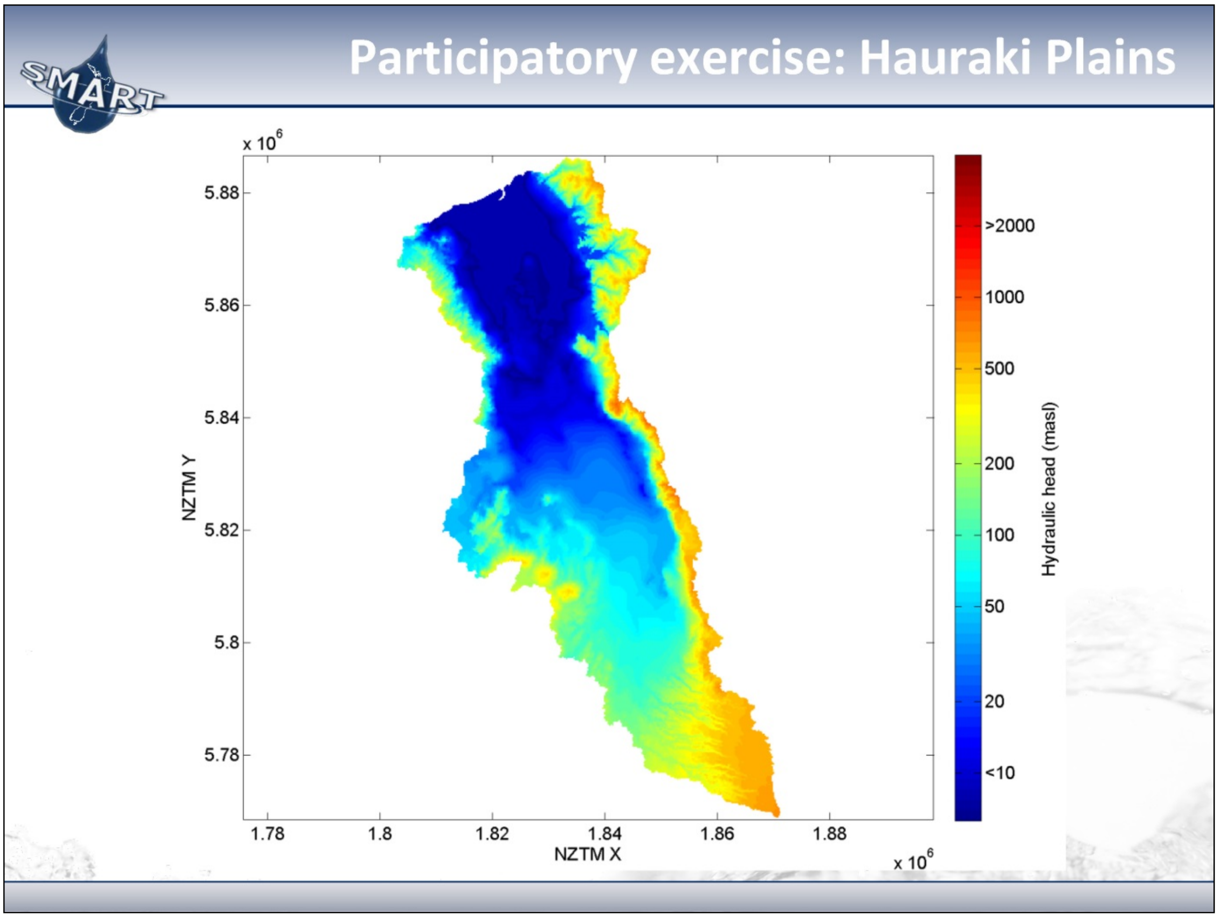
What other data have been used to estimate this?

Are there overall trends or patterns between or in datasets?

What is your opinion on what needs to be done to improve these nation-wide estimates?

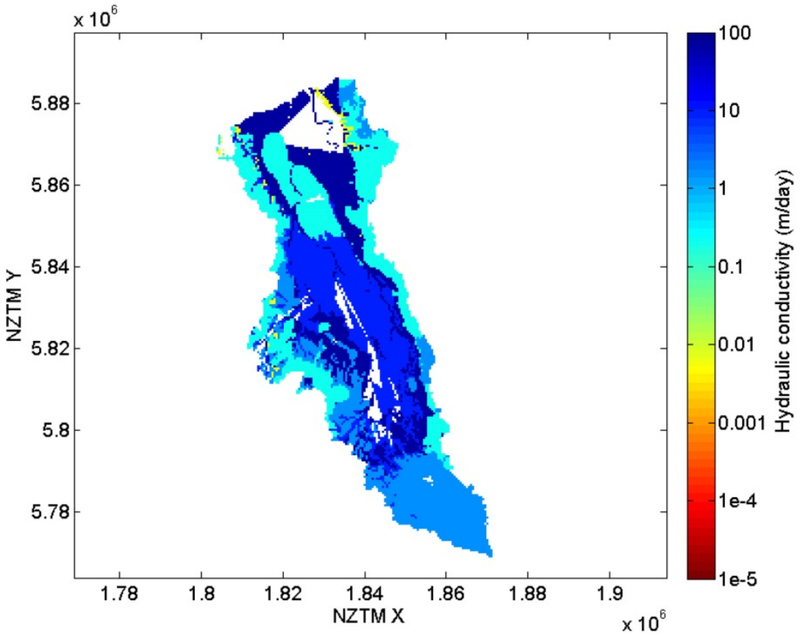


Participatory exercise: Hauraki Plains
SMART
x 10^6
5.92
5.9
5.88
5.86
5.84
5.82
5.8
5.78
5.76
5.74
NZTM Y
1.82
1.84
1.86
NZTM X
x 10^6
>2000
1000
500
200
100
50
20
<10
Potential recharge (mm/yr)
Actual Recharge (mm/yr)

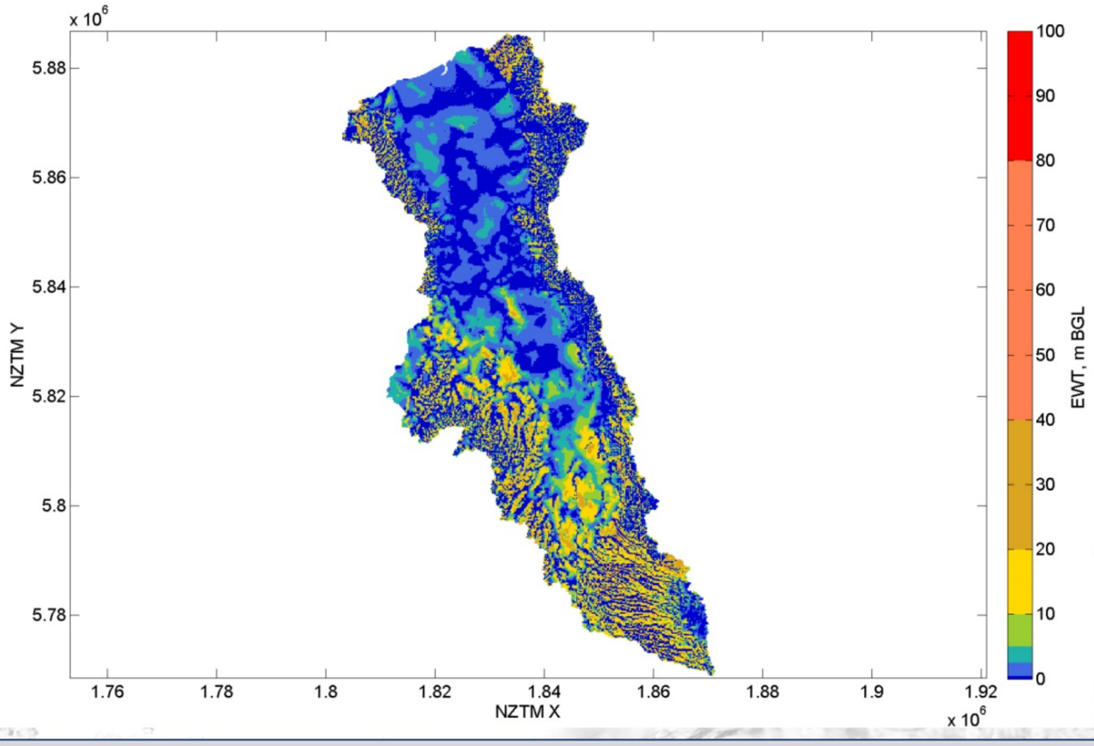


Participatory exercise: Hauraki Plains
SMART
x 10^6
5.88
5.86
5.84
5.82
5.8
5.78
NZTM Y
1.78
1.8
1.82
1.84
1.86
1.88
NZTM X
x 10^6
>2000
1000
500
200
100
50
20
<10
Hydraulic head (masl)

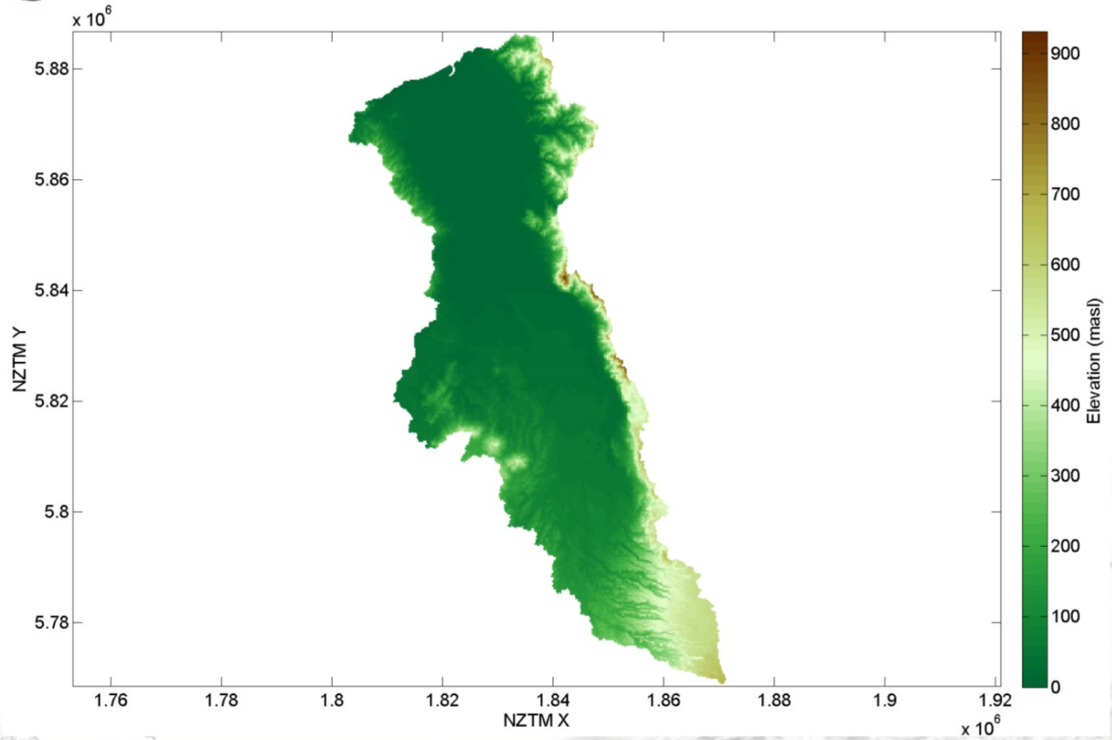
Participatory exercise: Hauraki Plains



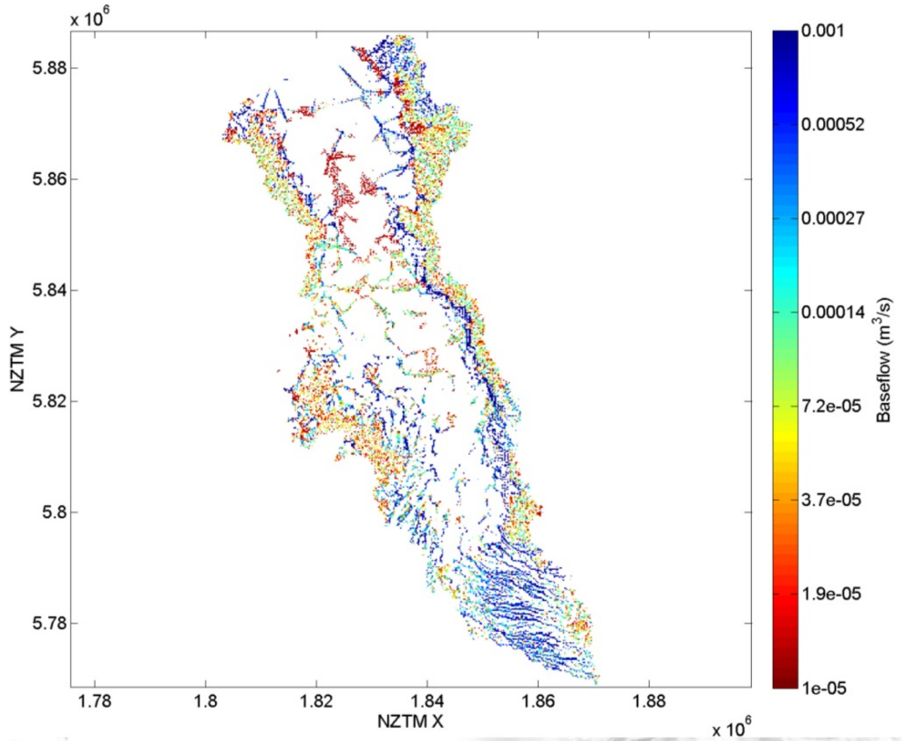
Participatory exercise: Hauraki Plains



Participatory exercise: Hauraki Plains



Participatory exercise: Hauraki Plains



Participatory exercise: Hauraki Plains

- **North Island: QUIZ**

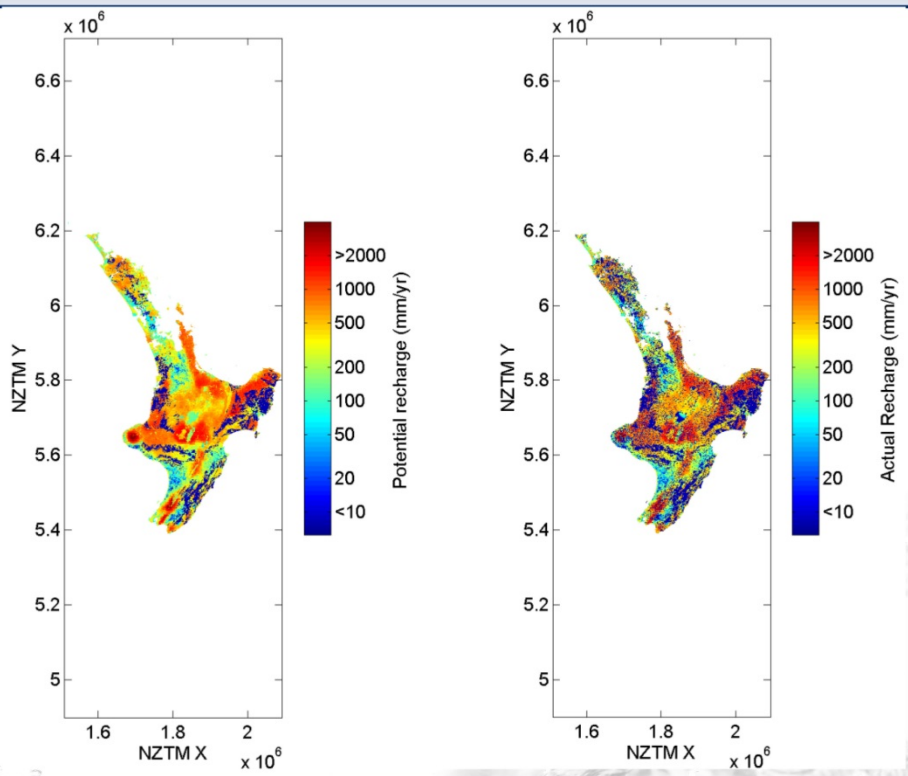
In what order were these outputs created?

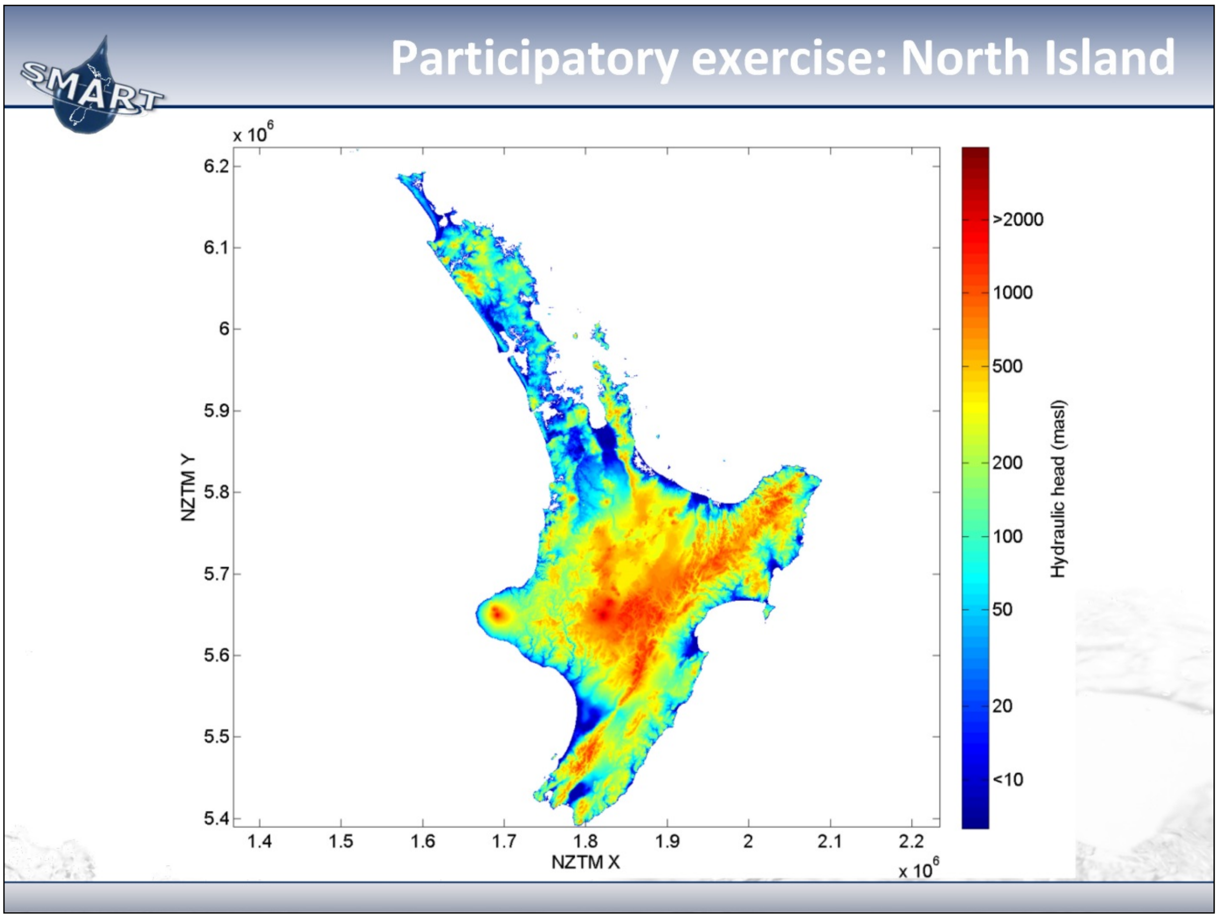
What other data have been used to estimate this?

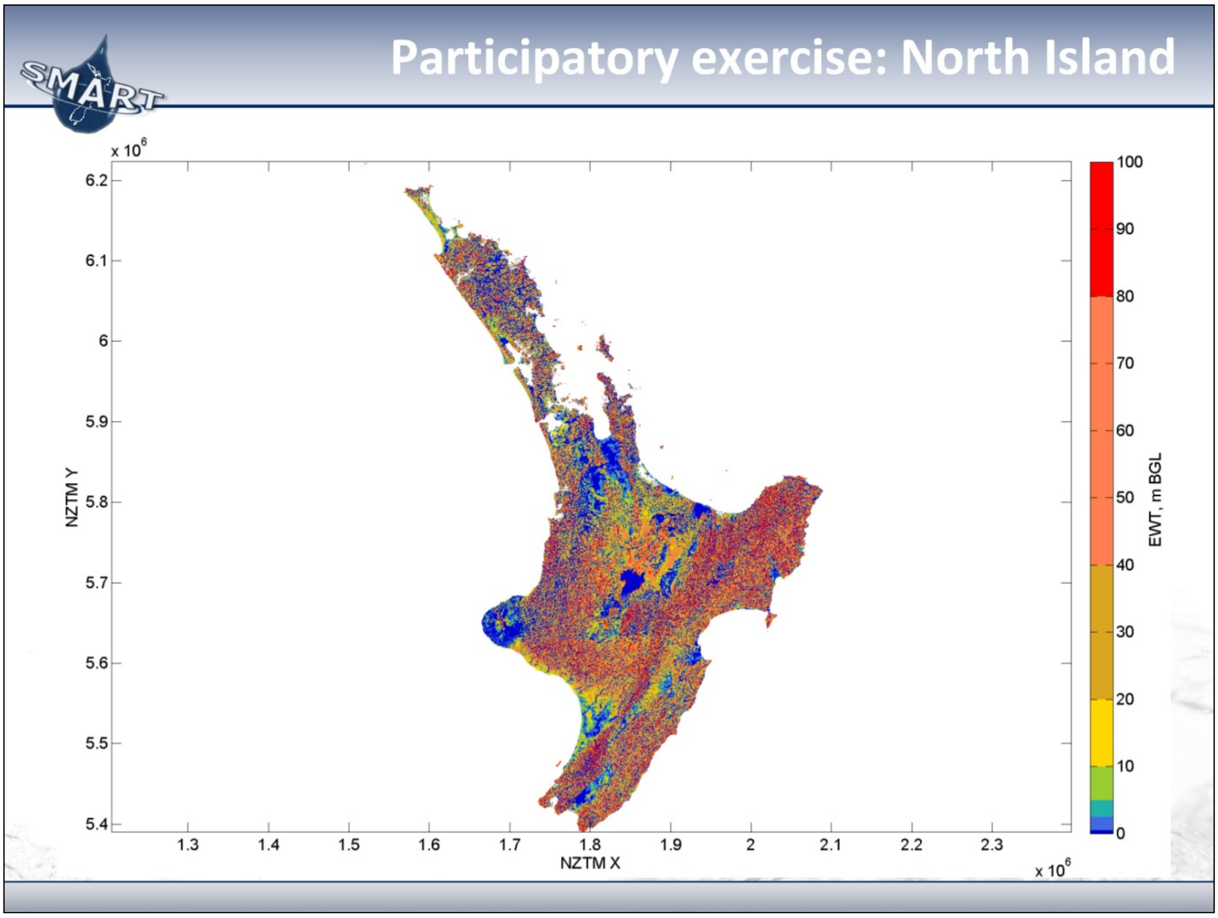
Are there overall trends or patterns between or in datasets?

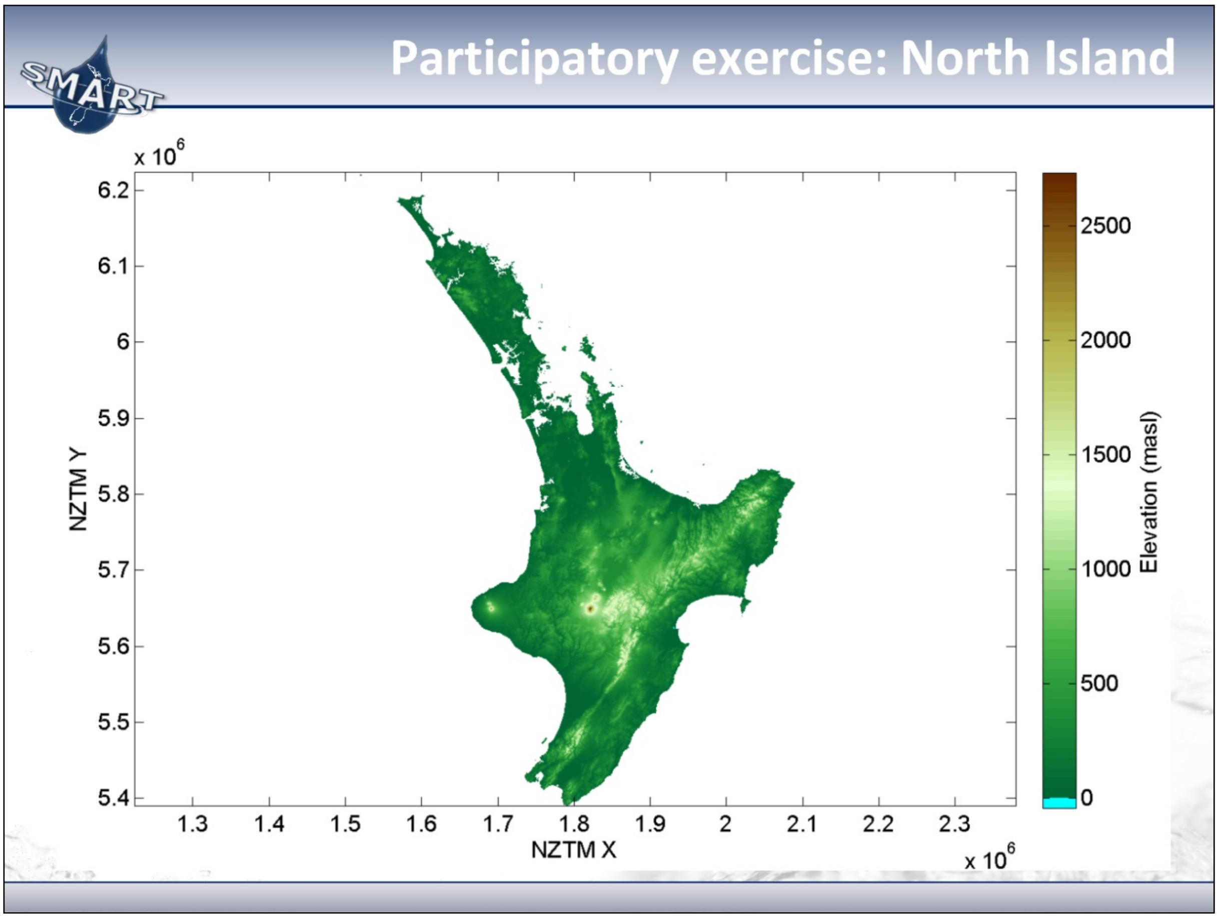
What is your opinion on what needs to be done to improve these nation-wide estimates?

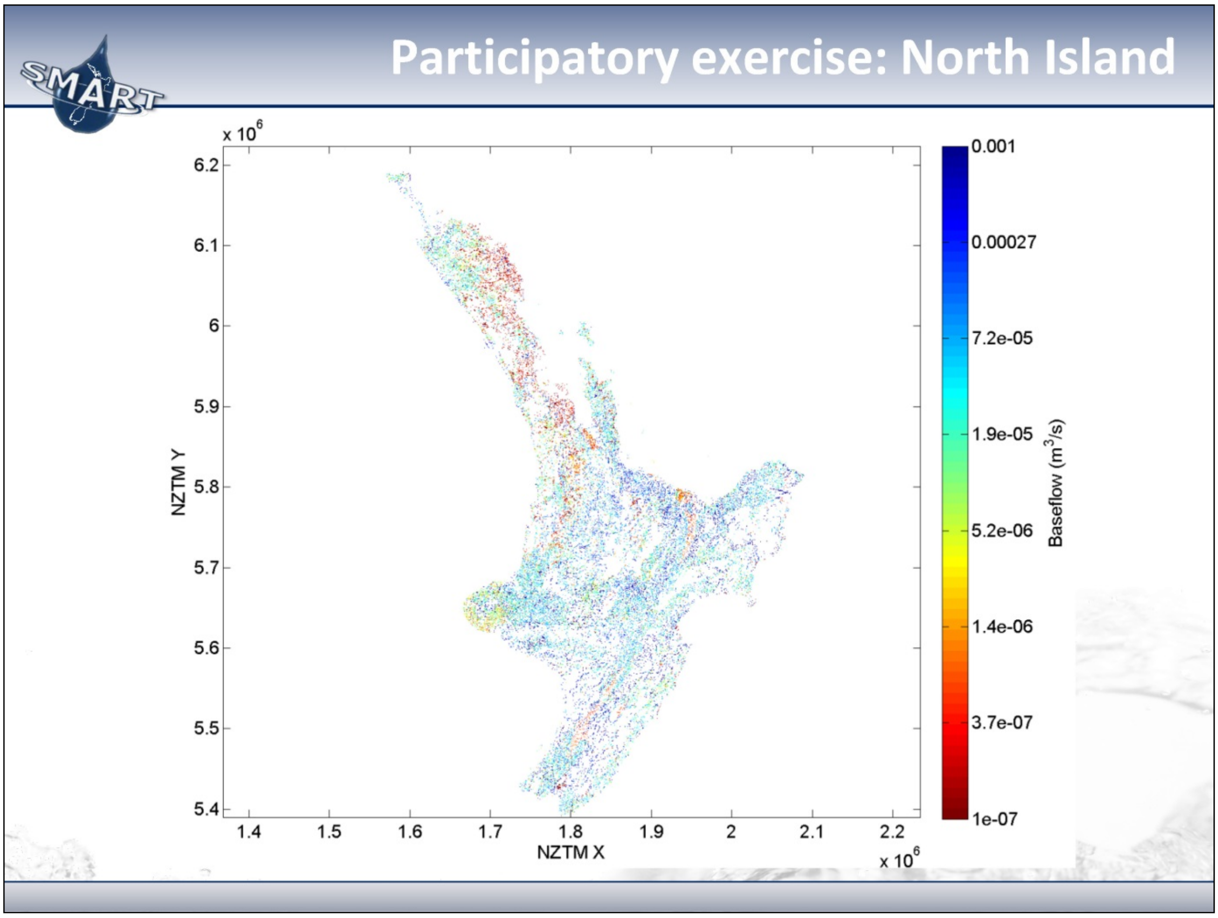
Participatory exercise: North Island




Participatory exercise: North Island
SMART
x 10^6
6.2
6.1
6
5.9
5.8
5.7
5.6
5.5
5.4
NZTM Y
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
NZTM X
x 10^6
>2000
1000
500
200
100
50
20
<10
Hydraulic head (masl)


Participatory exercise: North Island
SMART
x 10^6
6.2
6.1
6
5.9
5.8
5.7
5.6
5.5
5.4
NZTM Y
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
NZTM X
x 10^6
100
90
80
70
60
50
40
30
20
10
0
EWT, m BGL


Participatory exercise: North Island
SMART
x 10^6
6.2
6.1
6
5.9
5.8
5.7
5.6
5.5
5.4
NZTM Y
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
NZTM X
x 10^6
2500
2000
1500
1000
500
0
Elevation (masl)


Participatory exercise: North Island
SMART
x 10^6
6.2
6.1
6
5.9
5.8
5.7
5.6
5.5
5.4
NZTM Y
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
NZTM X
x 10^6
0.001
0.00027
7.2e-05
1.9e-05
5.2e-06
1.4e-06
3.7e-07
1e-07
Baseflow (m^3/s)

SESSION 3: STREAM DEPLETION
FACILITATOR: MIKE TOEWS, GNS SCIENCE

3.1 INTRODUCTION

- Objective 1: Identify why calculating stream depletion is important?
- Objective 2: Different methods of calculating stream depletion.
- Objective 3: Policies to manage stream depletion.

Session 3: Stream Depletion

Organiser: Mike Toews

Presenters:

- Catherine Moore (GNS Science / ESR)
- Aslan Perwick (PDP)
- Bruce Dudley (NIWA)
- Jan Diettrich (NIWA)
- Abby Matthews (Horizons Regional Council)

Format for Session 3

- Presentations (20-30 mins)
  - Catherine Moore, Aslan Perwick
- Participatory learning I (20-30 mins)
  - Each table
- Presentations (30 mins)
  - Bruce Dudley, Jan Diettrich, Abby Matthews
- Participatory learning II (20 mins)
- Summary/closure of session 3
  - 1 representative from each table to give 1-2 mins summary of their findings

Objectives

- What is stream depletion, why it is important
- Why calculating stream depletion is important
- Different methods of calculating stream depletion
- Riparian influences on stream depletion
- Policies to manage stream depletion

Stream Depletion Basics

- What: reduction of streamflow / volume
- Why streamflow changes
  - nearby pumping
  - changes to riparian zone
  - invasive vegetation
  - climate change
- Why it is important
  - Allow sustainable flows in waterways
  - Aquatic ecosystems

Session 3: Participatory learning I

- If a computer is available for each table, use the analytical spreadsheet calculator from Environment Canterbury for the questions provided (answers will follow)
- Using Puka Glen, discuss workflow for numerical modelling to characterise and quantify an identified potential stream depletion issue

Session 3: Participatory learning II

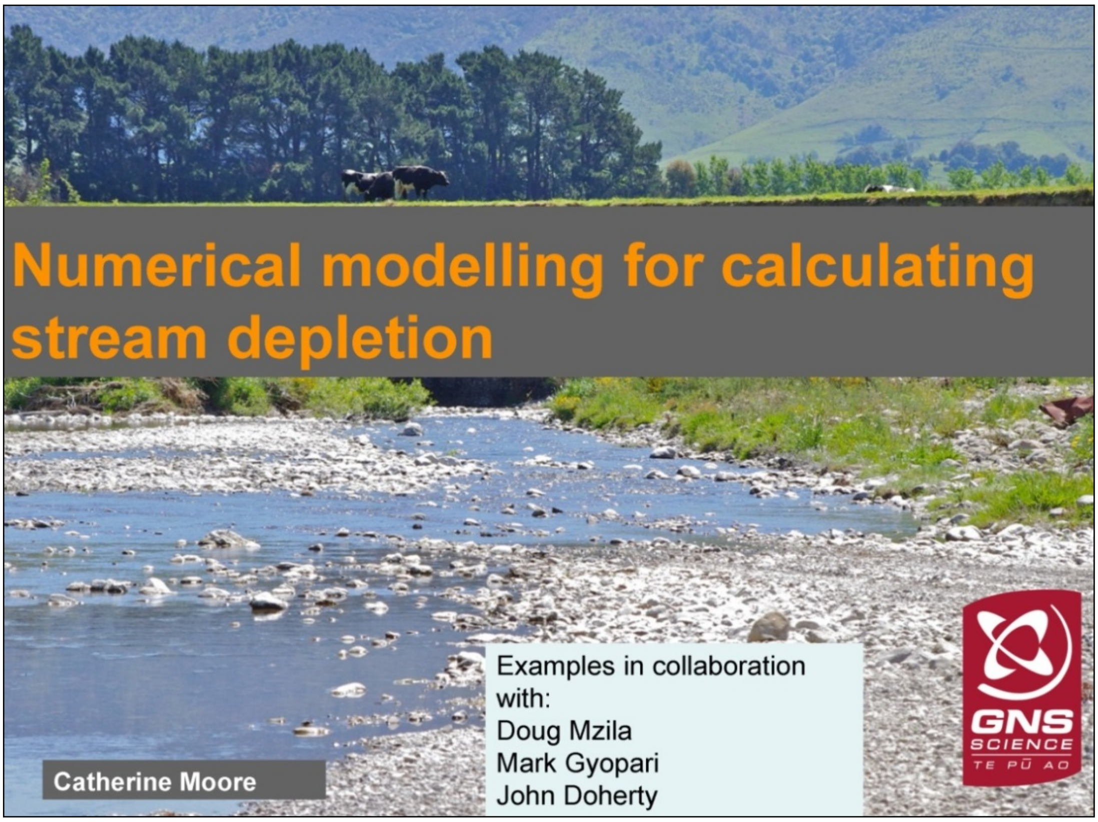
- Using Puka Glen, discuss how riparian changes may impact stream flows and ecology
- Pick one of these topics:
  - What physically-based parameters could be used to integrate reach-scale groundwater-surface water models
  - Draft policy for Puka Glen that could address stream depletion

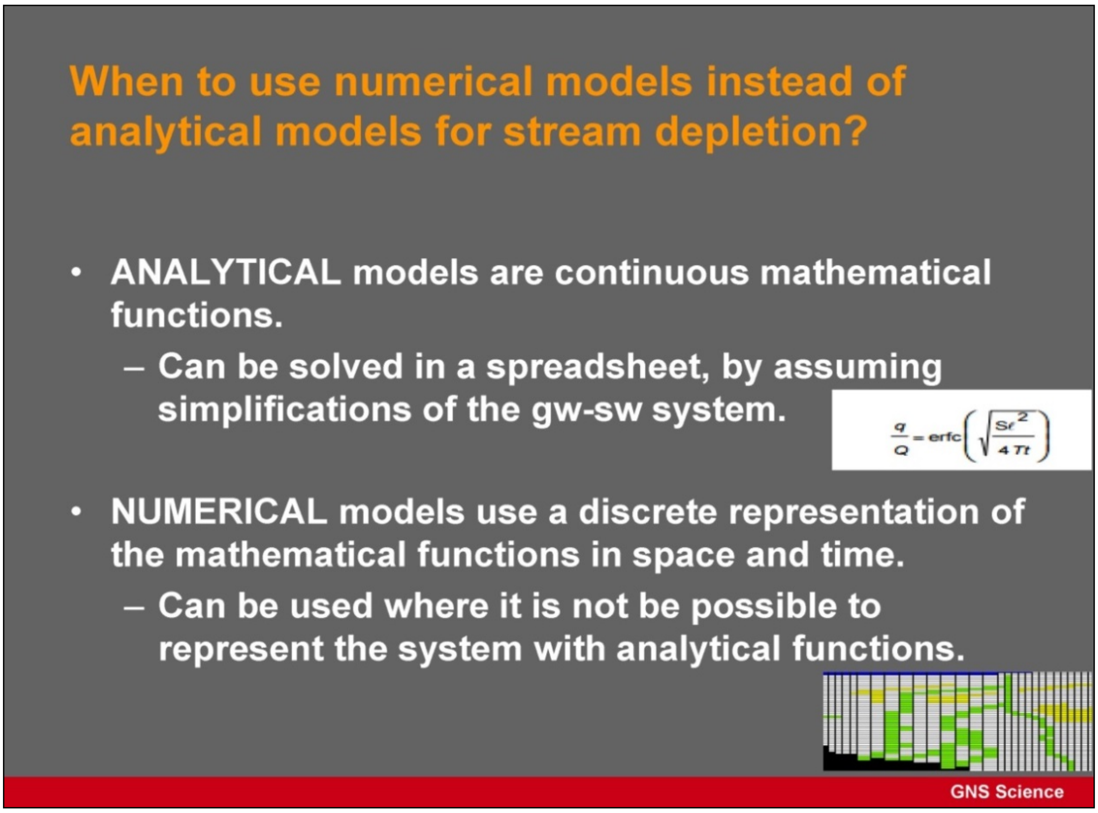
Summary/closure

- One representative to provide a key summary detail from this session. 1-2 mins each.

3.2 PRESENTATIONS

3.2.1 Numerical modelling of stream depletion
Facilitator: Catherine Moore, GNS Science





When to use a numerical model for stream depletion calculations continued…?

Numerical	Analytical
Pro's	Pro's
Use when approximations of analytical model are not appropriate.	Fast and easy to calculate.
Use for assessing cumulative impacts, or when precise quantification is required e.g. for environment court.	Robust for assessing the relative impacts of many pumping wells – e.g. A, B or C permits.
Use for complex system heterogeneity: ➢ Multiple streams close together ➢ Streams drying up and rewetting ➢ Complex geology	Robust for simple physical contexts.
Con's	Con's
Significant time and computing requirements.	Stream depletion estimates are at best approximate and at worst inaccurate.

GNS Science

Recipe for using a numerical model for stream depletion

1) **Define:**
   - model domain and boundaries and discretise in space and time, and initial groundwater level conditions.
   - aquifer properties – storage and hydraulic conductivity.
   - well location, depth and pumping regime.
   - surface water way locations in model, relationships between flow rate, river stage, river bottom elevation and cross section profile and river bed conductance.

2) Adopt a model solver and run.

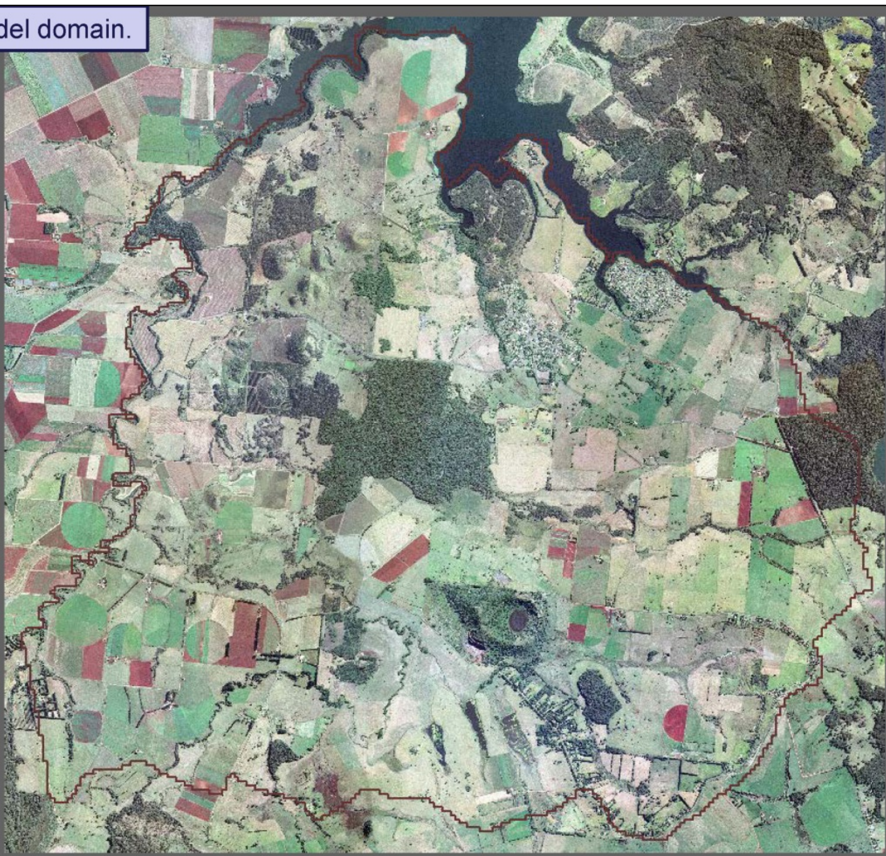
3) Calibrate to measured gw-sw fluxes, groundwater levels and isotopes and tracers as available.

4) If model is non-unique, prior information (usually implemented as regularisation devices) will be required – e.g. preferred parameter values or relationships, or mathematical methods such as SVD.

5) Run model with and without pumping and compare the sw-gw fluxes to determine stream depletion rates over time.

GNS Science

Extent of model domain.



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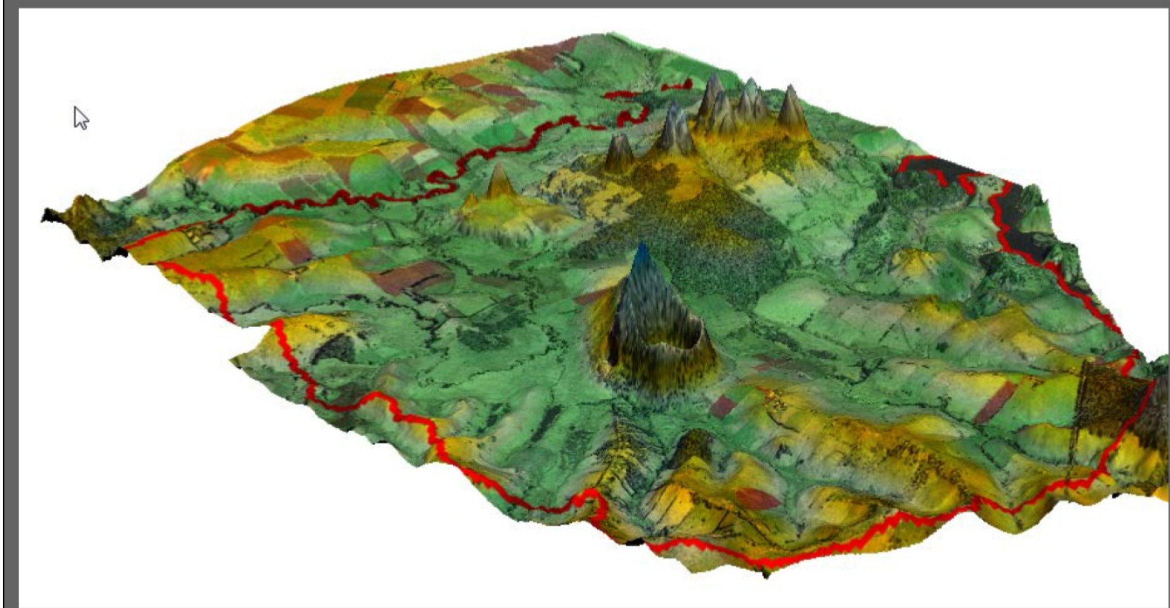
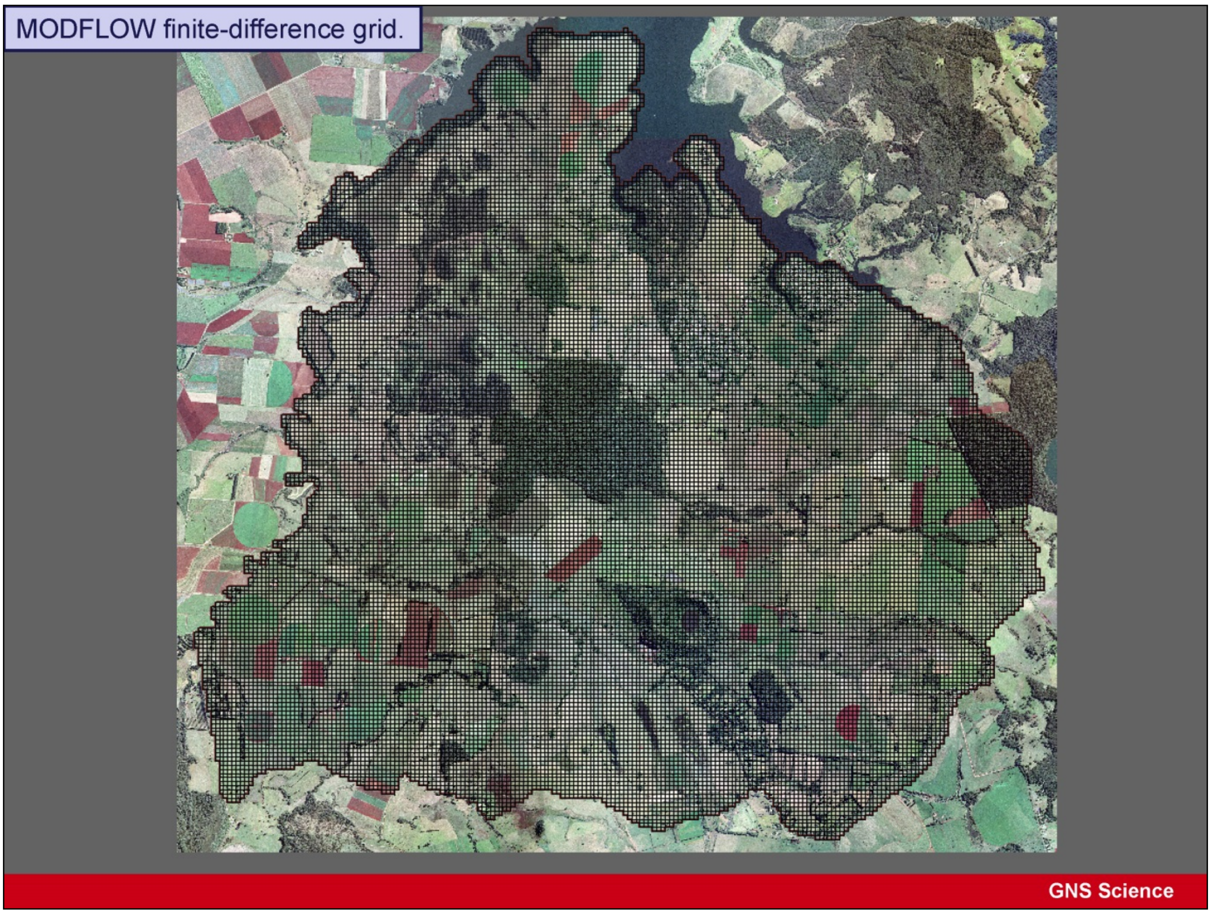
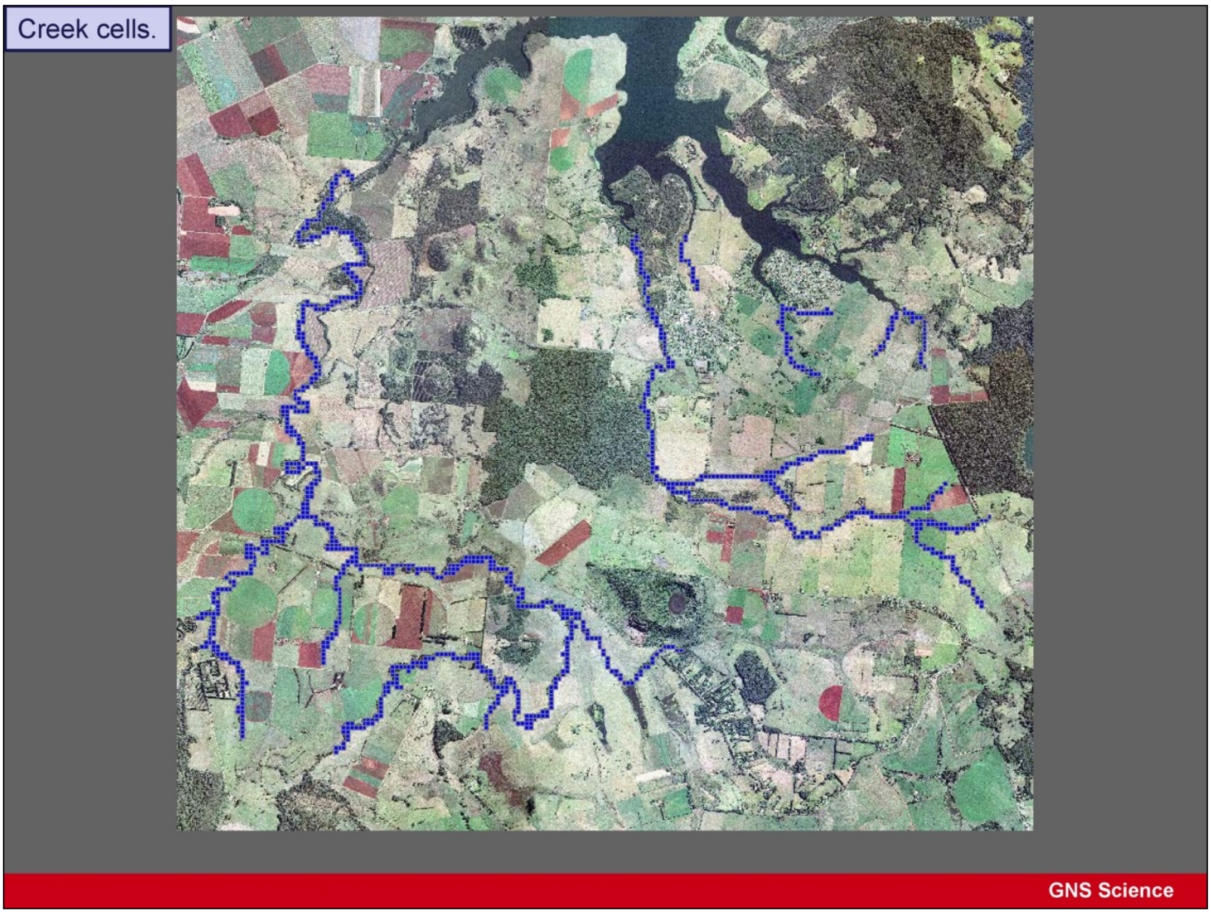
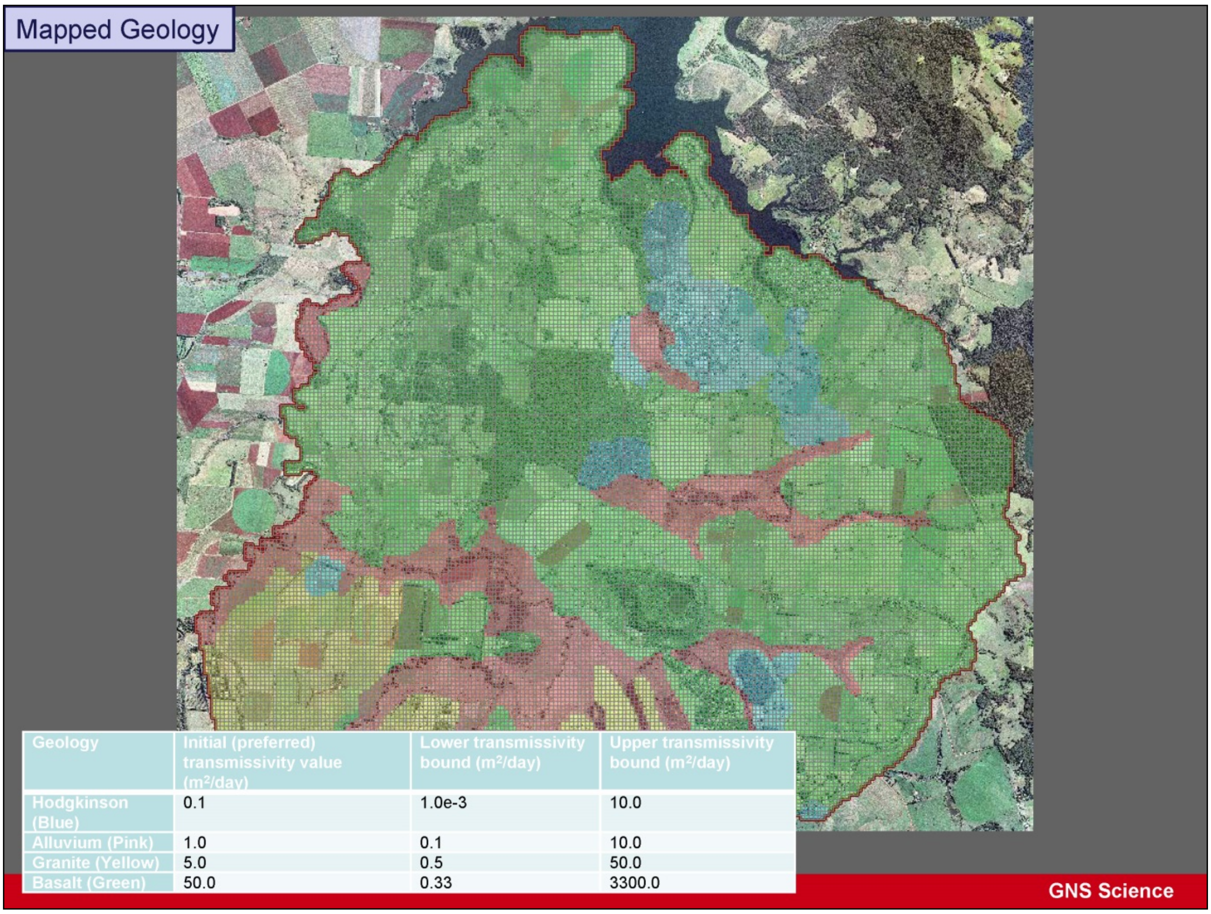
Model domain superimposed on topographic relief.



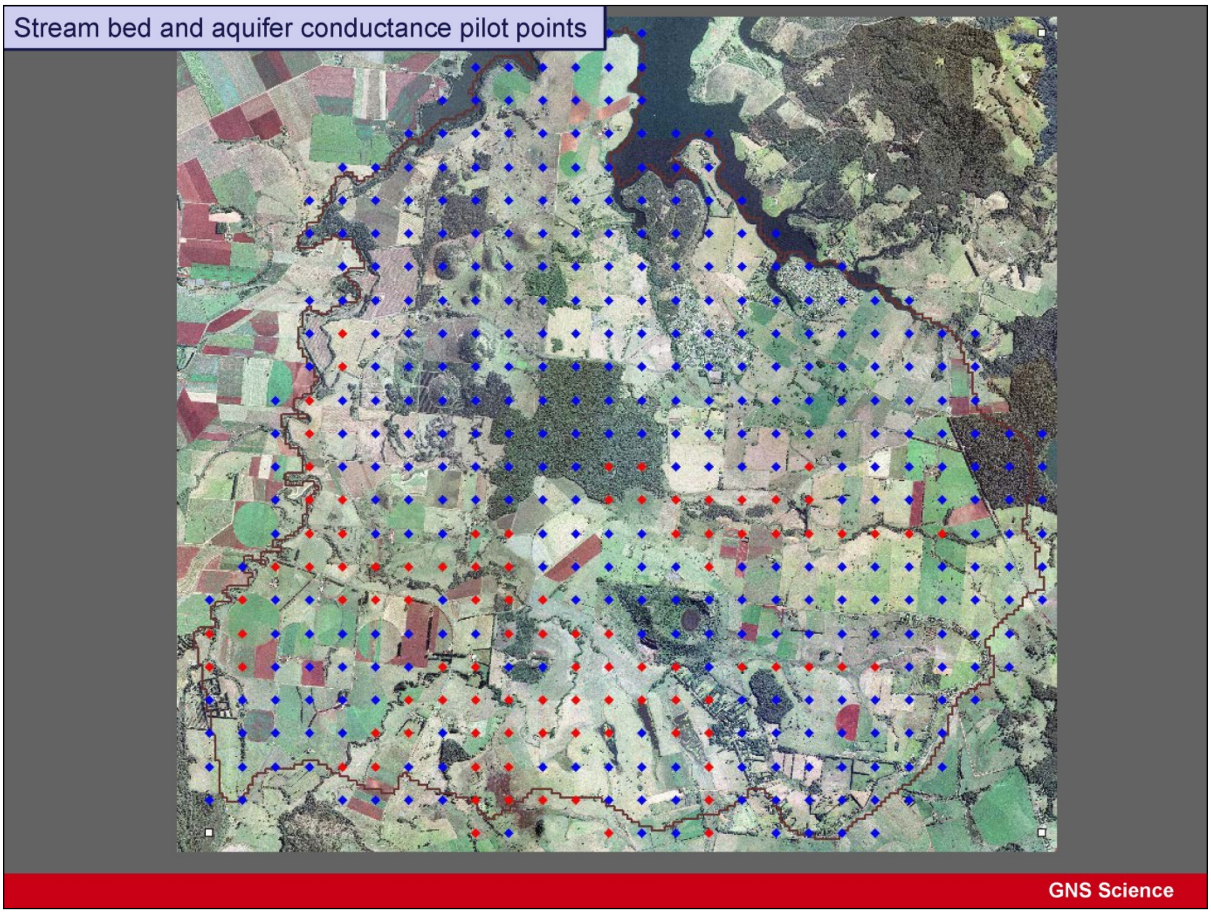
GNS Science

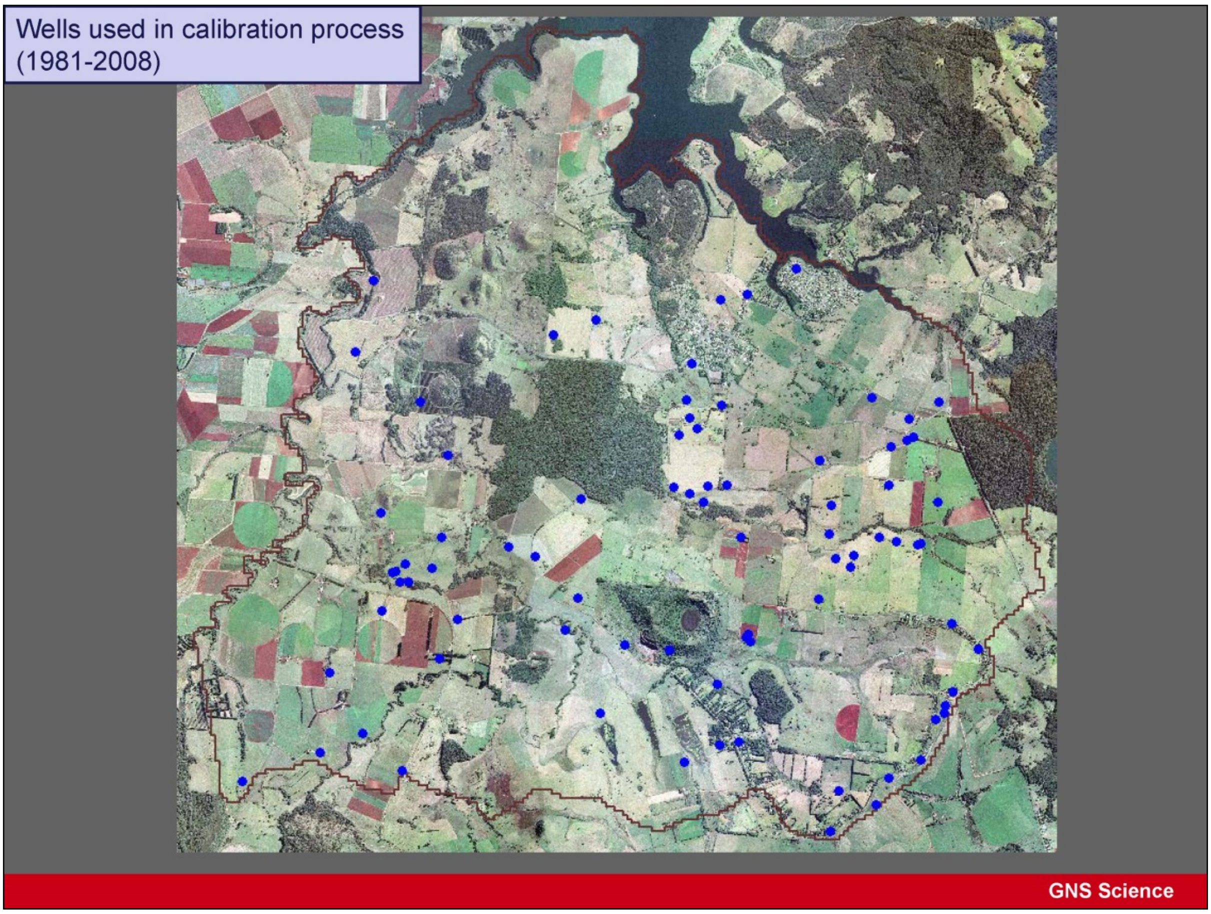

MODFLOW finite-difference grid.
GNS Science

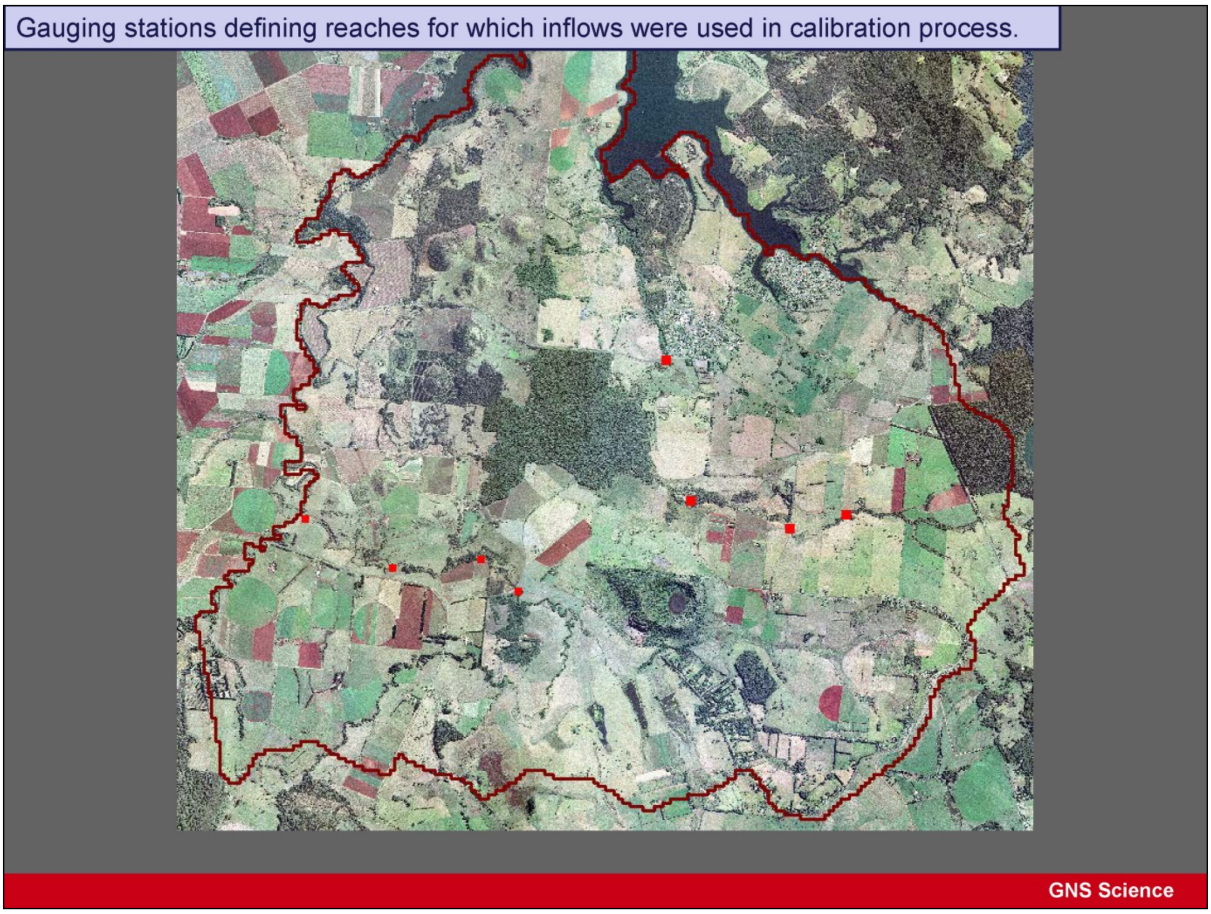

Creek cells.
GNS Science

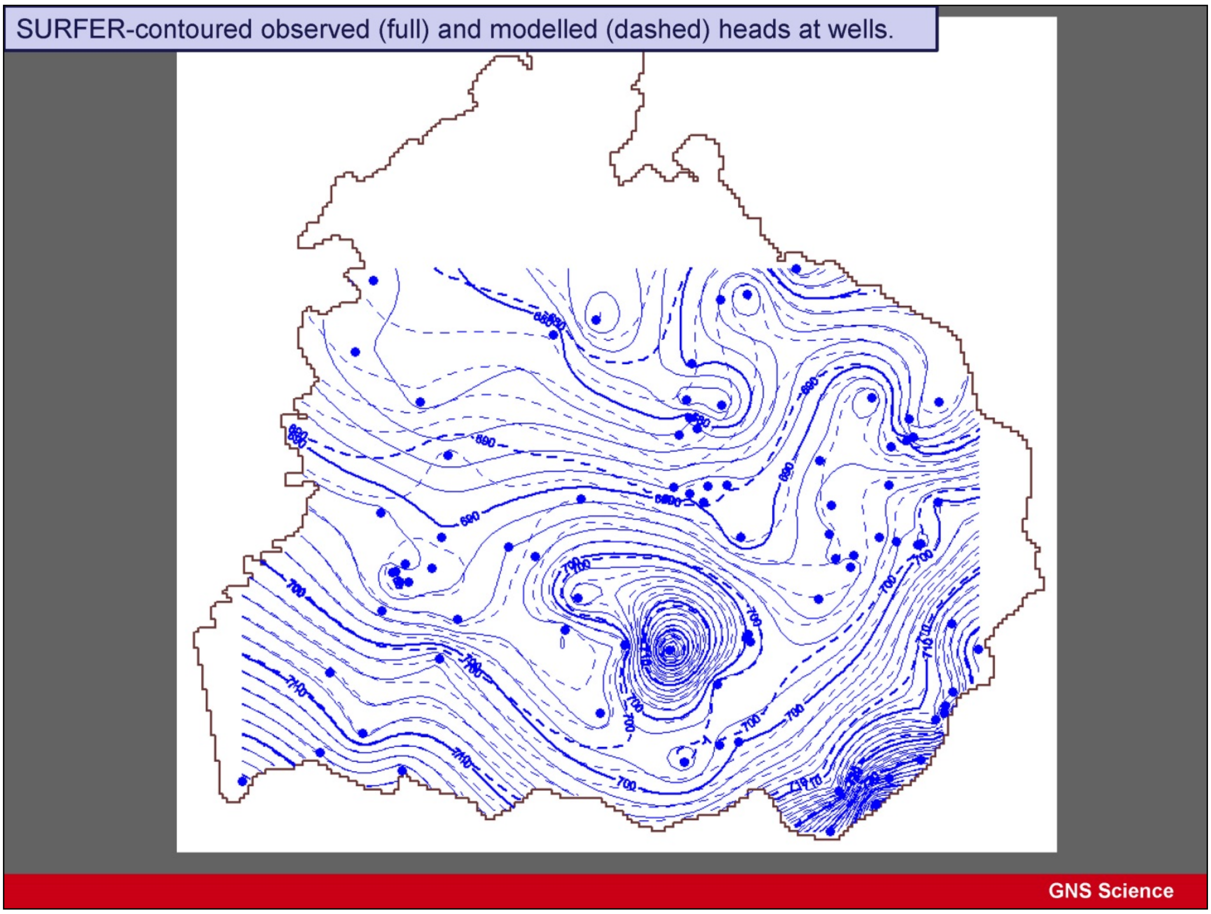


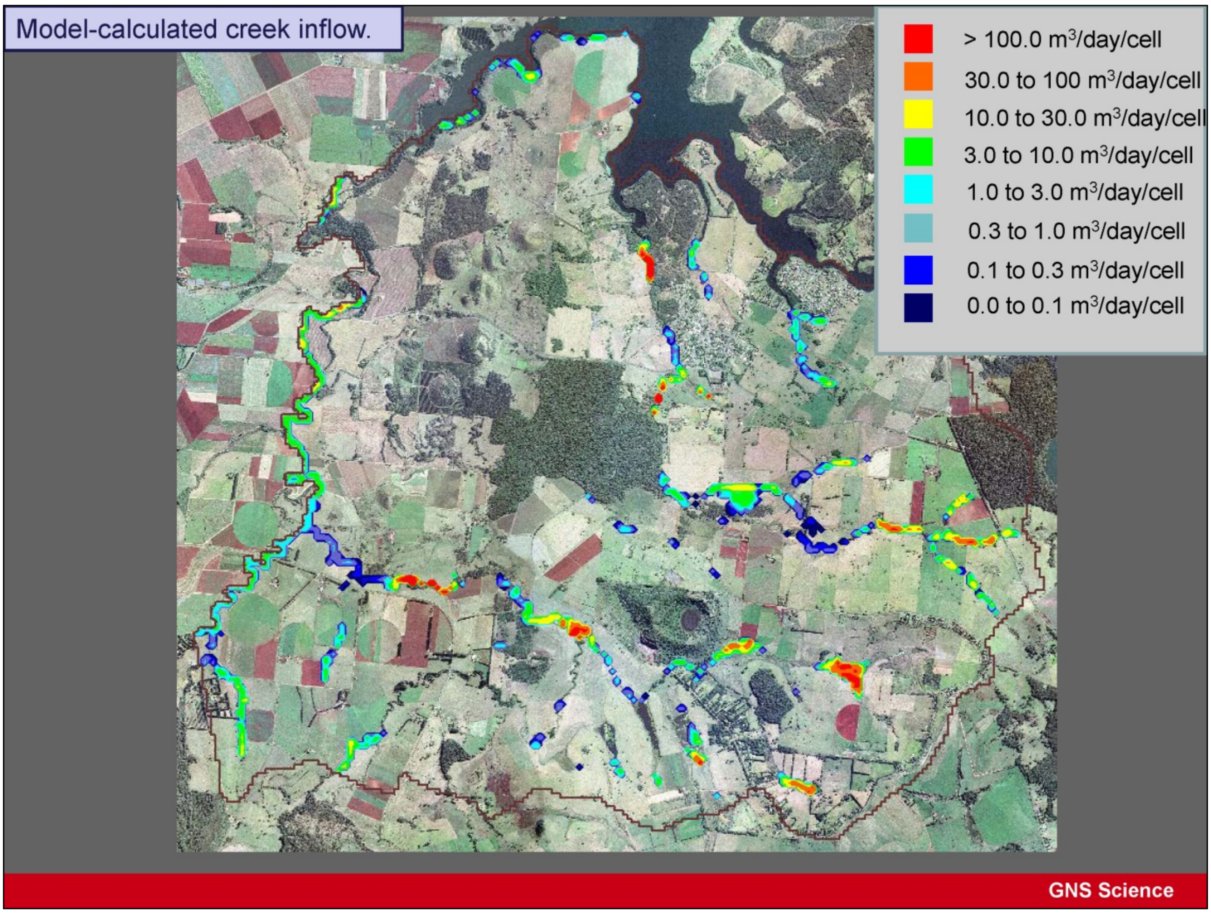
Geology	Initial (preferred) transmissivity value (m²/day)	Lower transmissivity bound (m²/day)	Upper transmissivity bound (m²/day)
Hodgkinson (Blue)	0.1	1.0e-3	10.0
Alluvium (Pink)	1.0	0.1	10.0
Granite (Yellow)	5.0	0.5	50.0
Basalt (Green)	50.0	0.33	3300.0

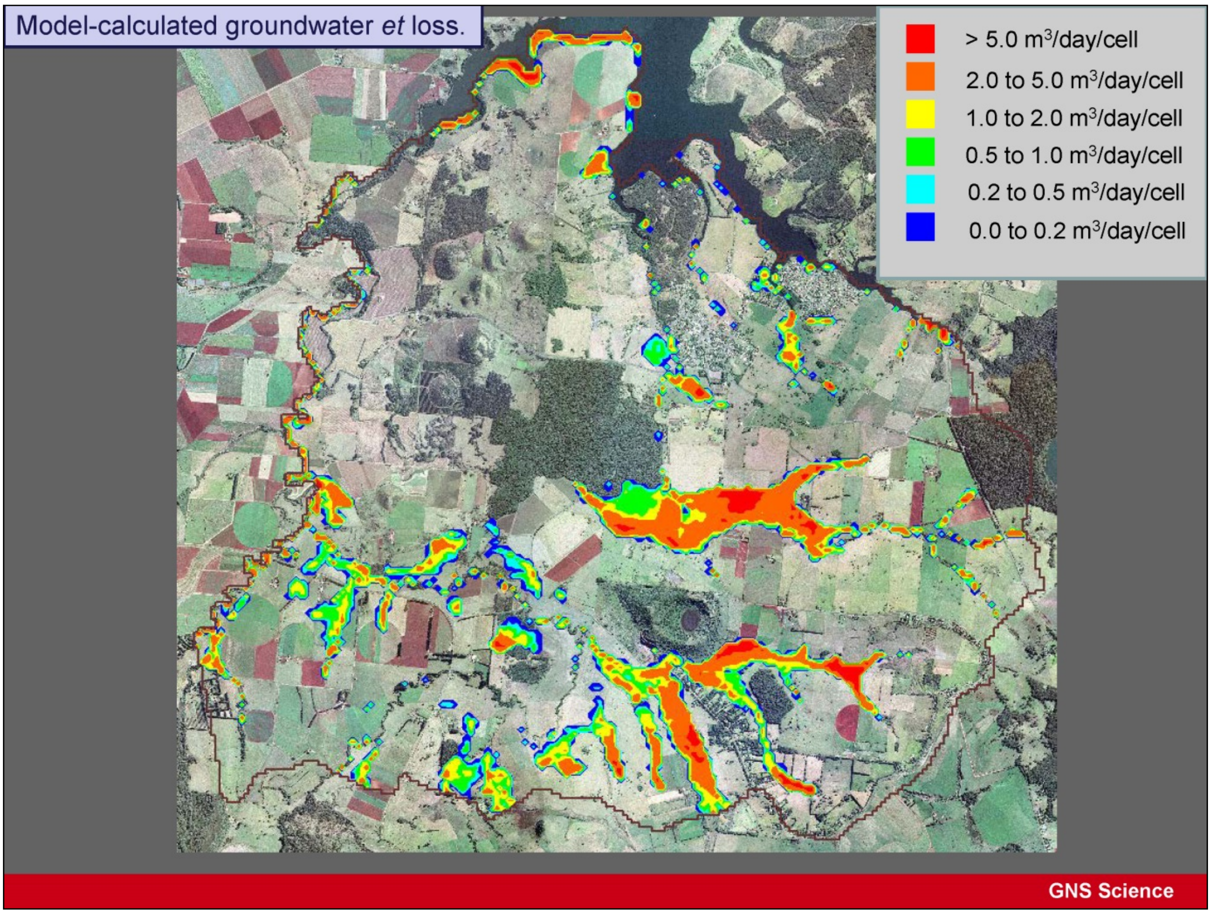


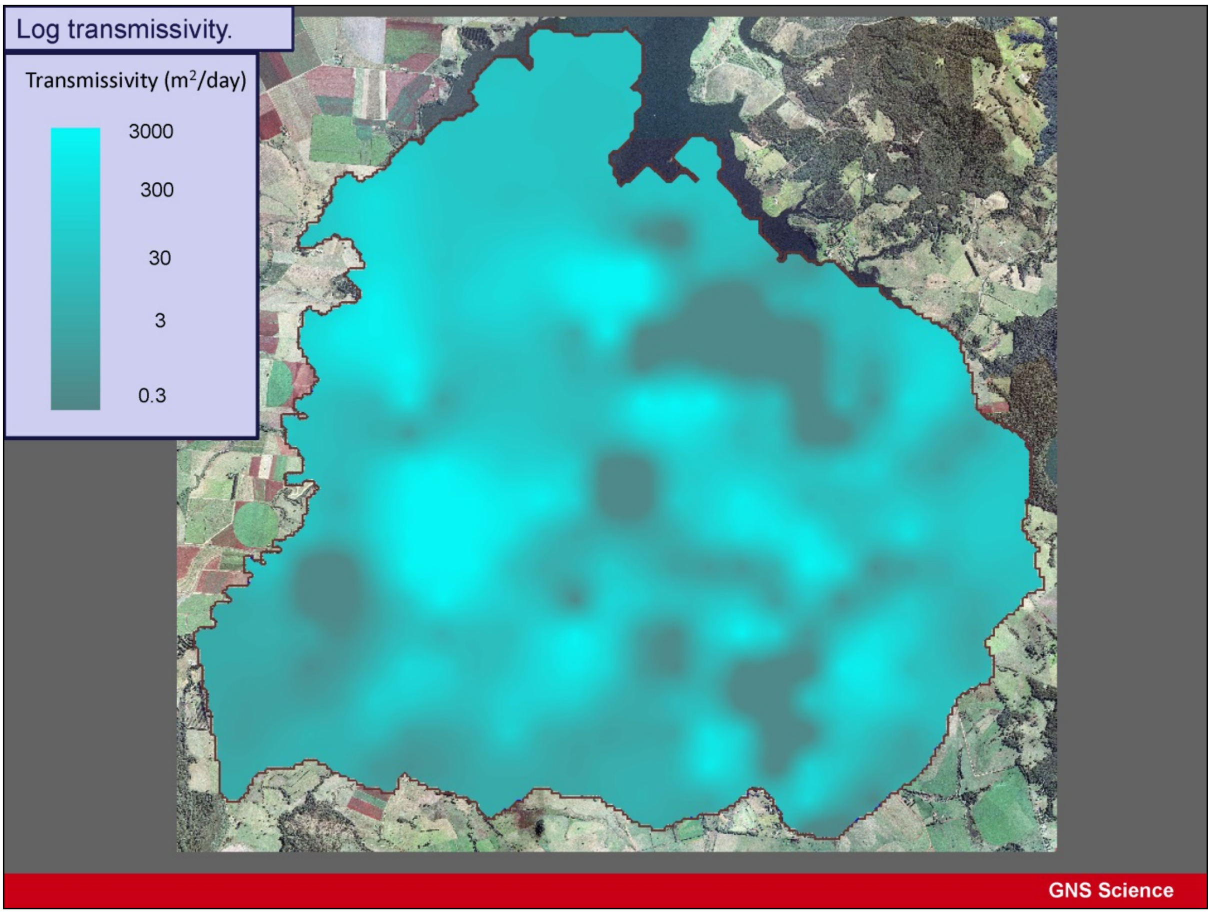

Wells used in calibration process (1981-2008)
GNS Science


Gauging stations defining reaches for which inflows were used in calibration process.
GNS Science

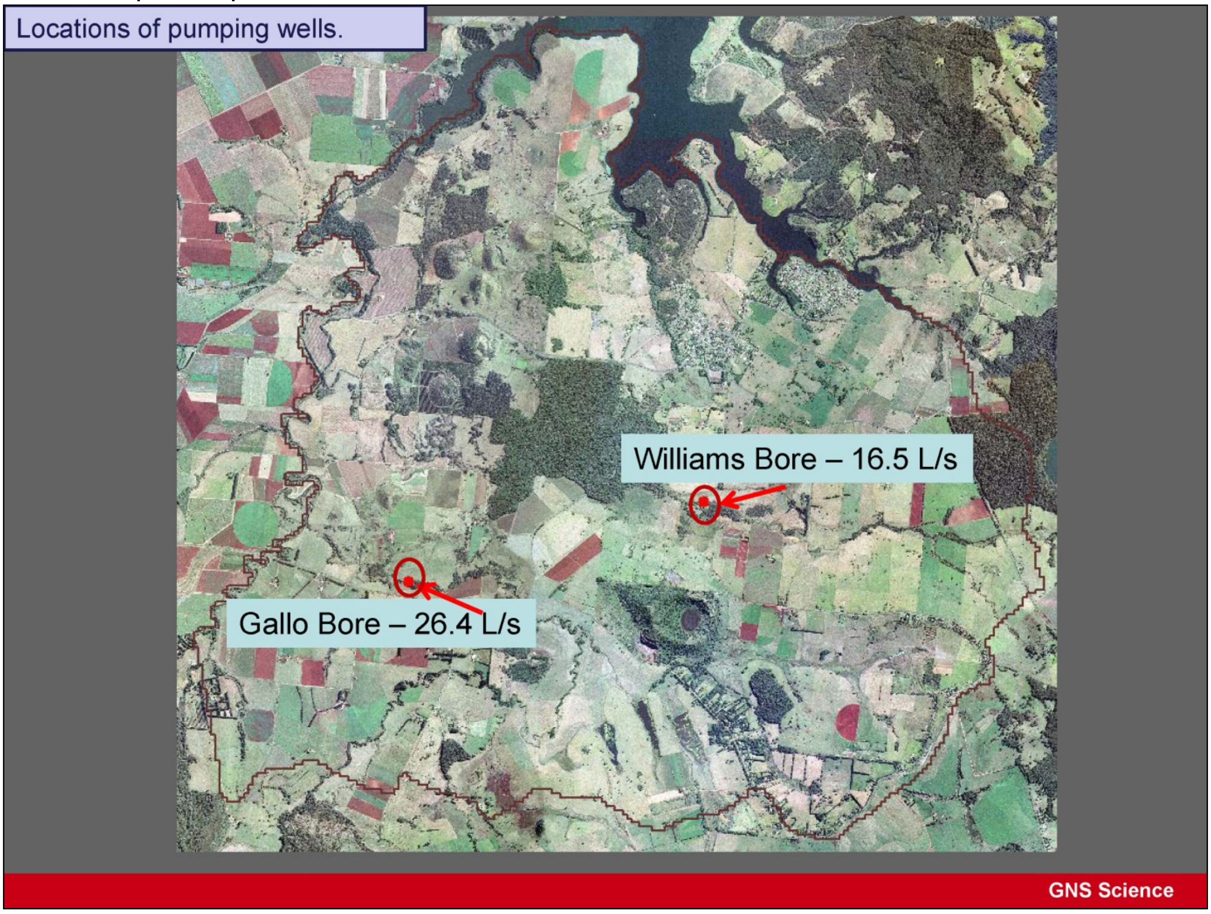

SURFER-contoured observed (full) and modelled (dashed) heads at wells.
690
700
710
GNS Science

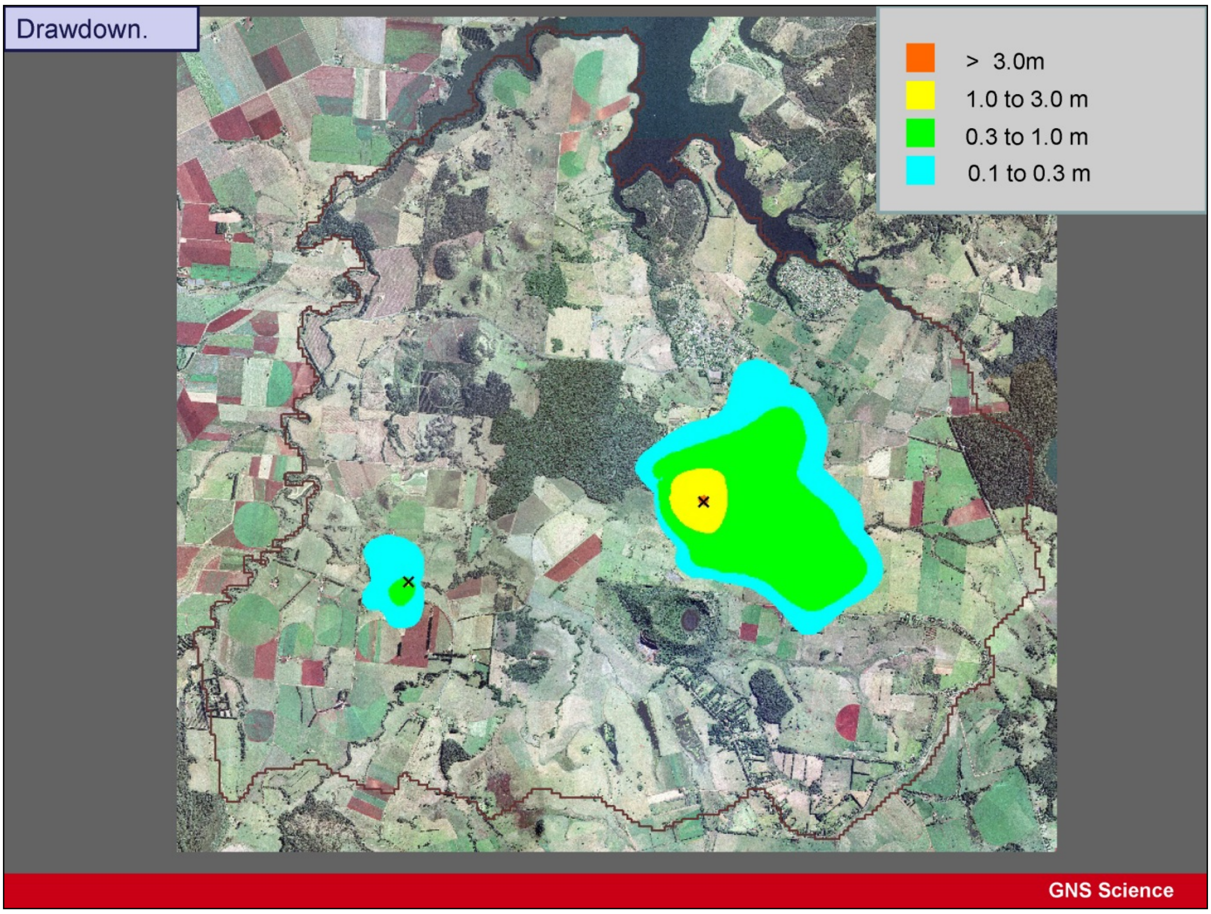

Model-calculated creek inflow.
> 100.0 m3/day/cell
30.0 to 100 m3/day/cell
10.0 to 30.0 m3/day/cell
3.0 to 10.0 m3/day/cell
1.0 to 3.0 m3/day/cell
0.3 to 1.0 m3/day/cell
0.1 to 0.3 m3/day/cell
0.0 to 0.1 m3/day/cell
GNS Science

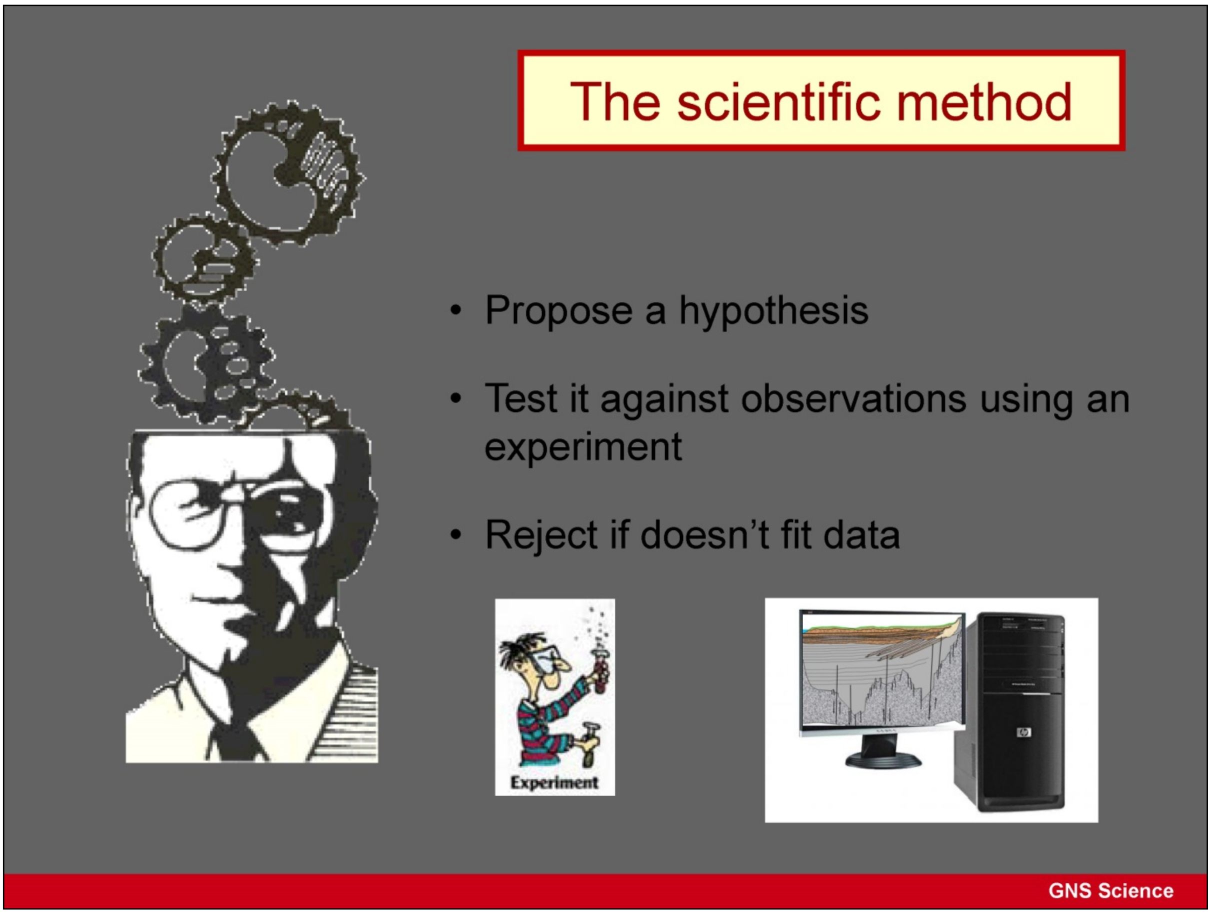

Model-calculated groundwater *et* loss.
> 5.0 m3/day/cell
2.0 to 5.0 m3/day/cell
1.0 to 2.0 m3/day/cell
0.5 to 1.0 m3/day/cell
0.2 to 0.5 m3/day/cell
0.0 to 0.2 m3/day/cell
GNS Science

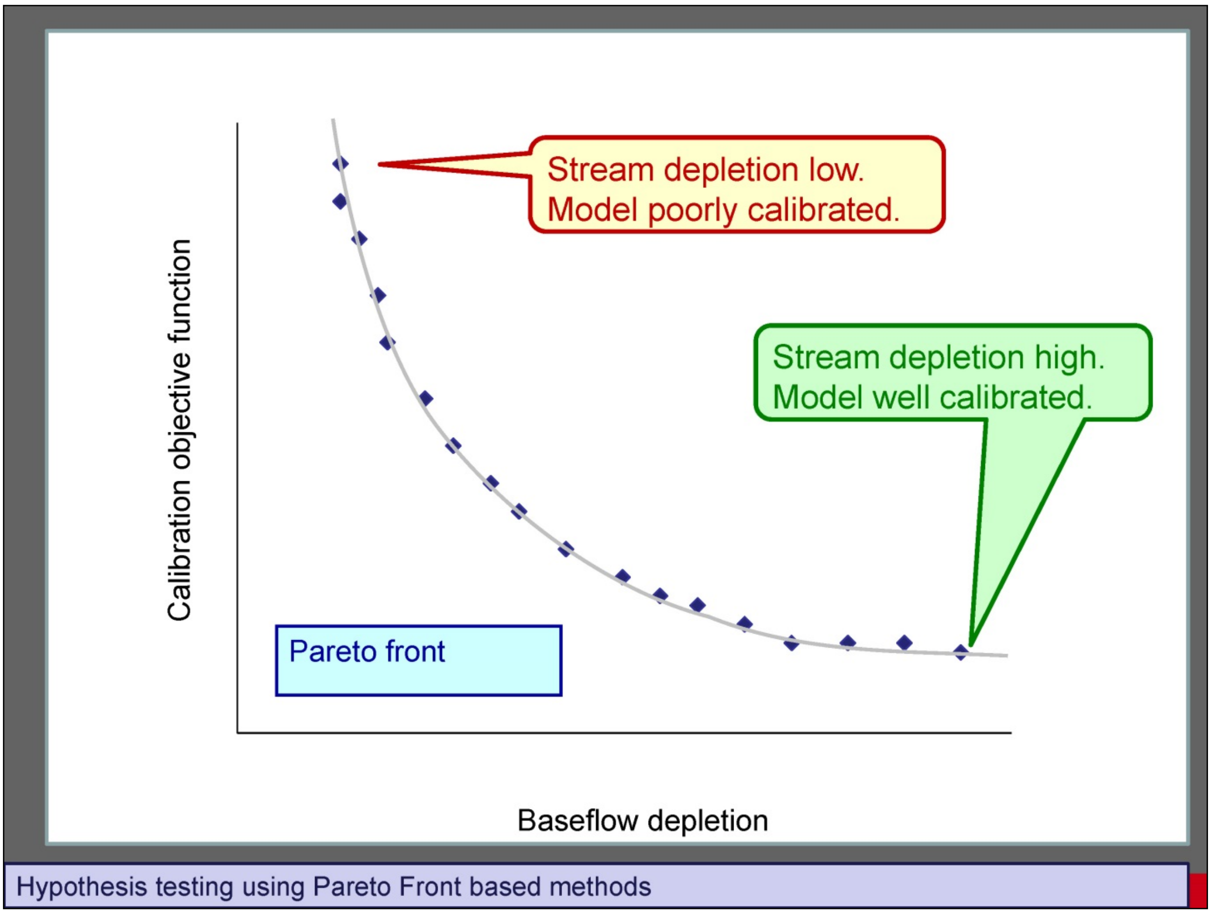

Log transmissivity.
Transmissivity (m2/day)
3000
300
30
3
0.3
GNS Science

Stream depletion prediction

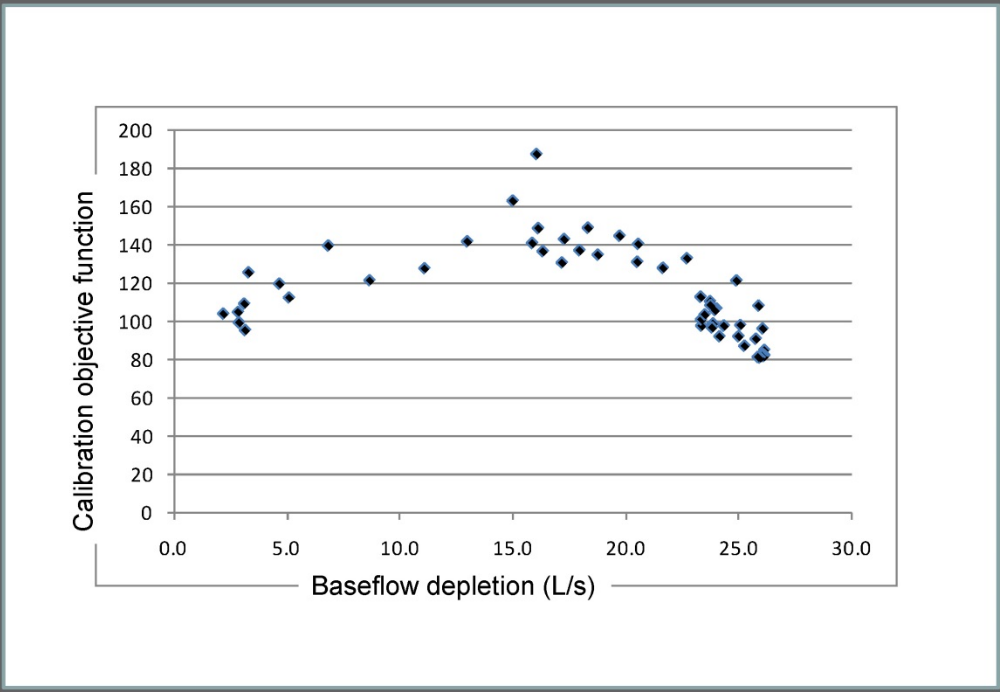




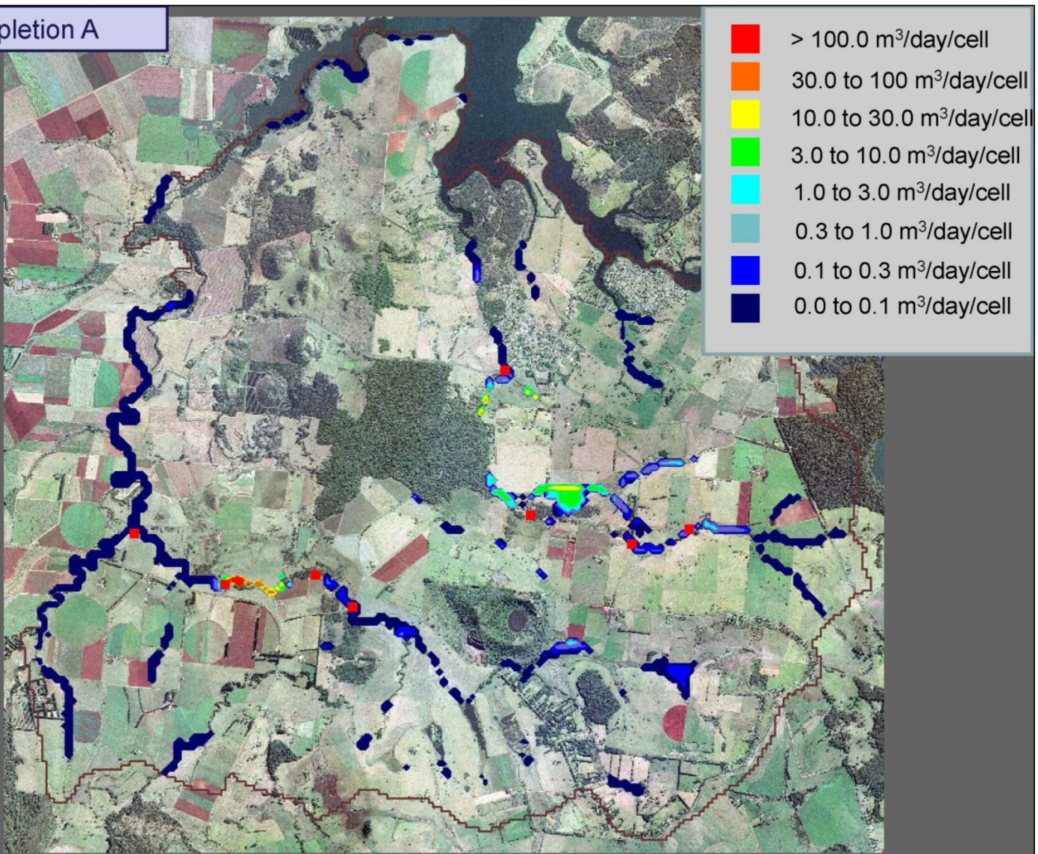

The scientific method
• Propose a hypothesis
• Test it against observations using an experiment
• Reject if doesn't fit data
Experiment
GNS Science

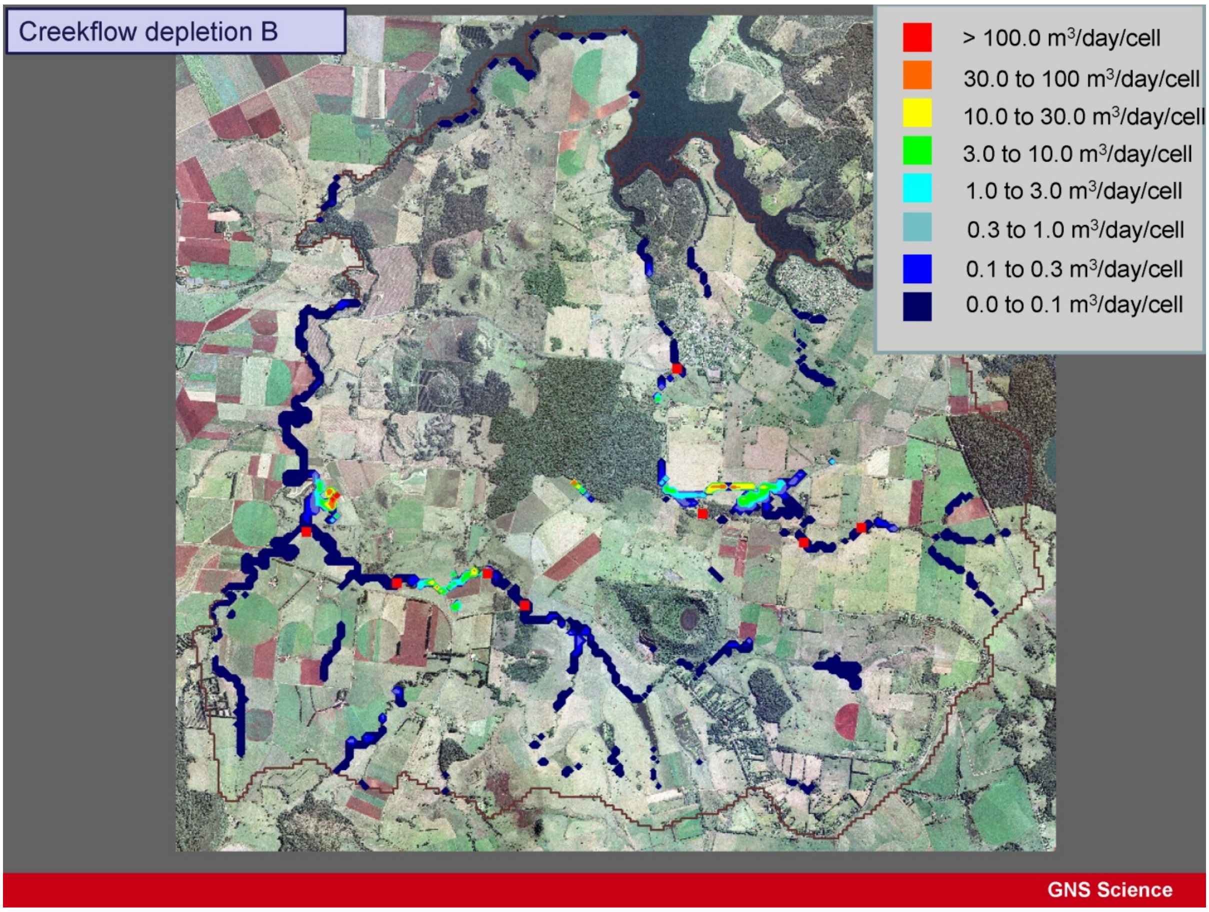

Stream depletion low.
Model poorly calibrated.
Stream depletion high.
Model well calibrated.
Pareto front
Calibration objective function
Baseflow depletion
Hypothesis testing using Pareto Front based methods

Outcomes of a PEST "Pareto mode" run.

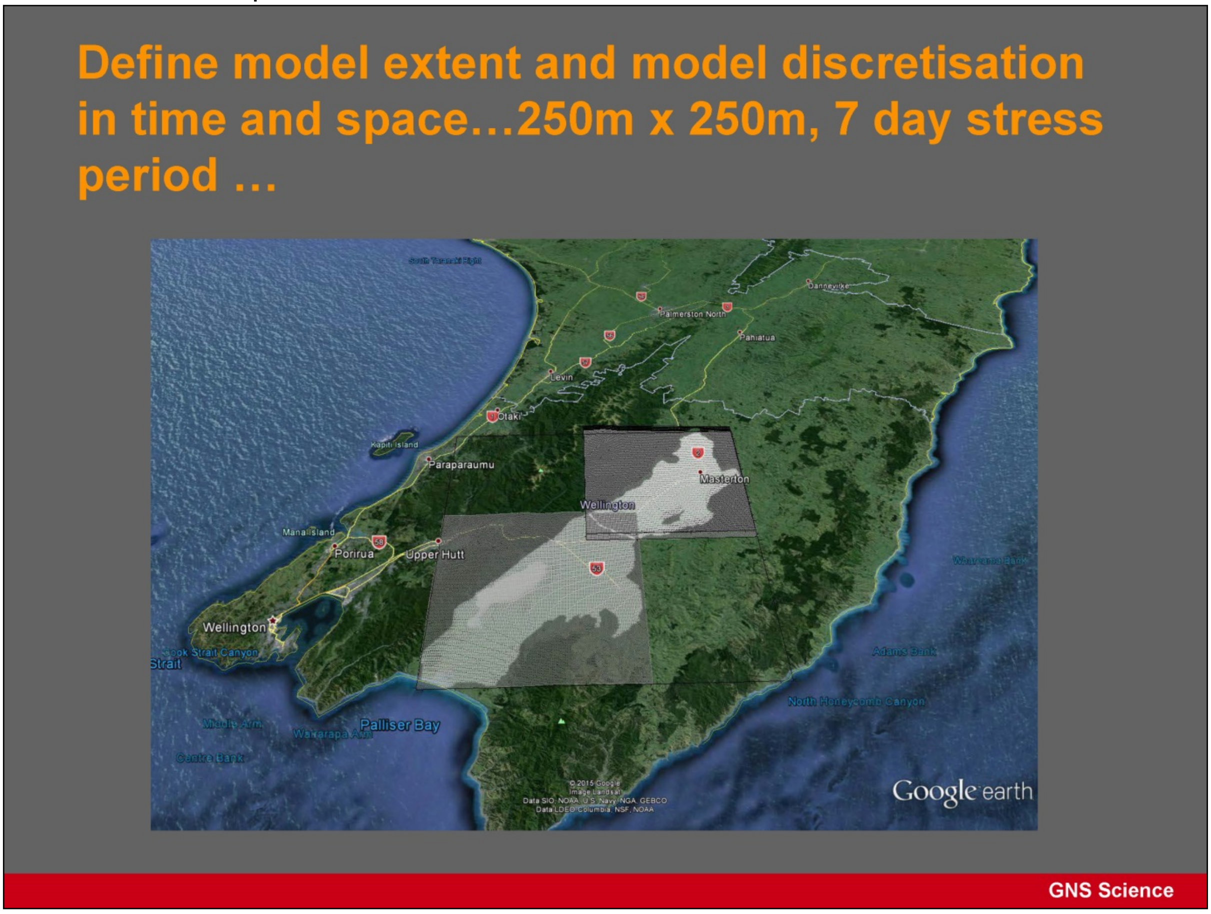


Creekflow depletion A

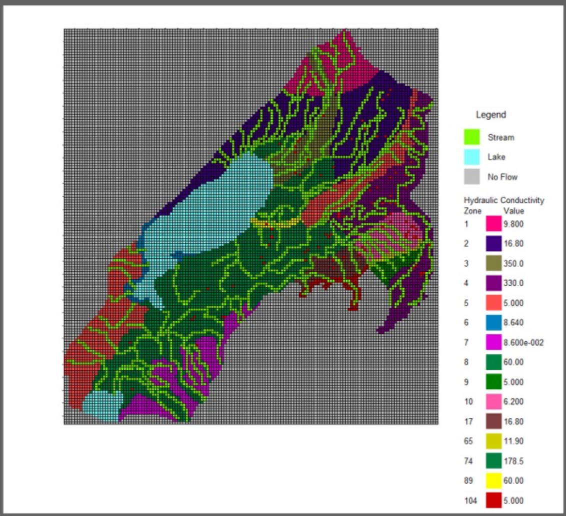


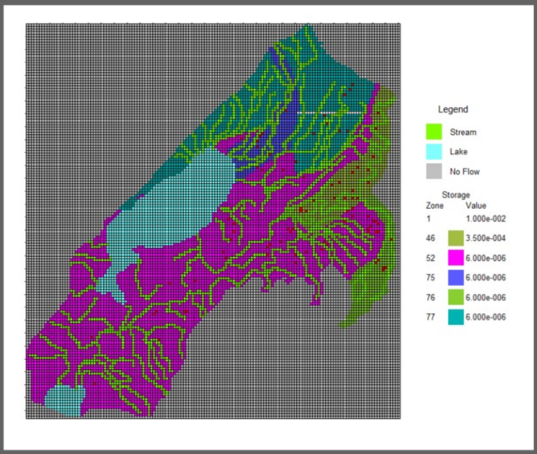


New Zealand example



Define hydraulic properties and their disposition, stream and well locations…





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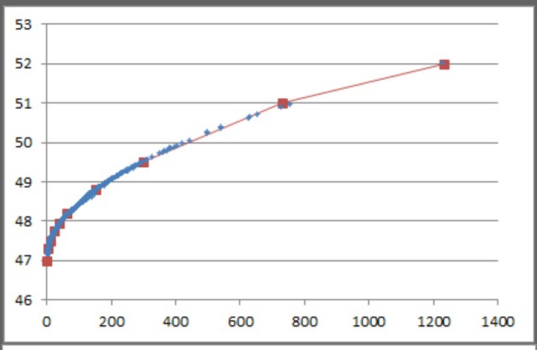
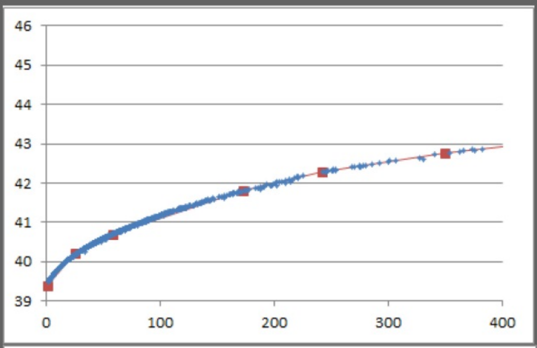
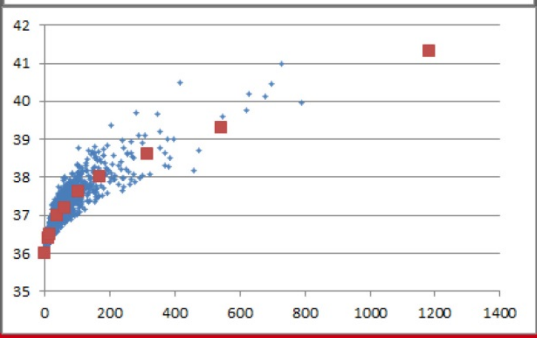
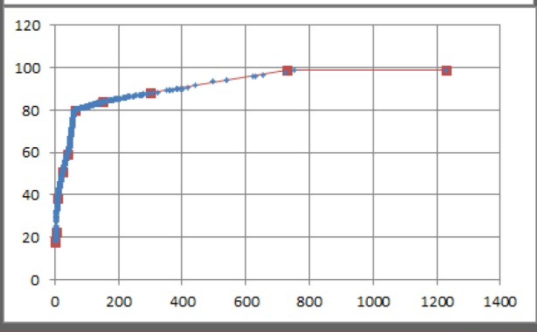
Define stream stage – flow relationships used in stream package





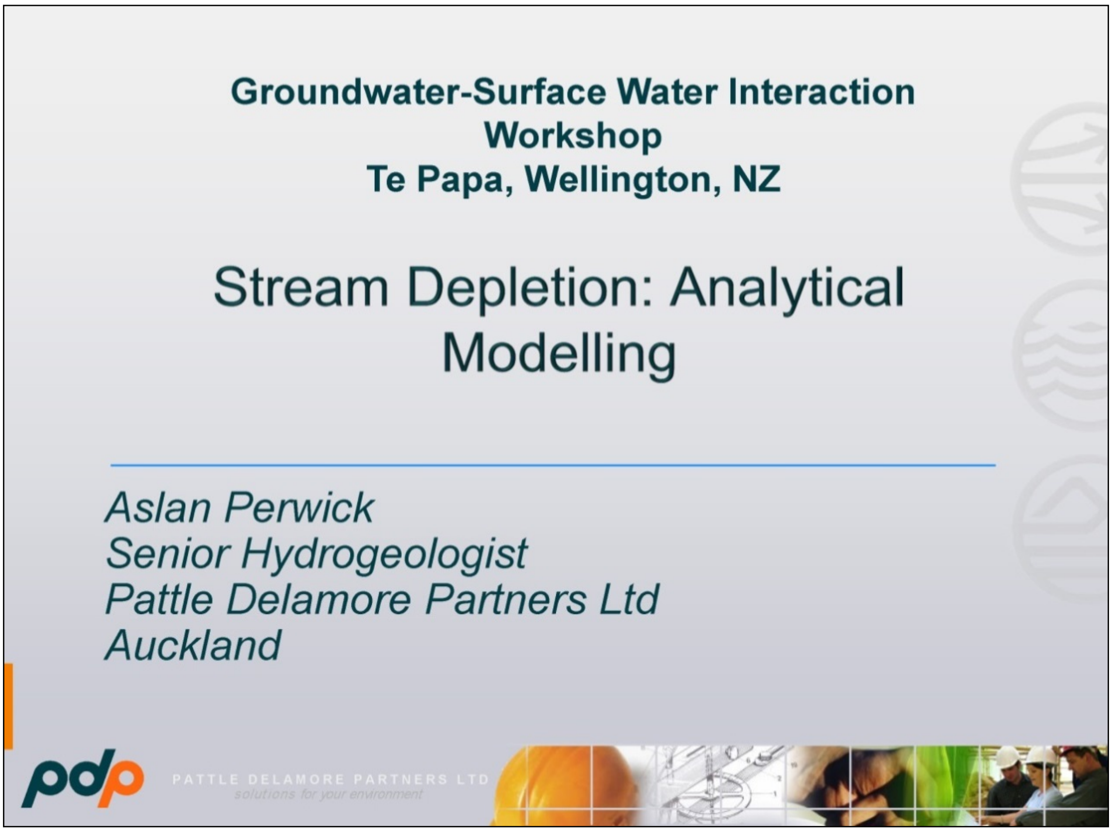


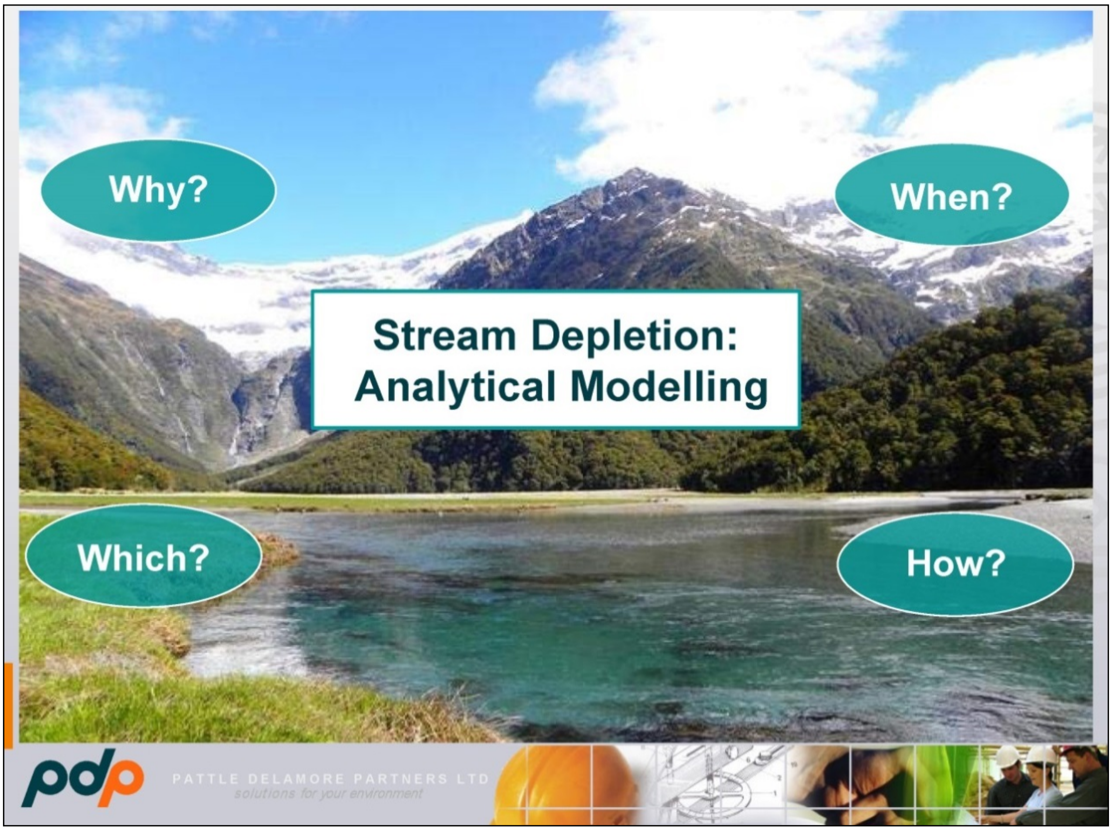


GNS Science

3.2.2 Analytical Solutions to determine groundwater pumping effects on surface waterways and to assist the determination of sustainable allocation limits

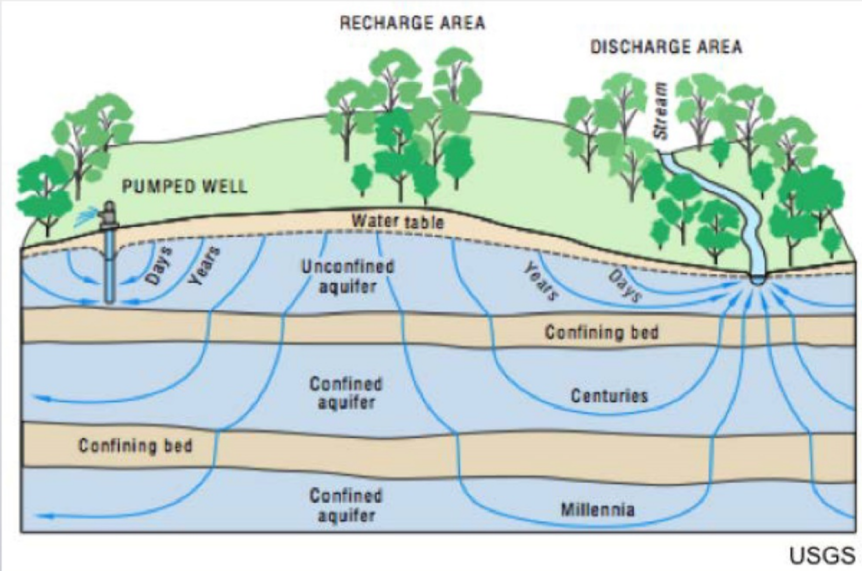
Facilitator: Aslan Perwick, Pattle Delamore Partners Ltd





Back to Basics – The Water Cycle

Time Scales



Source: *United State Geological Survey*

2

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Stream Depletion – When is a Stream NOT Connected?

- **Depth to water table below stream surface is >5 times the stream depth**

AND

- **Depth to water table below stream surface is >2 time the stream width**

BUT

- **Clogging layer?**
- **Upstream/downstream effects?**

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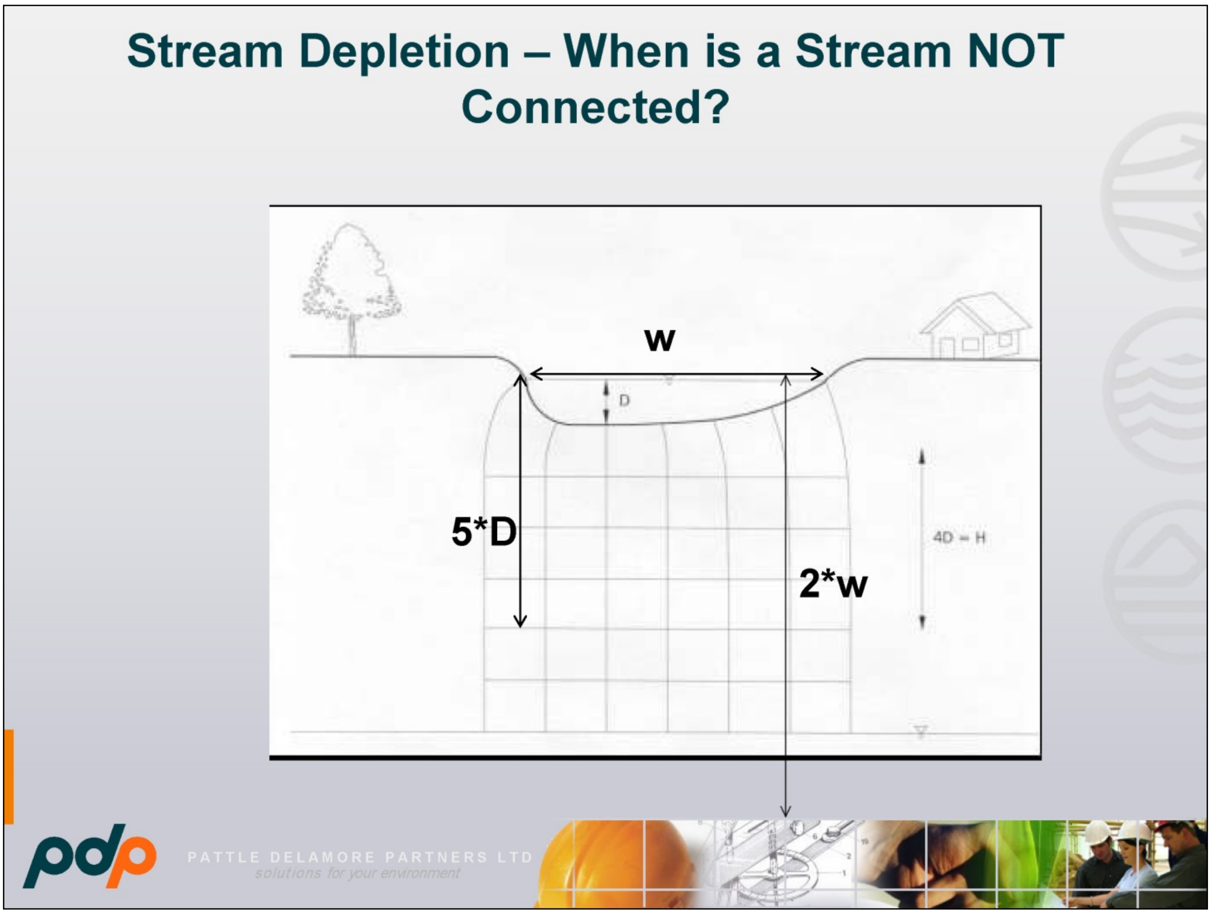
Stream Depletion – When is a Stream NOT Connected?
w
D
5*D
2*w
4D = H
pdp
PATTLE DELAMORE PARTNERS LTD
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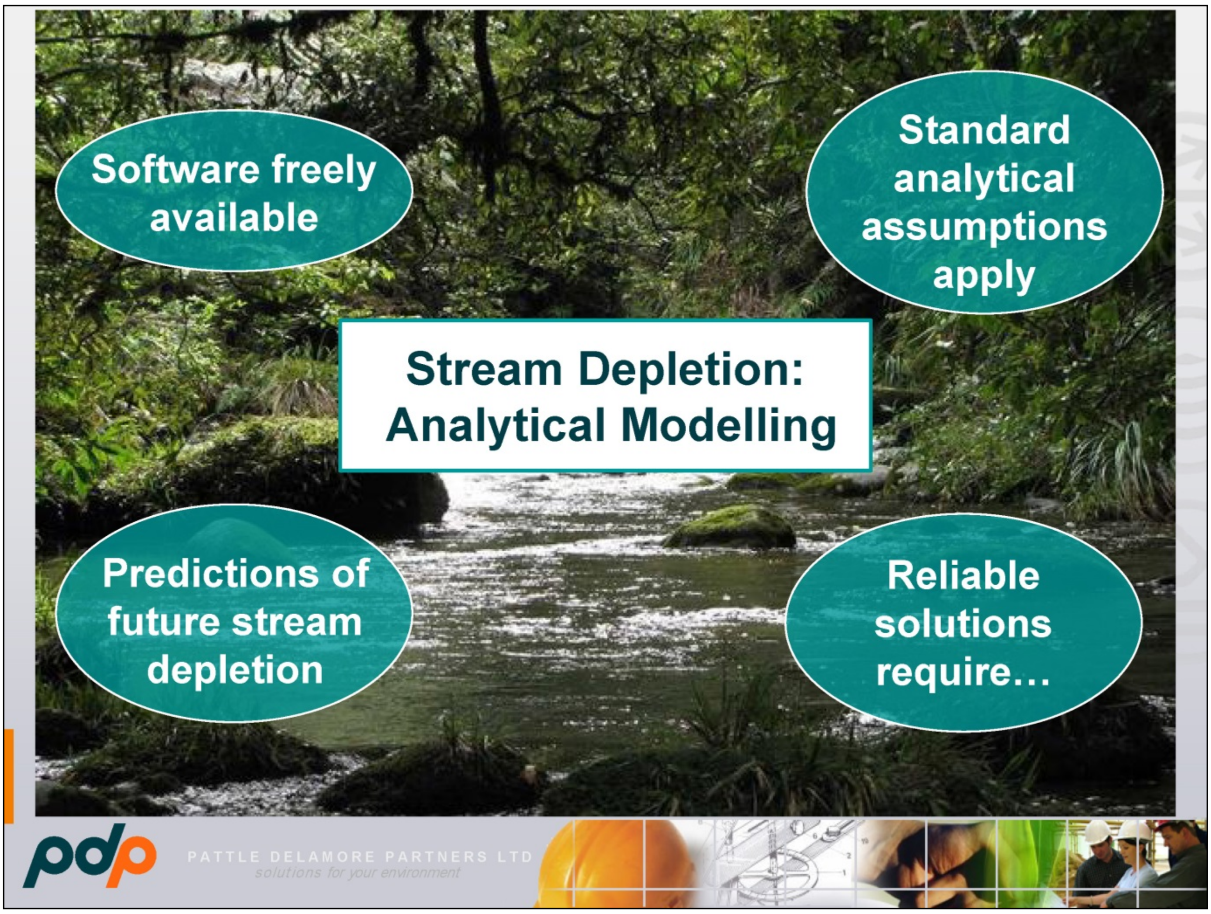
Software freely available
Standard analytical assumptions apply
Stream Depletion: Analytical Modelling
Predictions of future stream depletion
Reliable solutions require…
pdp
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What Parameters?

Inputs

- Pumping Rate (Q)
- Drawdown in observation bore (s) – pumped aquifer + other
- Distances from stream (x, y, L)
- Change in Stream Flow (ΔQ) – optional & potentially tricky

Outputs

- Aquifer Transmissivity (T)
- Storativity (S)
- Leakage (K'/B')
- Specific Yield (S_y)
- Overlying Aquifer Transmissivity (T_0)
- Stream bed Conductance (l)

8

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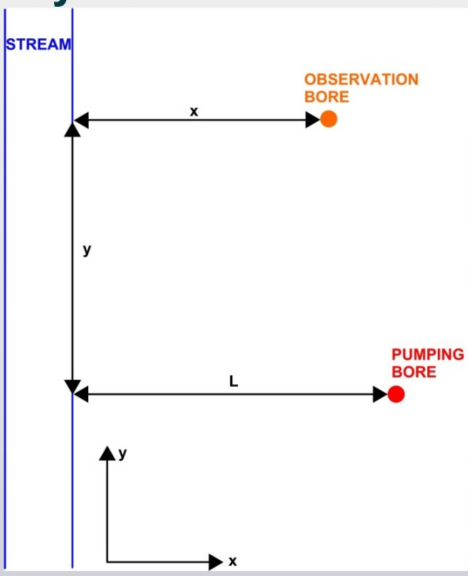
Analytical Model Plan View



'Rule-of-Thumb'

Within 2 km = Stream depletion must be considered

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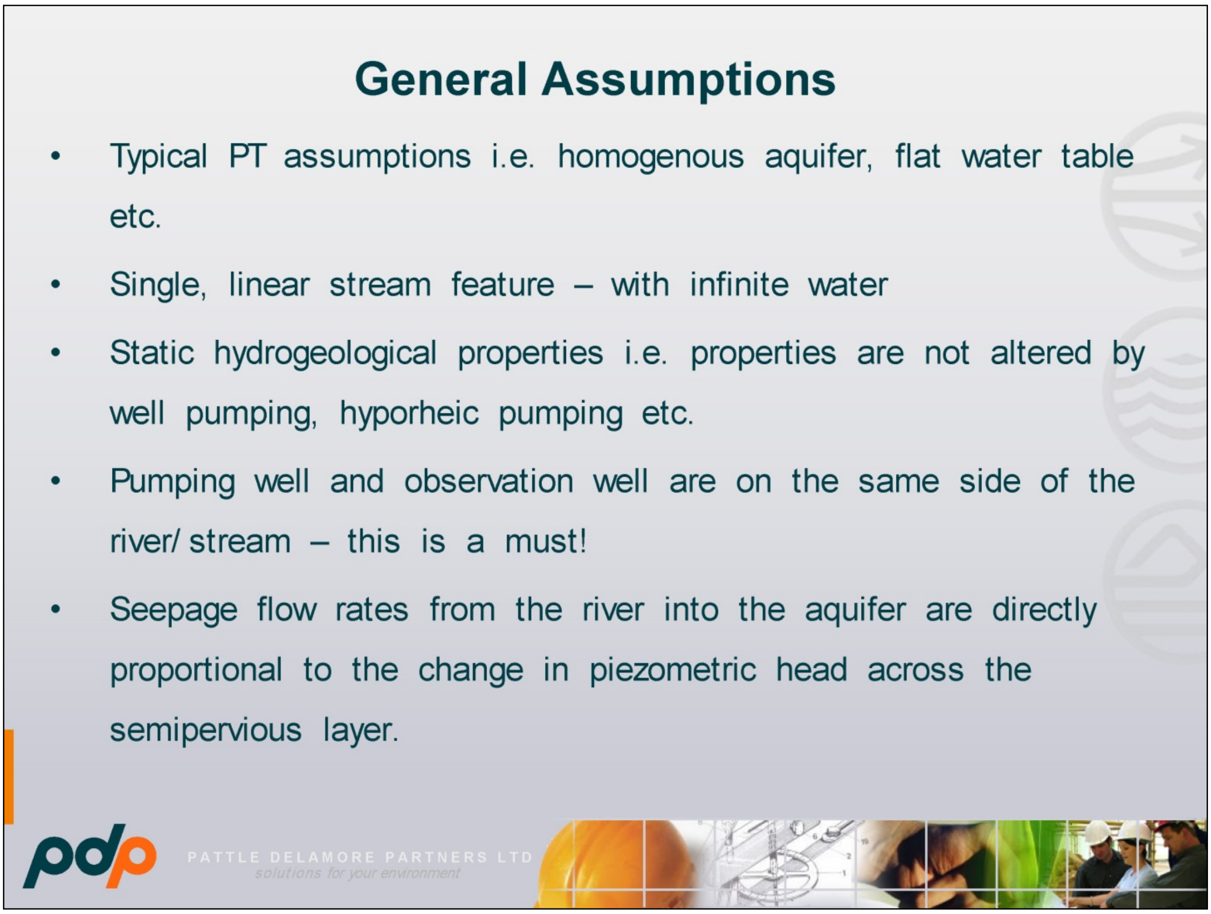
General Assumptions
• Typical PT assumptions i.e. homogenous aquifer, flat water table etc.
• Single, linear stream feature – with infinite water
• Static hydrogeological properties i.e. properties are not altered by well pumping, hyporheic pumping etc.
• Pumping well and observation well are on the same side of the river/ stream – this is a must!
• Seepage flow rates from the river into the aquifer are directly proportional to the change in piezometric head across the semipervious layer.
pdp
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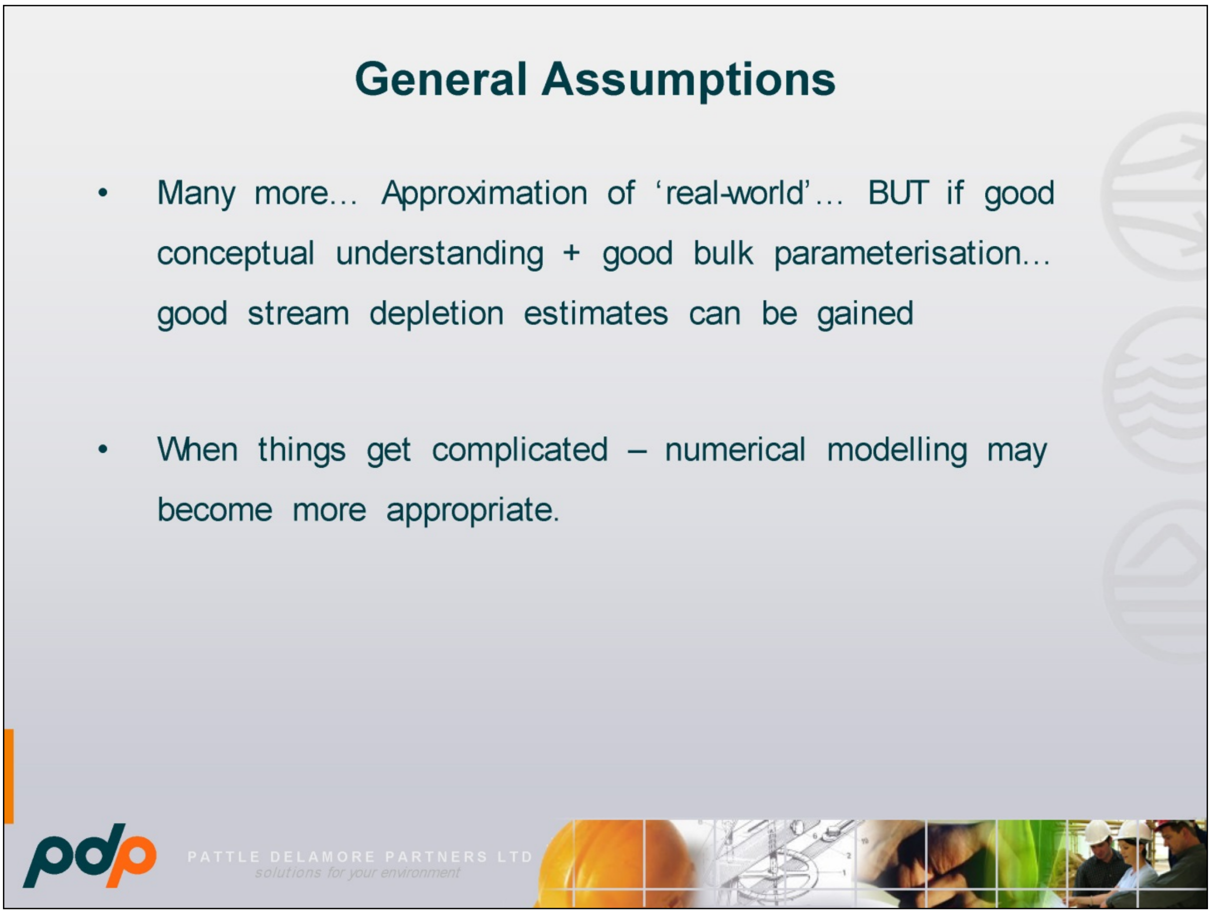
General Assumptions
• Many more… Approximation of 'real-world'… BUT if good conceptual understanding + good bulk parameterisation… good stream depletion estimates can be gained
• When things get complicated – numerical modelling may become more appropriate.
pdp
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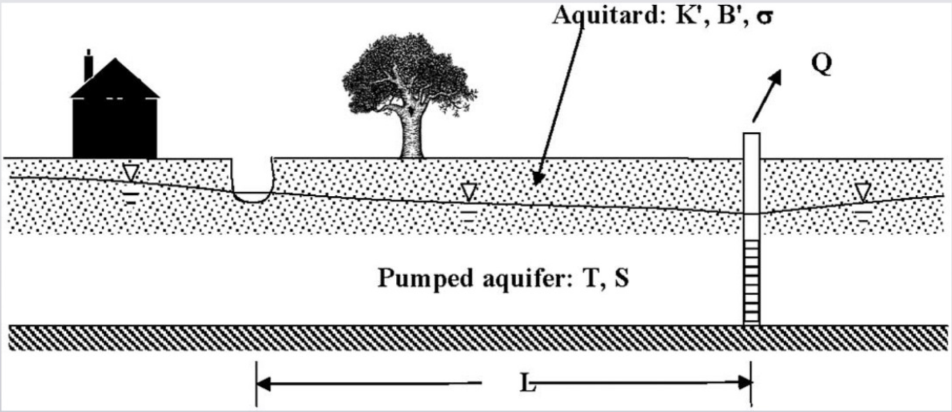
Hunt (2003) solution

- Pumping semi-confined aquifer
- If no aquitard present: K'/B' = 0, and S = S_y



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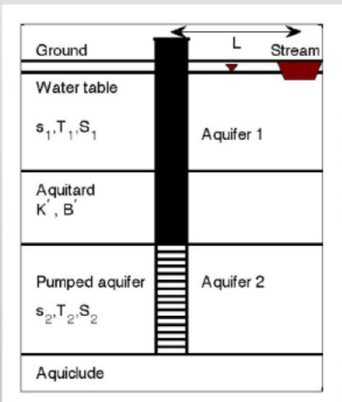
Dudley-Ward, & Lough (2011) Solution

- Pumping a semi-confined aquifer overlain by an unconfined aquifer.
- Preferable where horizontal flow in overlying layers can not be ignored – no depletion underestimate



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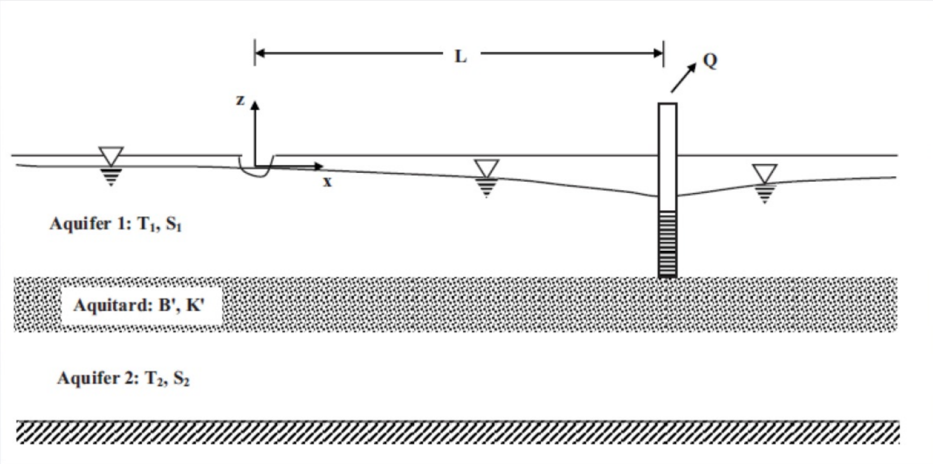
Hunt (2009) solution

- ➢ Pumping from the overlying unconfined aquifer



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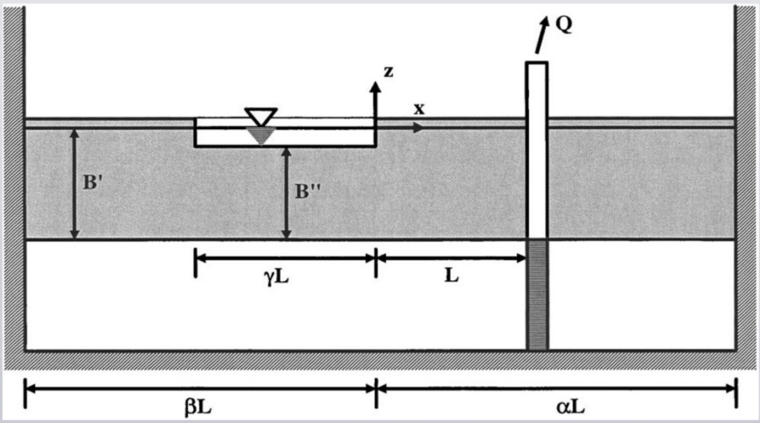
Hunt (2008) solution

- ➢ Pumping a semi-confined bounded aquifer.
- ➢ Can also model stream depletion from bounded unconfined/confined aquifers



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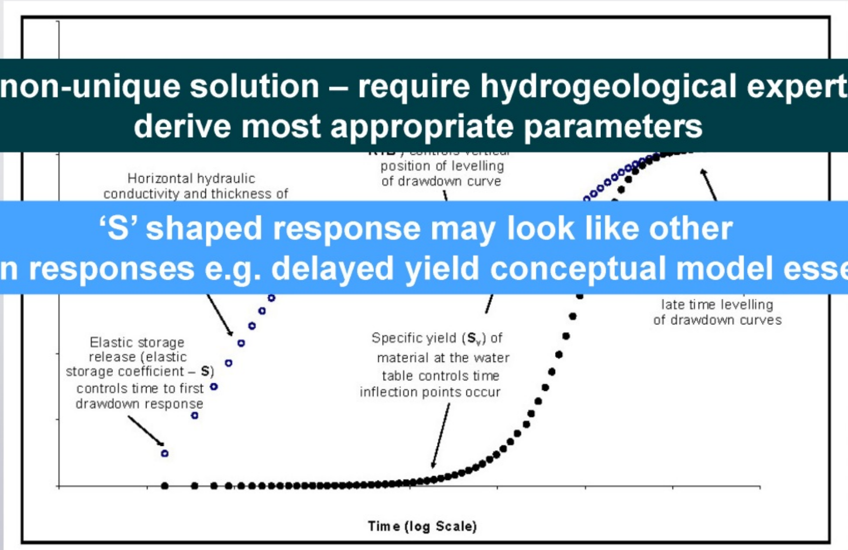
Analysis Example

Example response in pumped semi-confined aquifer and response in overlying unconfined aquifer – Hunt (2003) solution



Often non-unique solution – require hydrogeological expertise to derive most appropriate parameters

'S' shaped response may look like other known responses e.g. delayed yield conceptual model essential

Source: *Adapted from PDP and ECAN, 2005*

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Stream Depletion Prediction

Hunt(2003) - Example1

Stream depletion analysis - Hunt (2003) solution

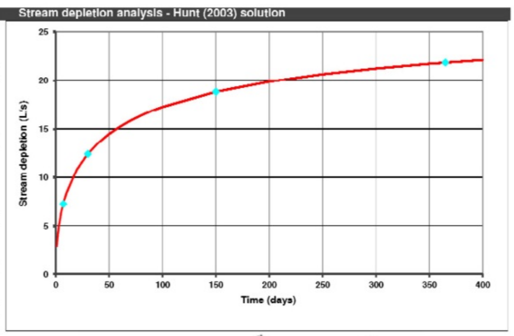
Pumped aquifer		
Transmissivity (T)	1900	(m^2/d)
Storage coefficient (S)	0.0004	-
Aquitard		
Hydraulic conductivity (K')	0.46	(m/d)
Thickness (B')	2	(m)
K'/B'	0.23	(d^{-1})
Specific yield (S_y)	0.01	-
Streambed		
Hydraulic conductivity (K'')	1	(m/d)
Thickness (B'')	1	(m)
Width (W)	1	(m)
Stream bed conductance (λ)	1	(m/d)
Well		
Pumping rate (Q)	28.9	(L/s)
Separation distance (L)	66	(m)
Application efficiency		
Irrigation efficiency	100%	
Separation distance (L2)	300	(m)

Stream depletion after

Time (days)	q (L/s)	%
7	7	25%
30	12	43%
150	19	65%
365	22	76%

Only the values in shaded cells can be updated - all other cells are dependent on those input values.

Setting K'/B' to zreo gives Hunt 1999 solution



Time (days)	Depletion Rate @100% (L/s)	@100% (L/s)
1.0	2.9	2.9
2.0	4.1	4.1
3.0	5.0	5.0
4.0	5.7	5.7
5.0	6.3	6.3
6.0	6.8	6.8
7.0	7.3	7.3
8.0	7.7	7.7
9.0	8.0	8.0
10.0	8.4	8.4
20.0	10.8	10.8
30.0	12.4	12.4
40.0	13.6	13.6
50.0	14.5	14.5
60.0	15.2	15.2
70.0	15.8	15.8
80.0	16.4	16.4
90.0	16.8	16.8
100.0	17.3	17.3
150.0	18.8	18.8
200.0	19.9	19.9
250.0	20.6	20.6
300.0	21.2	21.2
350.0	21.7	21.7
400.0	22.1	22.1

Page 1

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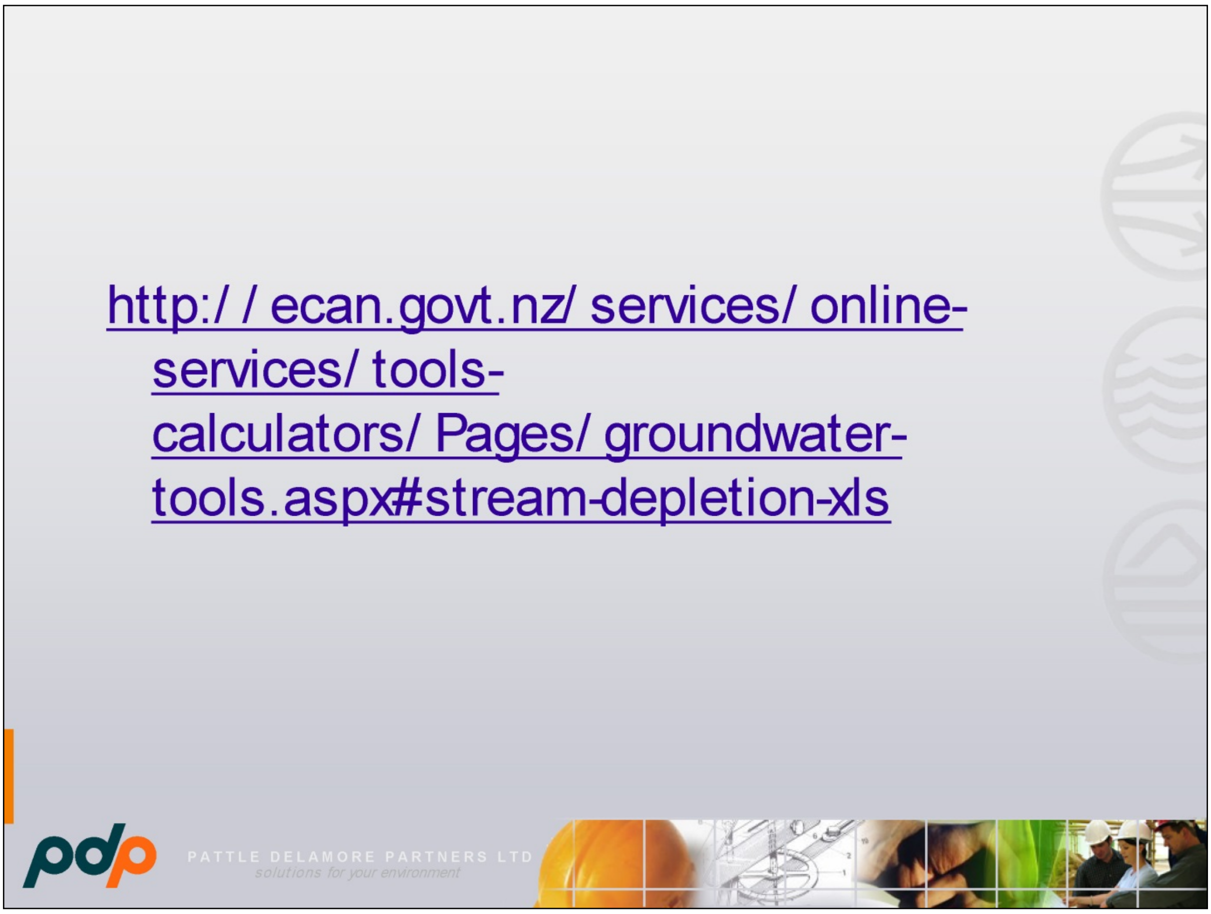
http:/ / ecan.govt.nz/ services/ online-services/ tools-calculators/ Pages/ groundwater-tools.aspx#stream-depletion-xls
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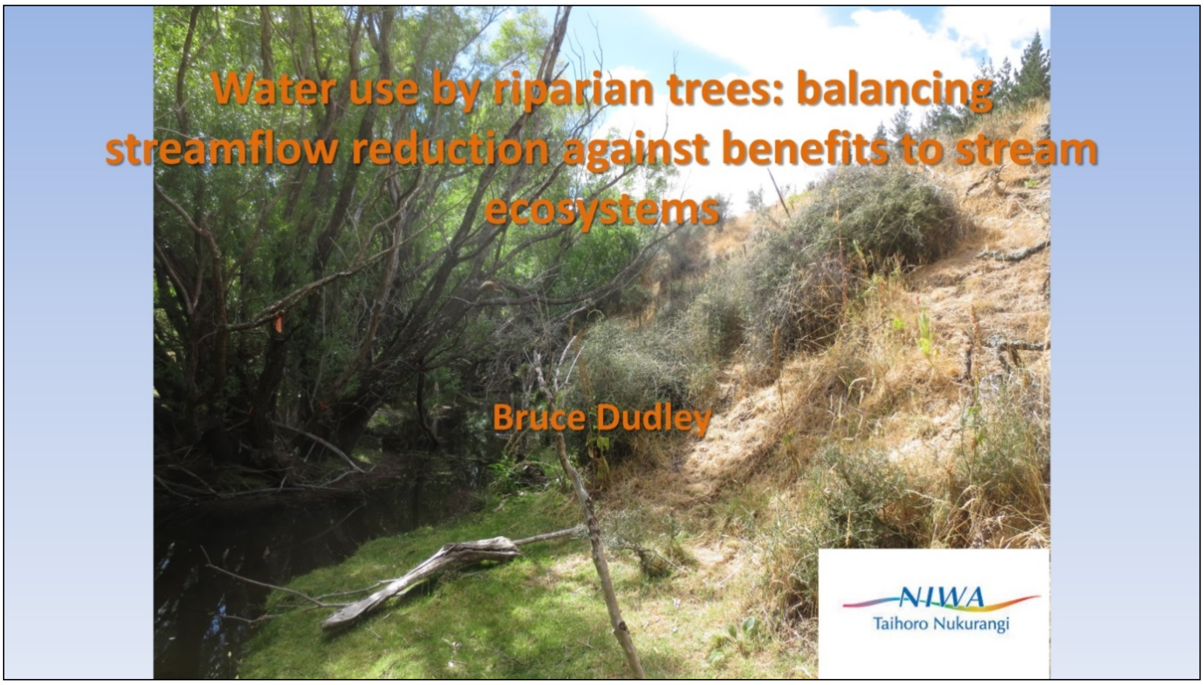
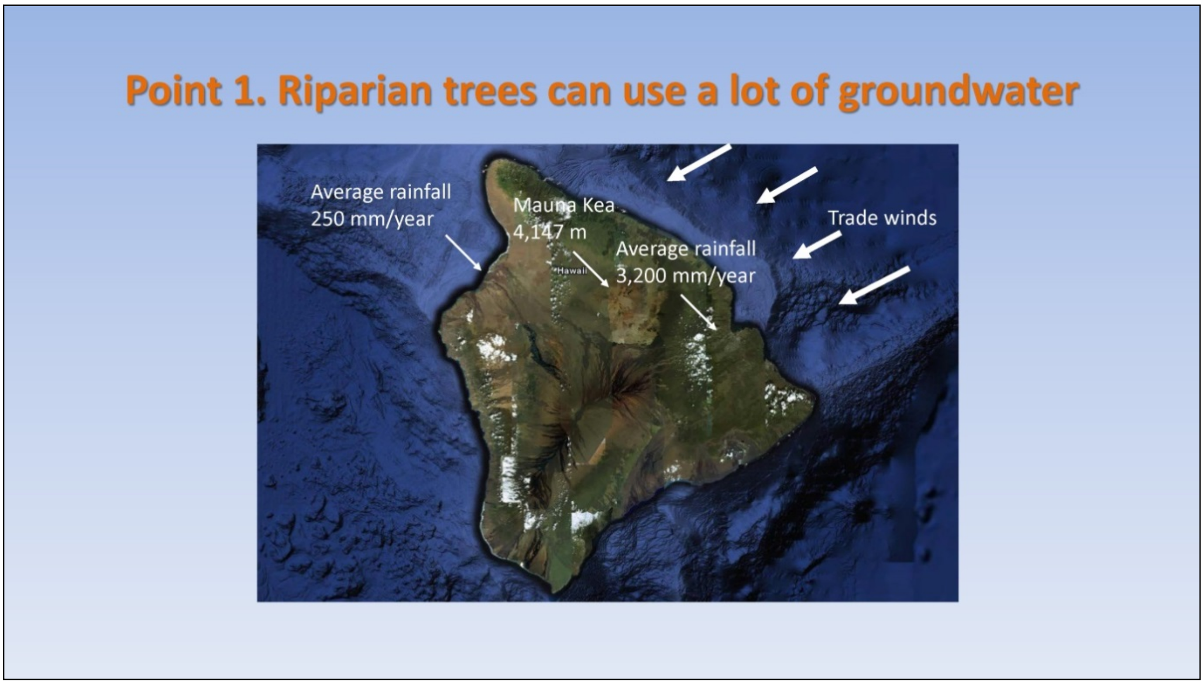
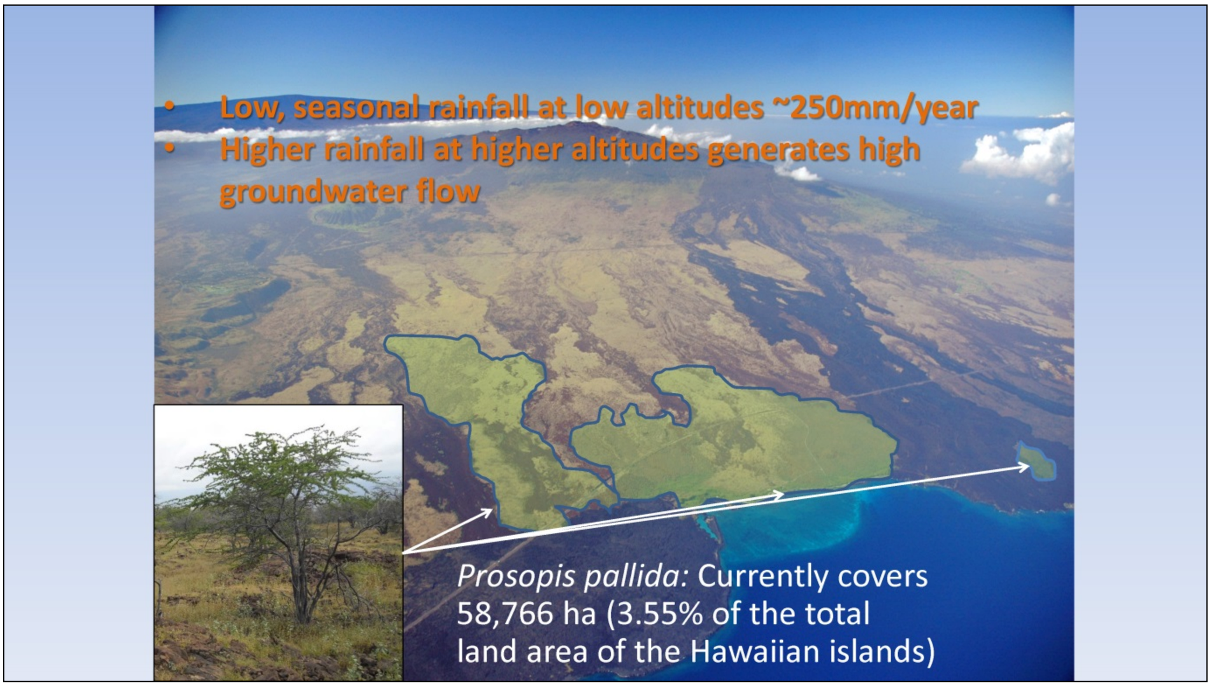
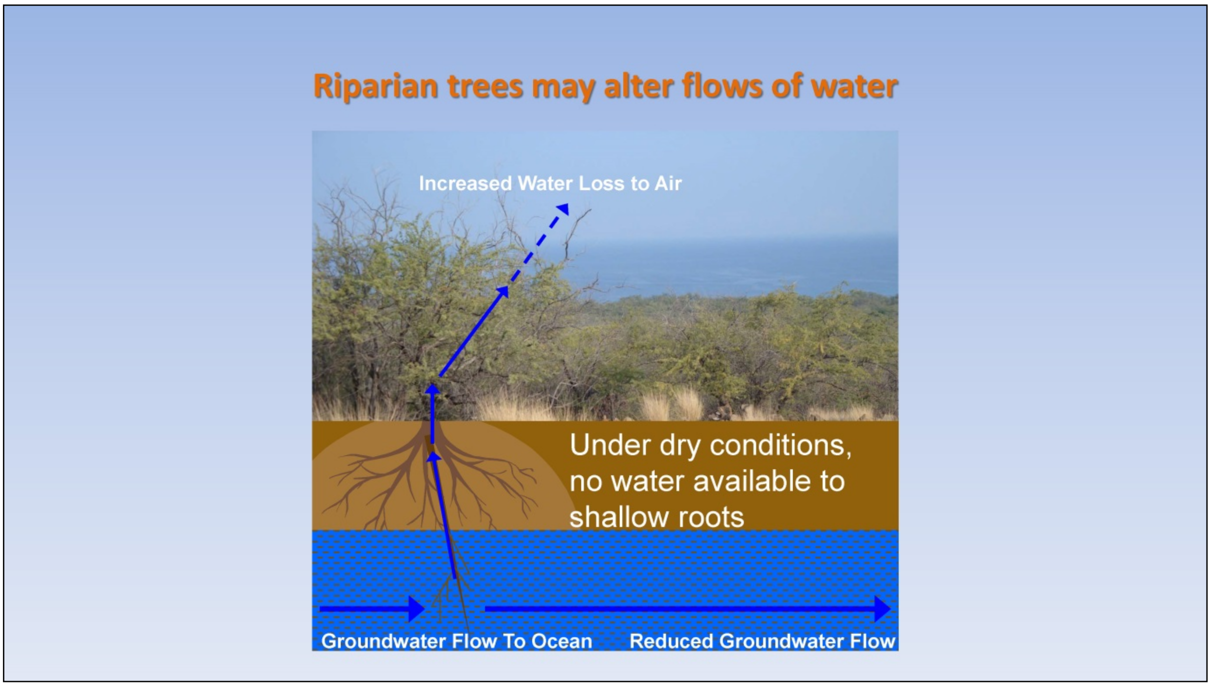
3.2.3 Water use by riparian trees: Balancing streamflow reduction against benefits to stream ecosystems
Facilitator: Bruce Dudley, NIWA



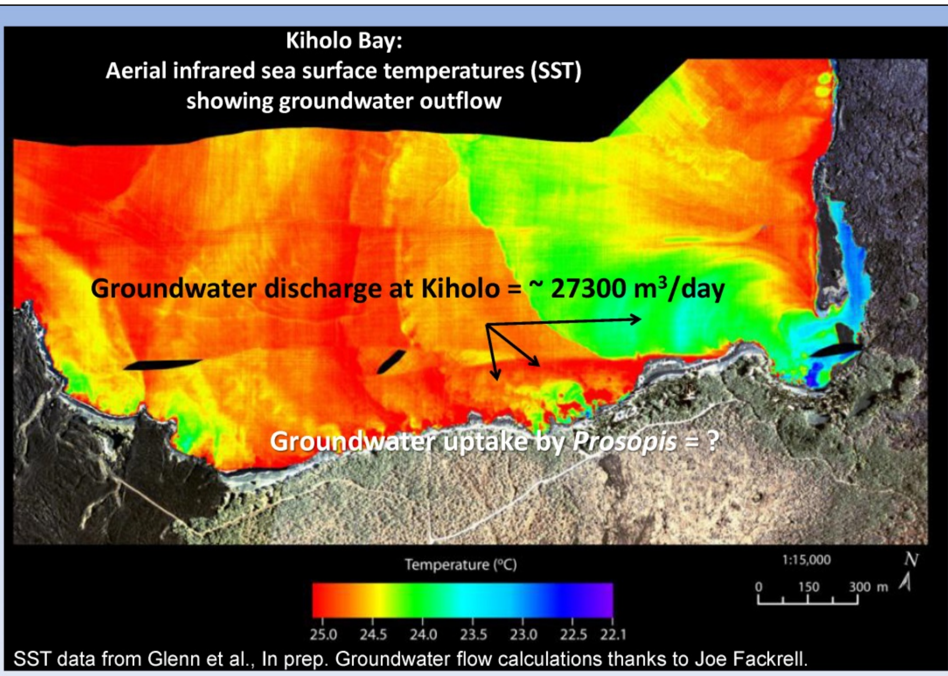




• Low, seasonal rainfall at low altitudes ~250mm/year
• Higher rainfall at higher altitudes generates high groundwater flow
Prosopis pallida: Currently covers 58,766 ha (3.55% of the total land area of the Hawaiian islands)



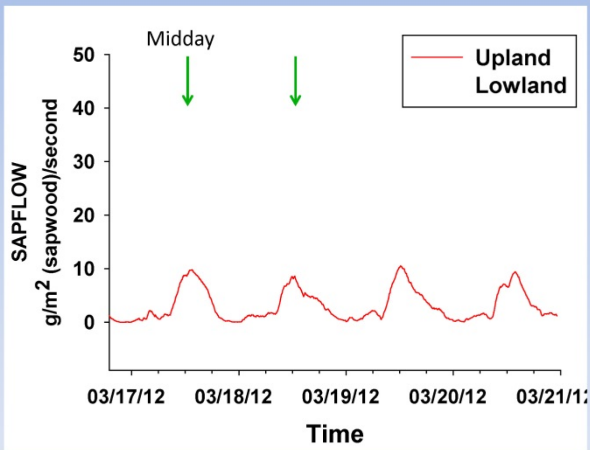
Riparian trees may alter flows of water
Increased Water Loss to Air
Under dry conditions, no water available to shallow roots
Groundwater Flow To Ocean
Reduced Groundwater Flow



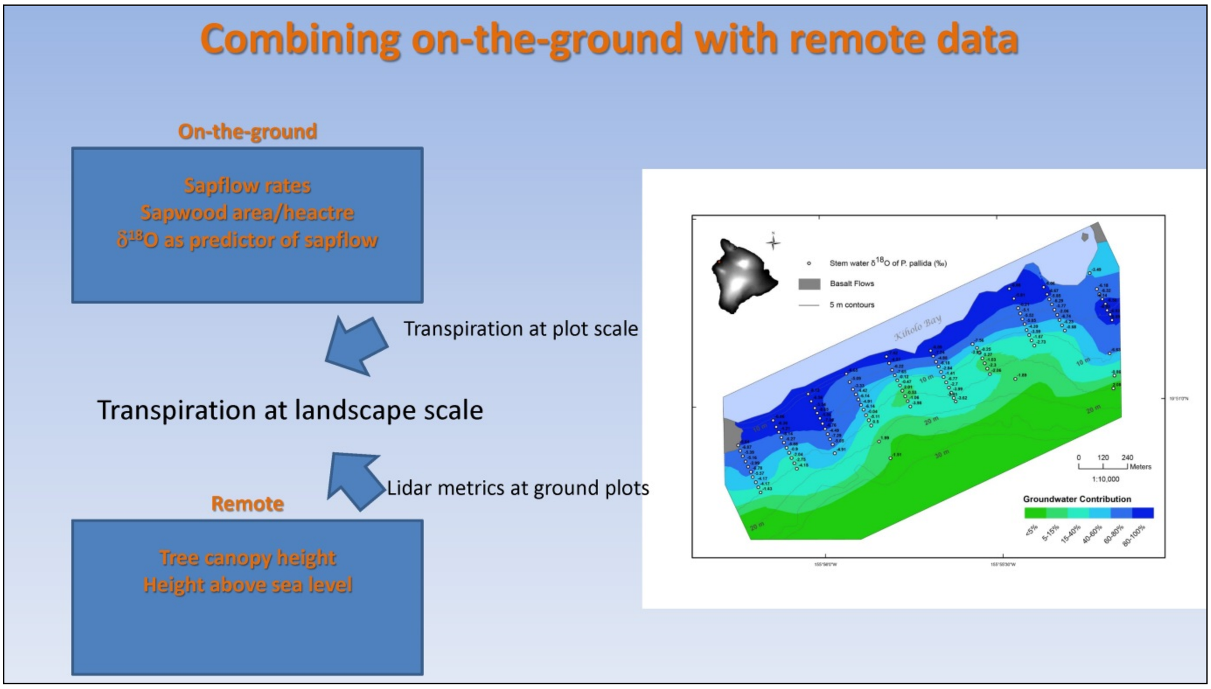
How much groundwater do *Prosopis* transpire?

Step 1: Measure sap flow rates

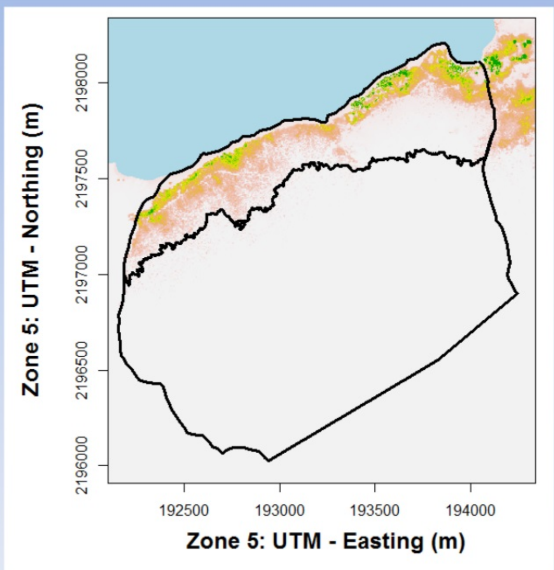
Sap flow – March 2012

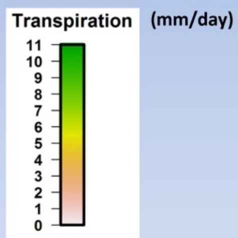



Step 2: Derive transpiration at a plot scale


Combining on-the-ground with remote data
On-the-ground
Sapflow rates
Sapwood area/heactre
δ18O as predictor of sapflow
Transpiration at plot scale
Transpiration at landscape scale
Lidar metrics at ground plots
Remote
Tree canopy height
Height above sea level
Basalt Flows
5 m contours
Groundwater Contribution

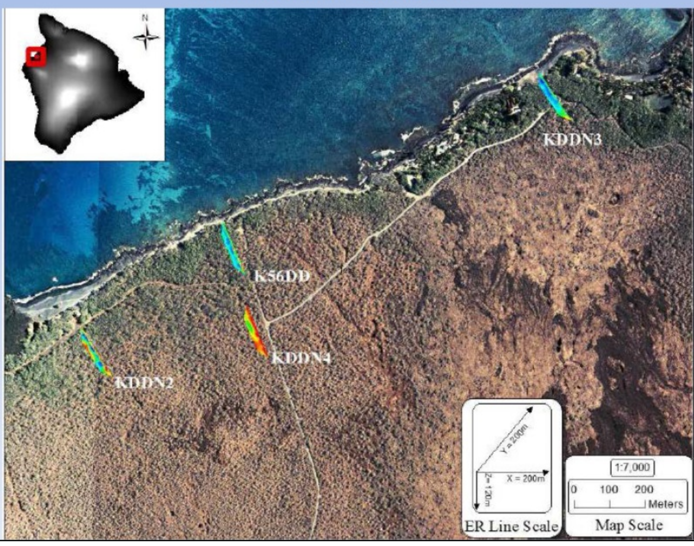
Transpiration measurements at landscape scale

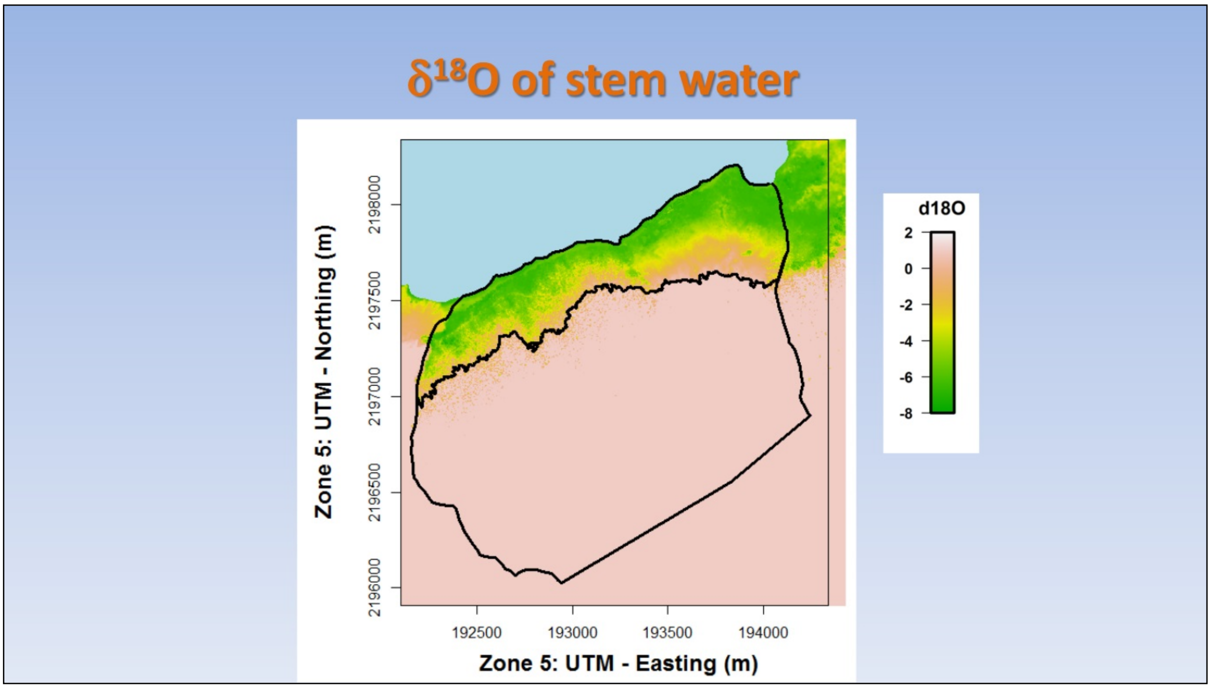


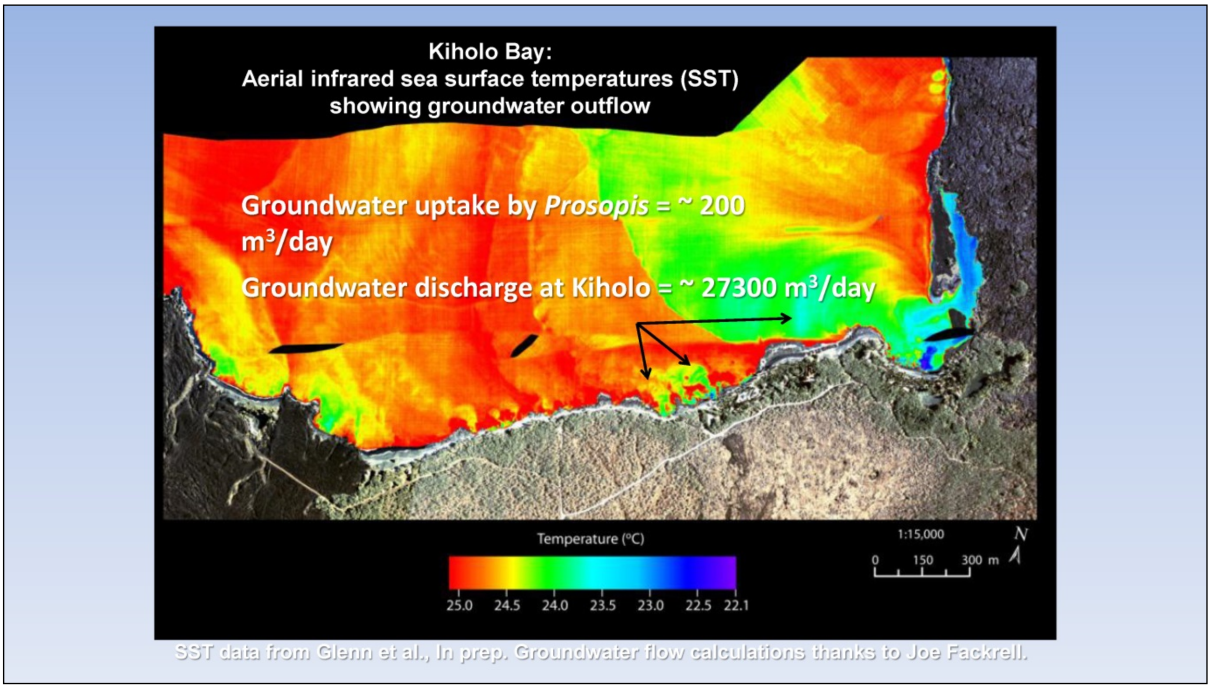


LiDAR data care of Carnegie Airborne Observatory

Point 1b! – Tree location may determine effects on surface water

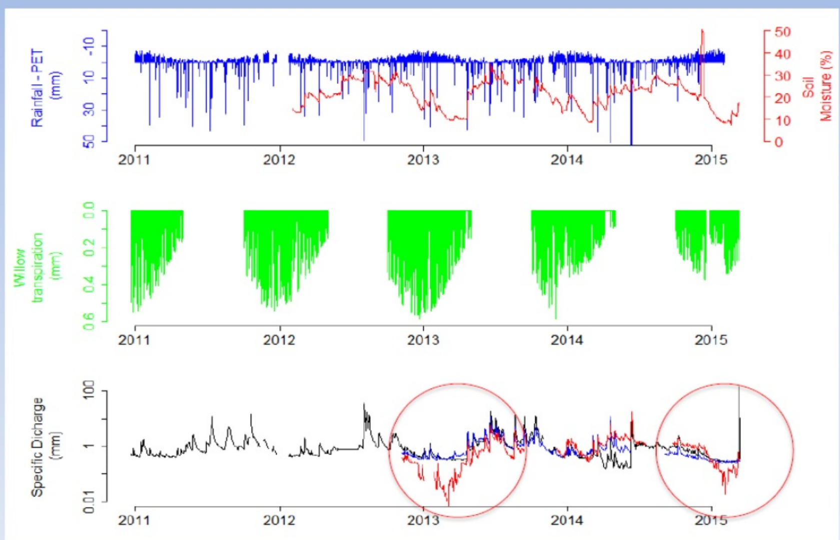



δ18O of stem water
Zone 5: UTM - Northing (m)
2196000
2196500
2197000
2197500
2198000
192500
193000
193500
194000
Zone 5: UTM - Easting (m)
d18O
2
0
-2
-4
-6
-8


Kiholo Bay:
Aerial infrared sea surface temperatures (SST)
showing groundwater outflow
Groundwater uptake by Prosopis = ~ 200 m3/day
Groundwater discharge at Kiholo = ~ 27300 m3/day
Temperature (ºC)
25.0 24.5 24.0 23.5 23.0 22.5 22.1
1:15,000
0 150 300 m
N
SST data from Glenn et al., In prep. Groundwater flow calculations thanks to Joe Fackrell.

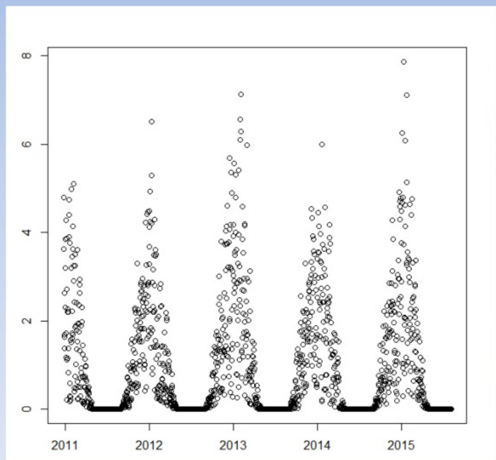
Point 2. Consideration of net water saving from removing in-stream trees

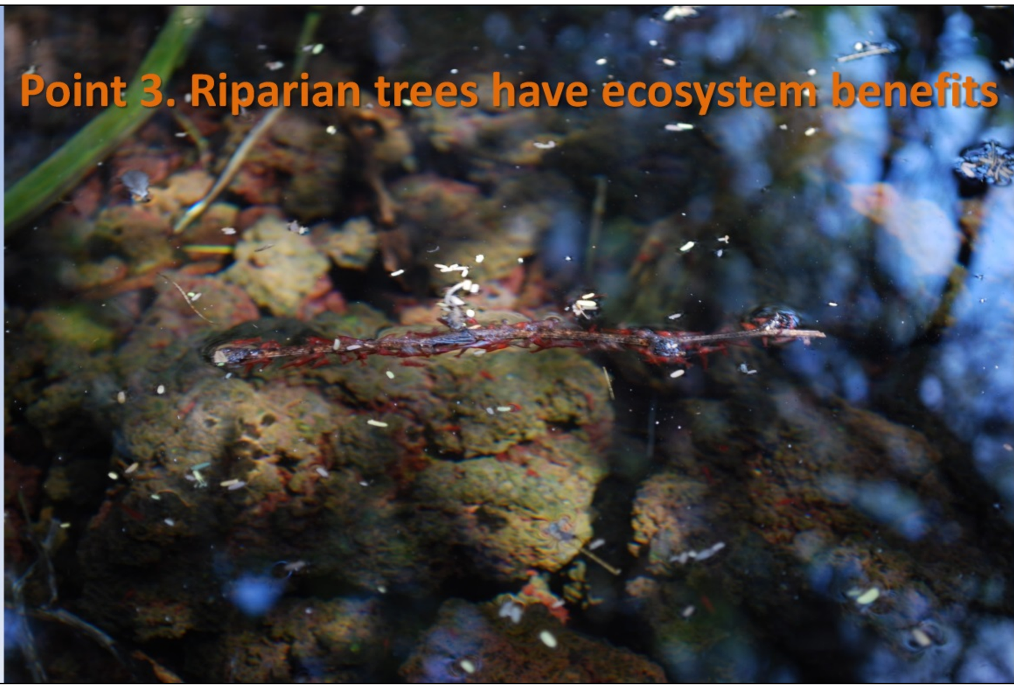
What happens during dry periods?



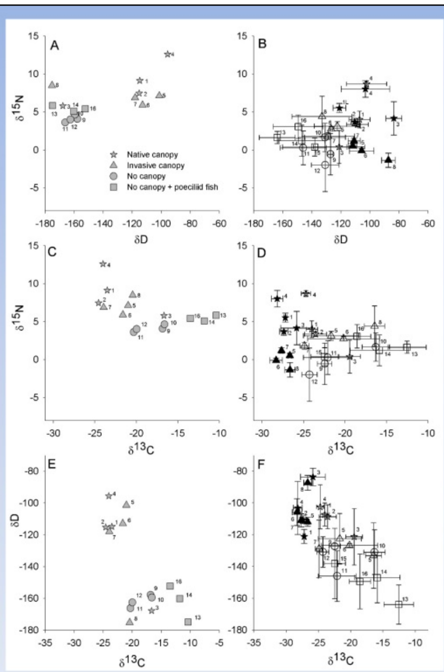
$ET_{willows} - T_{open\ water}$ = water savings

- ET in forest, and from open water depend heavily on climate, and can be modelled based on local climate data.
- We are currently calculating water savings that would result from removing willow around it's invasive range in New Zealand

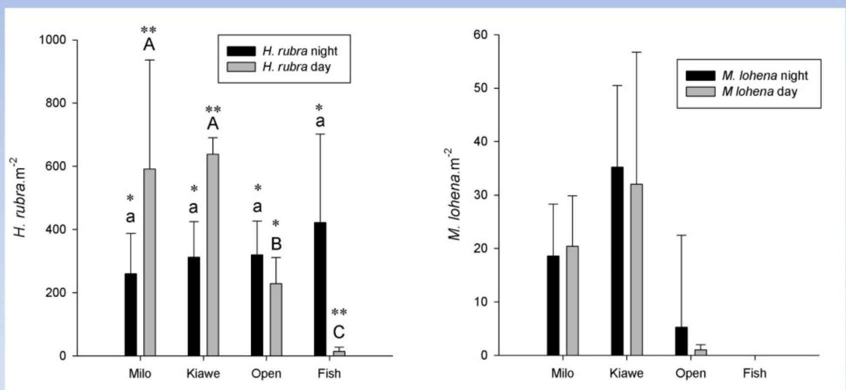




- In this case leaf litter fuels the base of pond food webs, whether these trees are native or invasive.



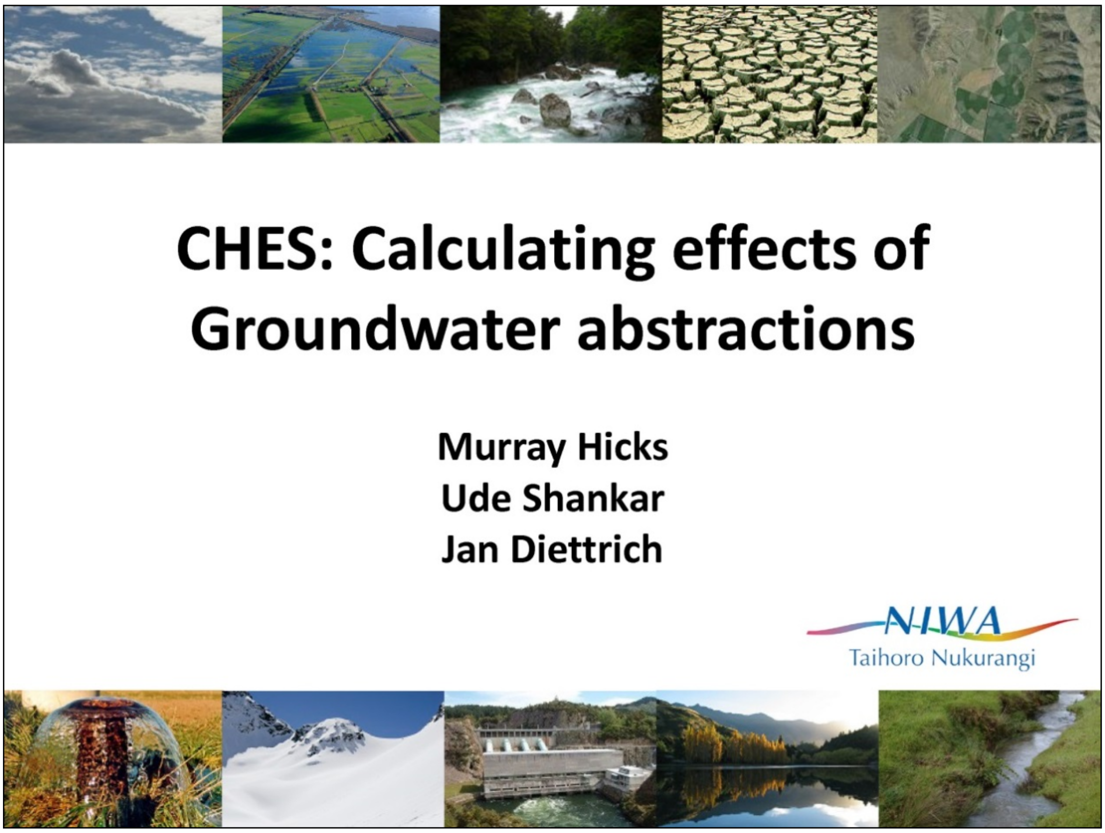
Invasive trees were not the problem for aquatic invertebrate populations

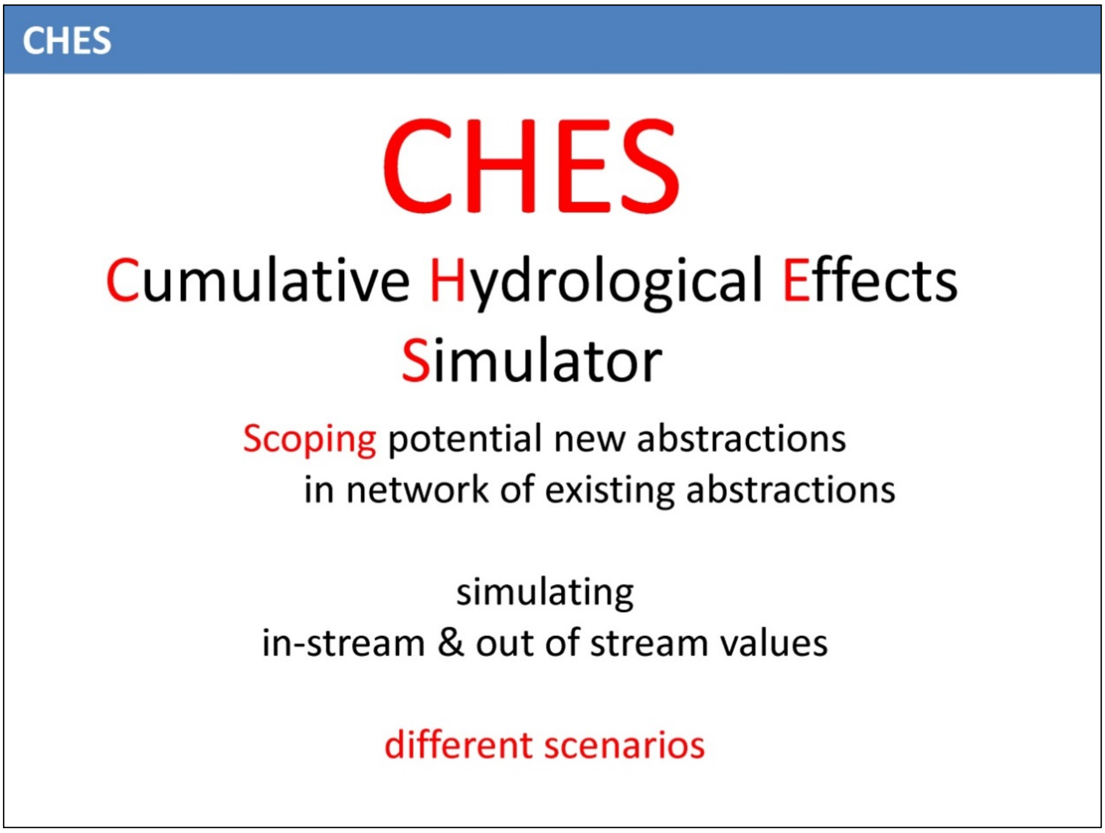


Summary

- Riparian trees can transpire a considerable amount of water, so invasions and land use change can change surface water flows
- Position relative to the surface water body and root depth are important
- Removal of invasives should focus on net water savings
- Even invasive riparian trees may have benefits to aquatic ecosystems

3.2.4 Calculating the effect of groundwater abstraction on surface flows in the Cumulative Hydrological Effects Simulator
Facilitator: Jan Diettrich, NIWA



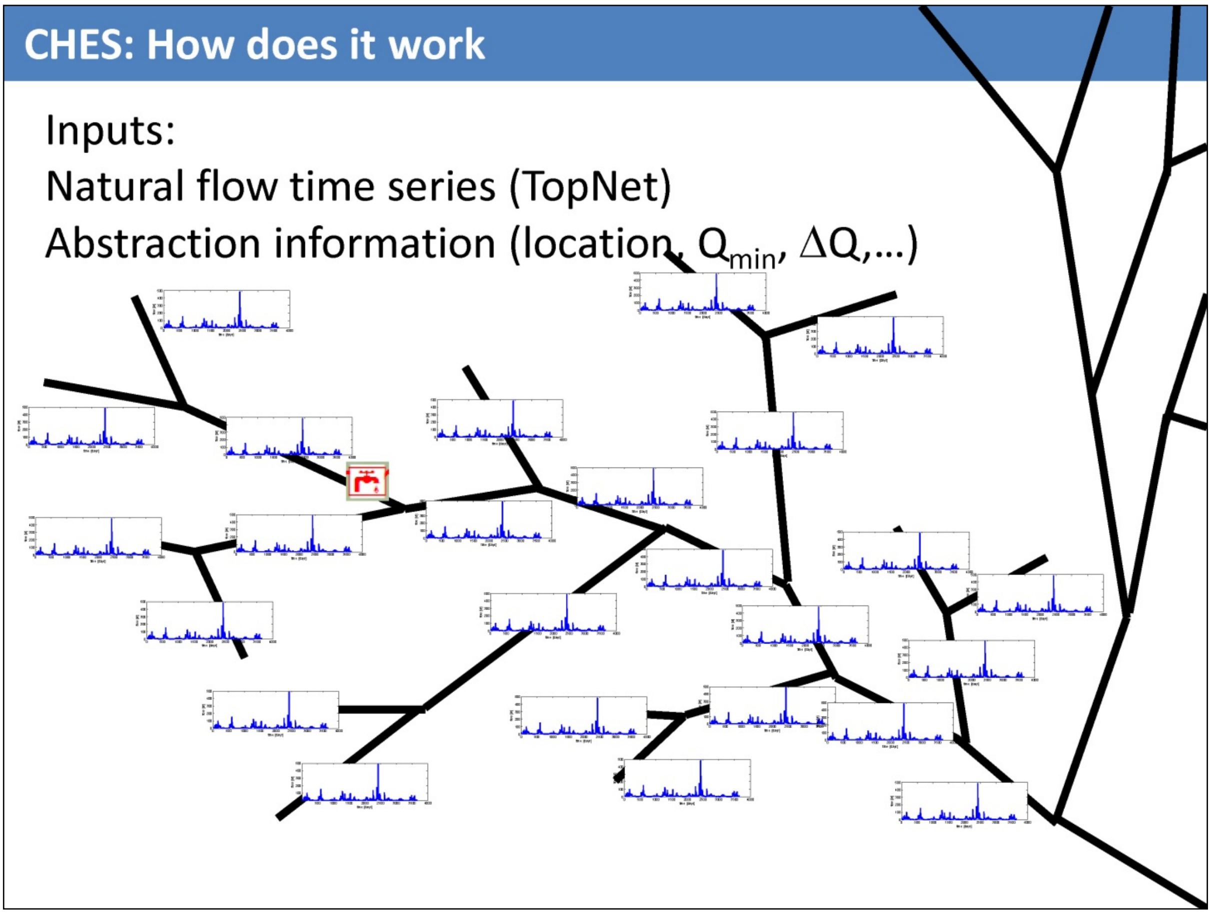


CHES: How does it work

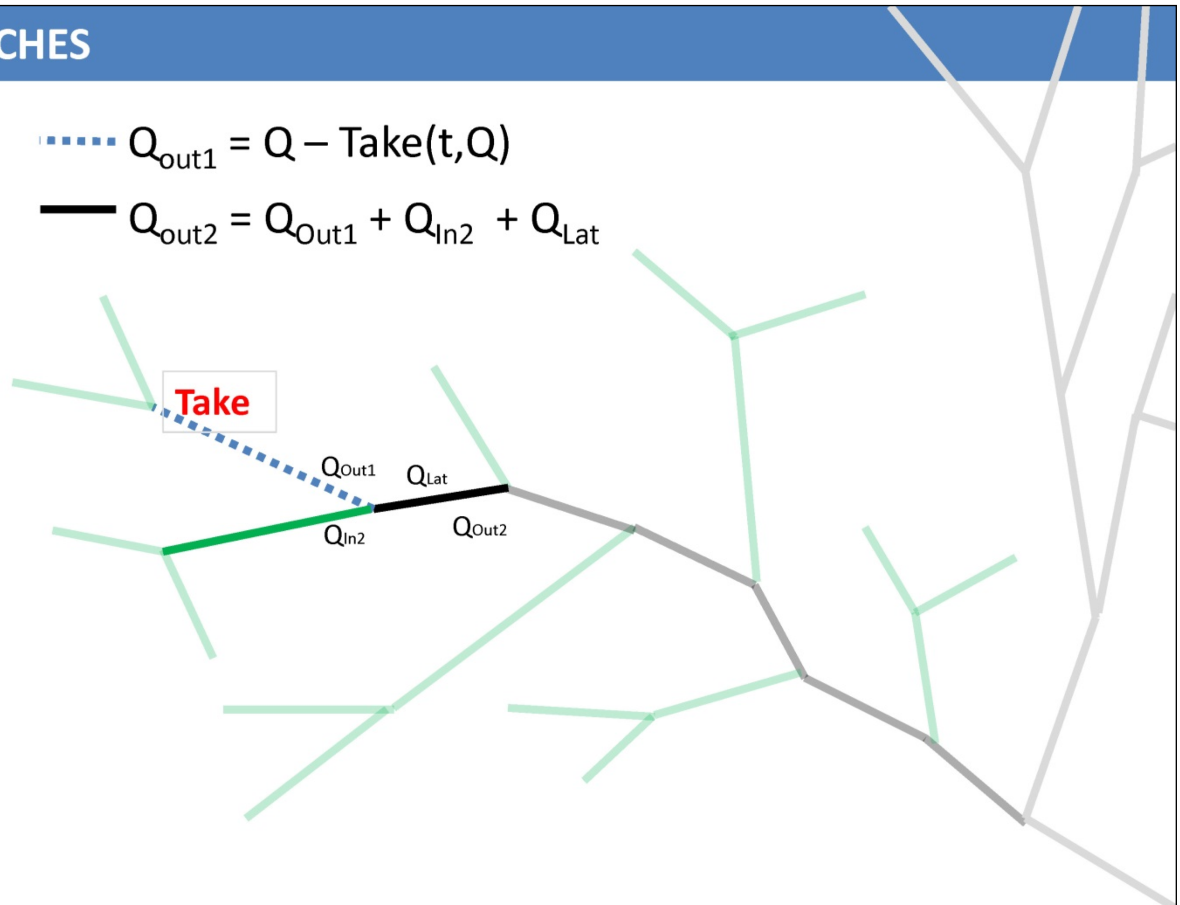
Inputs:

Natural flow time series (TopNet)

Abstraction information (location, Q_{min}, ΔQ,…)

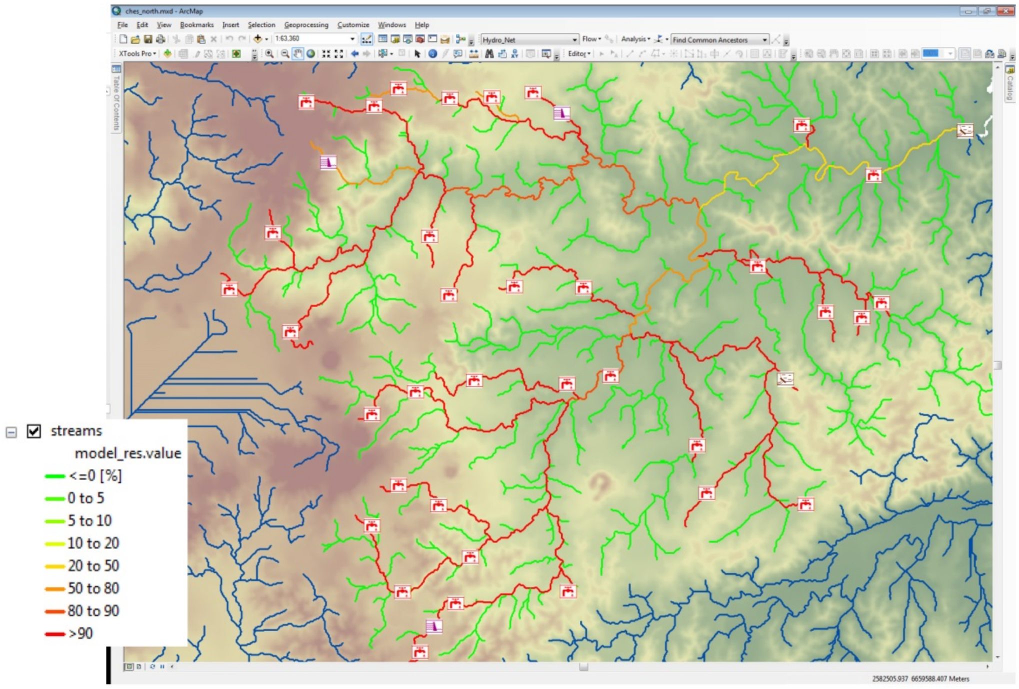


CHES



CHES: Map Plots

Time habitat reduces (in % time) for bluegill bully



CHES: Types of SWGW in CHES

- GW abstraction
  - Jenkins equations
  - Exponential equations
- GW-SW flows
  - Artificial diversions
  - ELFMod
  - Conceptual GWSW TopNet
  - TopNet ModFlow

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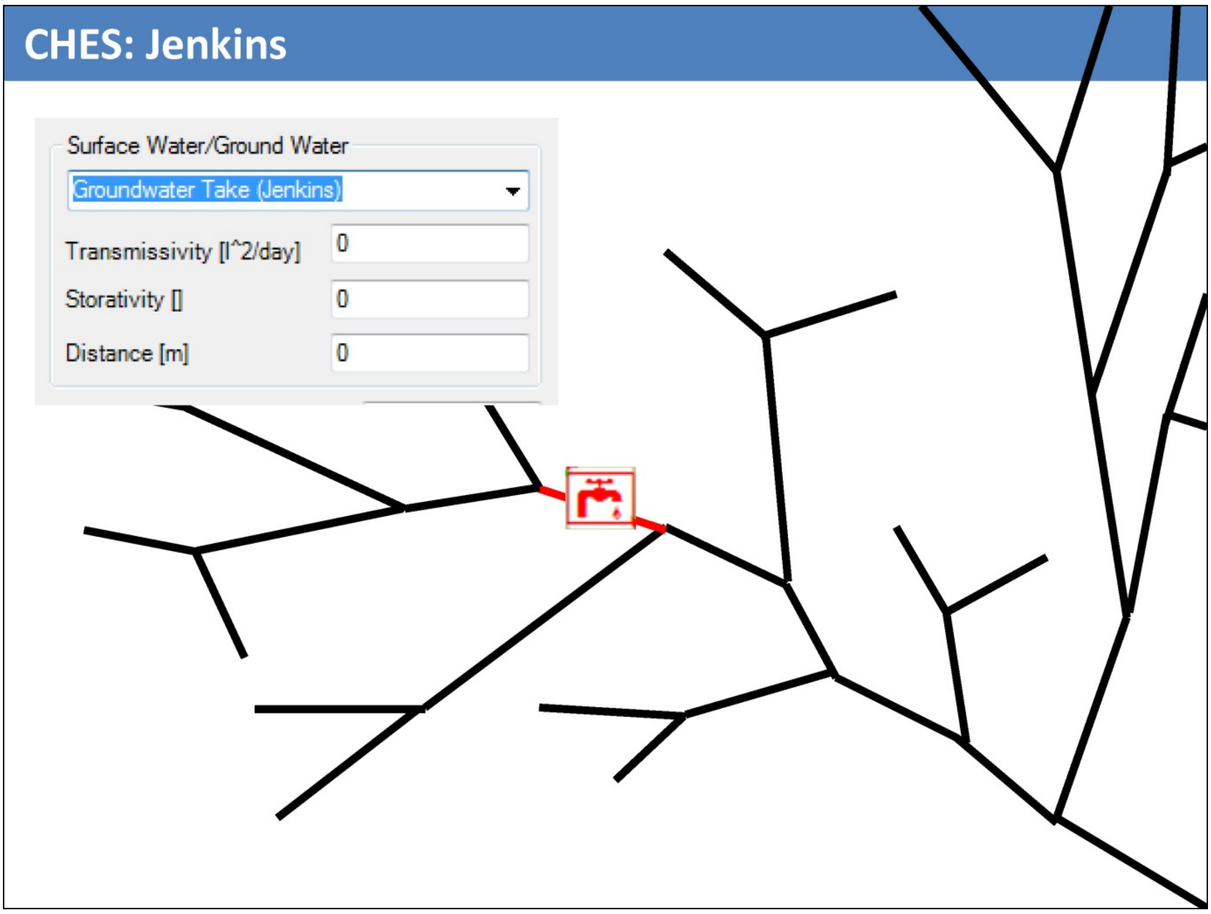
CHES: Jenkins



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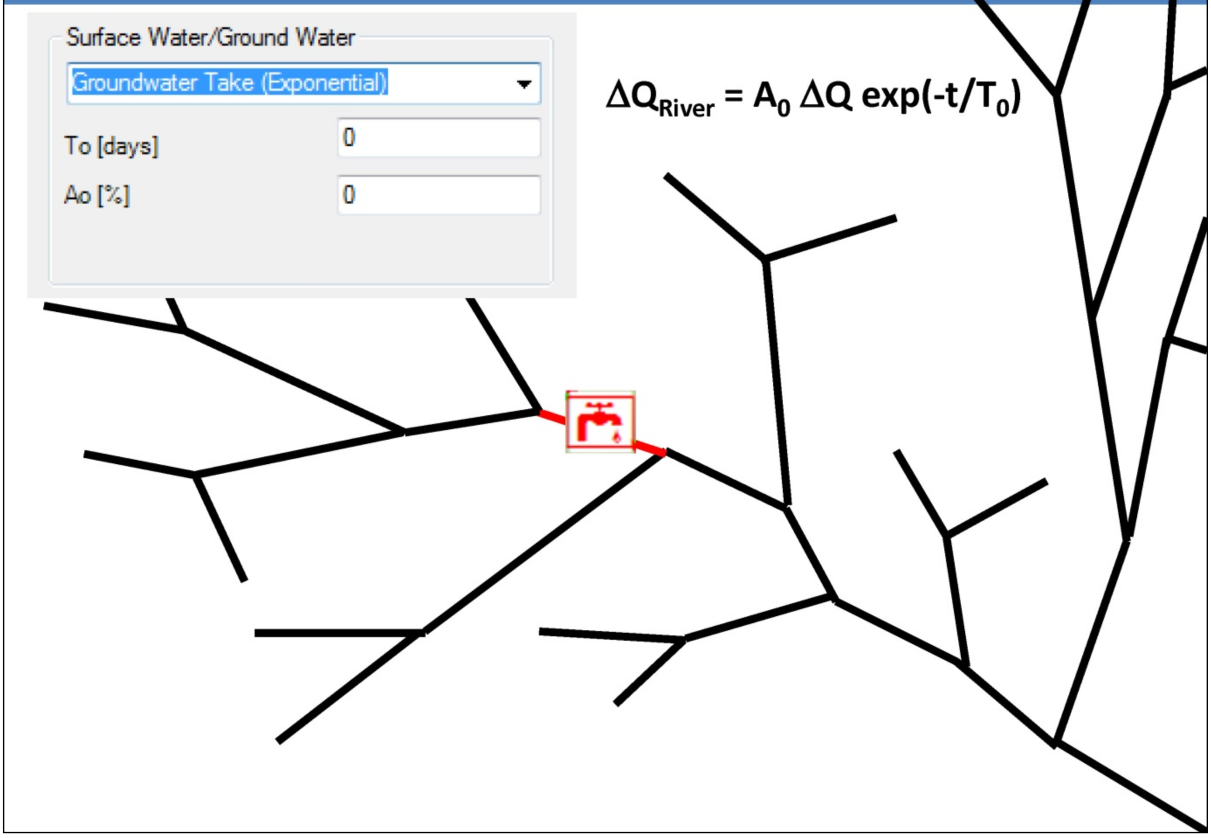
  - TopNet ModFlow

CHES: Exponential



$$\Delta Q_{River} = A_0 \, \Delta Q \, \exp(-t/T_0)$$

CHES: Types of SWGW in CHES

- GW abstraction
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  - Exponential equations
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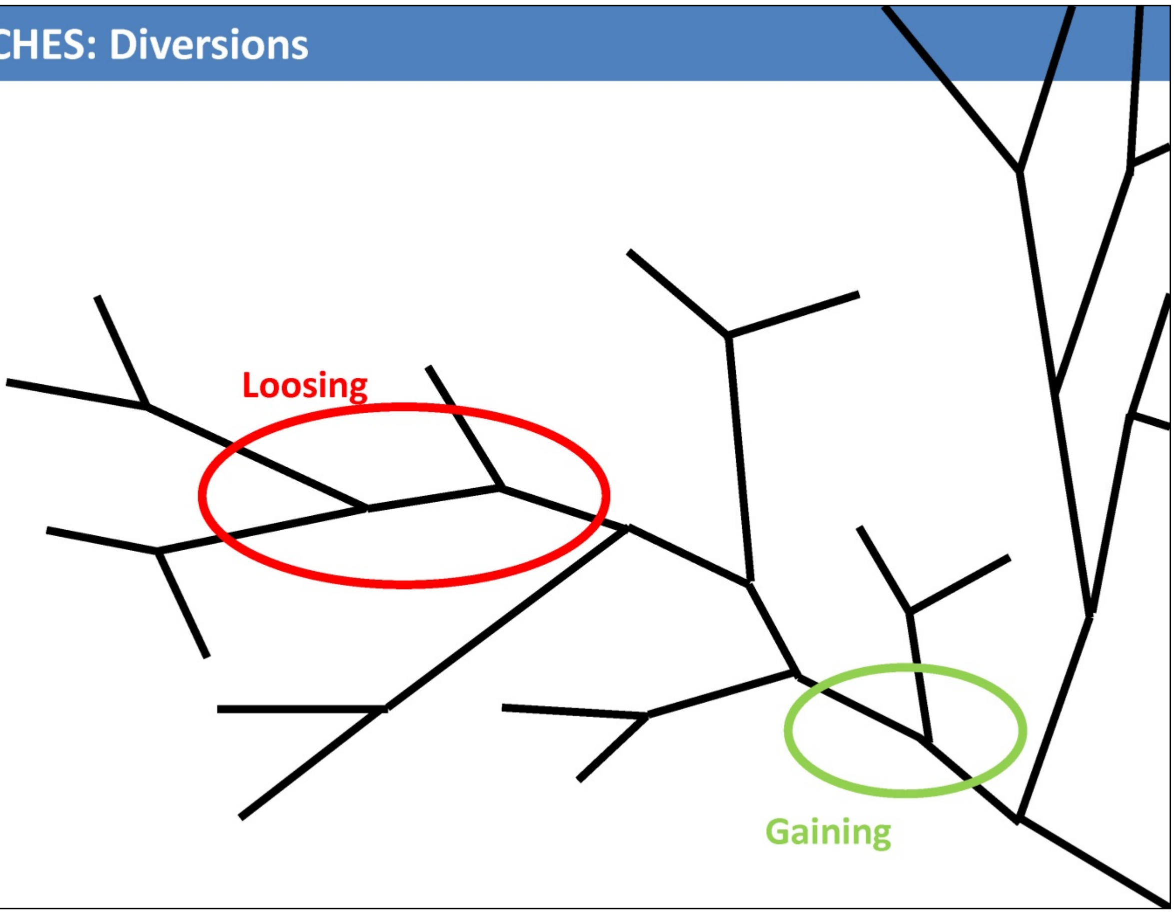
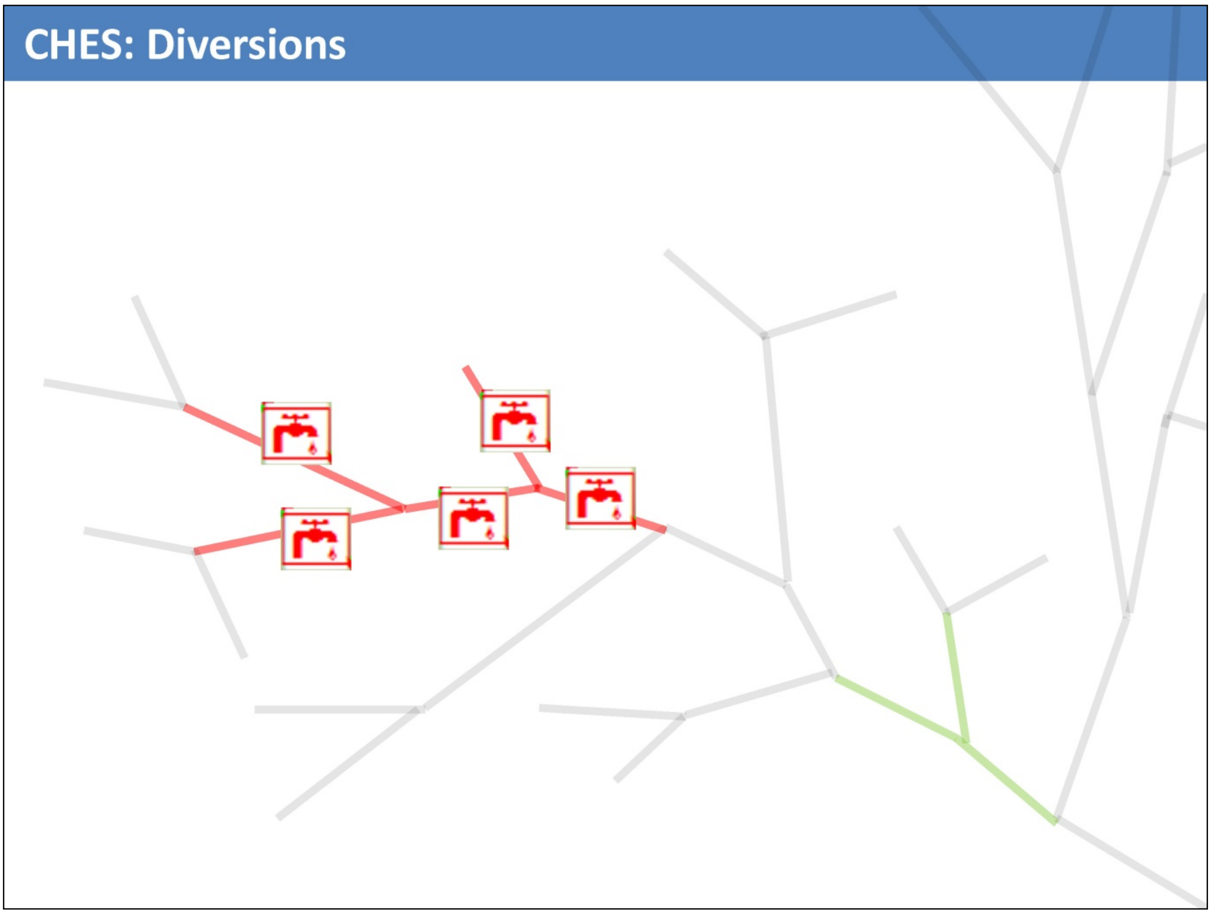
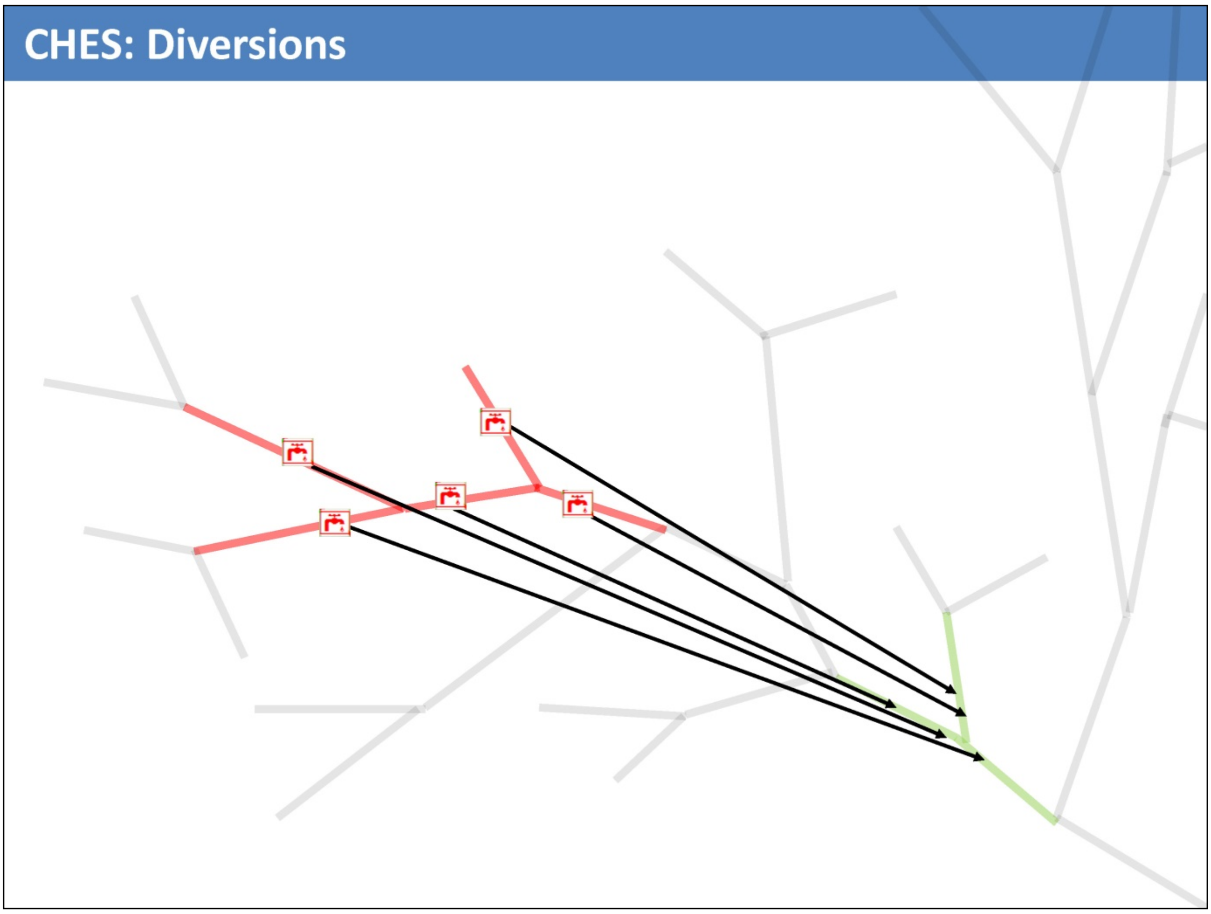
CHES: Diversions




CHES: Diversions


CHES: Diversions

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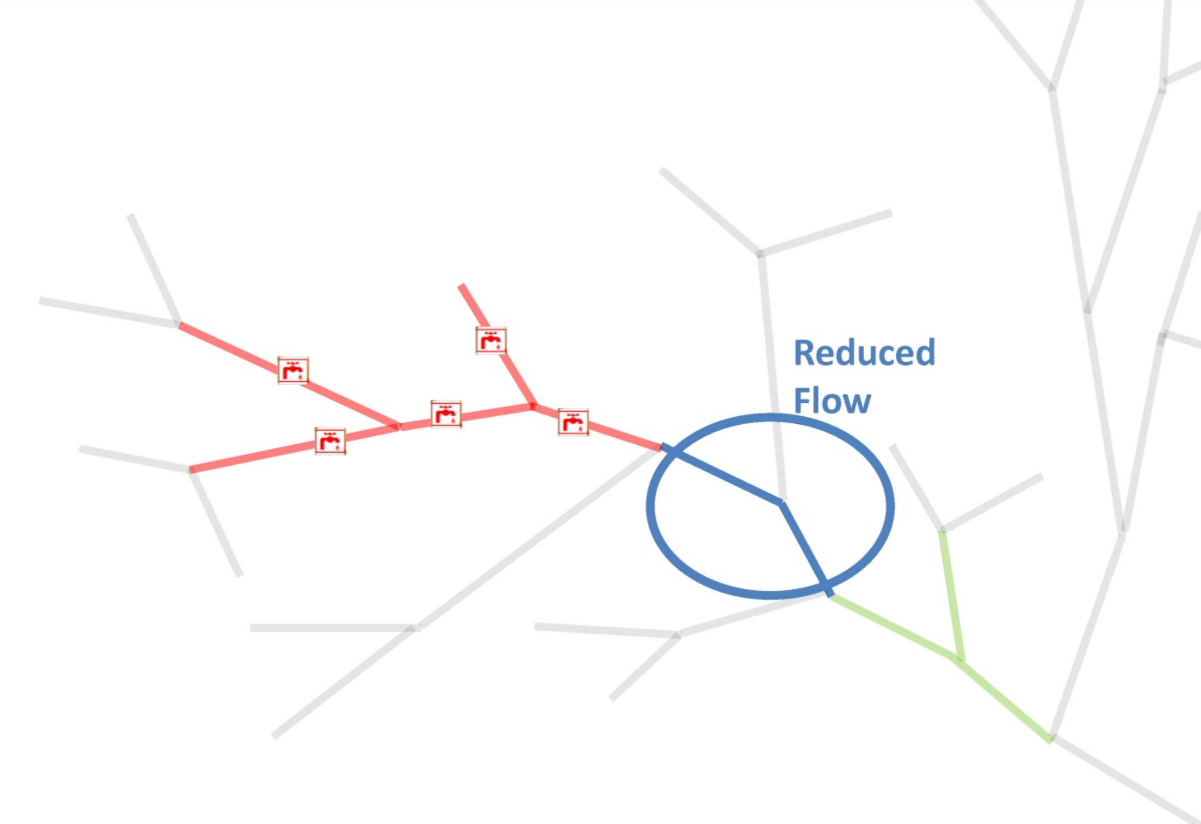

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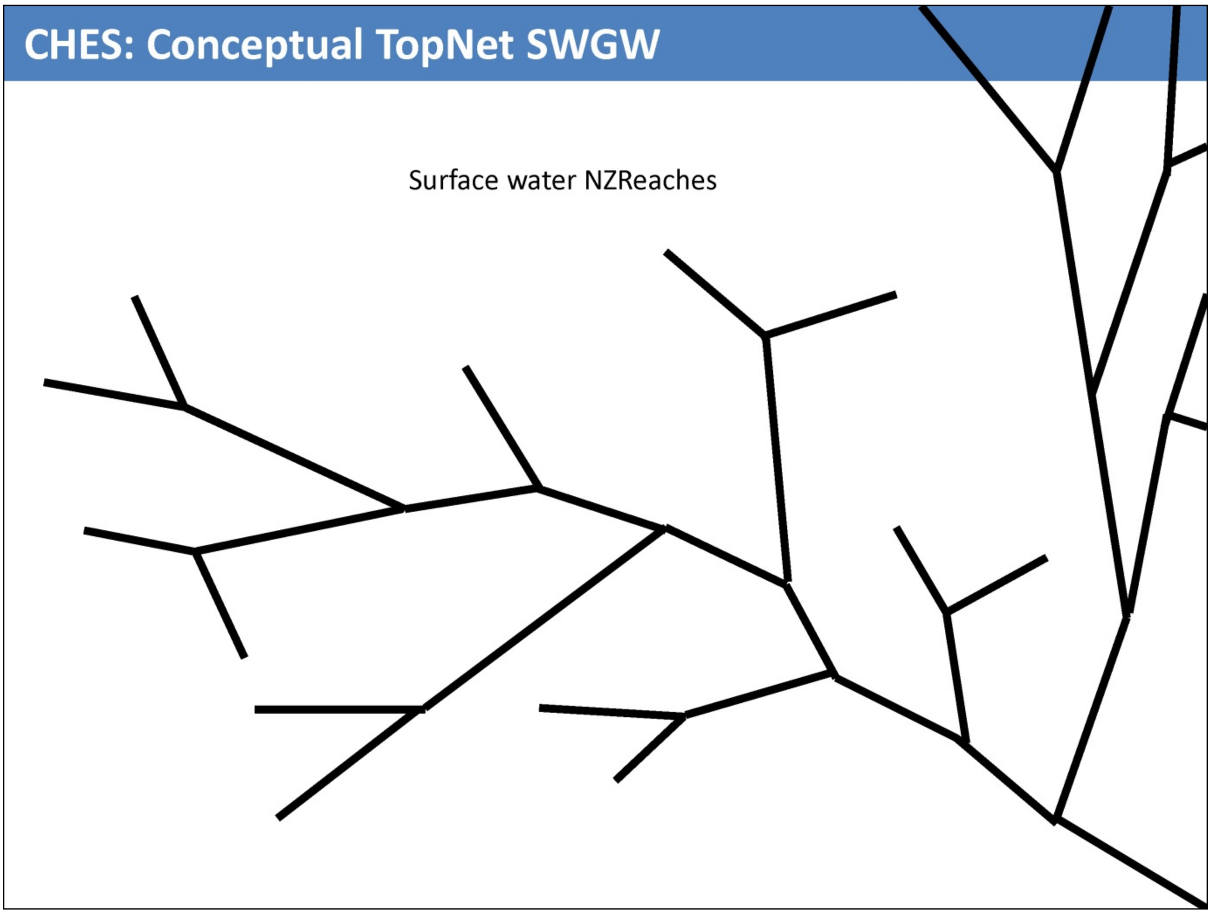
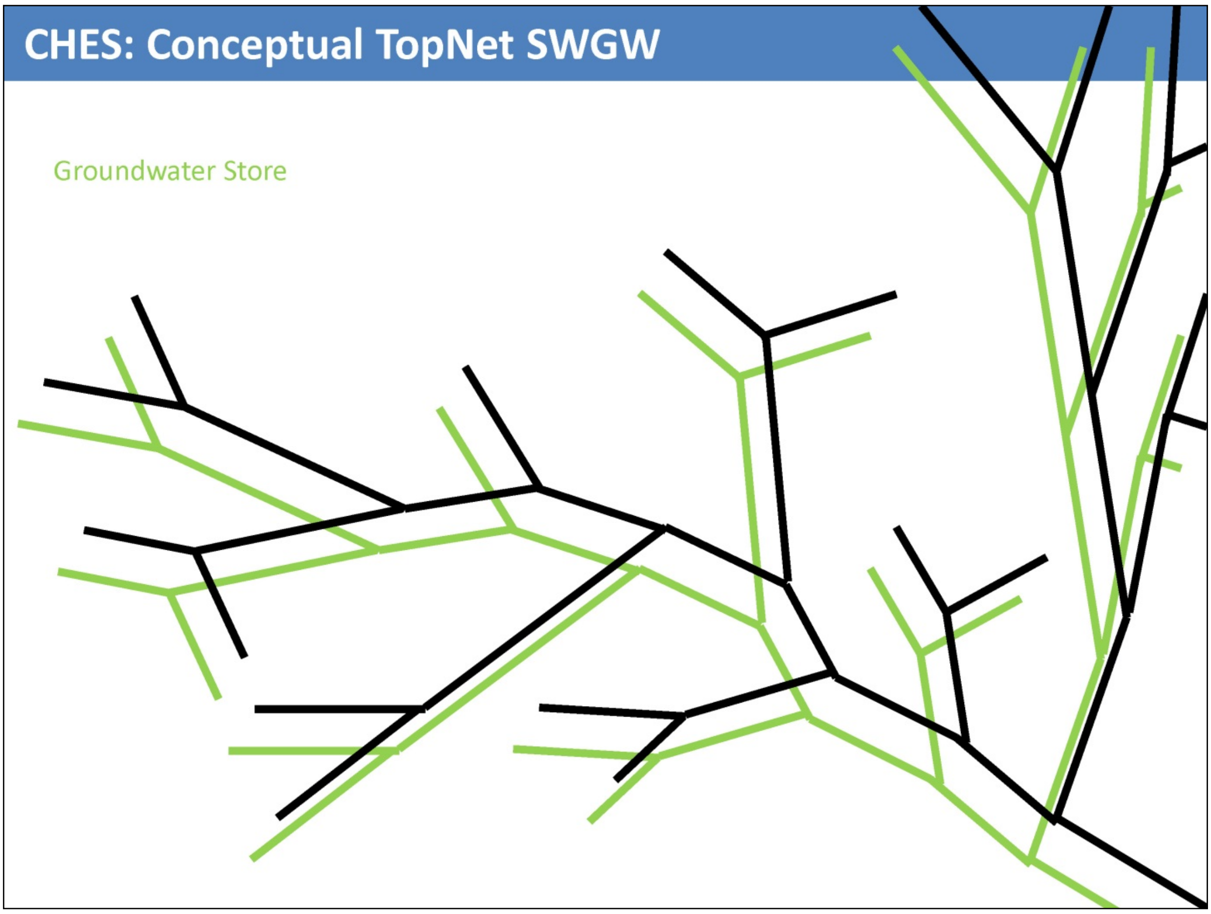
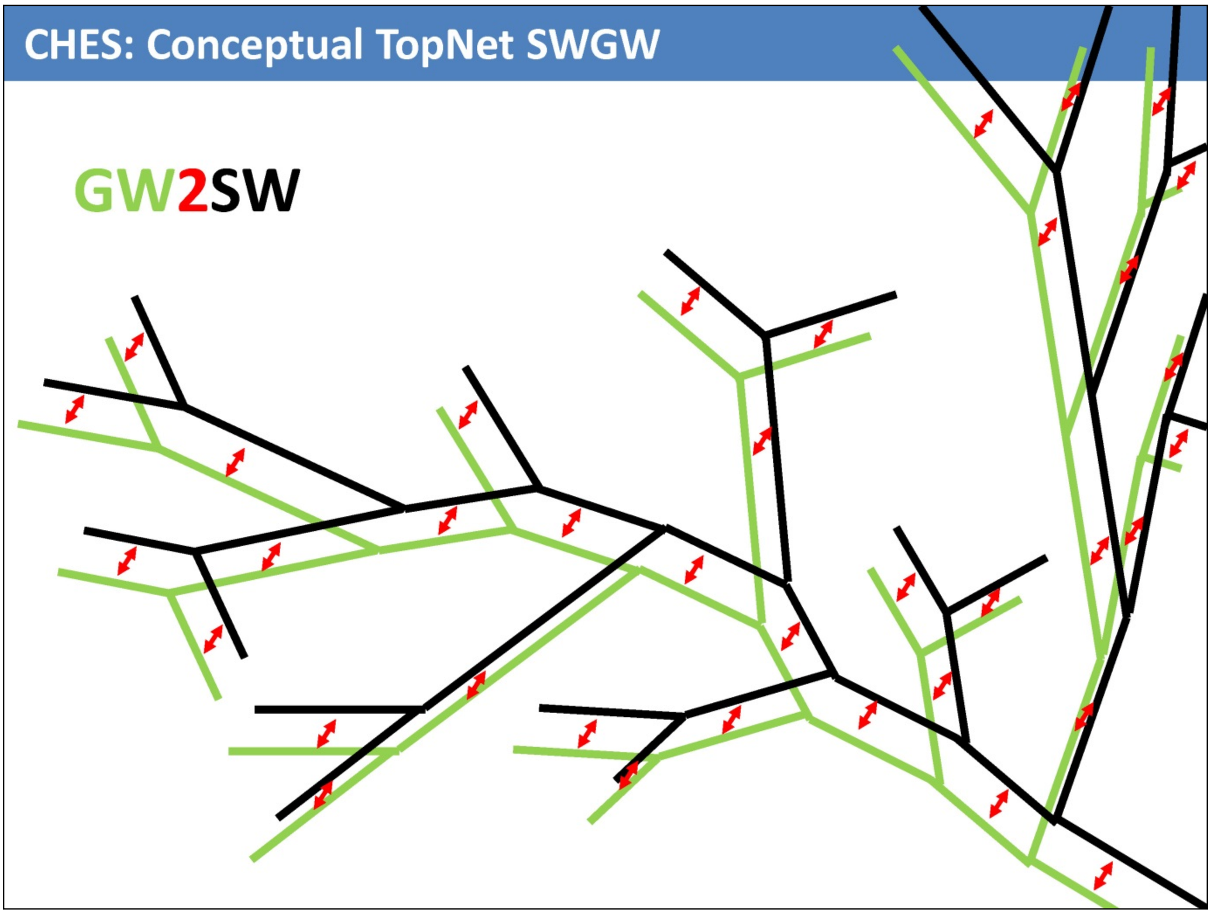
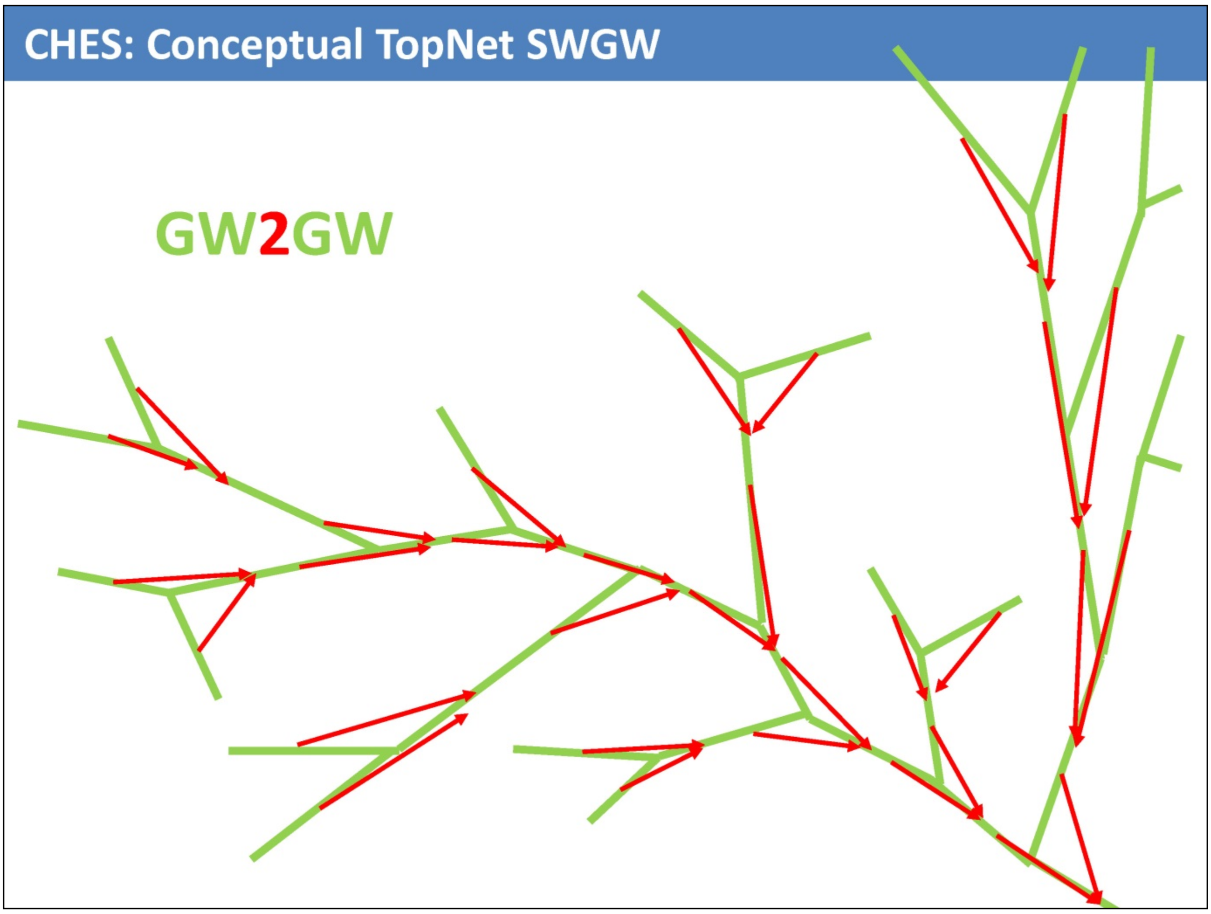
  - Conceptual GW-SW TopNet
  - TopNet ModFlow

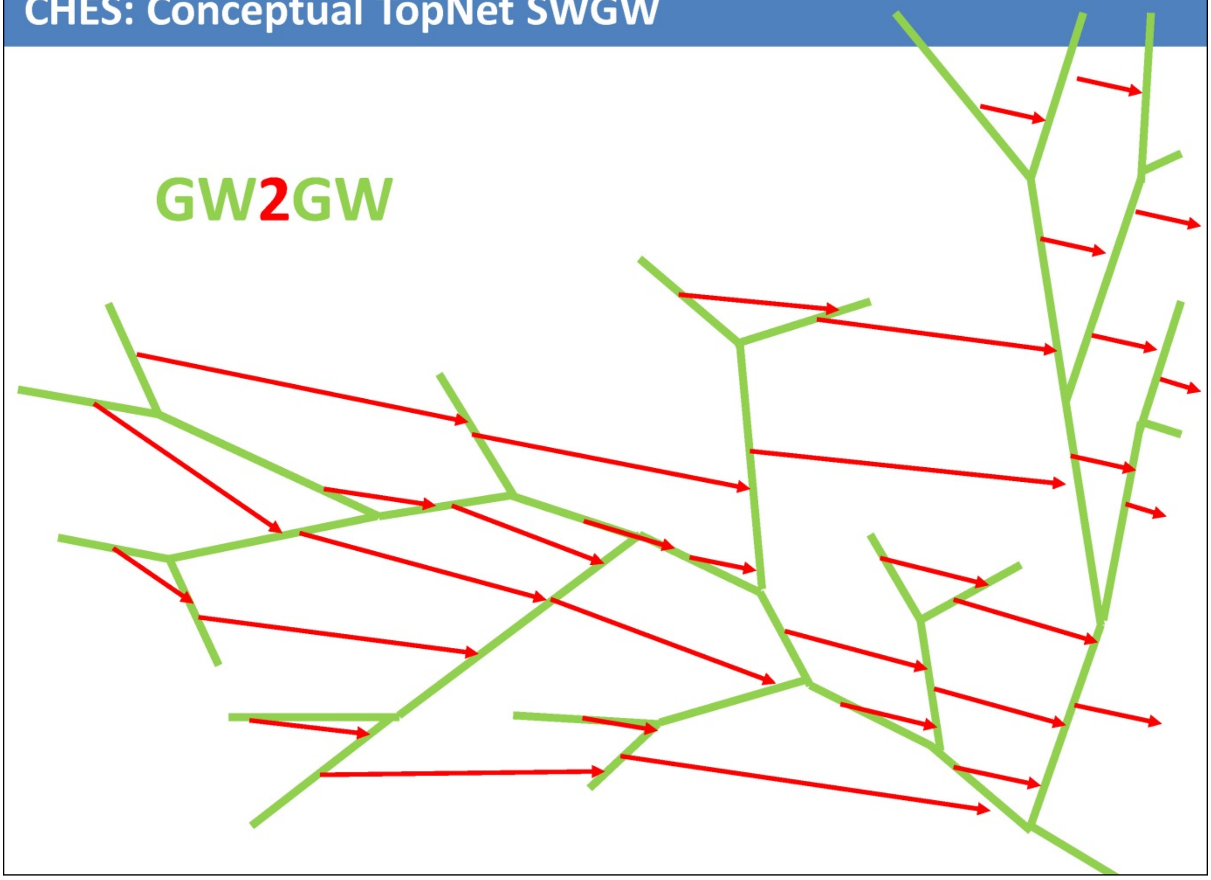

CHES: Conceptual TopNet SWGW
Surface water NZReaches


CHES: Conceptual TopNet SWGW
Groundwater Store


CHES: Conceptual TopNet SWGW
GW2SW


CHES: Conceptual TopNet SWGW
GW2GW

CHES: Conceptual TopNet SWGW



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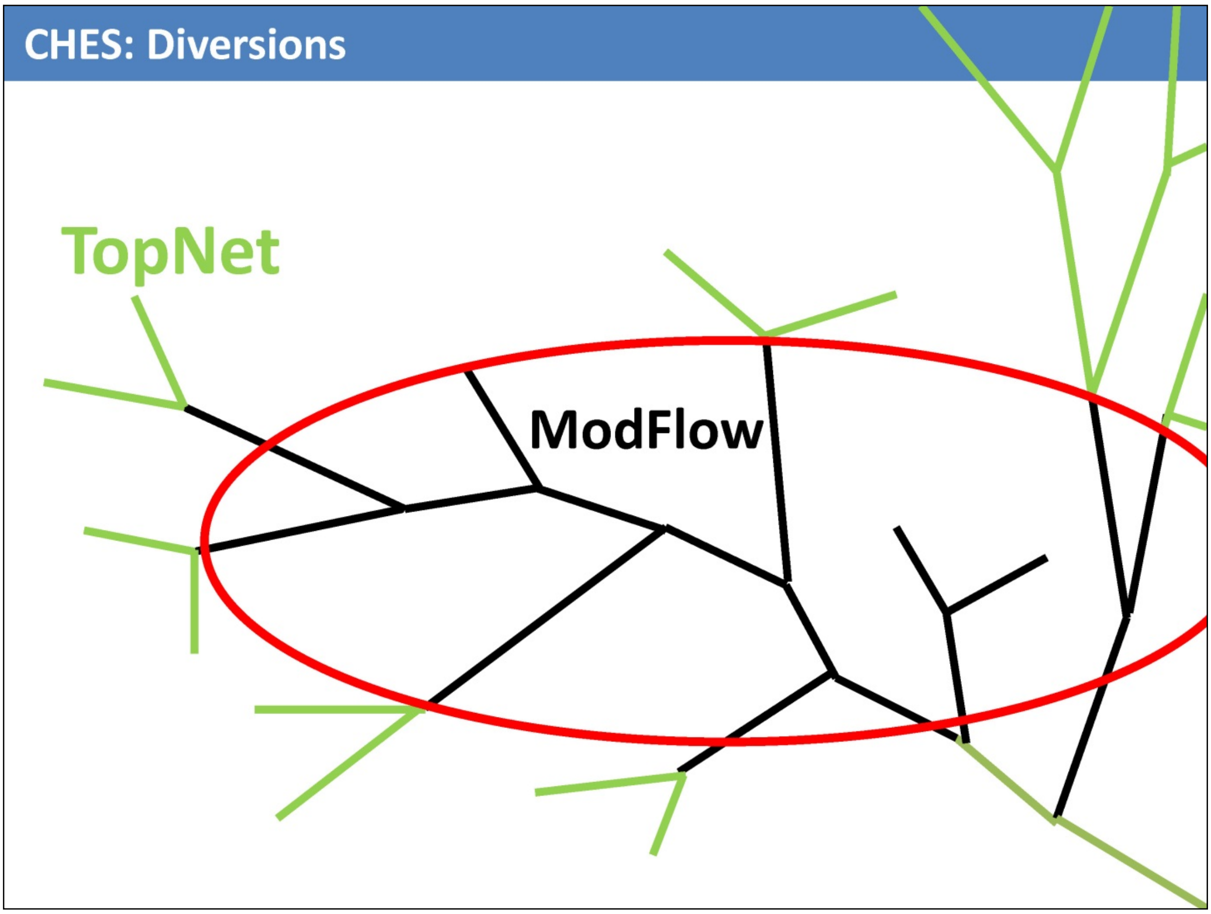
CHES: Diversions



CHES: Types of SWGW in CHES

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    - Jenkins equations
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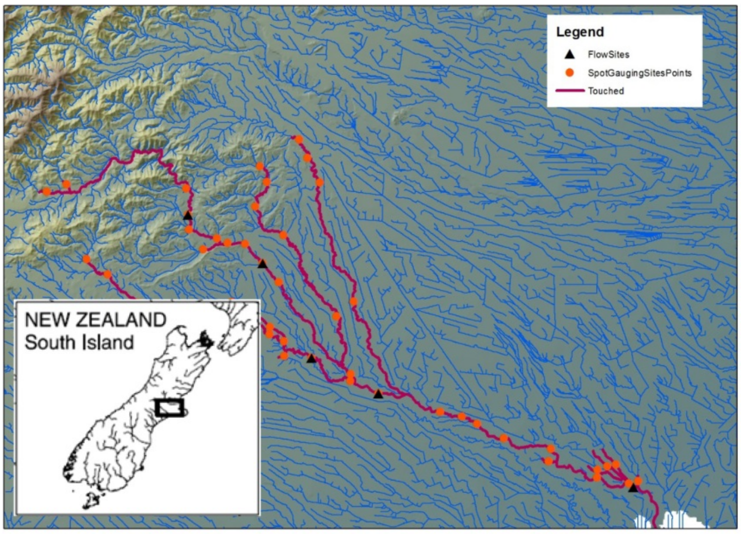
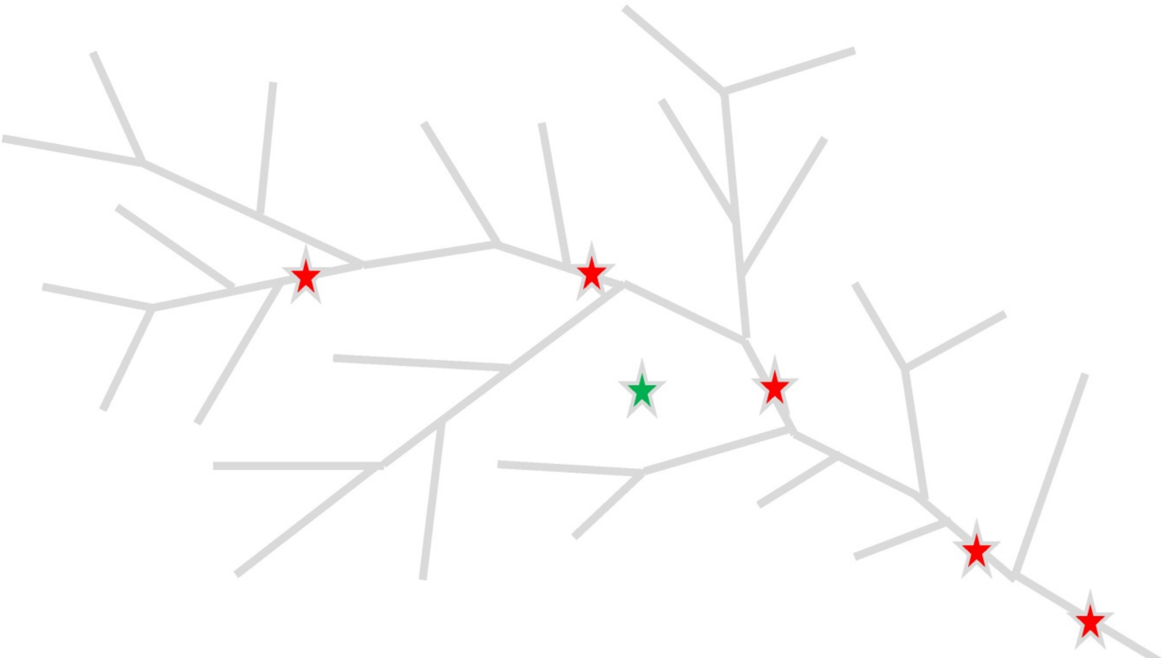
- GW-SW flows
    - Artificial diversions
    - ELFMod
    - Conceptual GW-SW TopNet
    - TopNet ModFlow

CHES: ELFMod Background

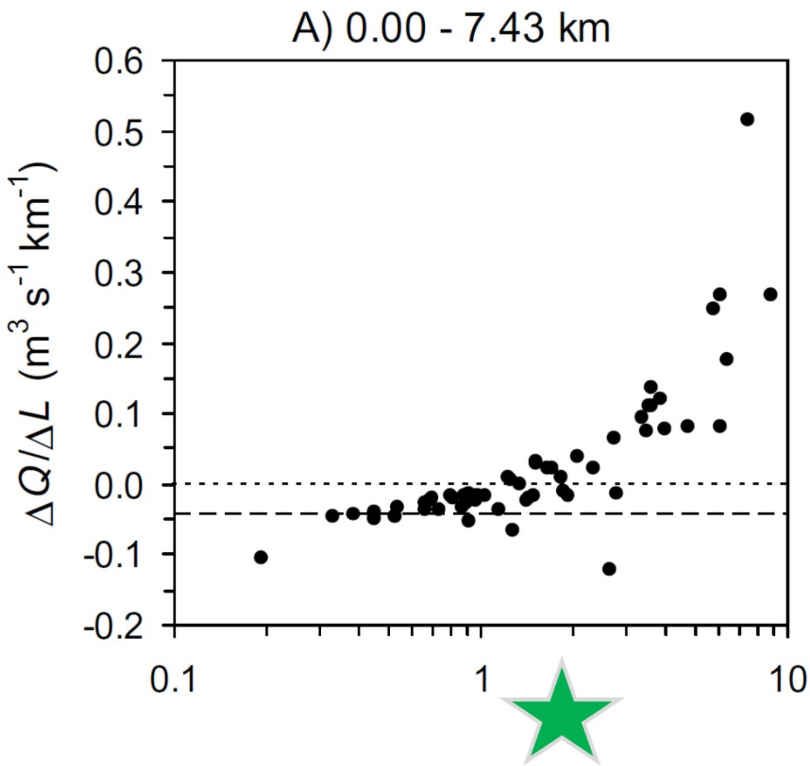
- Statistical approach
- Done on Selwyn and other Canterbury rivers



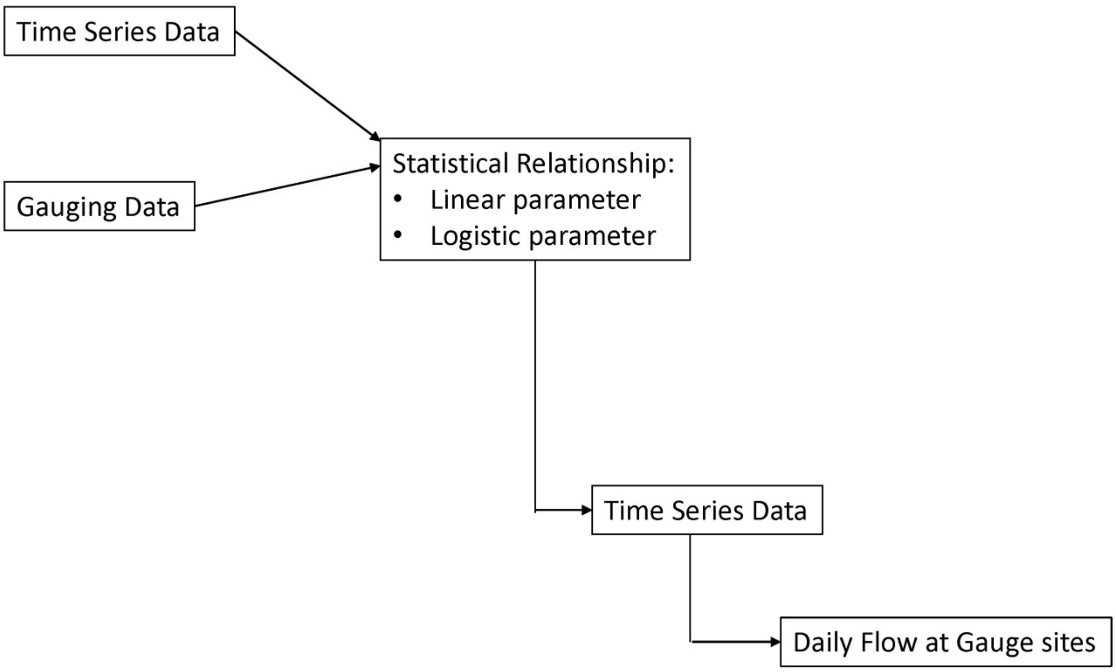
CHES: ELFMod Background



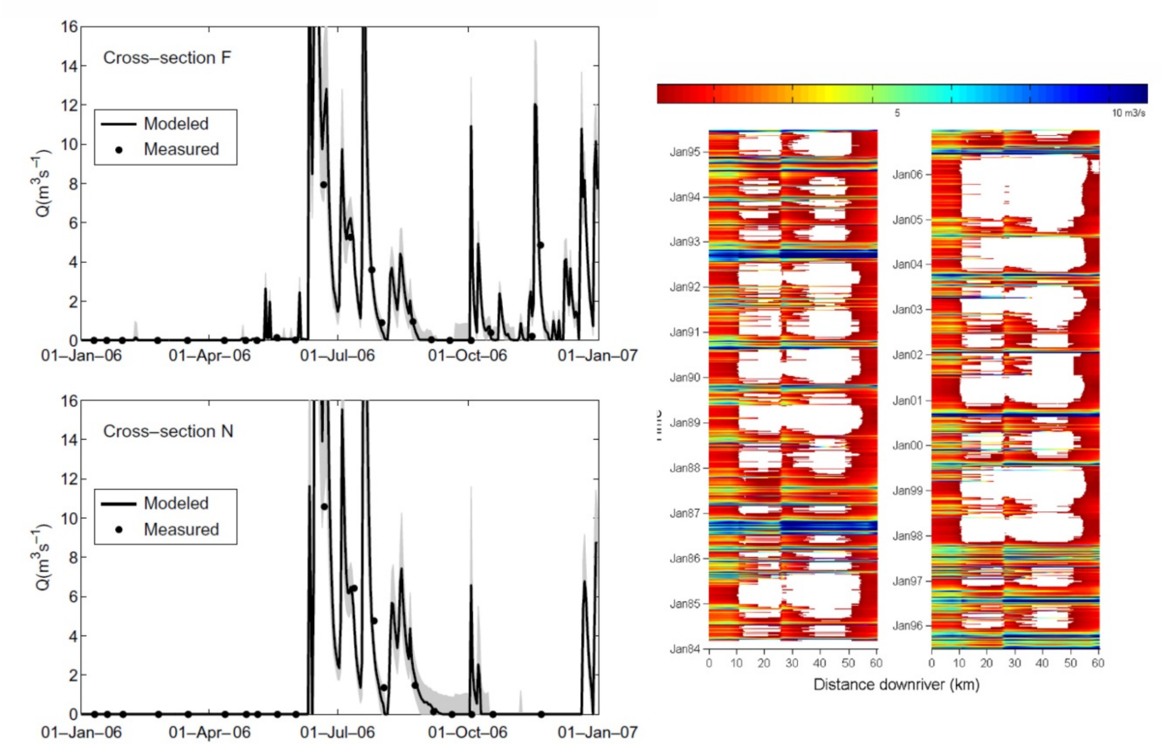
CHES: ELFMod Background



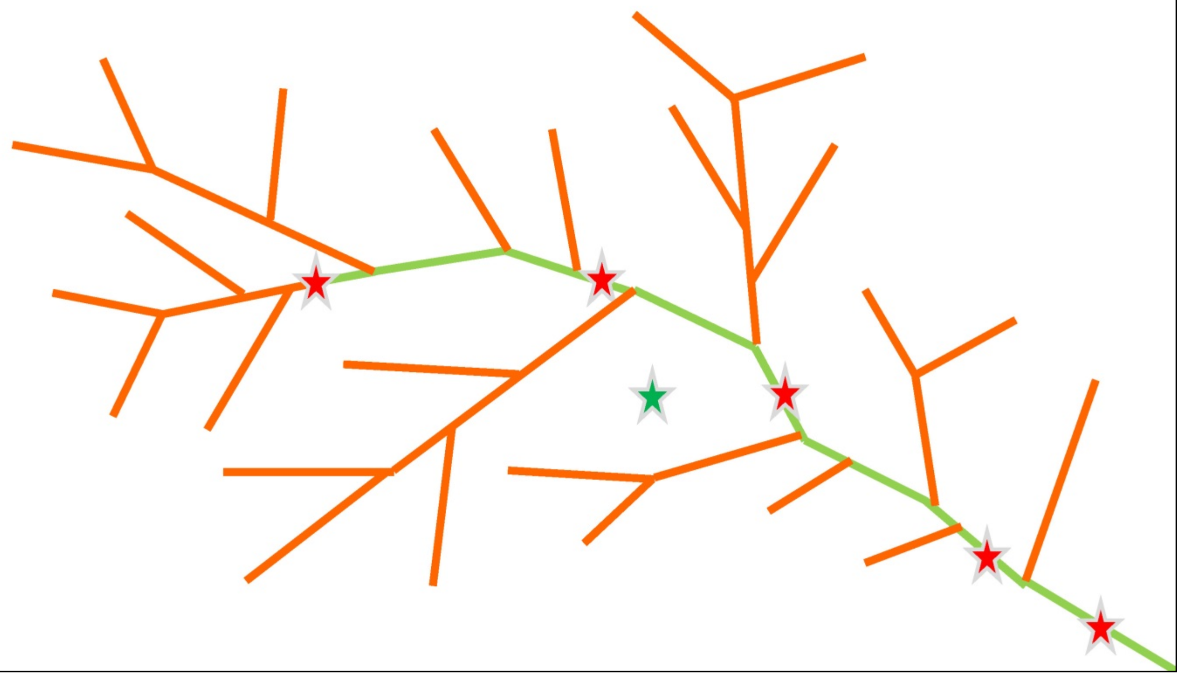
CHES: ELFMod Background



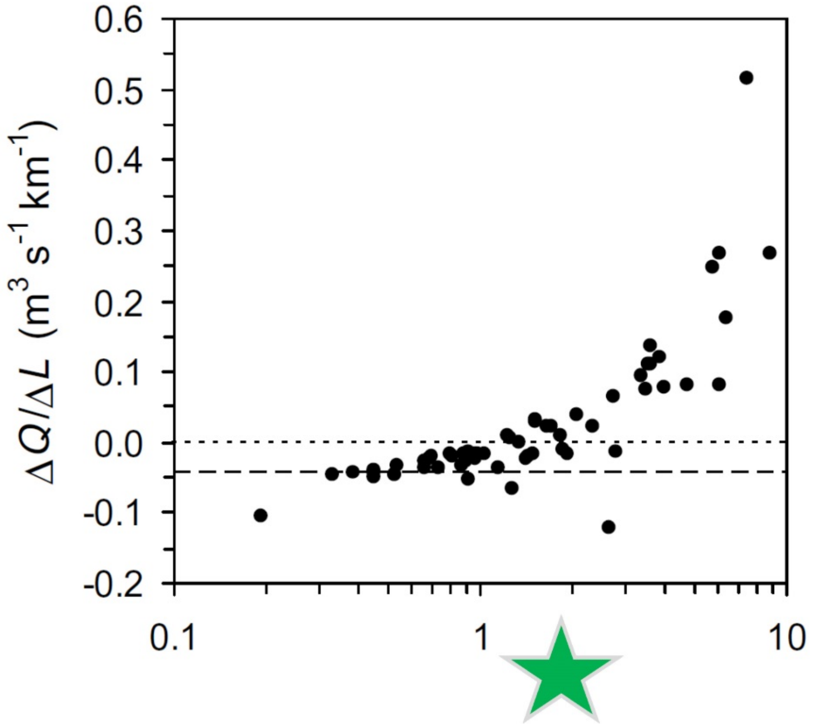
CHES: ELFMod Results



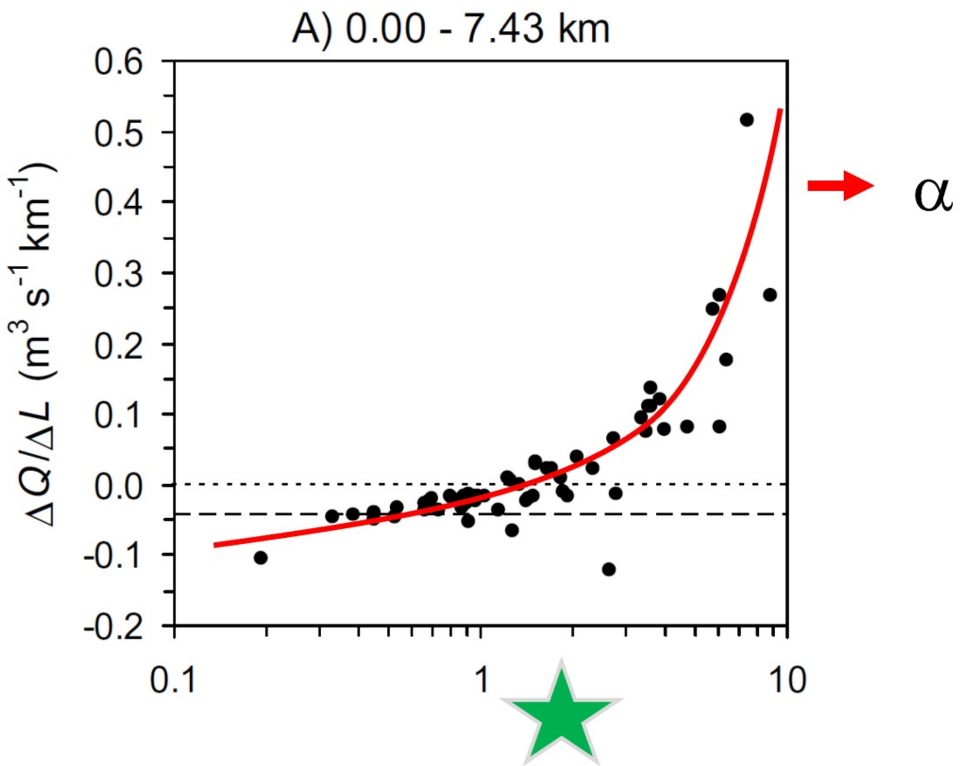
CHES: ELFMod extrapolation



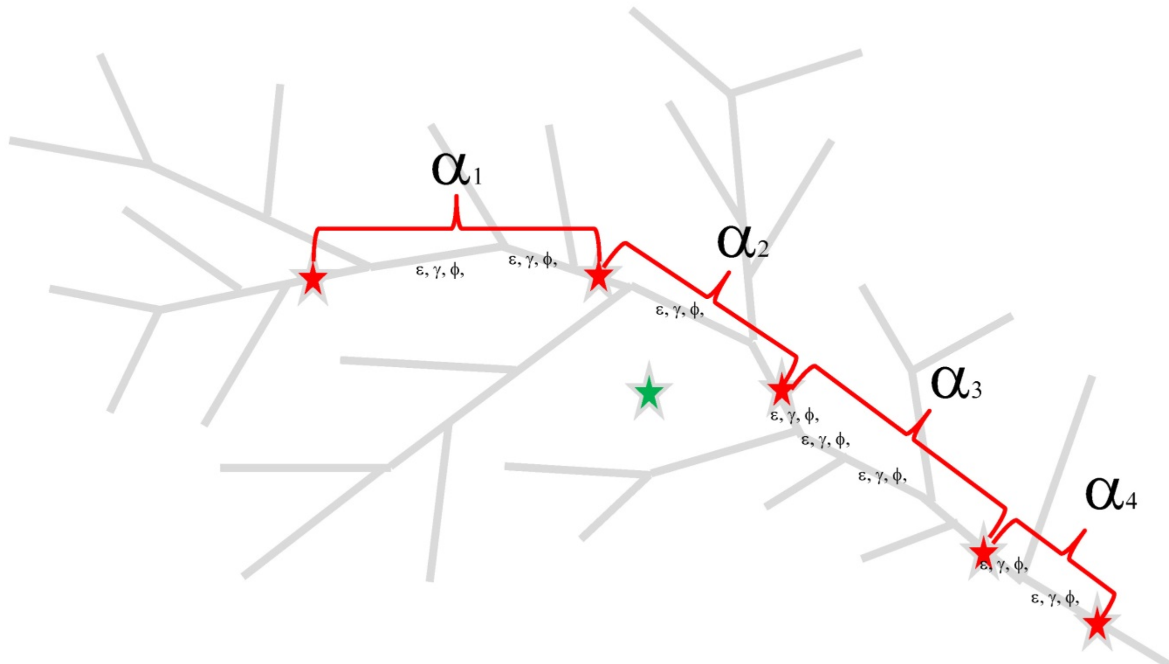
ELFMod: How does ELFMOD work



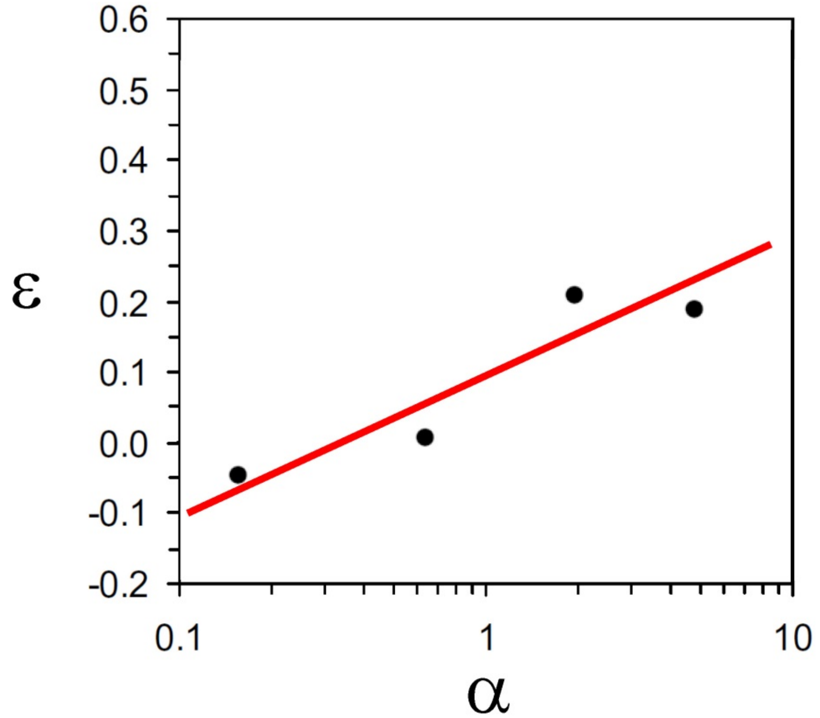
ELFMod: How does ELFMOD work



CHES: Diversions



CHES: ELFMod Extrapolation



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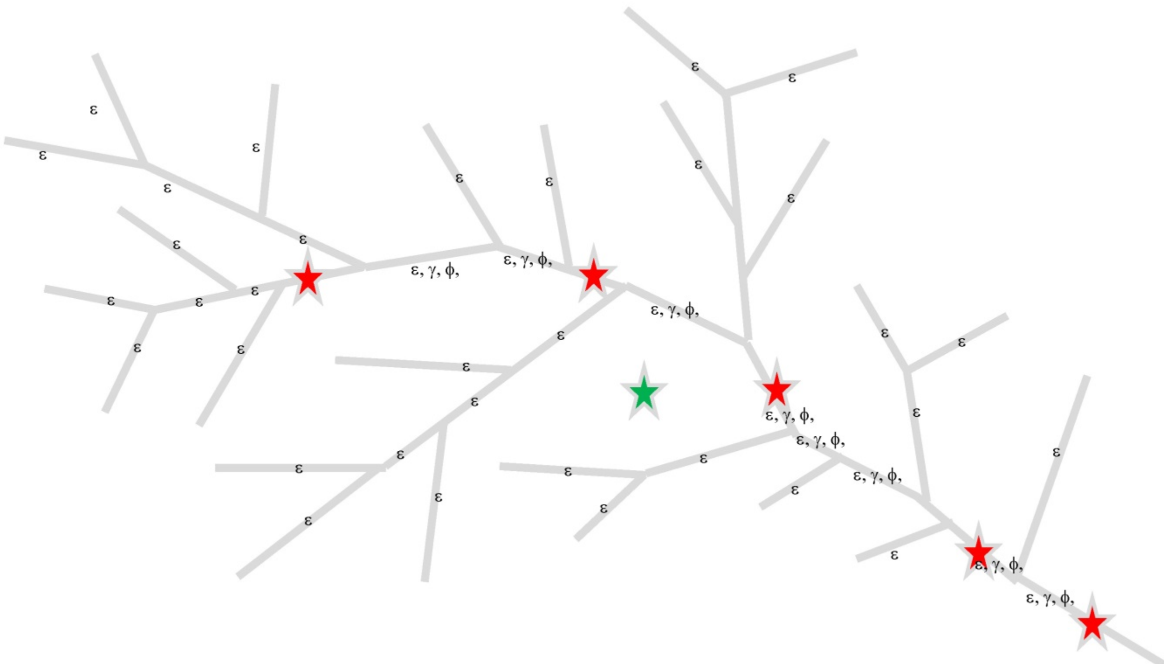
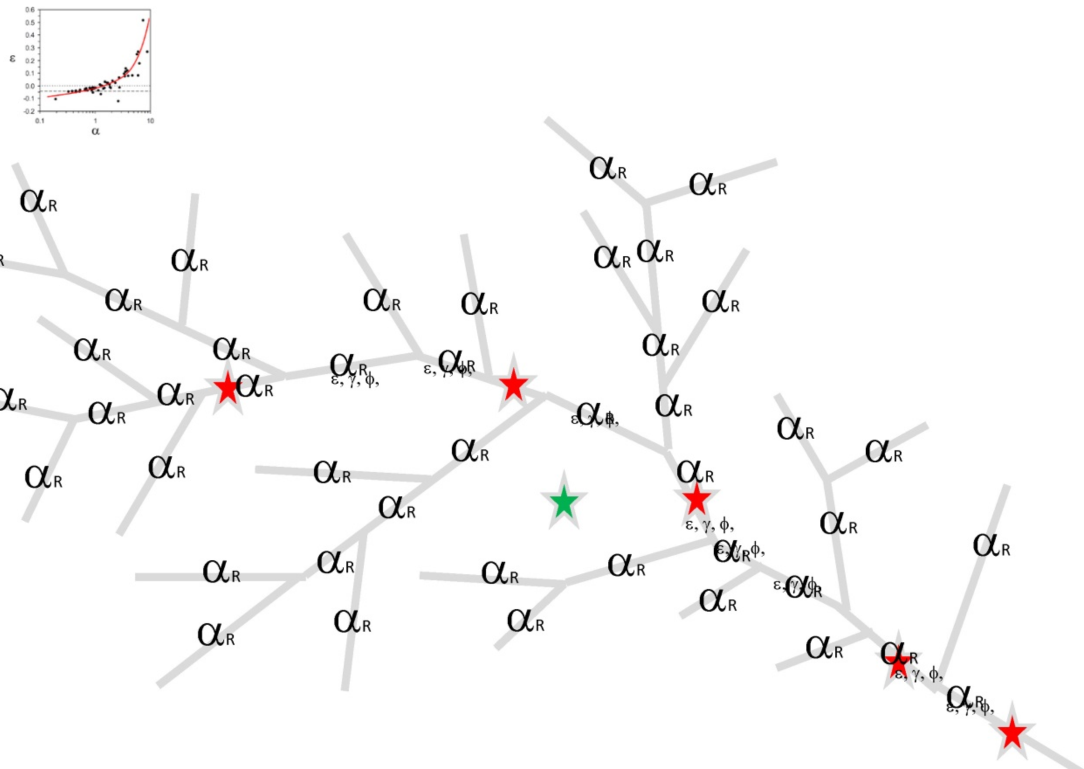


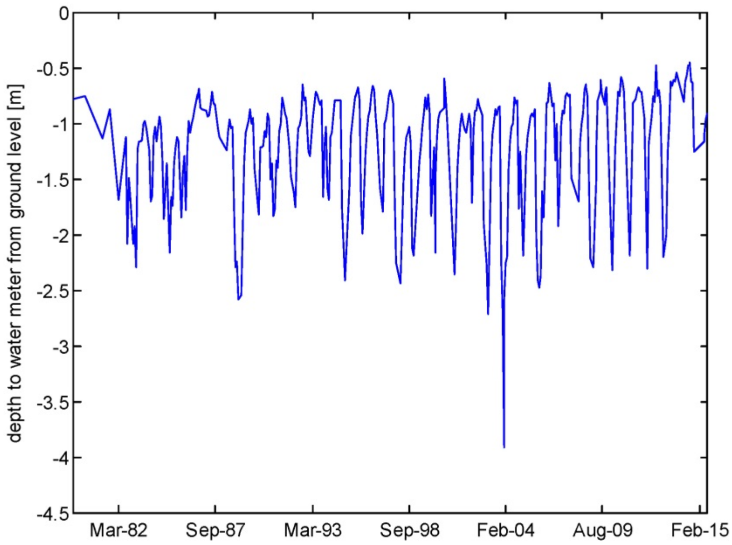
CHES: ELFMod Extrapolation



CHES: ELFMod

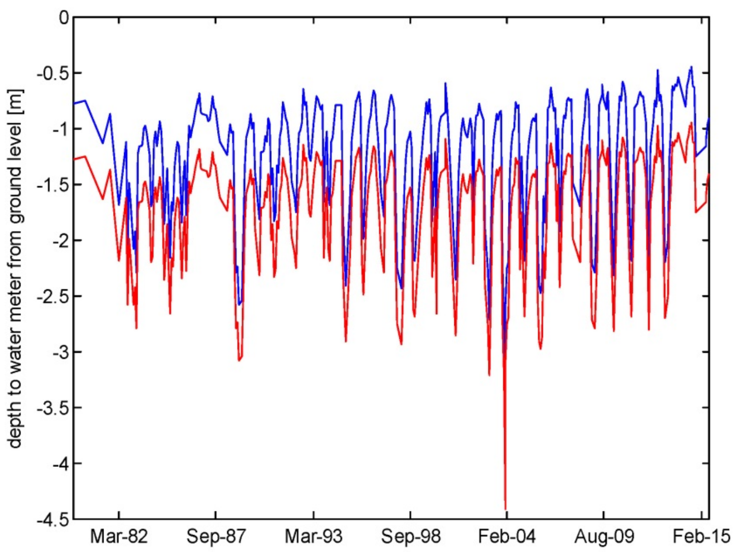
GW-level → GW-Volume

Abstraction → ΔGW-Volume



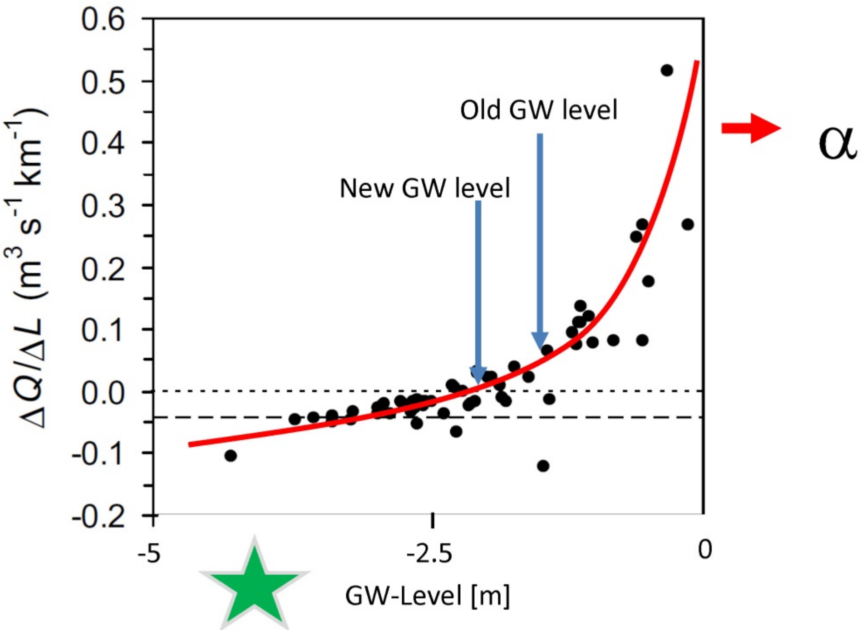
CHES: ELFMod

ΔGW-Volume → ΔGW-Level



CHES: ELFMod

ΔGW-Level → new ΔQ/ΔL

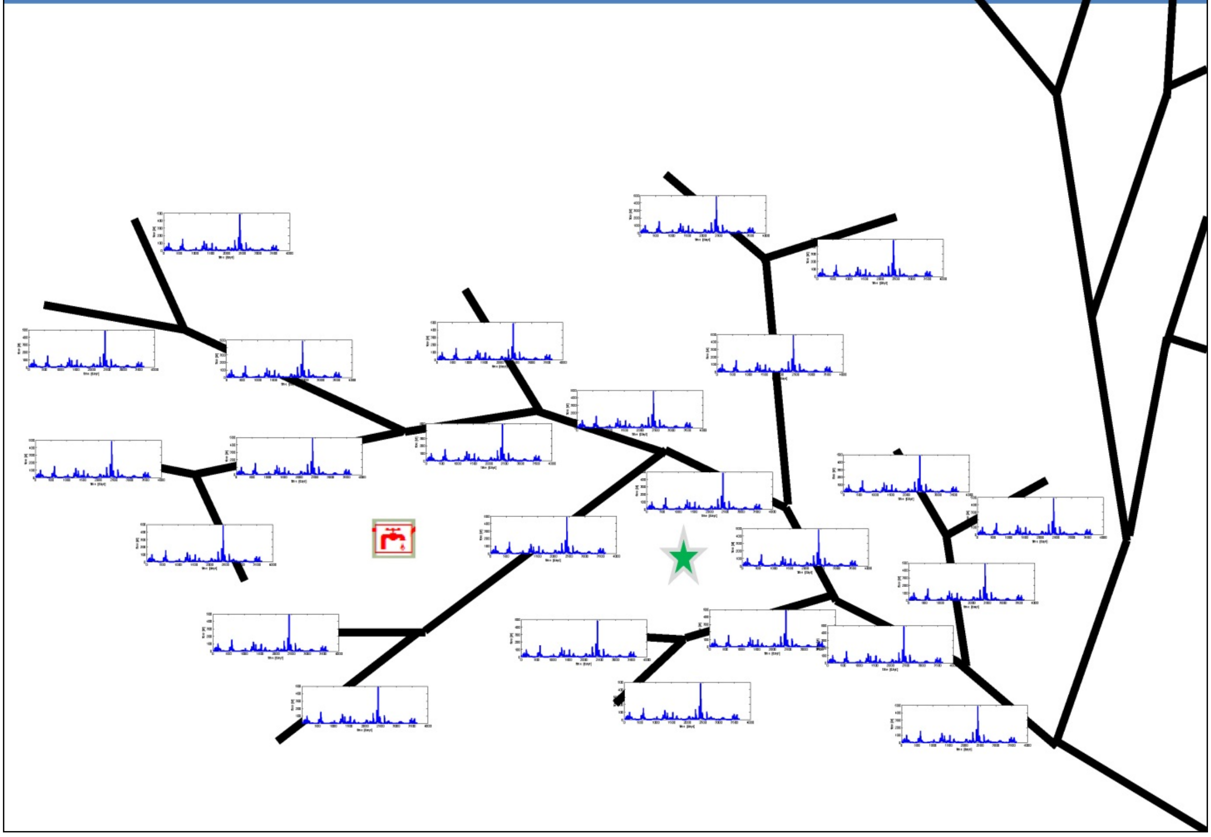


CHES: ELFMod

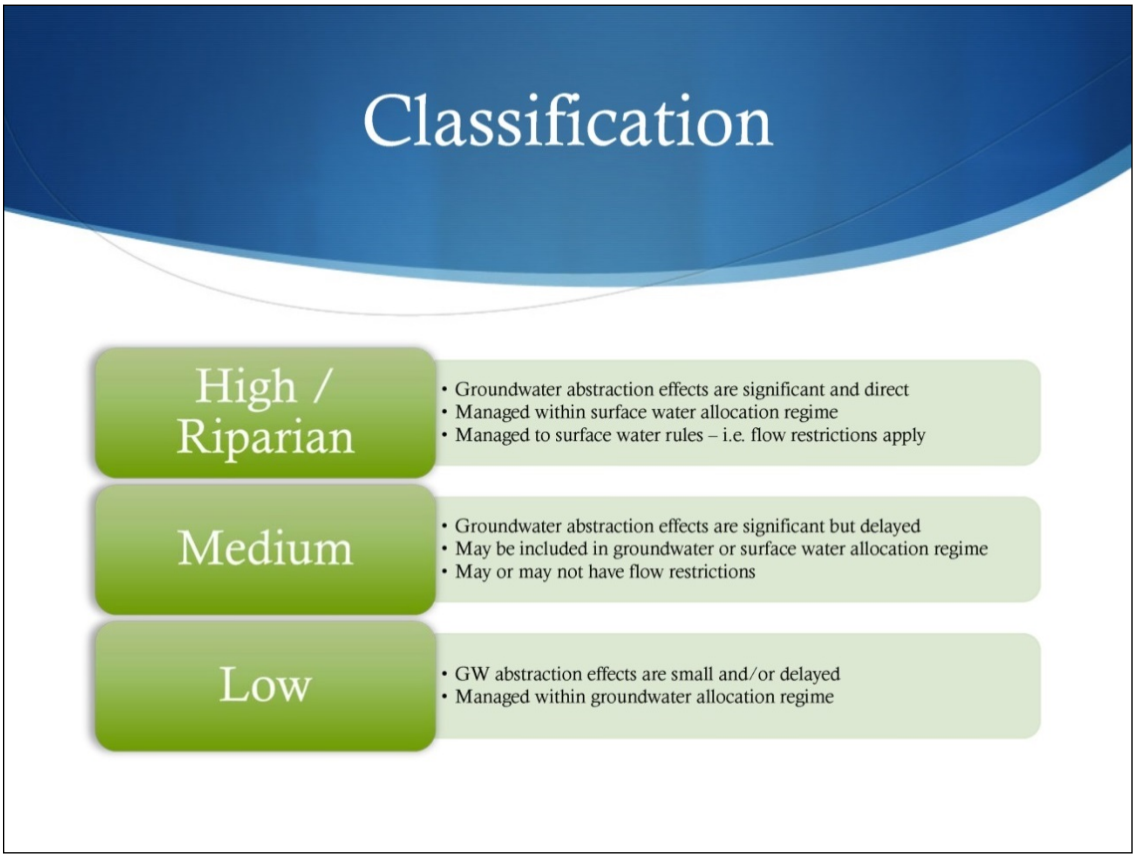
ELFMod Summary, on daily time steps, simplified:

Q	**= Q – SW_{Take}**
GW-level-new	**= GW-level – GW_{Take}**
ΔQ/ΔL	**= f(α, GW-level-new)**
Q-new	**= Q – ΔQ/ΔL**

CHES: ELFMod



3.2.5 Regional council rules for managing stream depletion
Facilitator: Abby Matthews, Horizons Council



Zonation

- Categorised as riparian (direct connection), high, moderate and low connection
- Spatial zonation based on degree of hydraulic connection (distance and depth)
- Requires good conceptual understanding of geology and hydrology

Greater Wellington

Interpreting the map

Management zones

Upper Ruamahanga — Zone name and boundary

Abstraction categories – spatial extent

Category A

Category B

Category C

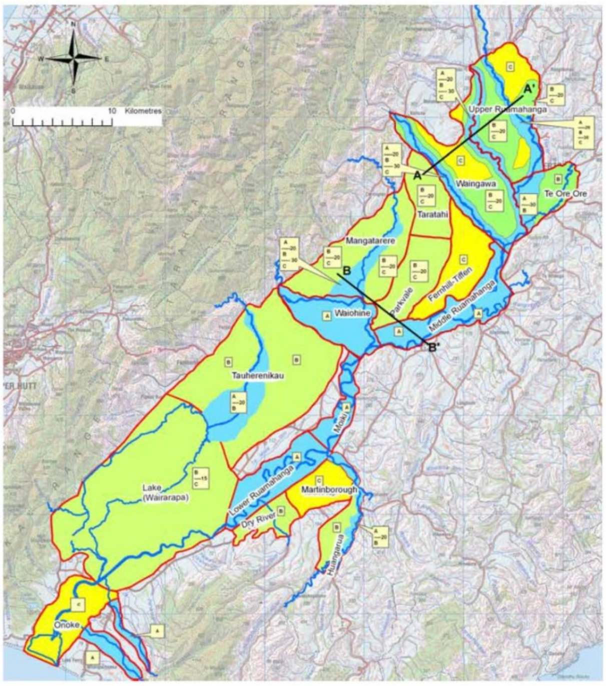
Abstraction categories – depth extent

A
—20
B
—30
C

This example is for a bore located within a Category A spatial zone (e.g. like that in the Mangatarere management zone in the map).

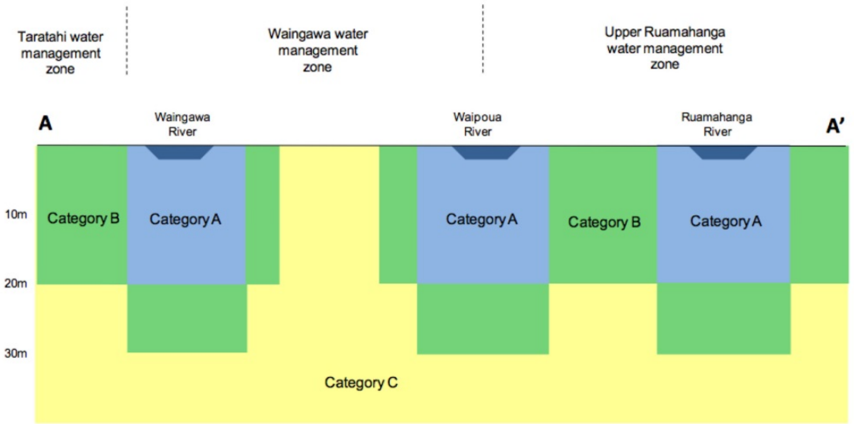
Bores drawing water from a depth of less than 20 m remain Category A, but if they are between 20 and 30 m they become Category B and Category C if they are deeper than 30 m

See Figures 3.7 and 3.8 for further illustration of depth categories



Hydraulic connectivity zonation - Wairarapa Valley (Hughes & Gyopari, 2011)

Greater Wellington



Hydraulic connectivity zonation - Wairarapa Valley (Hughes & Gyopari, 2011)

Classification of connection between groundwater and surface water		General description of the magnitude of surface water depletion effect and aquifer characteristics	General management approach
Category A groundwater	Groundwater directly connected to surface water	Stream depletion effects are immediate and increase rapidly over subsequent days. Depletion effects dissipate quickly when pumping stops. Aquifers are generally shallow, highly permeable gravels (riparian).	Groundwater takes subject to the same limits and restrictions as surface water takes **unless there is clear hydrogeological evidence** demonstrating otherwise. Must not cause saltwater intrusion.
Category B groundwater		Stream depletion effects are delayed but the volume of groundwater pumped represents at least 60% flow depletion from local surface waters. Depletion effects dissipate more slowly. Includes: • groundwater with a weekly average rate of take at the point of abstraction of > 5 L/s, and • groundwater which over the course of a pumping season represents a flow depletion from local surface waters of > 60% of the rate of take or > 10 L/s. Takes not directly connected to surface water account for the remaining balance (i.e. up to 40%).	Takes are subject to the same allocation limits and restrictions as surface water. Groundwater that is not directly connected to surface water is subject to separate groundwater allocation limits. A pumping test is required by a resource consent applicant for new takes or existing consented users seeking an increase. Where weekly average abstraction <5 L/s – managed as groundwater takes. Must not cause saltwater intrusion.
	Groundwater not directly connected to surface water		
Category C groundwater		Groundwater takes may contribute to stream flow depletion at a catchment scale but effects are much less immediate and significant Low permeability geology and/or separated from surface water (e.g. deep confined aquifers).	Managed within groundwater allocation limits. A pumping test is required for new or existing consented takes seeking to increase.

Horizons

- Policy 16-6 - The effects of groundwater takes on surface water bodies, including wetlands, must be managed in the following manner:
  - An appropriate scientific method must be used to calculate the likely degree of connection between groundwater and surface at the location of the groundwater take.
  - Subject to (a), the potential adverse effects of groundwater takes on surface water depletion must be managed in accordance with table 16.1…

Horizons

Classification of Surface Water Depletion Effect	Magnitude of Surface Water Depletion Effect	Management Approach
Riparian	Any groundwater take screened within the geologically recent bed strata of a surface water body.	The groundwater take is subject to the same restrictions as a surface water take, unless there is clear hydrogeological evidence that demonstrates that the effect^ of pumping will not impact on the surface water body.
High	The surface water depletion effect is calculated as 90% or greater of the groundwater pumping rate after seven days of pumping, or 50% or greater of the average groundwater pumping rate after 100 days of pumping.	The groundwater take is subject to the same restrictions as a surface water abstraction.
Medium	The surface water depletion effect is calculated as 20% or greater and less than 50% of the groundwater pumping rate after 100 days of pumping.	The calculated loss of surface water is included in the surface water allocation regime, but no specific minimum flow restrictions are imposed on the groundwater take.
Low	The surface water depletion effect is calculated as less than 20% of the groundwater pumping rate after 100 days of pumping.	The calculated loss of surface water is not included in the surface water allocation regime and no specific minimum flow restrictions are imposed on the groundwater take.

Horizons

- Challenges:
  - Historic takes not yet subject to restrictions
    - voluntary restrictions /common catchment expiry
    - community buy-in
  - "Safe yields" not yet defined
    - groundwater recharge needs to be identified and quantified
  - Cumulative effects of multiple takes
    - groundwater levels reduced due to cumulative abstraction at depth despite "low connection" takes
  - Paper allocation versus actual use
    - regionally, consent holders use approximately 30% of consented annual volume
  - Overly restrictive?
    - should individual consent limits be apportioned between groundwater and surface water to ensure some surety of supply during restrictions?

3.2.6 Participatory exercise

3.2.6.1 *ECAN calculator*

Hunt(2003) - Example1

Stream depletion analysis - Hunt (2003) solution

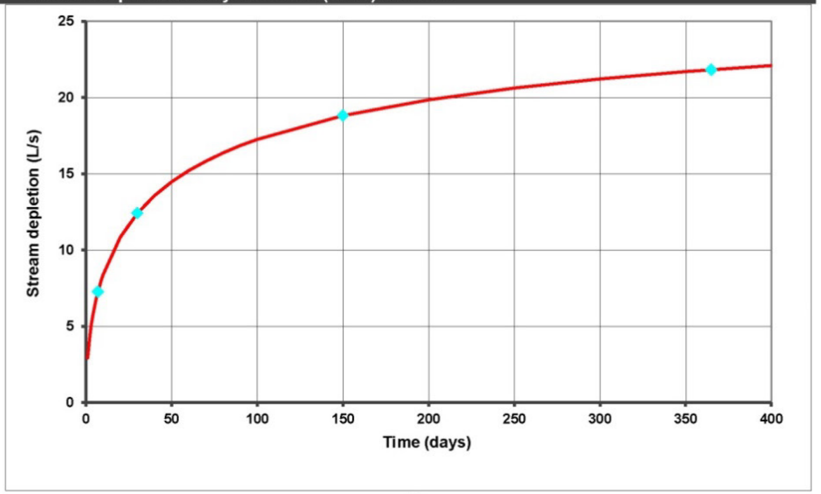
Pumped aquifer		
Transmissivity (T)	1900	(m^2/d)
Storage coefficient (S)	0.0004	-
Aquitard		
Hydraulic conductivity (K')	0.46	(m/d)
Thickness (B')	2	(m)
K'/B'	0.23	(d^{-1})
Specific yield (S_y)	0.01	-
Streambed		
Hydraulic conductivity (K")	1	(m/d)
Thickness (B")	1	(m)
Width (W)	1	(m)
Stream bed conductance (λ)	1	(m/d)
Well		
Pumping rate (Q)	28.9	(L/s)
Separation distance (L)	66	(m)
Application efficiency		
Irrigation efficiency	100%	
Separation distance (L2)	300	(m)

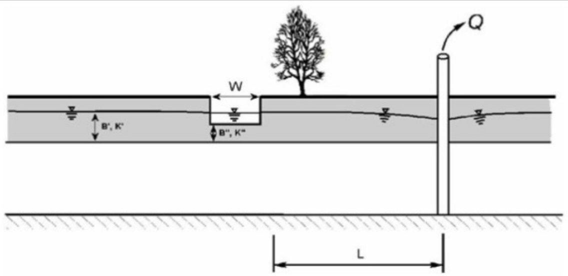
Stream depletion after

Time (days)	q (L/s)	%
7	7	**25%**
30	12	**43%**
150	19	**65%**
365	22	**76%**

Only the values in shaded cells can be updated - all other cells are dependent on those input values.

Setting K'/B' to zreo gives Hunt 1999 solution





Time	Depletion Rate	
	@100%	@100%
(days)	(L/s)	(L/s)
1.0	2.9	2.9
2.0	4.1	4.1
3.0	5.0	5.0
4.0	5.7	5.7
5.0	6.3	6.3
6.0	6.8	6.8
7.0	7.3	7.3
8.0	7.7	7.7
9.0	8.0	8.0
10.0	8.4	8.4
20.0	10.8	10.8
30.0	12.4	12.4
40.0	13.6	13.6
50.0	14.5	14.5
60.0	15.2	15.2
70.0	15.8	15.8
80.0	16.4	16.4
90.0	16.8	16.8
100.0	17.3	17.3
150.0	18.8	18.8
200.0	19.9	19.9
250.0	20.6	20.6
300.0	21.2	21.2
350.0	21.7	21.7
400.0	22.1	22.1

Page 1

Stream depletion analysis - Theis (Jenkins) solution

Pumped aquifer

Transmissivity (T)	1500	(m^2/d)
Storage coefficient (S)	0.1	-

Well

Pumping rate (Q)	0	(L/s)
Separation distance (L)	1500	(m)
Stream depletion factor (sdf)	150	(days)

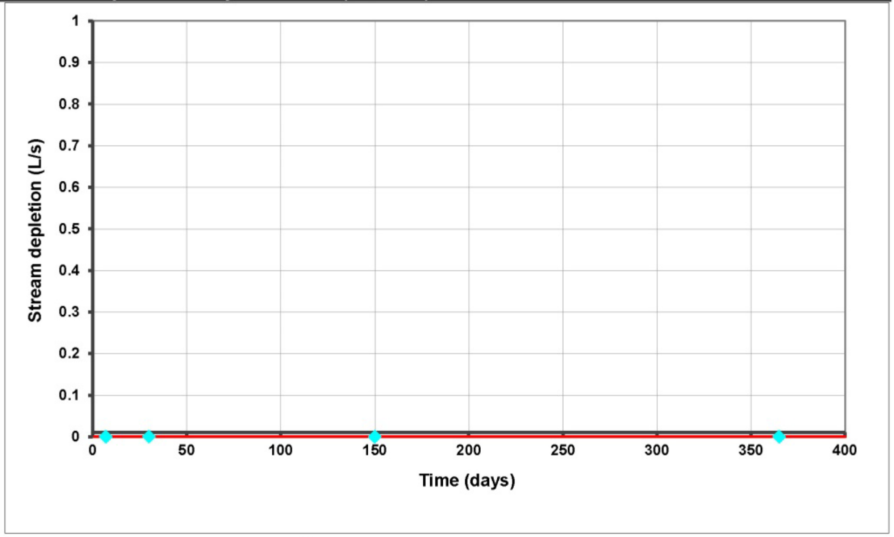
Application efficiency

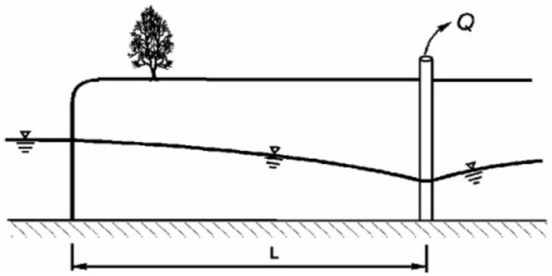
Irrigation efficiency	100%	
Separation distance (L2)	1500	(m)

Stream depletion after

Time (days)	q (L/s)	%
7	0	**0%**
30	0	**11%**
150	0	**48%**
365	0	**65%**

Only the values in shaded cells can be updated - all other cells are dependent on those input values.





Time (days)	Depletion Rate @100% (L/s)	@100% (L/s)
1.0	0.0	0.0
2.0	0.0	0.0
3.0	0.0	0.0
4.0	0.0	0.0
5.0	0.0	0.0
6.0	0.0	0.0
7.0	0.0	0.0
8.0	0.0	0.0
9.0	0.0	0.0
10.0	0.0	0.0
15.0	0.0	0.0
20.0	0.0	0.0
25.0	0.0	0.0
30.0	0.0	0.0
50.0	0.0	0.0
60.0	0.0	0.0
70.0	0.0	0.0
80.0	0.0	0.0
90.0	0.0	0.0
100.0	0.0	0.0
150.0	0.0	0.0
200.0	0.0	0.0
250.0	0.0	0.0
300.0	0.0	0.0
400.0	0.0	0.0

Stream depletion analysis - Hunt (1999) solution

Pumped aquifer

Transmissivity (T)	1000	(m^2/d)
Storage coefficient (S)	0.1	-

Streambed

Hydraulic conductivity (K")	1000	(m/d)
Thickness (B")	1	(m)
Width (W)	1	(m)
Stream bed conductance (λ)	1000	(m/d)

Well

Pumping rate (Q)	0	(L/s)
Separation distance (L)	1000	(m)

Application efficiency

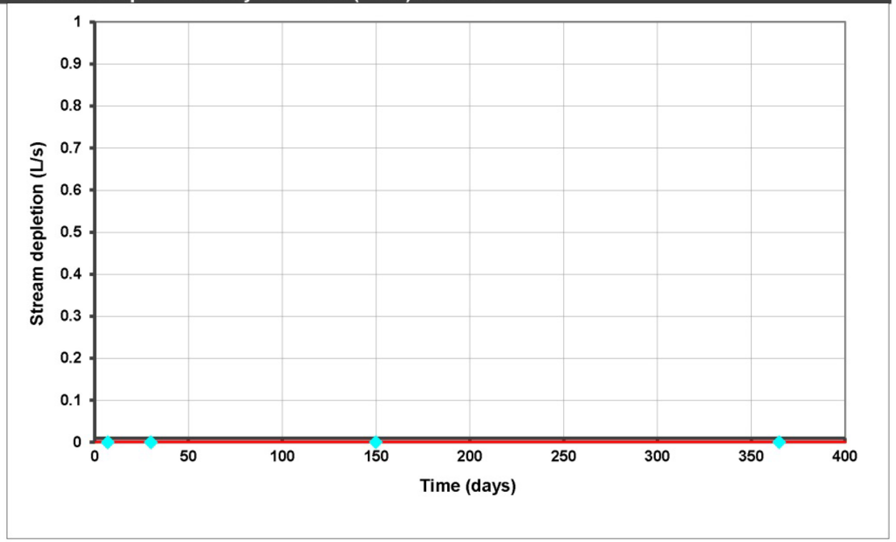
Irrigation efficiency	100%	
Separation distance (L2)	1000	(m)

Stream depletion after

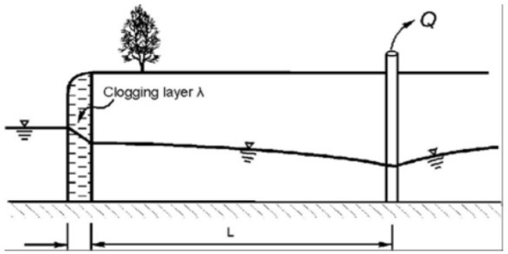
Time (days)	q (L/s)	%
7	0	1%
30	0	20%
150	0	56%
365	0	71%

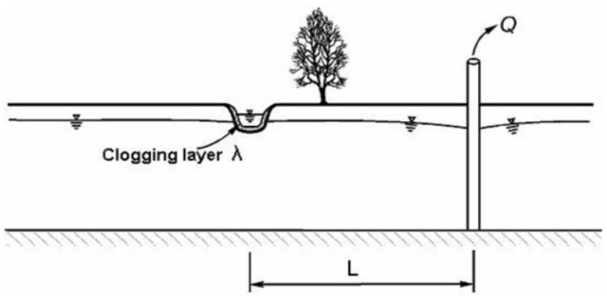
Only the values in shaded cells can be updated - all other cells are dependent on those input values.

Setting lambda to a very high value will give Theis solution



Time (days)	Depletion Rate @100% (L/s)	@100% (L/s)
1.0	0.0	0.0
2.0	0.0	0.0
3.0	0.0	0.0
4.0	0.0	0.0
5.0	0.0	0.0
6.0	0.0	0.0
7.0	0.0	0.0
8.0	0.0	0.0
9.0	0.0	0.0
10.0	0.0	0.0
15.0	0.0	0.0
20.0	0.0	0.0
25.0	0.0	0.0
30.0	0.0	0.0
50.0	0.0	0.0
60.0	0.0	0.0
70.0	0.0	0.0
80.0	0.0	0.0
90.0	0.0	0.0
100.0	0.0	0.0
150.0	0.0	0.0
200.0	0.0	0.0
250.0	0.0	0.0
300.0	0.0	0.0
400.0	0.0	0.0





Environment Canterbury Disclaimer

This spreadsheet is supplied on an as-is basis. Environment Canterbury offers no warranty, expressed or implied, as to its accuracy or completeness and are not obligated to provide the user with any support, consulting, training or assistance of any kind with regard to its use, operation, and performance nor to provide the user with any updates, revisions, new versions or "bug fixes".

The user assumes all risk for any damages whatsoever resulting from loss of use, data, or profits arising in connection with the access, use, quality, or performance of this software.

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Acknowledgement

This workbook uses Visual Basic functions supplied by Dr Bruce Hunt

3.2.6.2 Questions

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Stream Depletion: Analytical Modelling

Groundwater-Surface Water Interaction Workshop

Aslan Perwick and Chris Woodhouse

1.0 Problem One

1.1 Setting

Puka Glen Growers Ltd is cultivating the Puka Sprout, an endemic species of vegetable, and wish to take 2,500 m^3/day of groundwater for irrigation over a season of 100 days. They have drilled an abstraction bore adjacent to a tributary of the Puka Glen River, and the Puka Sprout plantation is sited 300 m south-east of the abstraction bore. Soil characteristics indicate that around 60 % of the irrigated water will be retained in the soil. Puka Glen Council (PGC) requires that a pumping test is undertaken in order to quantify any environmental effects.

Two bores are installed to the south of the stream – a pumping bore and observation bore – with a further observation bore north of the stream. These bores are 10 m deep, and screened within a gravel aquifer containing some sand. The pumped bore is screened from 6 – 10 m below ground level. There was a 2 m thick mud layer overlying the target aquifer, and static water levels were around 1.5 m below ground level, suggesting the aquifer is semi-confined. No obvious barrier boundaries are present. However, storage parameters derived from other pumping tests in the area are consistent with the target aquifer being semi-confined. The stream is fed by springs, and flows at an average rate of 60 L/s during winter, but is flashy during summer, and can dry up.

- *Can you devise a cross-sectional conceptual model for this setting?*

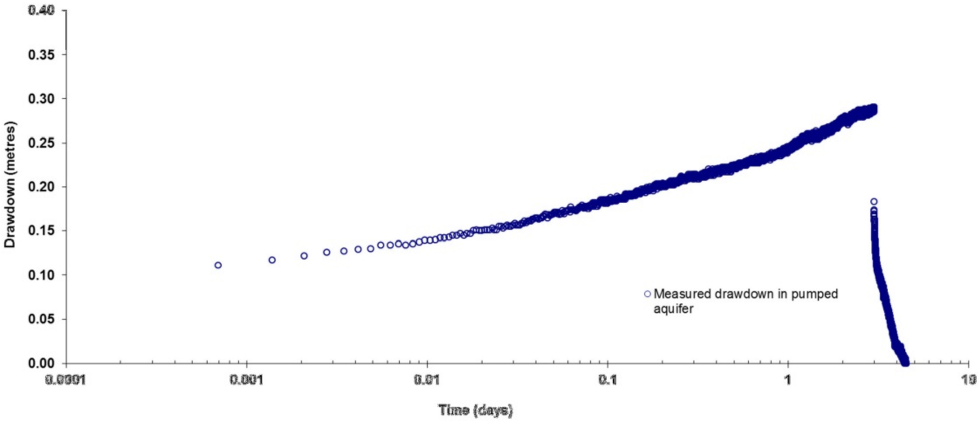
1.2 Pumping Test

The pumping bore is located 66 m from the stream, and the bores are separated by 16 m. In order to investigate effects on the stream, a 3 day pumping test was undertaken, both bores were monitored for the duration of the test, and the pumping bore was pumped at a rate of 2,579 m^3/day. This test was undertaken during winter, and some rainfall occurred half a day after test completion, and nothing is known about the stream bed. Drawdown was also observed in the observation bore north of the stream. Table 1 summarises the input data.

Table 1: Input parameters

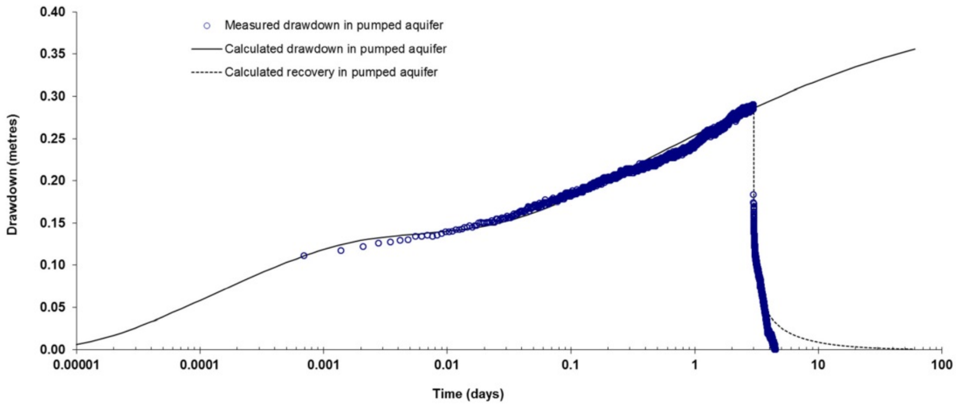
Discharge (m^3/day)	x (m)	y (m)	L (m)
2,579	46	16	66

Drawdown versus time data from the observation bore is shown below:



- *How would you interpret this drawdown and recovery response?*
- *Which analytical solution would you apply?*

1.3 Analysis



The Hunt (2003) solution was applied to the data. The following fit was obtained:

Table 2 shows the parameters calculated for this fit.

Table 2: Hunt (2003) calculated parameters

Transmissivity (m^2/day)	Storage	Leakage (K'/B') (day^{-1})	Specific Yield	Stream bed conductance (λ) (m/d)
6,000	0.0004	0.23	0.01	1

- *Based on this solution, how do you think the stream would be affected? How might the drawdown response look after 100 days pumping in summer?*
-
- *Is a flow restriction required?*

2.0 Problem Two

2.1 Setting

The population of Puka Glen township is expanding rapidly, and requires a new water supply to supplement this growth. Currently, water is abstracted from the Puka Glen River, but this is approaching the allocation limit. The Council decides to supplement the supply with groundwater, and drills a water supply bore upstream from the township adjacent to the Puka Glen River. They plan to abstract up to 6,000 m^3/day for water supply.

Two bores are installed to the east of the river – a pumping bore and observation bore. These bores are screened from 14 – 20 m depth within a clay-bound sandy gravel aquifer. Static water levels were around 8.4 m below ground level. The aquifer is interpreted to be unconfined or semi-confined. No obvious barrier boundaries are present, and the river bed is inferred to be comprised of gravel. Groundwater flows towards the river year round. River flow is typically around 60,000 L/s during winter, but can be as low as 10,000 L/s in summer.

- *Can you devise a cross-sectional conceptual model for this setting?*

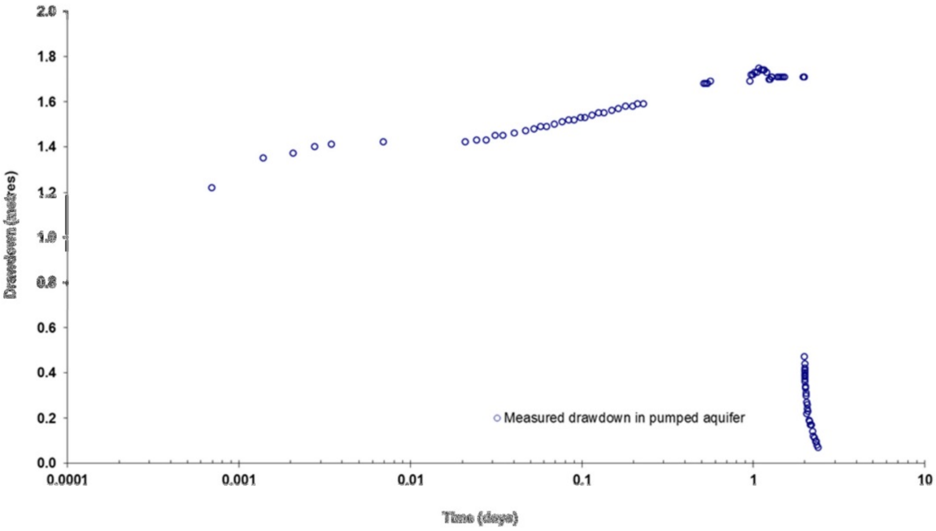
2.2 Pumping Test

The pumping bore is located 97 m from the river, and is 13 m from the observation bore. In order to investigate effects on the river, a 2 day pumping test was undertaken, both bores were monitored for the duration of the test, and the pumping bore was pumped at a rate of 6,048 m^3/day. No rainfall occurred during the test, and nothing is known about the river bed. Table 3 summarises the input data.

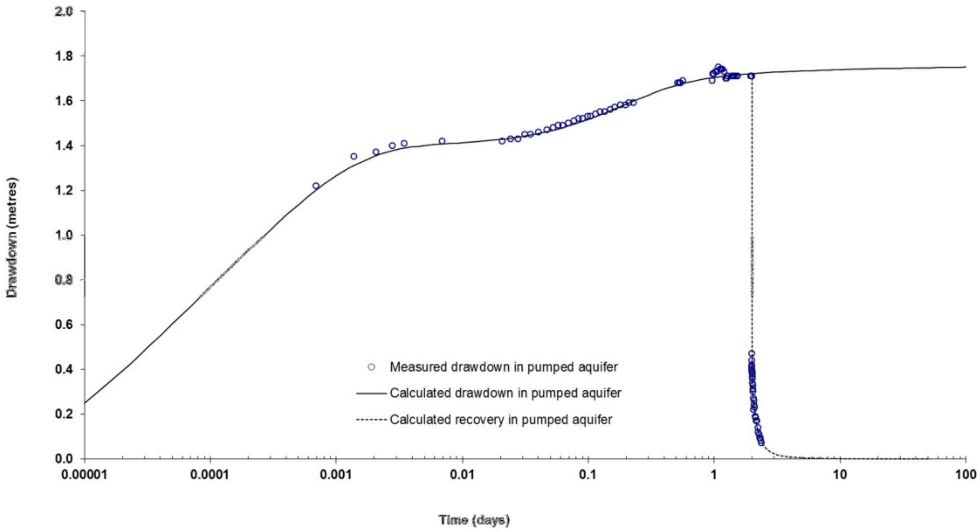
Table 3: Input parameters

Discharge (m^3/day)	x (m)	y (m)	L (m)
6,048	97	4	92

Drawdown versus time data from the observation bore is shown below:



- How would you interpret this drawdown and recovery response?
- Why do you think this response is different to Problem One?
- Which analytical solution would you apply?



3.0 Analysis

The Hunt (2003) solution was applied to the data. The following fit was obtained:

Table 4 shows the parameters calculated for this fit.

Table 4: Hunt (2003) calculated parameters

Transmissivity (m^2/day)	Storage	Leakage (K'/B') (day^{-1})	Specific Yield	Stream bed conductance (λ) (m/d)
1,900	0.0005	0.18	0.02	1,000

- *Based on this solution, how do you think the river would be affected?*

- *Would it be appropriate to include this groundwater take in a surface water allocation block?*

- *Is a flow restriction required? What about in an ecologically important tributary with a mean flow of 100* L/s *located 500 m to the north?*

3.2.6.3 Answers

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Two bores are installed to the south of the stream – a pumping bore and observation bore – with a further observation bore north of the stream. These bores are 10 m deep, and screened within a gravel aquifer containing some sand. The pumped bore is screened from 6 – 10 m below ground level. There was a 2 m thick mud layer overlying the target aquifer, and static water levels were around 1.5 m below ground level, suggesting the aquifer is semi-confined. No obvious barrier boundaries are present. However, storage parameters derived from other pumping tests in the area are consistent with the target aquifer being semi-confined. The stream is fed by springs, and flows at an average rate of 60 L/s during winter, but is flashy during summer, and can dry up.

- *Can you devise a cross-sectional conceptual model for this setting?*
  - See conceptual model image

1.2 Pumping Test

The pumping bore is located 66 m from the stream, and the bores are separated by 16 m. In order to investigate effects on the stream, a 3 day pumping test was undertaken, both bores were monitored for the duration of the test, and the pumping bore was pumped at a rate of 2,579 m^3/day. This test was undertaken during winter, and some rainfall occurred half a day after test completion, and nothing is known about the stream bed. Drawdown was also observed in the observation bore north of the stream. Table 1 summarises the input data.

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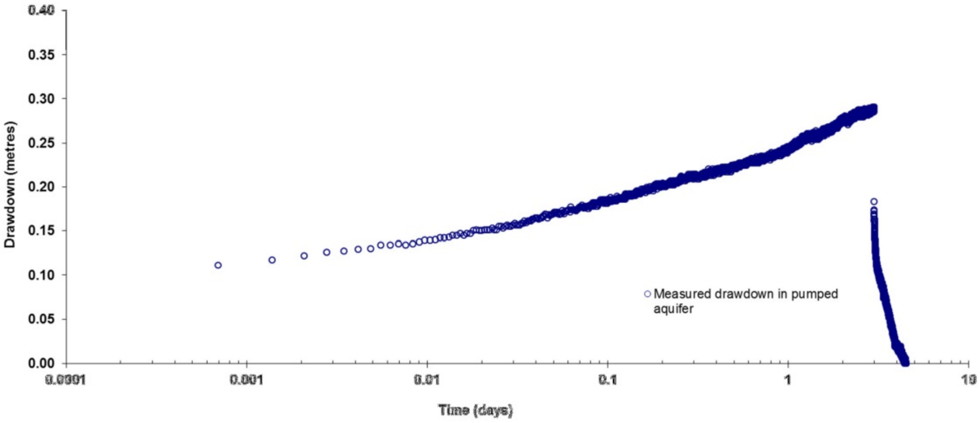


- *How would you interpret this drawdown and recovery response?*
  - Very rapid initial response, followed by mid-time flattening, but little distinct late time flattening
  - Rapid recovery, mostly due to high transmissivity, in part due to rainfall.
  - Relatively small drawdown magnitude in observation well despite proximity to pumped bore – again suggestive of high transmissivity
  - Low degree of flattening inferred to be due to low stream depletion – 3 day test likely to be sufficient for effects to develop.
  - In a short test, or where discharge is low, could be erroneously interpreted to be no stream depletion.
- *Which analytical solution would you apply?*
  - Hunt (2003) – semi-confined aquifer overlain by aquitard.

1.3 Analysis

The Hunt (2003) solution was applied to the data. The following fit was obtained:

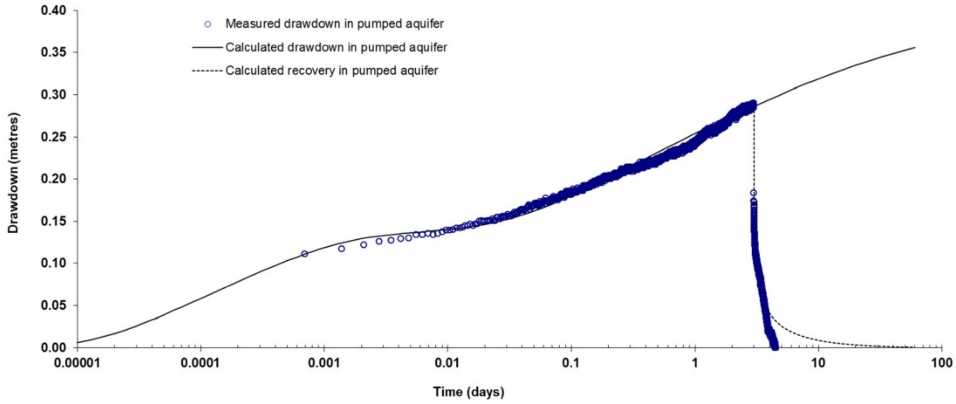
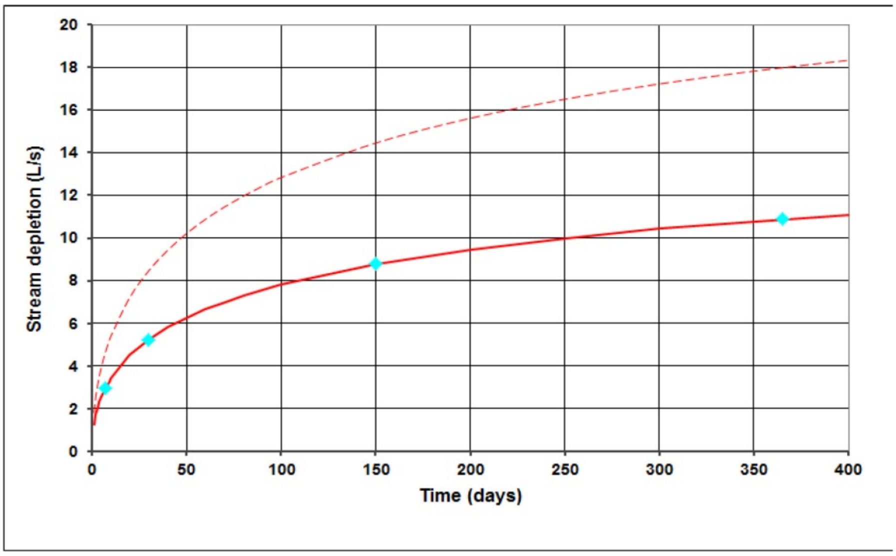


Table 2 shows the parameters calculated for this fit.

Table 2: Hunt (2003) calculated parameters				
Transmissivity (m^2/day)	Storage	Leakage (K'/B') (day^{-1})	Specific Yield	Stream bed conductance (λ) (m/d)
6,000	0.0004	0.23	0.01	1

- *Based on this solution, how do you think the stream would be affected? How might the drawdown response look after 100 days pumping in summer?*
  - Answer from ECan spreadsheet:



ductance and v little flattening - expect small stream depletion.

- Drawdown observed in observation bore on opposite stream bank – implies stream does not act as a complete recharge barrier.
- During summer, less flow so less likely to be significantly affected, especially if the stream is dry. But less depletion from stream, so drawdown less buffered and might increase with a steeper slope? But high aquifer transmissivity, so magnitude likely to be relatively low.

- *Is a flow restriction required?*
  - Abstraction for irrigation, so will mostly occur during summer.
  - Limited hydraulic connection to stream as implied by low streambed conductance and the stream not acting as a complete recharge boundary.
  - Stream is flashy, likely in response to storms – implies spring contribution is less during summer, likely due to low groundwater levels. Spring depletion may be more important than stream depletion. More appropriate to put flow triggers on spring?

2.0 Problem Two

2.1 Setting

The population of Puka Glen township is expanding rapidly, and requires a new water supply to supplement this growth. Currently, water is abstracted from the Puka Glen River, but this is approaching the allocation limit. The Council decides to supplement the supply with groundwater, and drills a water supply bore upstream from the township adjacent to the Puka Glen River. They plan to abstract up to 6,000 m^3/day for water supply.

Two bores are installed to the east of the river – a pumping bore and observation bore. These bores are screened from 14 – 20 m depth within a clay-bound sandy gravel aquifer. Static water levels were around 8.4 m below ground level. The aquifer is interpreted to be unconfined or semi-confined. No obvious barrier boundaries are present, and the river bed is inferred to be comprised of gravel. Groundwater flows towards the river year round. River flow is typically around 60,000 L/s during winter, but can be as low as 10,000 L/s in summer.

- *Can you devise a cross-sectional conceptual model for this setting?*
  - See conceptual model image

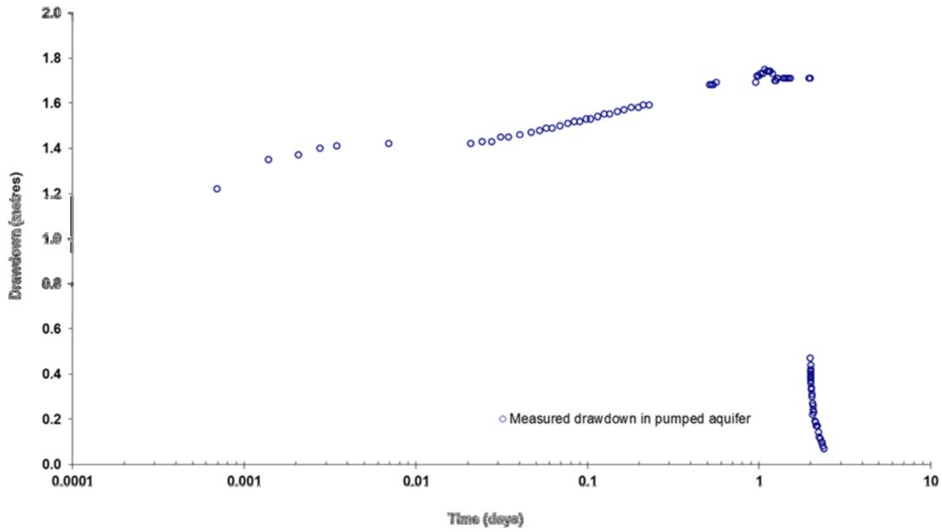
2.2 Pumping Test

The pumping bore is located 97 m from the river, and is 13 m from the observation bore. In order to investigate effects on the river, a 2 day pumping test was undertaken, both bores were monitored for the duration of the test, and the pumping bore was pumped at a rate of 6,048 m^3/day. No rainfall occurred during the test, and nothing is known about the river bed. Table 3 summarises the input data.

Table 3: Input parameters

Discharge (m^3/day)	x (m)	y (m)	L (m)
6,048	97	4	92

Drawdown versus time data from the observation bore is shown below:



- How would you interpret this drawdown and recovery response?
  - Rapid drawdown, followed by mid-time flattening, and then only a small drawdown increase due to significant flattening
  - Significant flattening implies high streambed conductance, and high stream depletion, especially given proximity to river.
- Why do you think this response is different to Problem One?
  - Main difference is flattening, caused by much strong hydraulic connection to river, than in Problem One.
- Which analytical solution would you apply?
  - Hunt (2003)
  - Hunt (2009) but insufficient evidence underlying confined layer.

3.0 Analysis

The Hunt (2003) solution was applied to the data. The following fit was obtained:

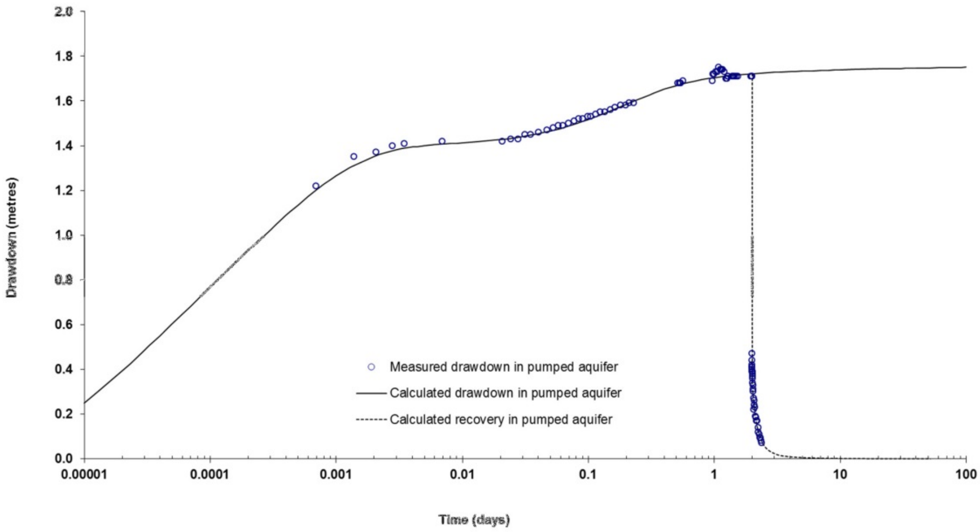
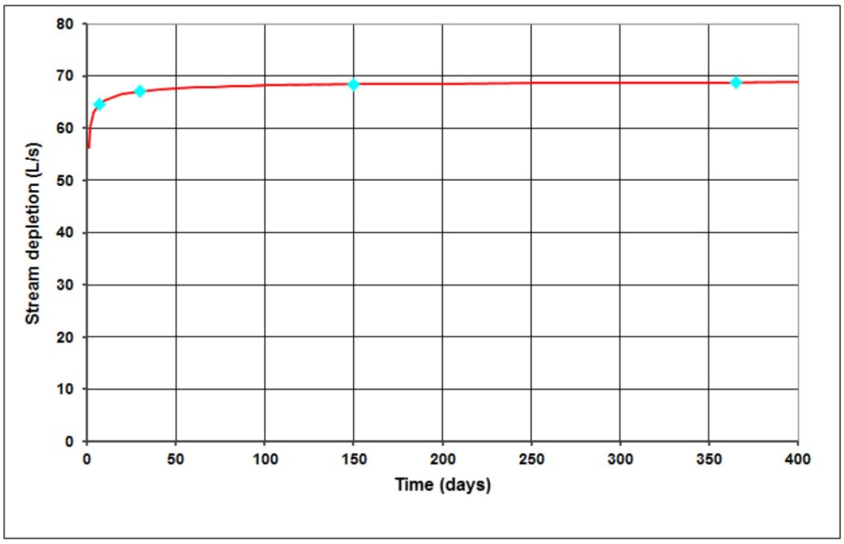


Table 4 shows the parameters calculated for this fit.

Table 4: Hunt (2003) calculated parameters

Transmissivity (m^2/day)	Storage	Leakage (K'/B') (day^{-1})	Specific Yield	Stream bed conductance (λ) (m/d)
1,900	0.0005	0.18	0.02	1,000

- *Based on this solution, how do you think the river would be affected?*
  - ECan Spreadsheet answer below
  - Good hydraulic connection with River, high stream depletion effect predicted



- *Would it be appropriate to include this groundwater take in a surface water allocation block?*
  - Yes, given such high depletion and rapid response – governed by streambed conductance.
  - Rapidly reaches steady-state, and water is essentially being sourced from the river.
- *Is a flow restriction required? What about in an ecologically important tributary with a mean flow of 100* L/s *located 500 m to the north?*
  - Open to debate – does it matter, given the low abstraction rate compared to river flow? Dependent on ecological characteristics?
  - Could be significant in the tributary – depends on the proportion of the abstracted GW being sourced from the tributary – need more test data to decide – an observation bore close to the tributary on the same side as the pumping bore
  - Analytical models not designed for such complexities. Would be better to utilise numerical techniques in this instance.

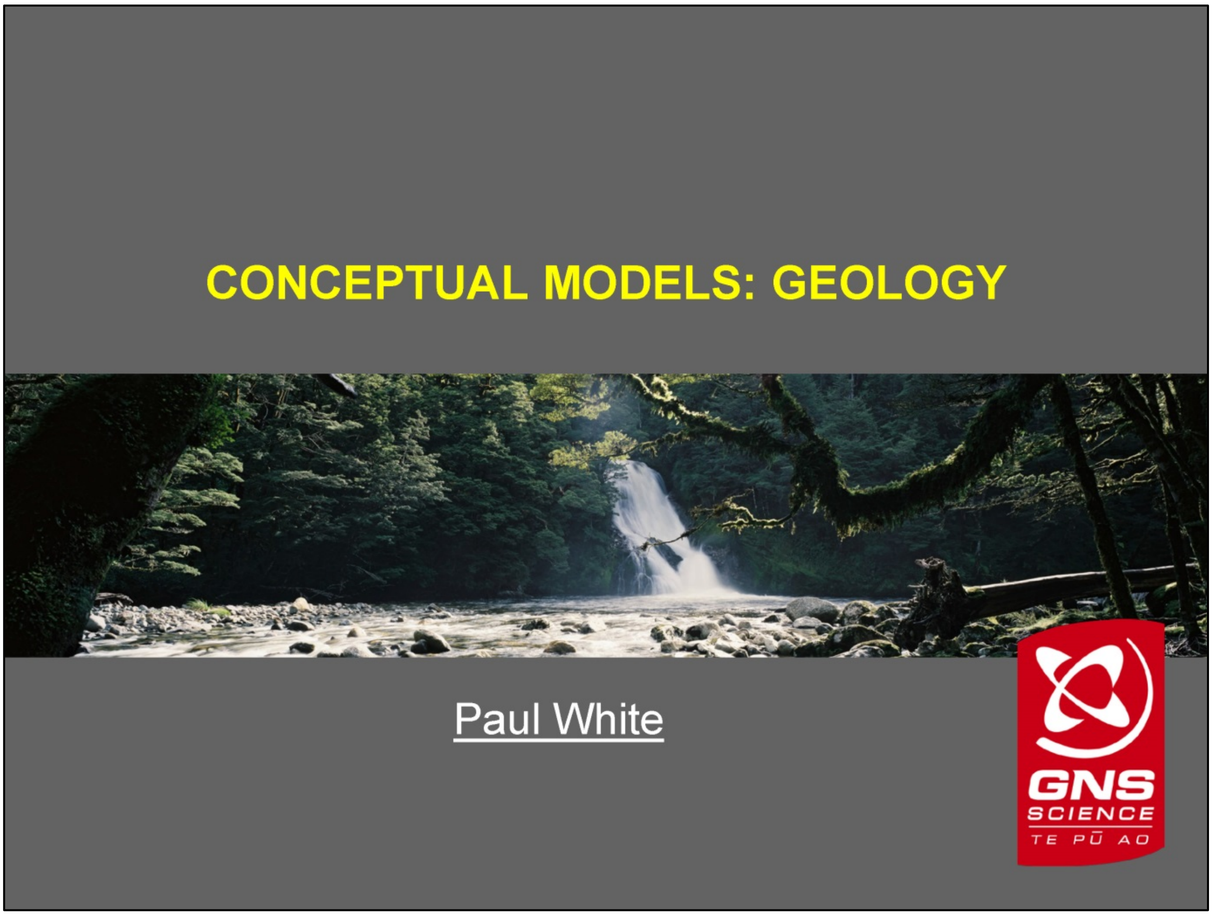
SESSION 4: GW-SW INTERACTION MODELLING
FACILITATOR: PAUL WHITE, GNS SCIENCE

4.1 INTRODUCTION

- Objective 1: Define conceptual models;
- Objective 2: Understand the principles of models;
- Objective 3: Understand different modelling approaches;
- Objective 4: Identify models strengths and weaknesses; and
- Objective 5: Be able to apply models and regional policies.

4.2 PRESENTATIONS

4.2.1 Groundwater-surface water interaction: conceptual models, geology
Facilitator: Paul White, GNS Science

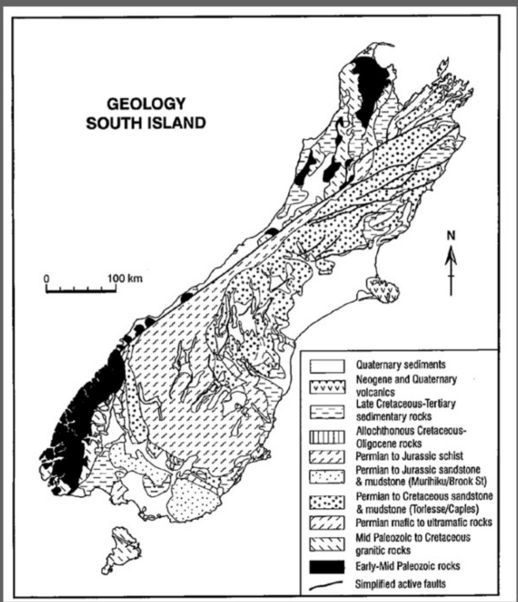


INTRODUCTION

- Summarise geology in NZ
- Summarise some of the major aquifer types and some features
- Summarise approaches to modelling geology
- Summarise some uses of geological models in gw-surface water interaction

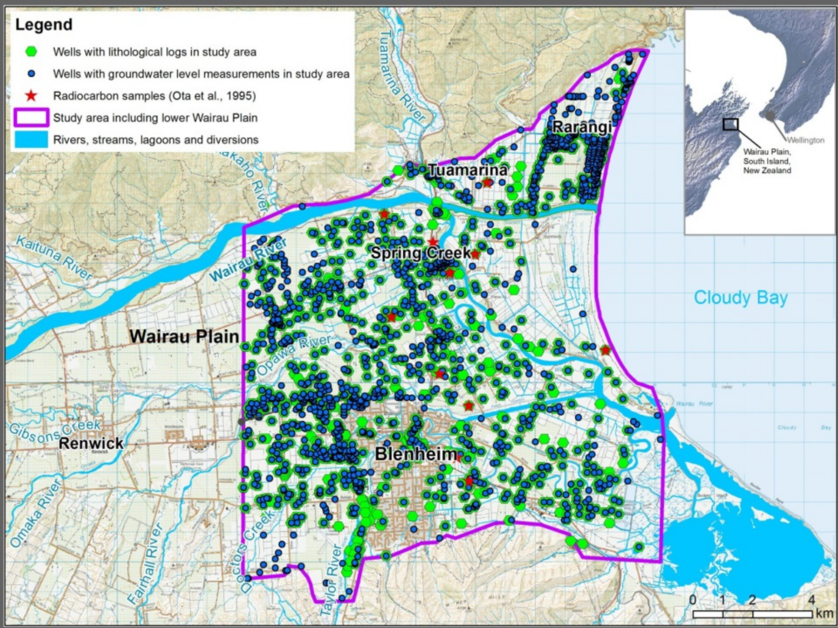
GNS Science

Geological maps are a great source of information: e.g., large scale and catchment scale



GNS Science

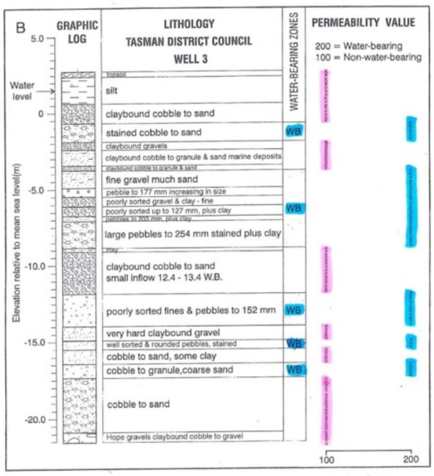
Geological logs are a great source of information: e.g., 1165 logs in this area in the Wairau Plains



GNS Science

Logs can tell you what is in the ground:

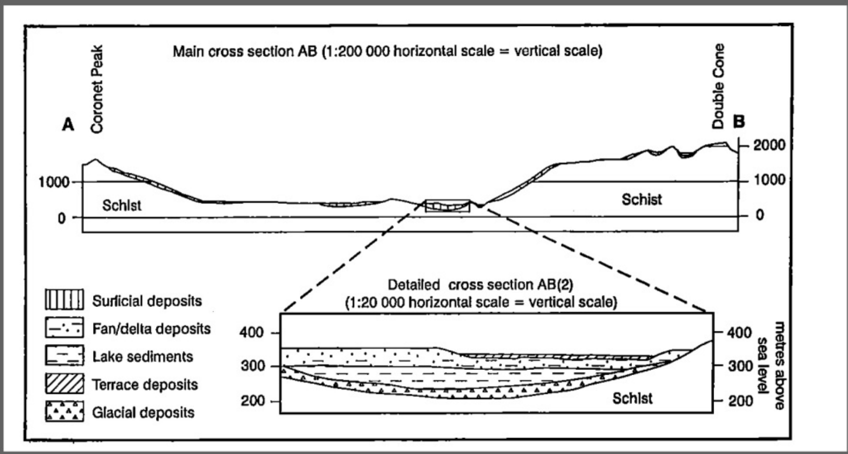
blue = water bearing
pink = other



Well log

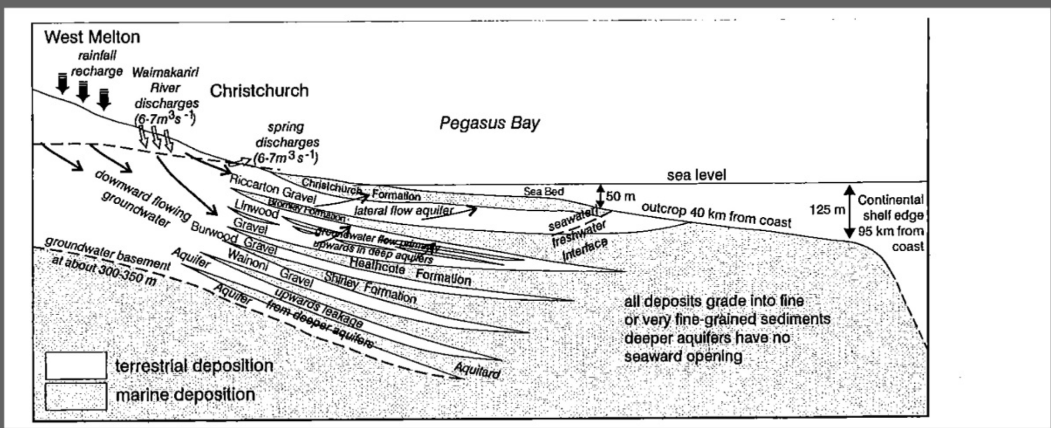
GNS Science

Aquifer system class :terrestrial deposition, e.g. Wanaka Basin



GNS Science

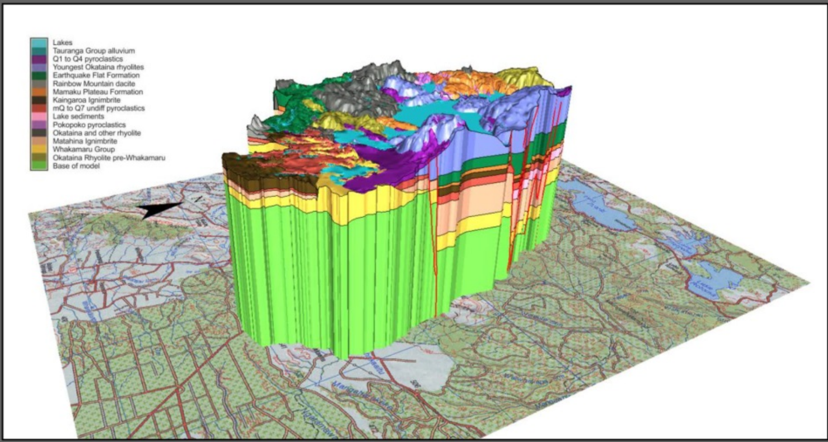
Aquifer system class: marine/terrestrial deposition, e.g. Christchurch



Conceptual models - used for assessing groundwater catchments of spring-fed streams

GNS Science

Aquifer system class: volcanic, e.g. Tarawera

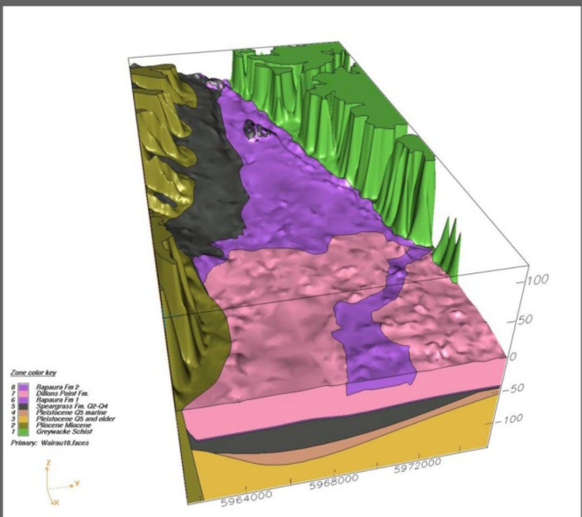


This model was part of an assessment of land use, groundwater flow and nitrogen discharge to lakes

GNS Science

Geological models: now used routinely to characterise geology of aquifer systems.

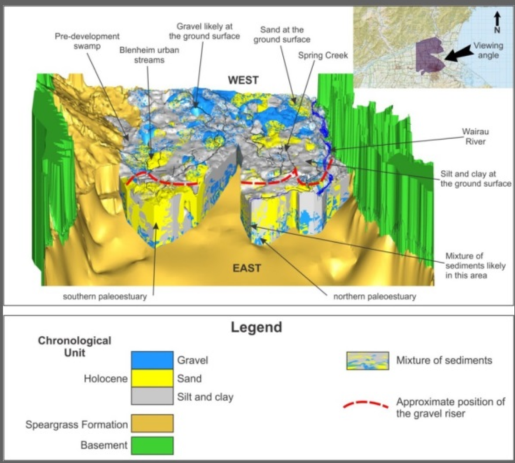
Geological units



This model was used to identify the location of groundwater recharge from surface water

GNS Science

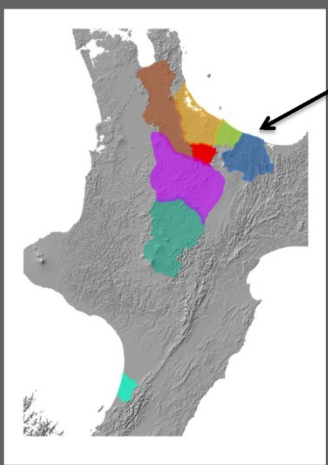
Geological model: now used routinely to characterise geology of aquifer systems.
Lithology

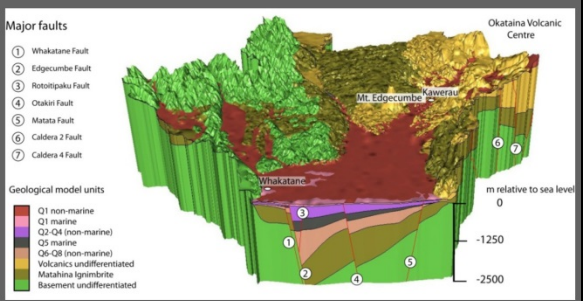


This model was used to assess water budgets and groundwater flow patterns from source to spring

GNS Science

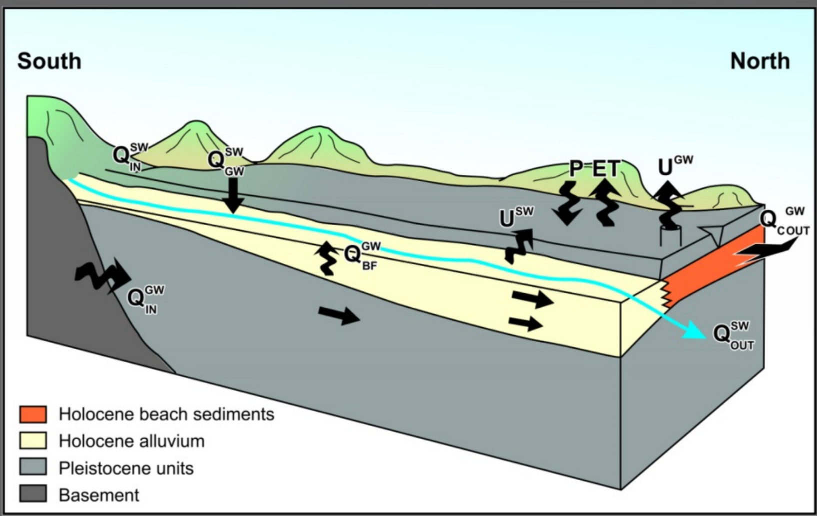
Web access to geological models: http://data.gns.cri.nz/ebof
Aims to provide model information to anyone





GNS Science

Conceptual geological models provide a framework for water budgets



This model was used to assess groundwater-surface water interaction in the Hauraki Plains

GNS Science

4.2.2 Groundwater-surface water interaction: conceptual models, water budgets Facilitator: Scott Wilson, Lincoln Agritech

Water Budgets
(a conceptual model with numbers)

LINCOLN AGRITECH LTD

Darcy's Law $Q = -K.A.dh/dl$

Flow exchange driven primarily by:
- Potential differences (water levels)
- Area of interaction (i.e. wetted perimeter of river bed)

The exchange is regulated by:
- Transmissivity
- Storage coefficient (e.g. springs, pumping effects)

For water quality assessments we include effective porosity

Must have conservation of mass: Outputs = Inputs ± Storage

Complications
- Anisotropy $K_x > K_z$
- Hydraulic connectivity
- Heterogeneity

MEASURE. MODEL. MANAGE.

Scale considerations

LINCOLN AGRITECH LTD

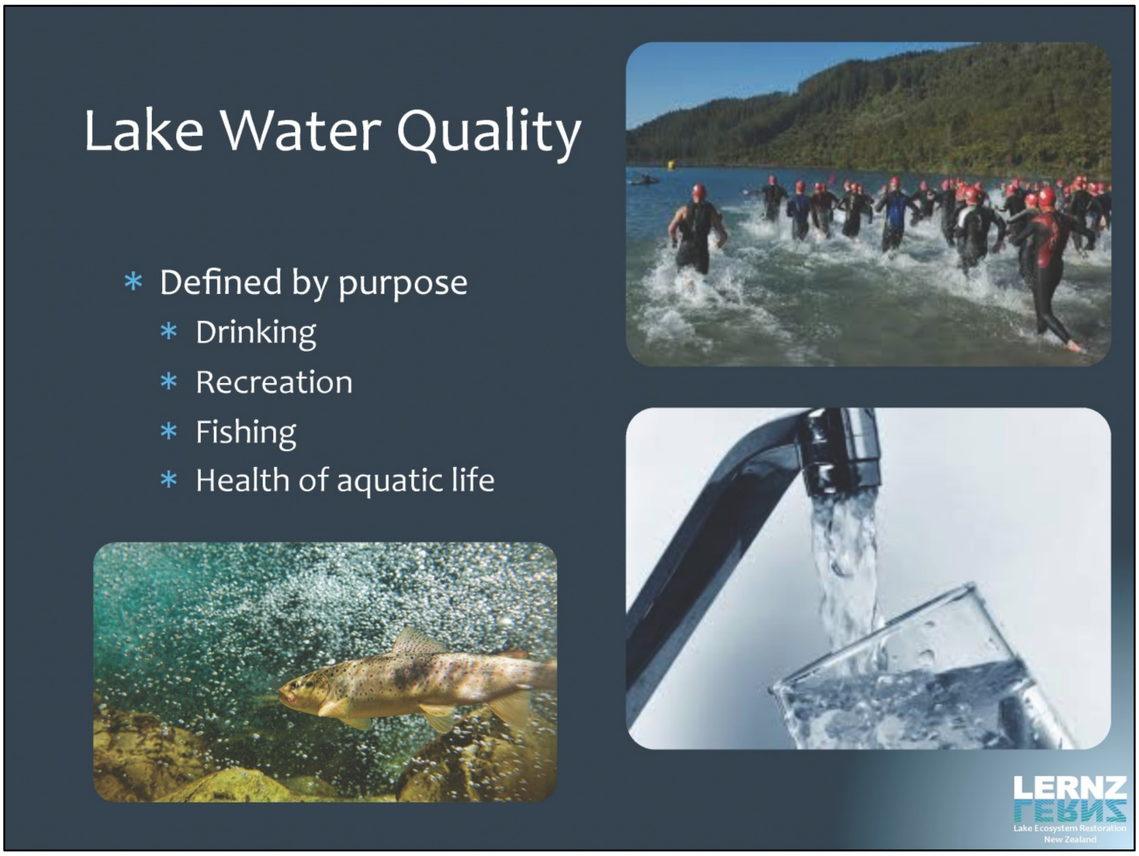
Spatial perspectives
- Catchment or Sub-catchment ↔ Reach
- River or Stream ↔ Aquifer

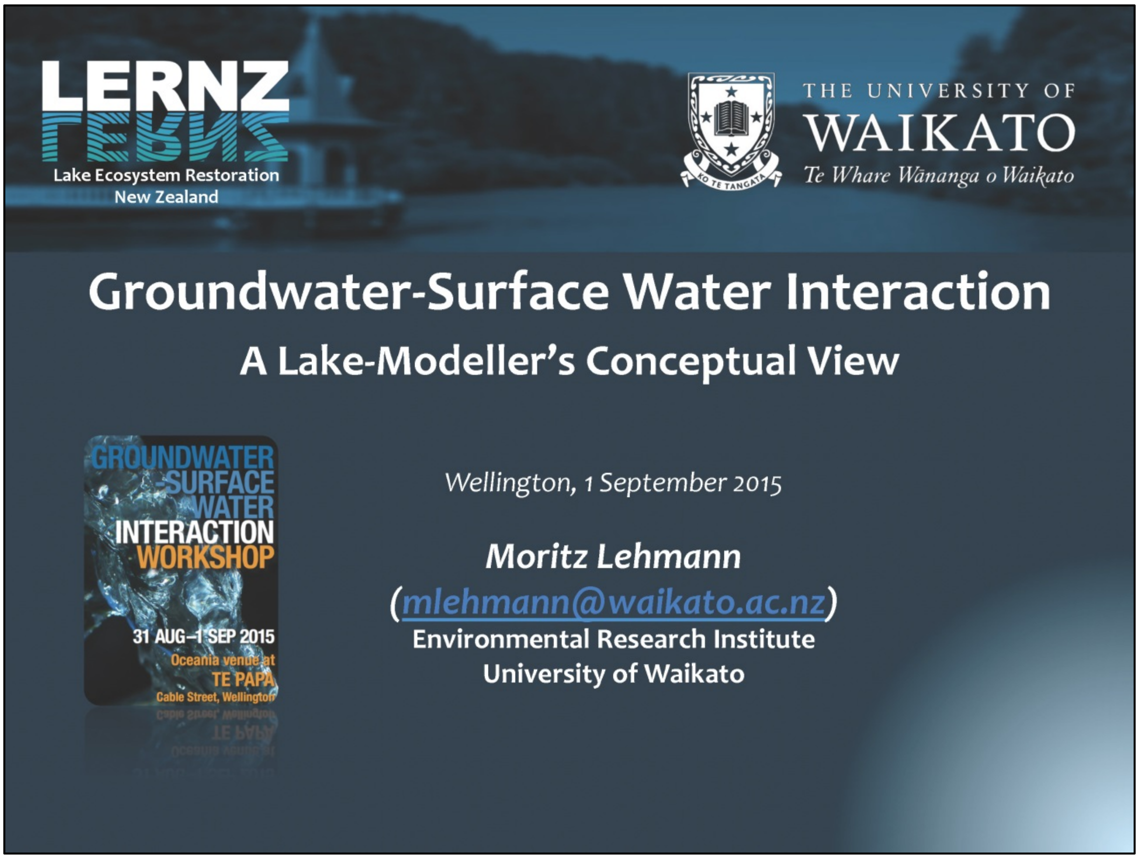
Temporal Perspectives
- Steady state (long term annual average)
- Transient (seasonal, monthly, daily daily)
- Event by event (continuous)

Resolution errors
- Streams are dynamic → choice of mass balance resolution generates error
- Antecedent conditions (groundwater and instream)
- Magnitude ↔ Event frequency (accrual of "baseflow")
- Time lags (vary with flow, rapid recession rates)
- Pragmatism → data availability and measurement error considerations (gauging error of ±8% → ±80 l/s potential error per cumec)

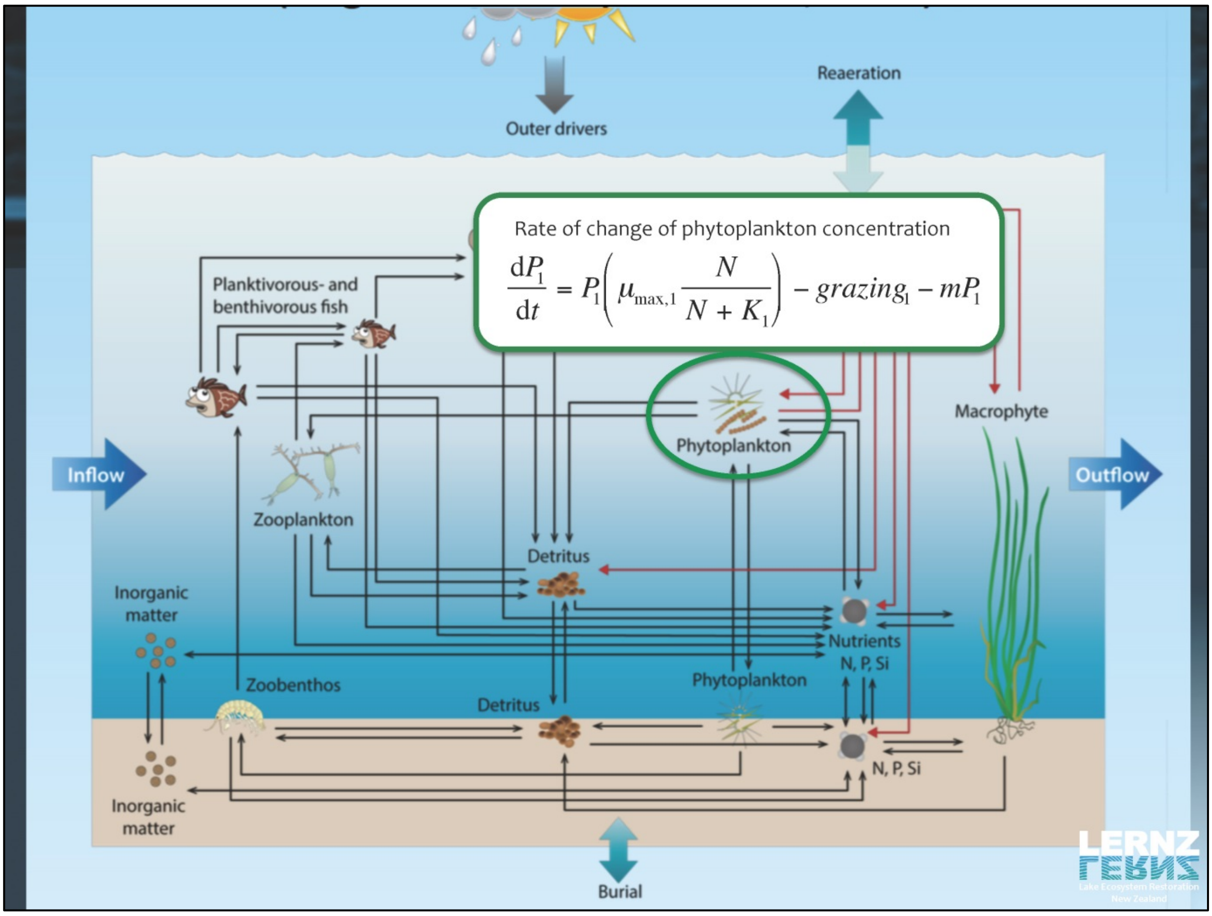
MEASURE. MODEL. MANAGE.

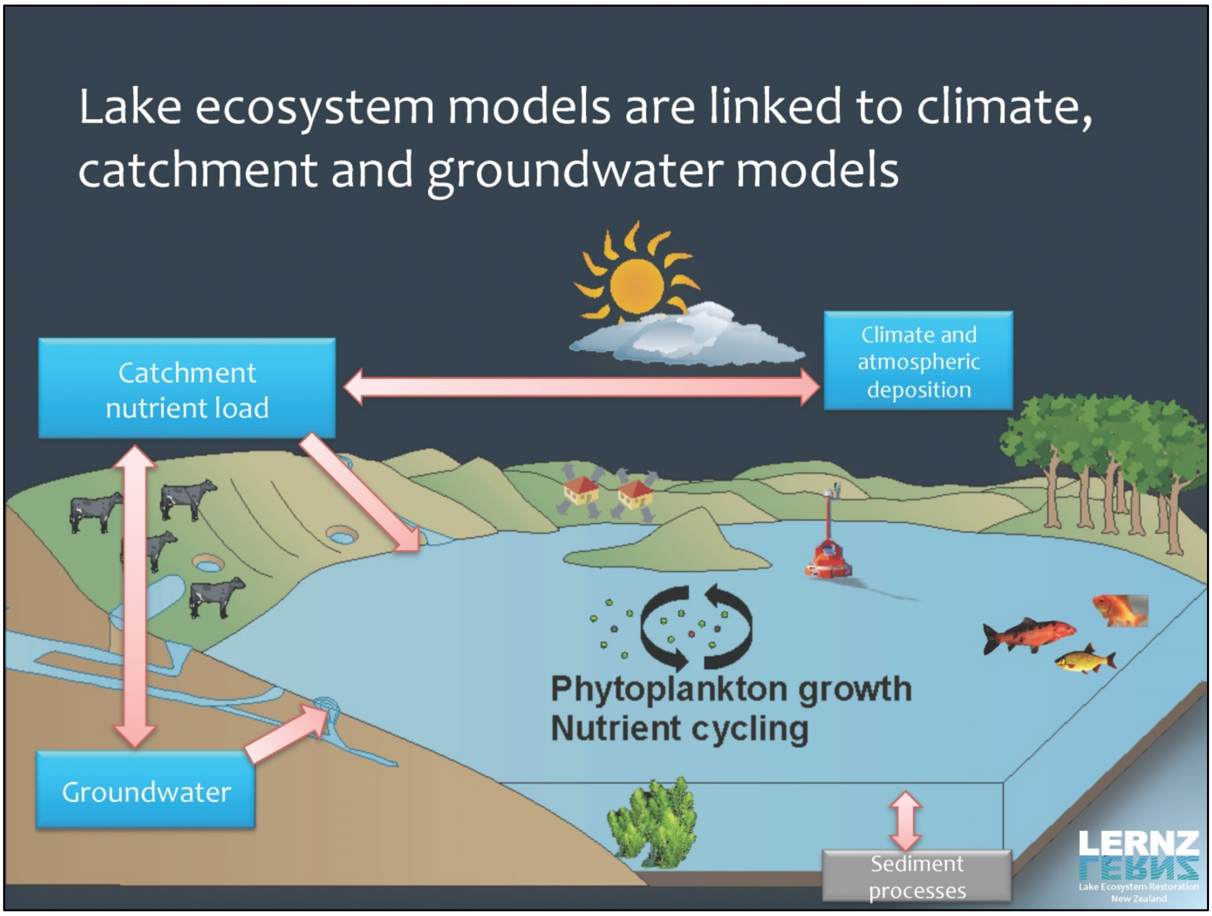
4.2.3 Groundwater and water quality of lakes and estuaries
Facilitator: Moritz Lehmann, University of Waikato

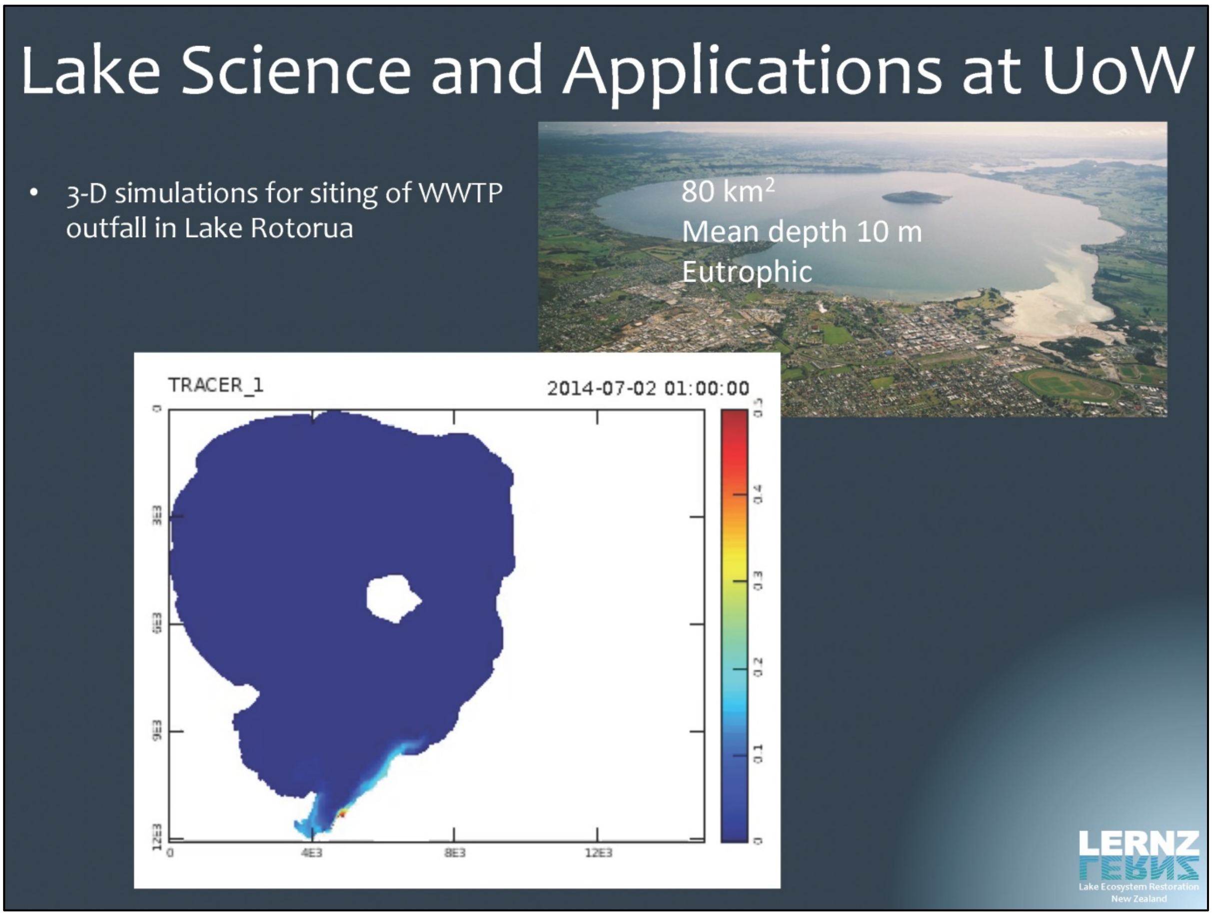


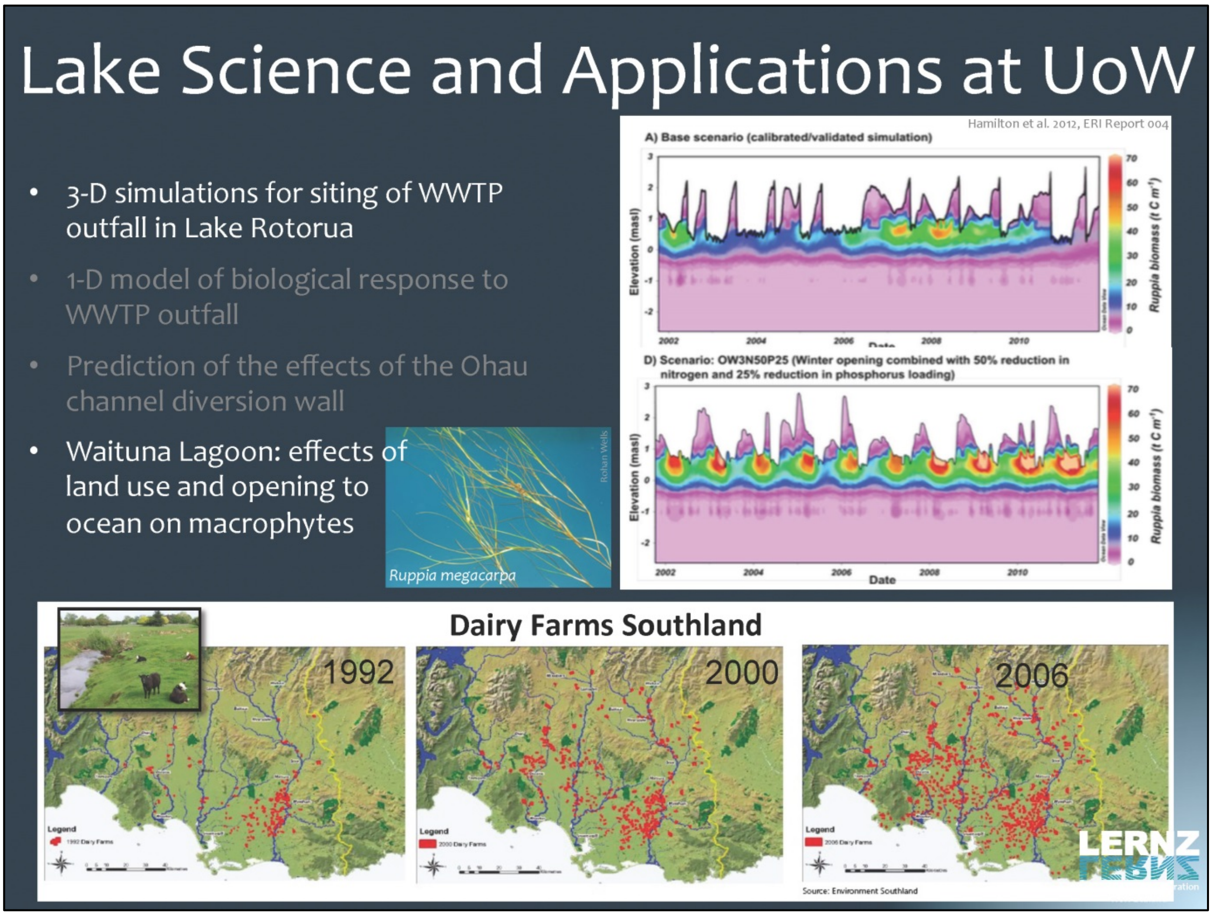



Poor Water Quality
Chain of cells from the cyanobacterium Anabaena, showing a heterocyte.
Image courtesy of Wendy Paul.
Algae blooms
Allergic reactions, asthma, eye irritations, rashes, gastrointestinal disorders
Can cause oxygen depletion of the bottom waters.
Livestock and animal poisoning
(image courtesy of Environment Bay of Plenty)
(John Clayton, NIWA)
LERNZ
Lake Ecosystem Restoration New Zealand

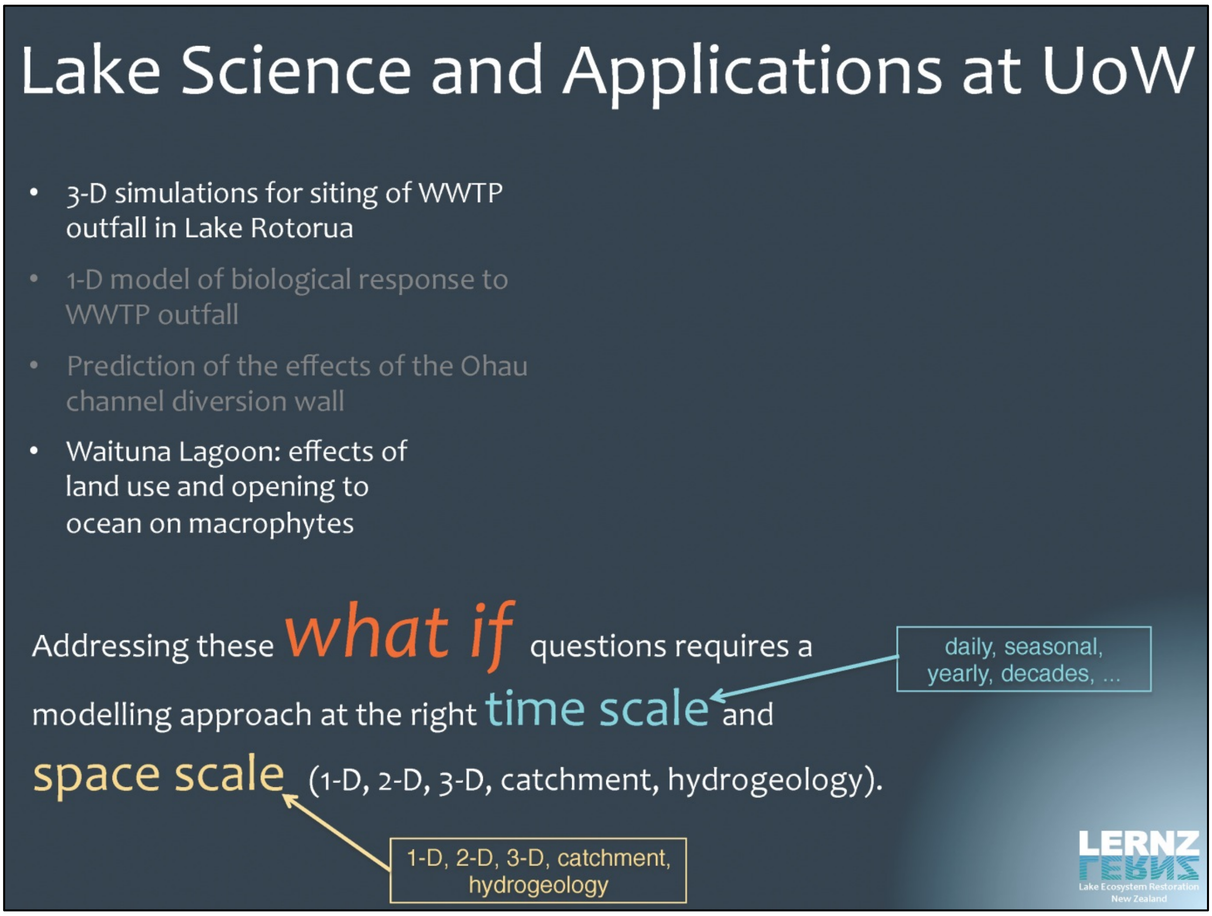

Outer drivers
Reaeration
Rate of change of phytoplankton concentration
$\frac{dP_1}{dt} = P_1\left(\mu_{max,1}\frac{N}{N+K_1}\right) - grazing_1 - mP_1$
Planktivorous- and benthivorous fish
Phytoplankton
Macrophyte
Inflow
Outflow
Zooplankton
Detritus
Inorganic matter
Nutrients N, P, Si
Zoobenthos
Phytoplankton
Detritus
N, P, Si
Inorganic matter
Burial
LERNZ


Lake ecosystem models are linked to climate, catchment and groundwater models
Catchment nutrient load
Climate and atmospheric deposition
Phytoplankton growth
Nutrient cycling
Groundwater
Sediment processes
LERNZ
Lake Ecosystem Restoration New Zealand


Lake Science and Applications at UoW
• 3-D simulations for siting of WWTP outfall in Lake Rotorua
80 km²
Mean depth 10 m
Eutrophic
TRACER_1
2014-07-02 01:00:00
0
4E3
8E3
12E3
LERNZ
Lake Ecosystem Restoration New Zealand



Lake Science and Applications at UoW
• 3-D simulations for siting of WWTP outfall in Lake Rotorua
• 1-D model of biological response to WWTP outfall
• Prediction of the effects of the Ohau channel diversion wall
• Waituna Lagoon: effects of land use and opening to ocean on macrophytes
Ruppia megacarpa
Hamilton et al. 2012, ERI Report 004
A) Base scenario (calibrated/validated simulation)
Elevation (masl)
Ruppia biomass (t C m⁻³)
D) Scenario: OW3N50P25 (Winter opening combined with 50% reduction in nitrogen and 25% reduction in phosphorus loading)
Date
2002
2004
2006
2008
2010
Dairy Farms Southland
1992
2000
2006
Legend
Source: Environment Southland
LERNZ



Lake Science and Applications at UoW
• 3-D simulations for siting of WWTP outfall in Lake Rotorua
• 1-D model of biological response to WWTP outfall
• Prediction of the effects of the Ohau channel diversion wall
• Waituna Lagoon: effects of land use and opening to ocean on macrophytes
Addressing these what if questions requires a modelling approach at the right time scale and space scale (1-D, 2-D, 3-D, catchment, hydrogeology).
daily, seasonal, yearly, decades, ...
1-D, 2-D, 3-D, catchment, hydrogeology
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Lake Science and Applications at UoW

	Days	Seasons	Years	Decades	Centuries
• 3-D simulations for siting of WWTP outfall in Lake Rotorua	X	X			
• 1-D model of biological response to WWTP outfall		X	X		
• Prediction of the effects of the Ohau channel diversion wall		X	X	X	
• Waituna Lagoon: effects of land use and opening to ocean on macrophytes			X	X	X

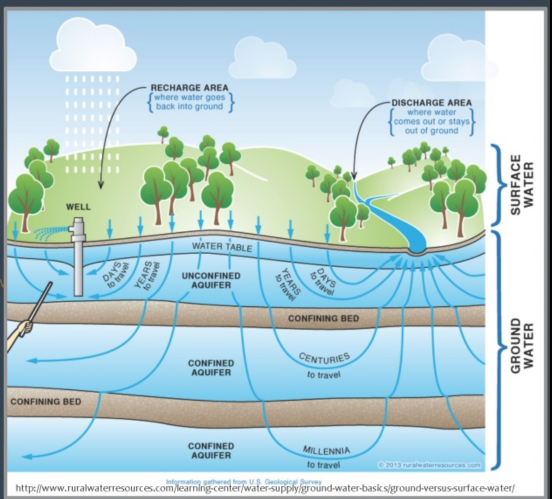
Addressing these *what if* questions requires a modelling approach at the right time scale and space scale (1-D, 2-D, 3-D, catchment, hydrogeology).

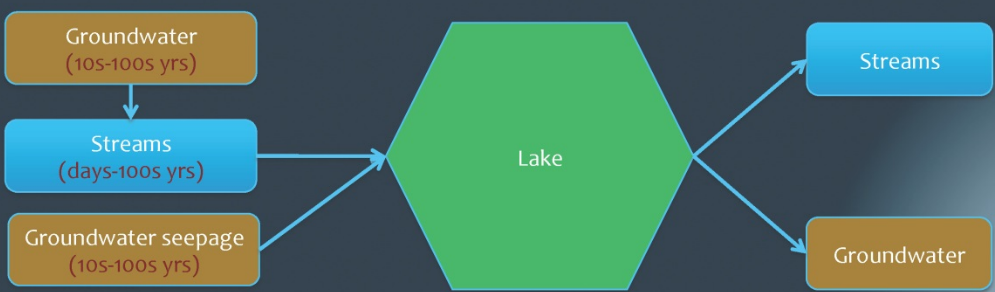
daily, seasonal, yearly, decades, ...

1-D, 2-D, 3-D, catchment, hydrogeology

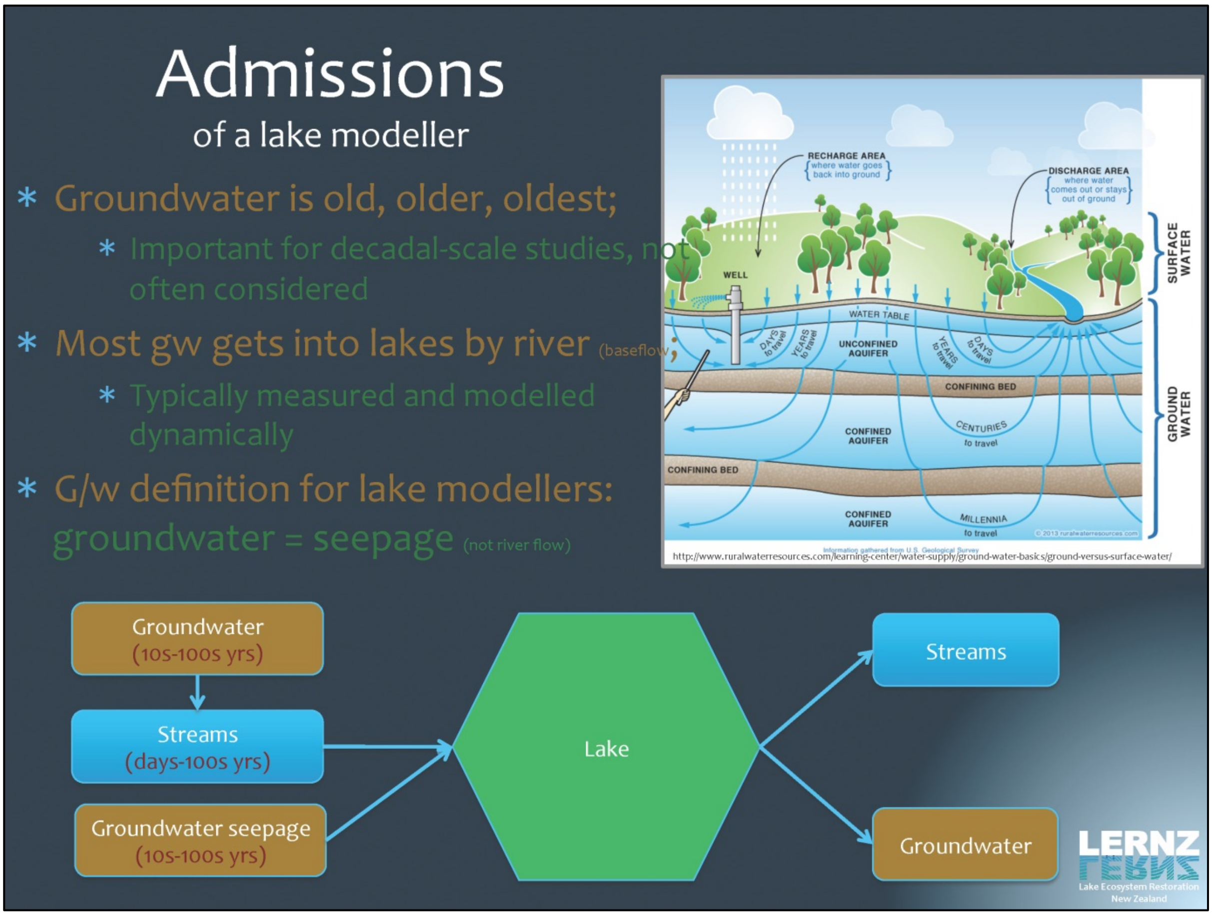
LERNZ Lake Ecosystem Restoration New Zealand

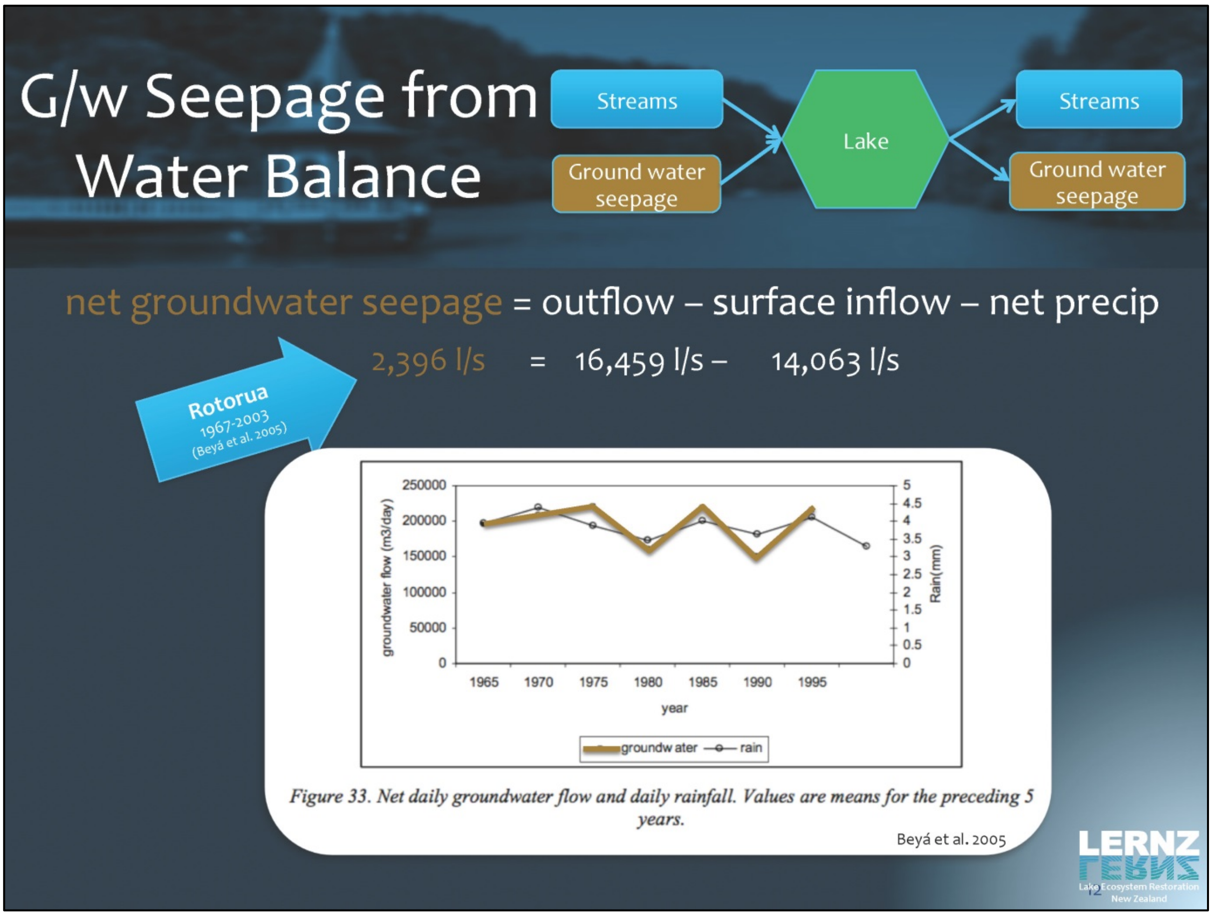
* Groundwater is old, older, oldest;
* Most gw gets into lakes by river (baseflow)
* G/w definition for lake modellers: groundwater = seepage (not river flow)

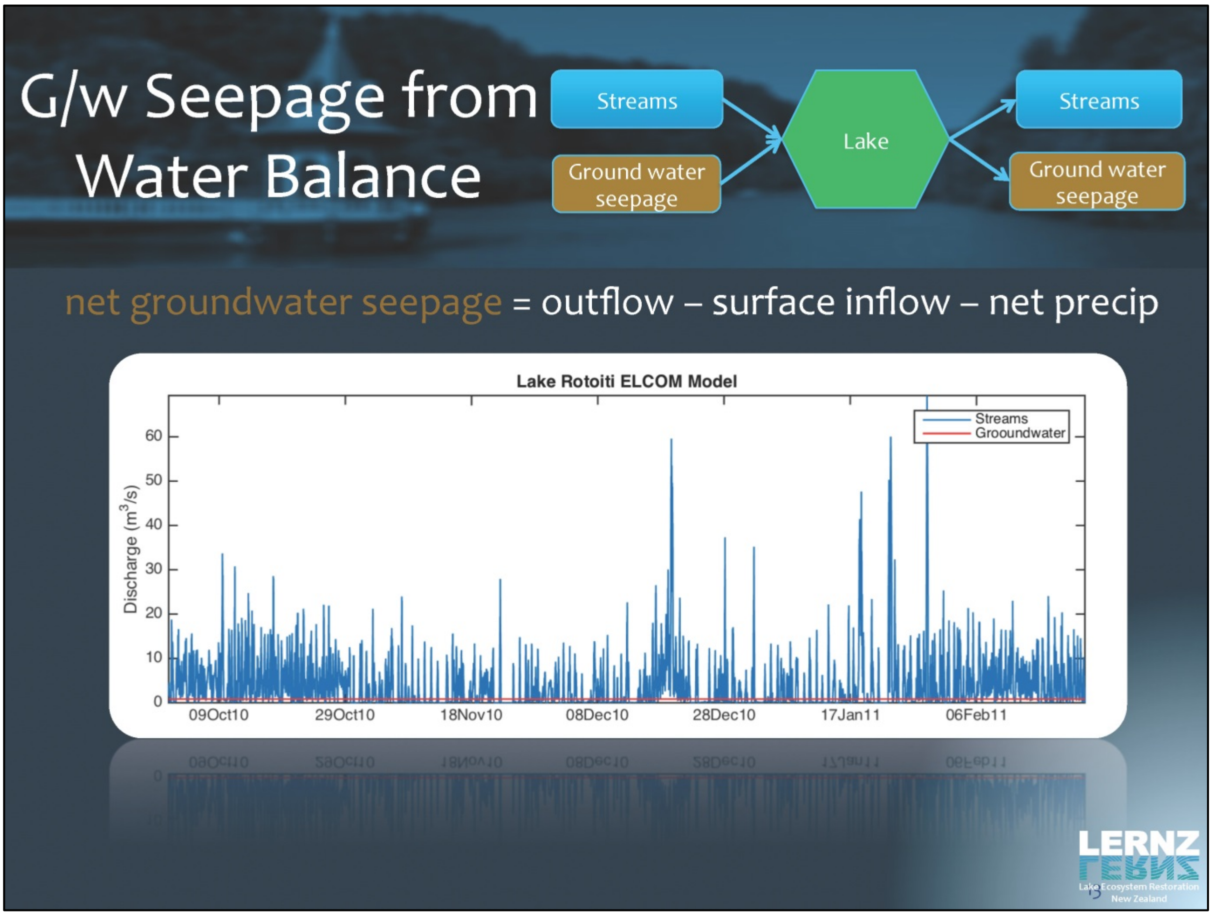


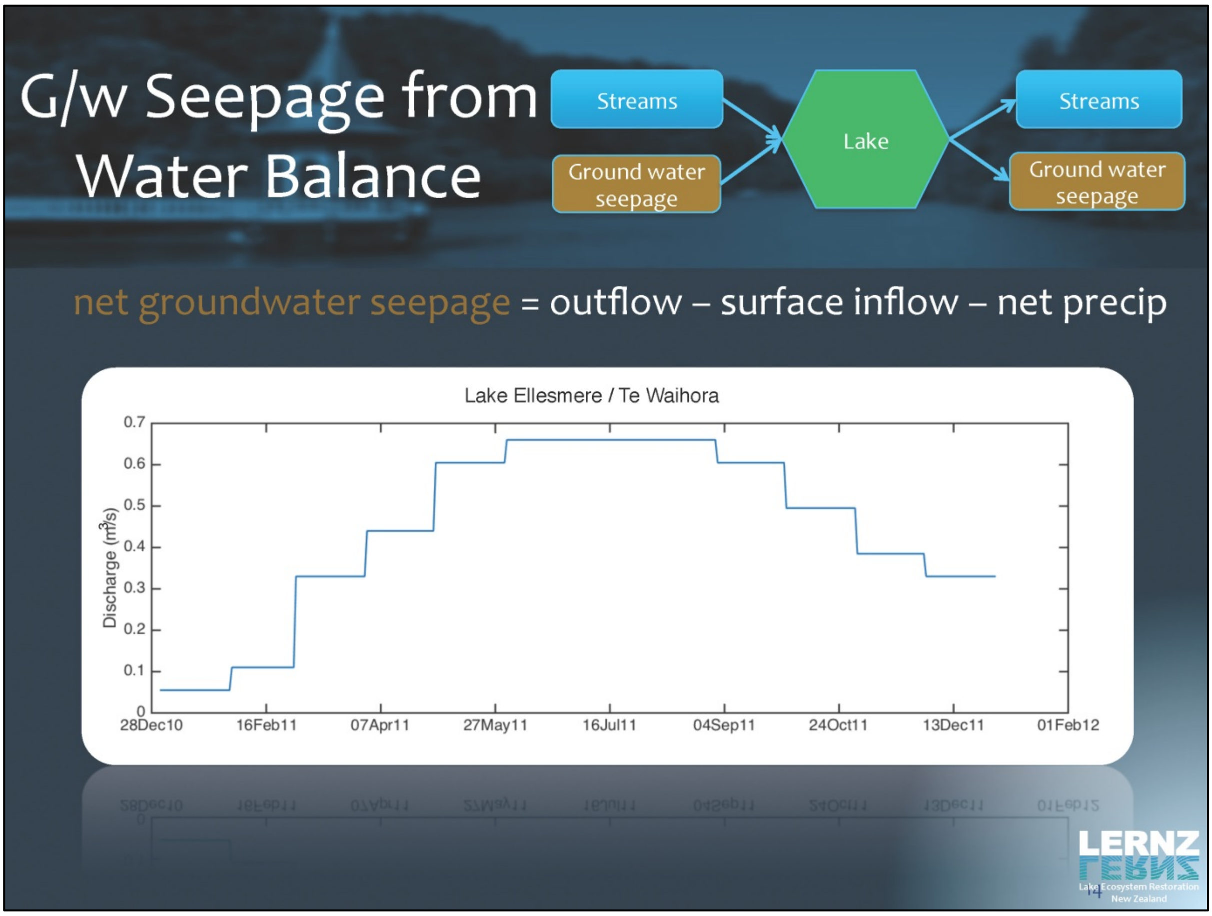


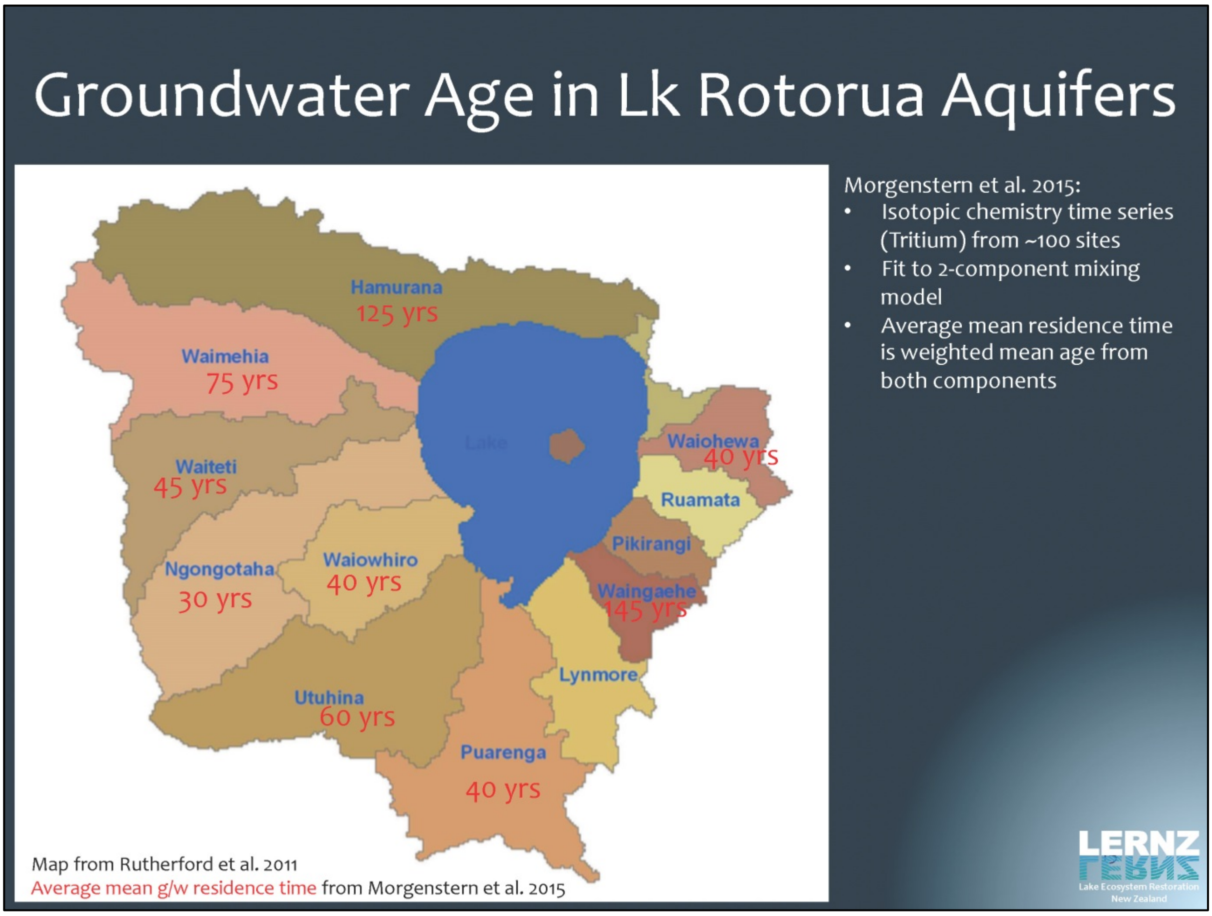
LERNZ Lake Ecosystem Restoration New Zealand


Admissions
of a lake modeller
* Groundwater is old, older, oldest;
* Important for decadal-scale studies, not often considered
* Most gw gets into lakes by river (baseflow);
* Typically measured and modelled dynamically
* G/w definition for lake modellers:
groundwater = seepage (not river flow)
RECHARGE AREA
where water goes back into ground
DISCHARGE AREA
where water comes out or stays out of ground
WELL
WATER TABLE
UNCONFINED AQUIFER
CONFINING BED
CONFINED AQUIFER
CENTURIES to travel
MILLENNIA to travel
SURFACE WATER
GROUND WATER
http://www.ruralwaterresources.com/learning-center/water-supply/ground-water-basics/ground-water-versus-surface-water/
Groundwater
(10s-100s yrs)
Streams
(days-100s yrs)
Groundwater seepage
(10s-100s yrs)
Lake
Streams
Groundwater
LERNZ
Lake Ecosystem Restoration New Zealand


G/w Seepage from Water Balance
Streams
Ground water seepage
Lake
Streams
Ground water seepage
net groundwater seepage = outflow – surface inflow – net precip
2,396 l/s = 16,459 l/s – 14,063 l/s
Rotorua
1967-2003
(Beyá et al. 2005)
groundwater flow (m3/day)
Rain(mm)
year
groundwater
rain
Figure 33. Net daily groundwater flow and daily rainfall. Values are means for the preceding 5 years.
Beyá et al. 2005
LERNZ
Lake Ecosystem Restoration New Zealand


G/w Seepage from Water Balance
Streams
Ground water seepage
Lake
Streams
Ground water seepage
net groundwater seepage = outflow – surface inflow – net precip
Lake Rotoiti ELCOM Model
Streams
Groondwater
Discharge (m³/s)
09Oct10
29Oct10
18Nov10
08Dec10
28Dec10
17Jan11
06Feb11
LERNZ
Lake Ecosystem Restoration New Zealand


G/w Seepage from Water Balance
Streams
Ground water seepage
Lake
Streams
Ground water seepage
net groundwater seepage = outflow – surface inflow – net precip
Lake Ellesmere / Te Waihora
Discharge (m³/s)
28Dec10
16Feb11
07Apr11
27May11
16Jul11
04Sep11
24Oct11
13Dec11
01Feb12
LERNZ
Lake Ecosystem Restoration New Zealand



Groundwater Age in Lk Rotorua Aquifers
Morgenstern et al. 2015:
• Isotopic chemistry time series (Tritium) from ~100 sites
• Fit to 2-component mixing model
• Average mean residence time is weighted mean age from both components
Hamurana 125 yrs
Waimehia 75 yrs
Waiteti 45 yrs
Ngongotaha 30 yrs
Waiowhiro 40 yrs
Utuhina 60 yrs
Puarenga 40 yrs
Lynmore
Waingaehe 145 yrs
Pikirangi
Ruamata
Waiohewa 40 yrs
Map from Rutherford et al. 2011
Average mean g/w residence time from Morgenstern et al. 2015
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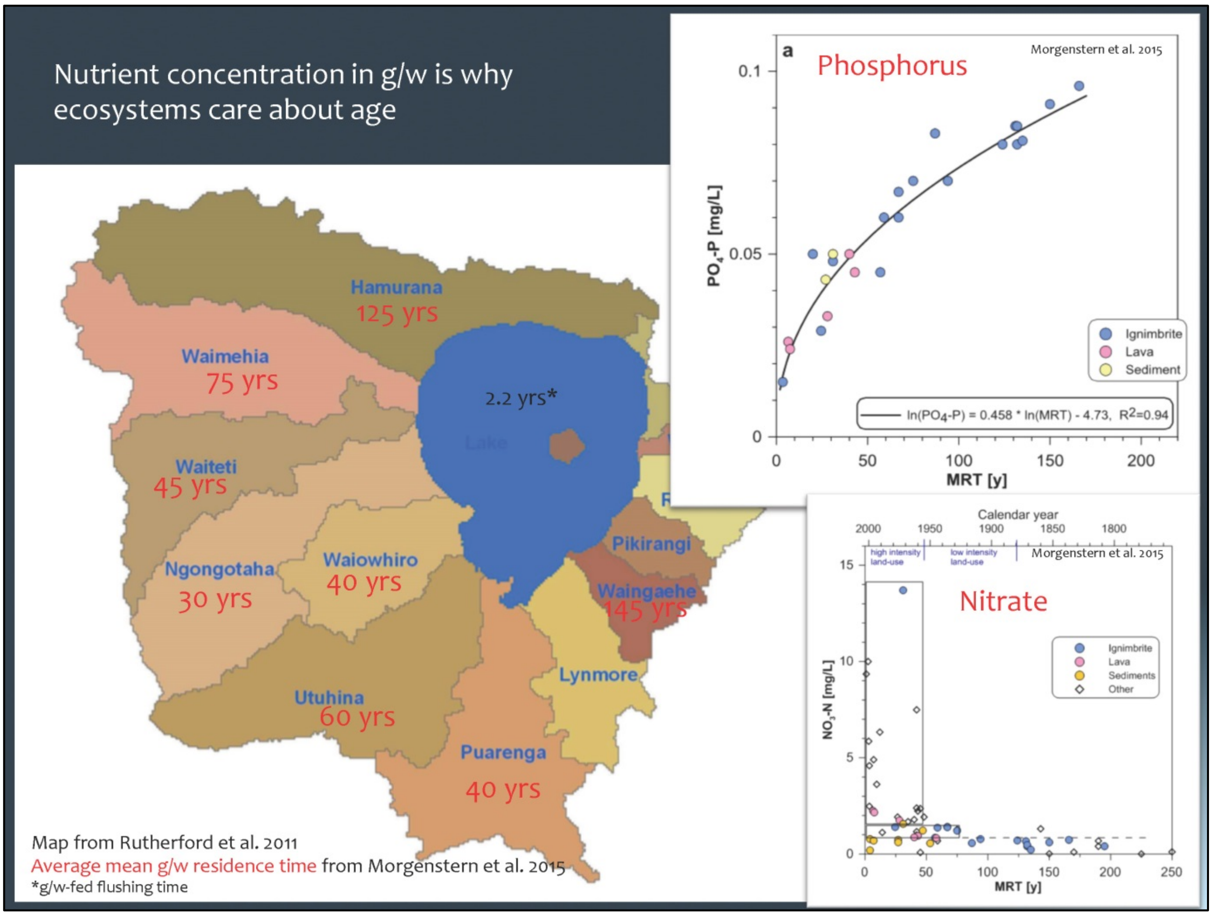
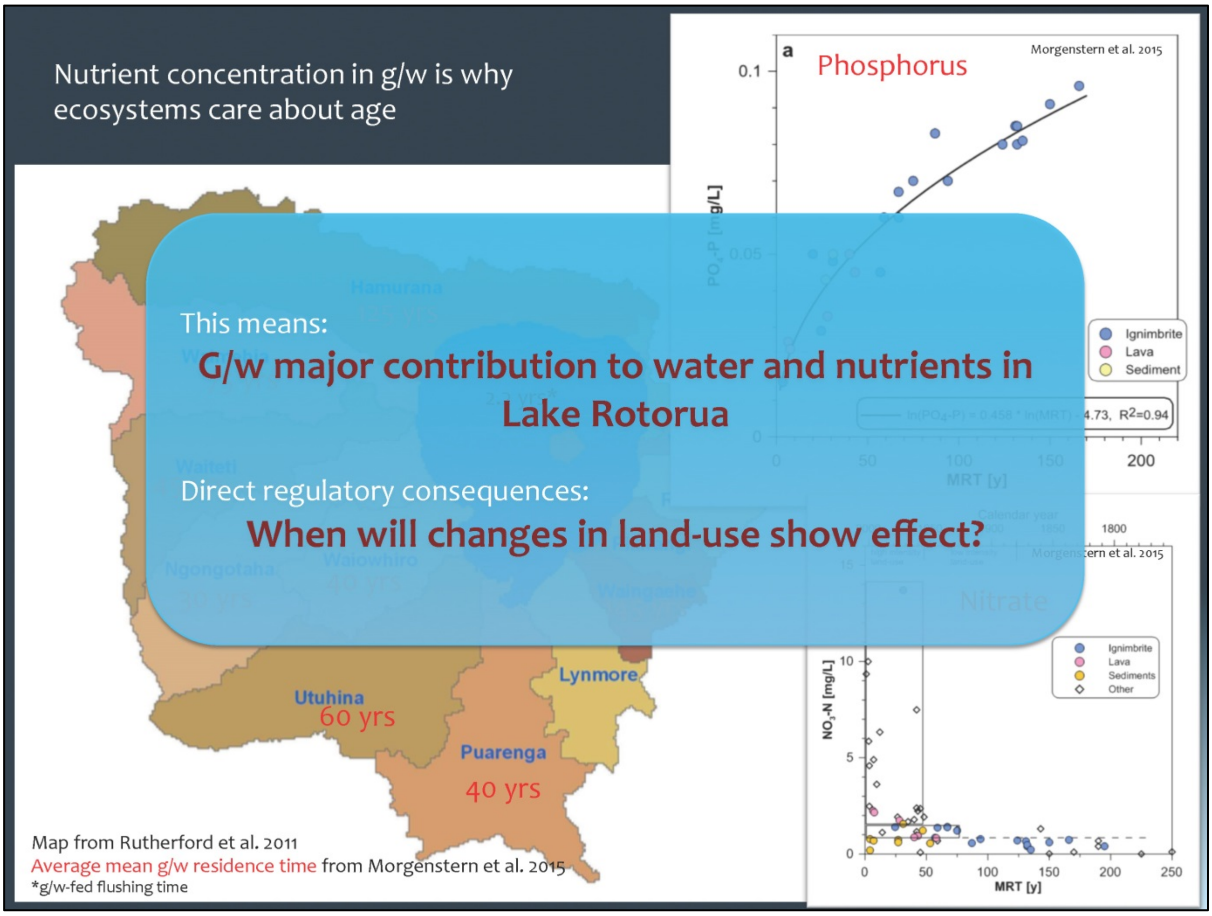
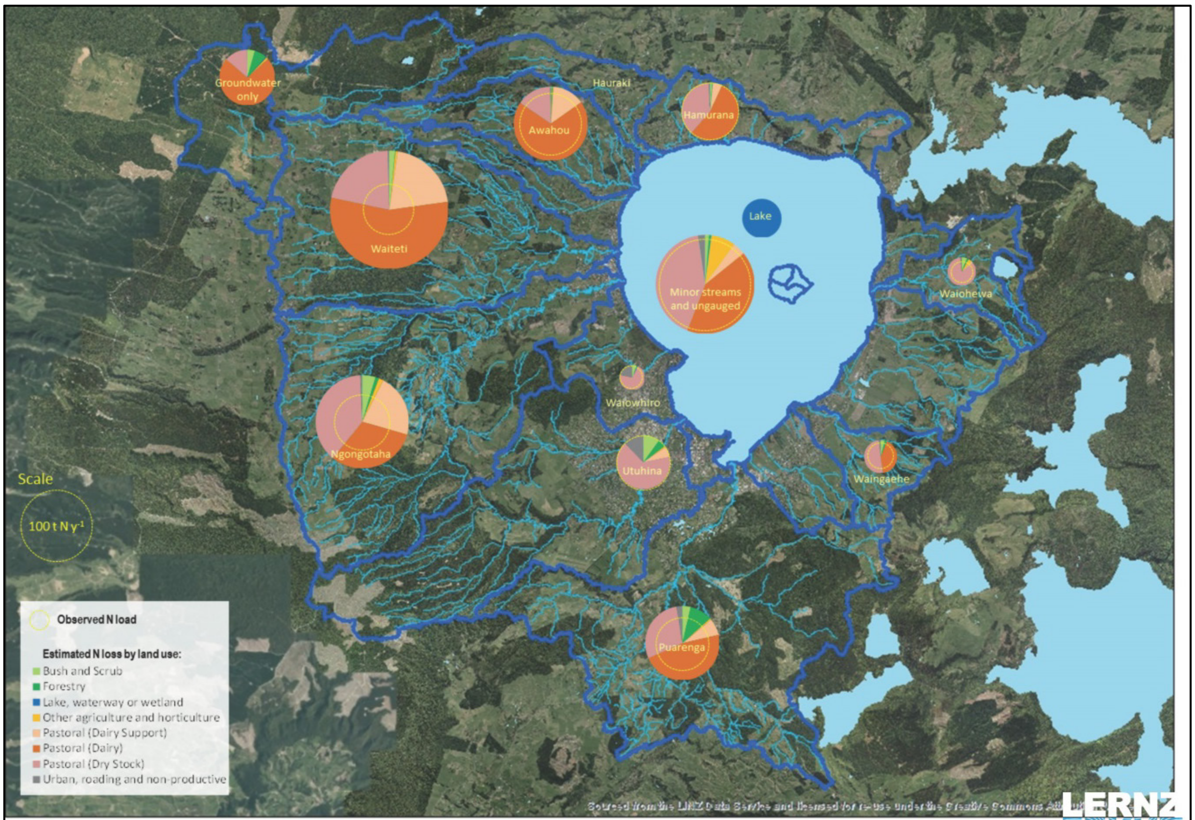
Lake Ecosystem Restoration New Zealand

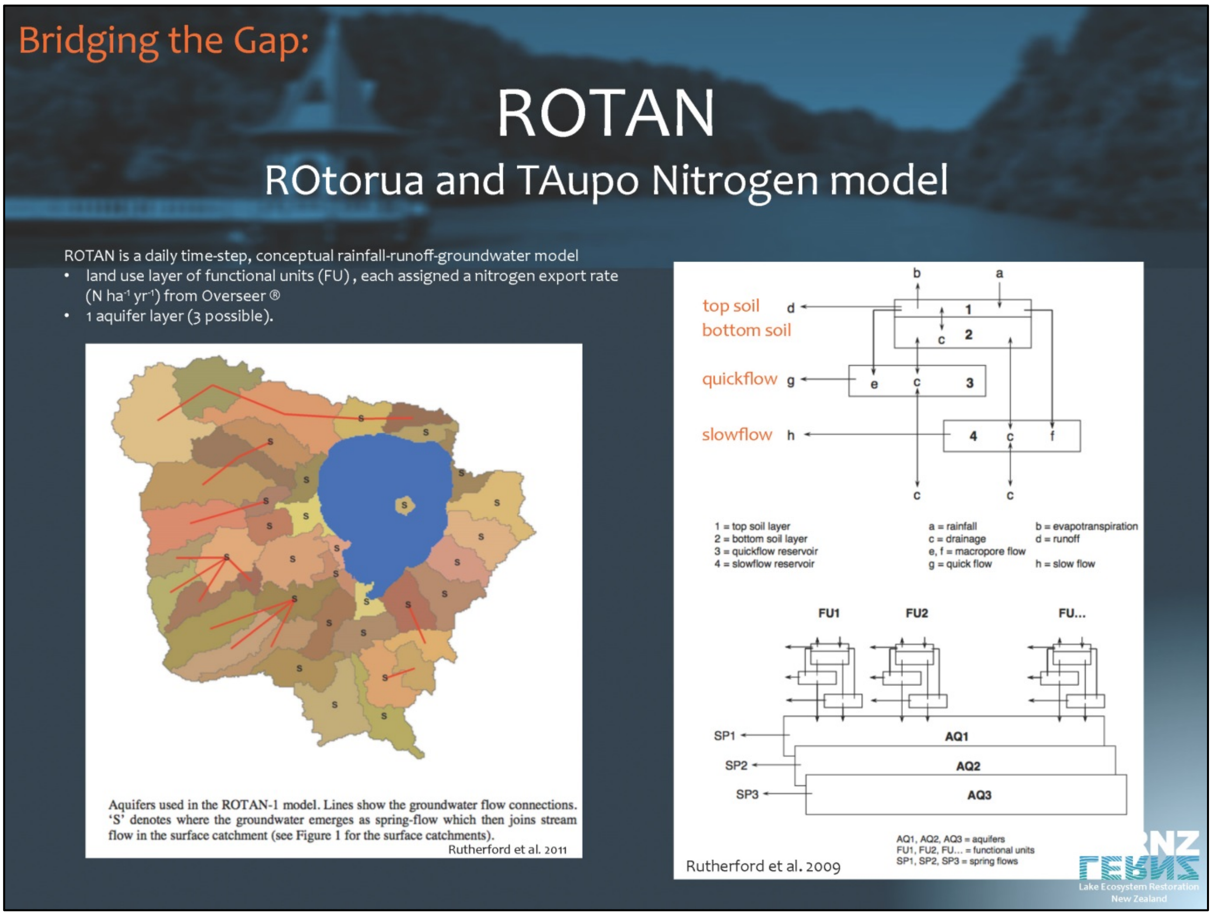


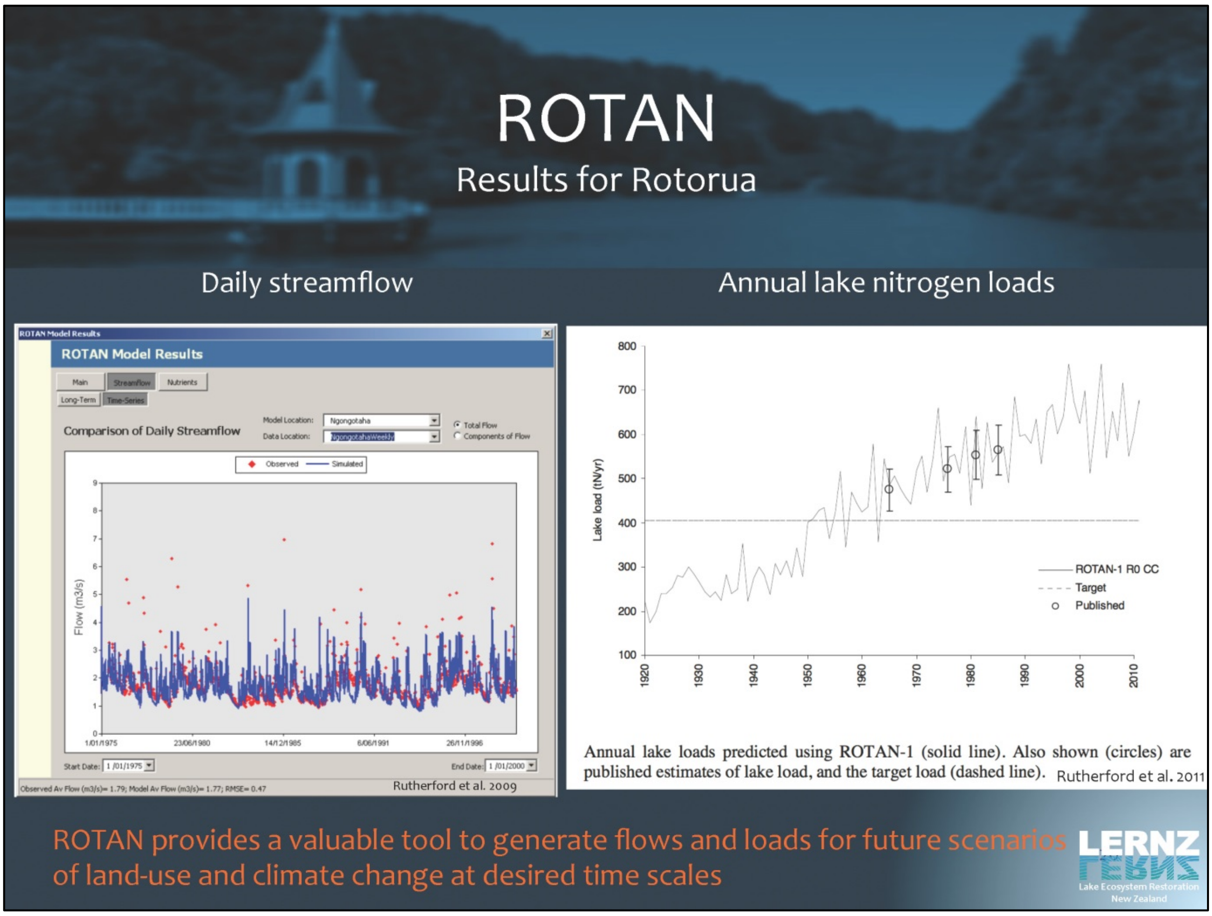
Nutrient concentration in g/w is why ecosystems care about age
Hamurana 125 yrs
Waimehia 75 yrs
Waiteti 45 yrs
Ngongotaha 30 yrs
Waiowhiro 40 yrs
Utuhina 60 yrs
Puarenga 40 yrs
Lynmore
Waingaehe 145 yrs
Pikirangi
2.2 yrs*
Map from Rutherford et al. 2011
Average mean g/w residence time from Morgenstern et al. 2015
*g/w-fed flushing time
a
Phosphorus
Morgenstern et al. 2015
PO4-P [mg/L]
MRT [y]
Ignimbrite
Lava
Sediment
ln(PO4-P) = 0.458 * ln(MRT) - 4.73, R2=0.94
Nitrate
Calendar year
high intensity land-use
low intensity land-use
NO3-N [mg/L]
Ignimbrite
Lava
Sediments
Other





McBride CG, MacCormick A, and Hamilton DP (*in prep*). Catchment and subcatchment nitrogen loads to Lake Rotorua. ERI report.


Bridging the Gap:
ROTAN
ROtorua and TAupo Nitrogen model
ROTAN is a daily time-step, conceptual rainfall-runoff-groundwater model
• land use layer of functional units (FU), each assigned a nitrogen export rate (N ha-1 yr-1) from Overseer ®
• 1 aquifer layer (3 possible).
Aquifers used in the ROTAN-1 model. Lines show the groundwater flow connections. 'S' denotes where the groundwater emerges as spring-flow which then joins stream flow in the surface catchment (see Figure 1 for the surface catchment).
Rutherford et al. 2011
top soil
bottom soil
quickflow
slowflow
1 = top soil layer
2 = bottom soil layer
3 = quickflow reservoir
4 = slowflow reservoir
a = rainfall
c = drainage
e, f = macropore flow
g = quick flow
b = evapotranspiration
d = runoff
h = slow flow
FU1
FU2
FU...
SP1
SP2
SP3
AQ1
AQ2
AQ3
AQ1, AQ2, AQ3 = aquifers
FU1, FU2, FU... = functional units
SP1, SP2, SP3 = spring flows
Rutherford et al. 2009
Lake Ecosystem Restoration New Zealand


ROTAN
Results for Rotorua
Daily streamflow
Annual lake nitrogen loads
ROTAN Model Results
Comparison of Daily Streamflow
Observed
Simulated
Flow (m3/s)
Rutherford et al. 2009
Lake load (tN/yr)
ROTAN-1 R0 CC
Target
Published
Annual lake loads predicted using ROTAN-1 (solid line). Also shown (circles) are published estimates of lake load, and the target load (dashed line).
Rutherford et al. 2011
ROTAN provides a valuable tool to generate flows and loads for future scenarios of land-use and climate change at desired time scales
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Ongoing GW-SW Studies at THE UNIVERSITY OF WAIKATO Te Whare Wānanga o Waikato

Question:

What is the effect of groundwater discharge on

* water balance,
* nutrient budgets, and
* water quality?

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GW-Nutrient Dynamics Lakes Rotokakahi and Tikitapu

Katie Noakes (M.Sc. Research)

* Both lakes largely gw-fed, but not enough data to know for sure;
* ^{222}Rn survey in lake and surrounding boreholes for water budget; and
* Concurrent nutrient samples to quantify gw nutrient input to lakes.

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Coastal Ocean

The work of Karin Bryan et al.

* Estuaries and mud flats:
  * Highly productive environments; and
  * Cycling of nutrients and organic matter;
* Submarine groundwater discharge (SGD) enhances fluxes

Coastal Ocean

The work of Karin Bryan et al.

* Estuaries and mud flats:
  * Highly productive environments; and
  * Cycling of nutrients and organic matter;
* Submarine groundwater discharge (SGD) enhances fluxes

Santos et al. 2014

- Rn often enriched in g/w or porewater relative to surface water;
- Combined Rn and nutrient budgets suggest that g/w is source for nutrients in mud-flat surface water (Tauranga Harbour)

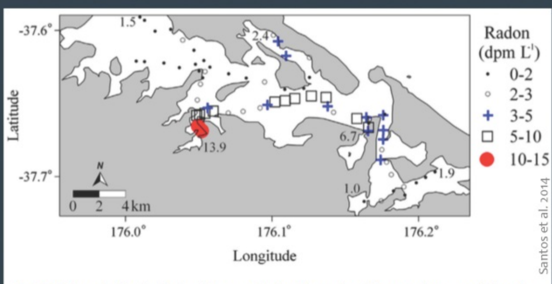
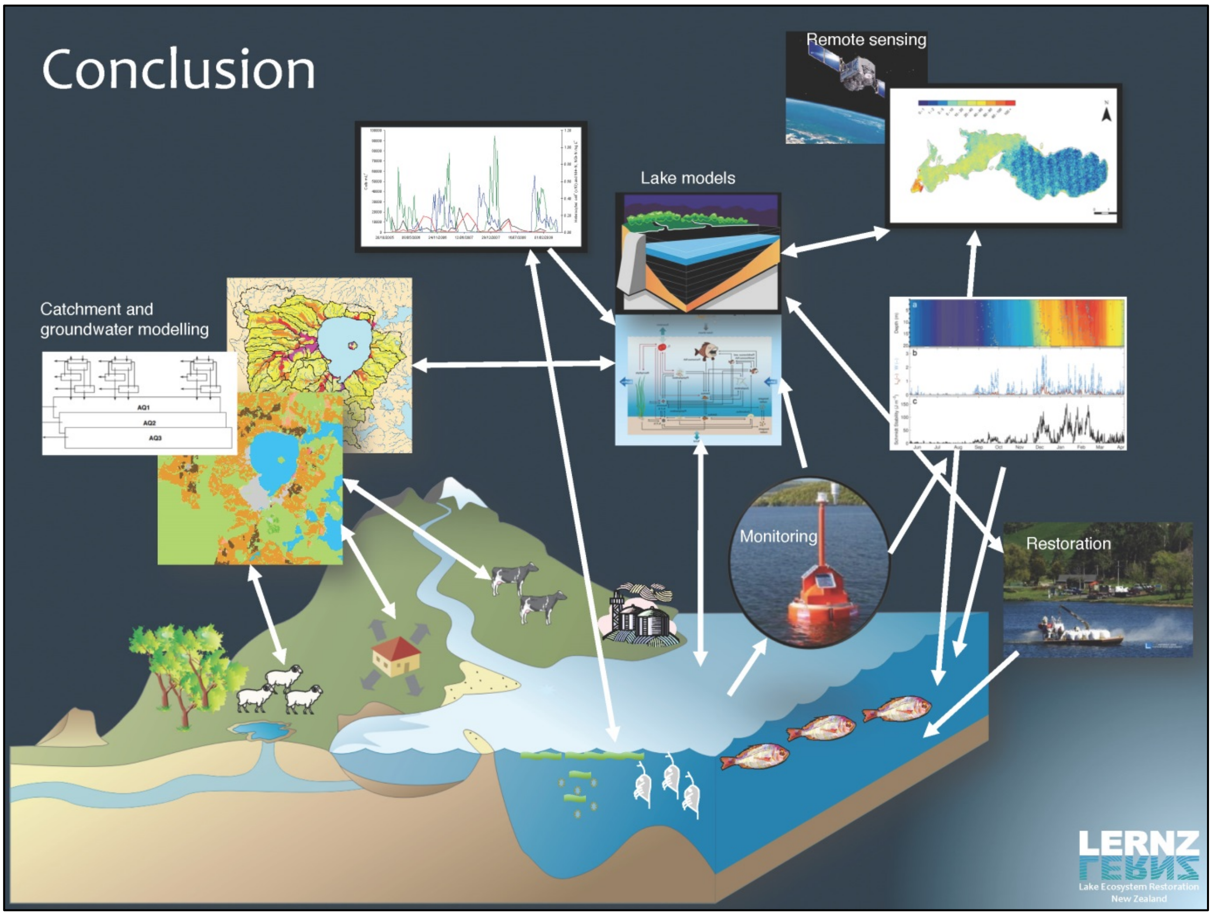


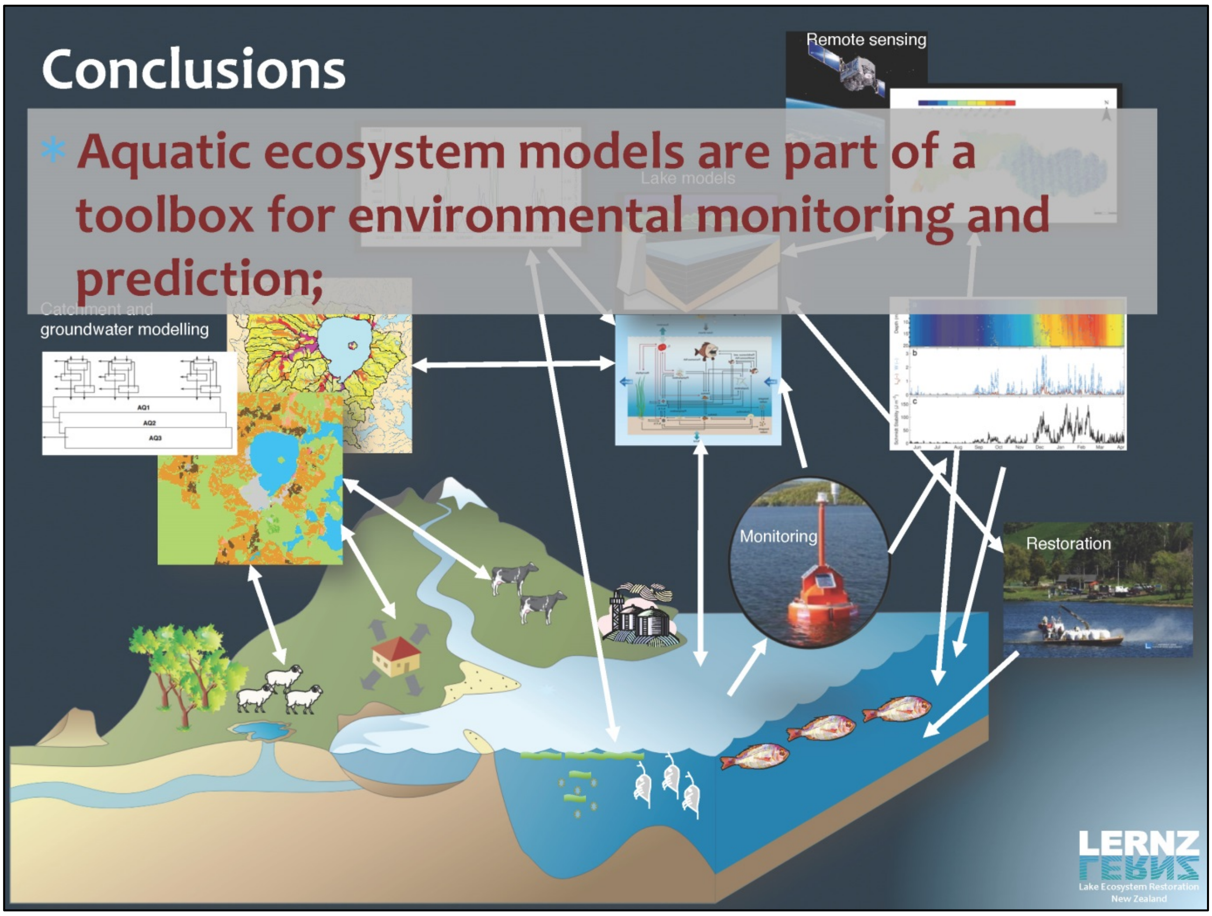
Fig. 3. Salinity and radon distribution in Tauranga Harbor. The numbers illustrate values at specific locations.

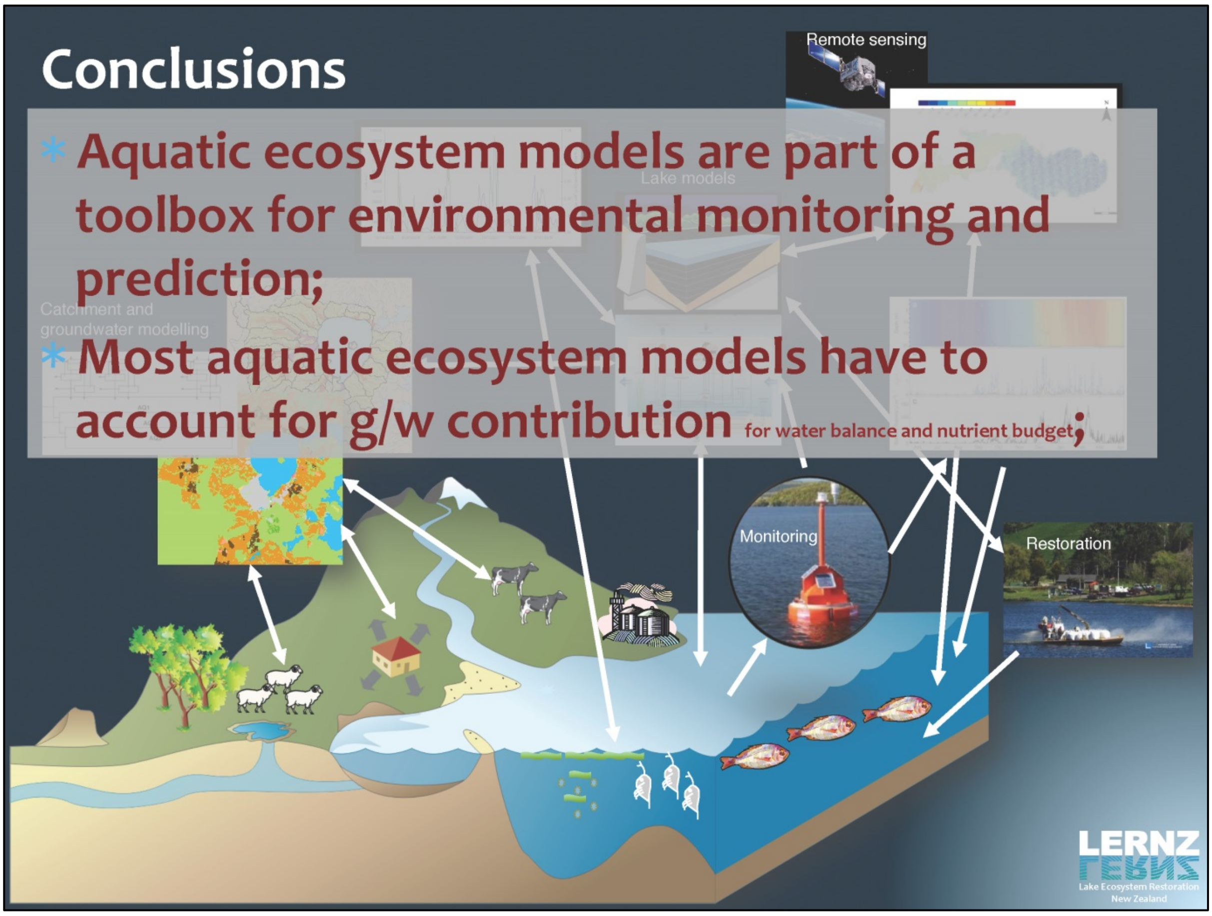
Future Work

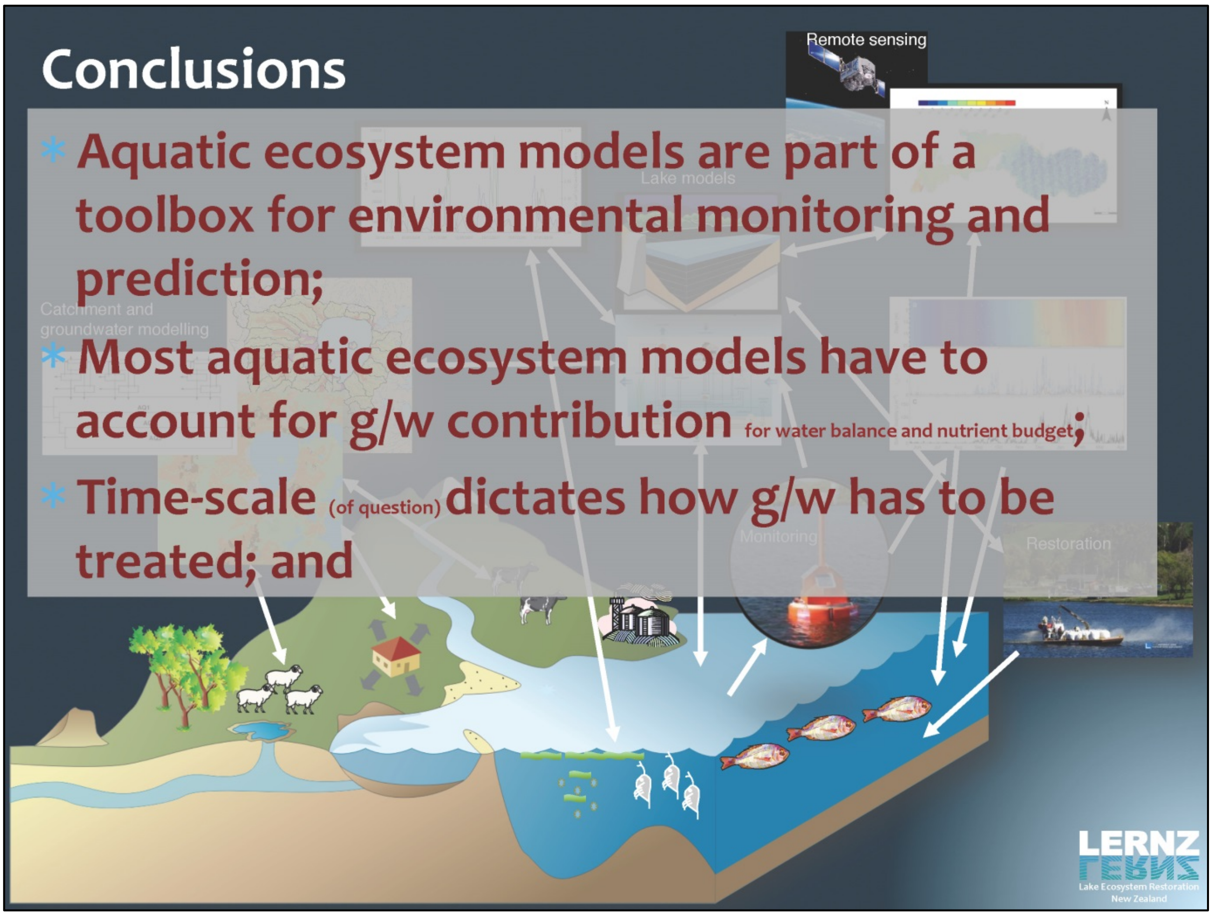
(Ben Stewart's PhD project):

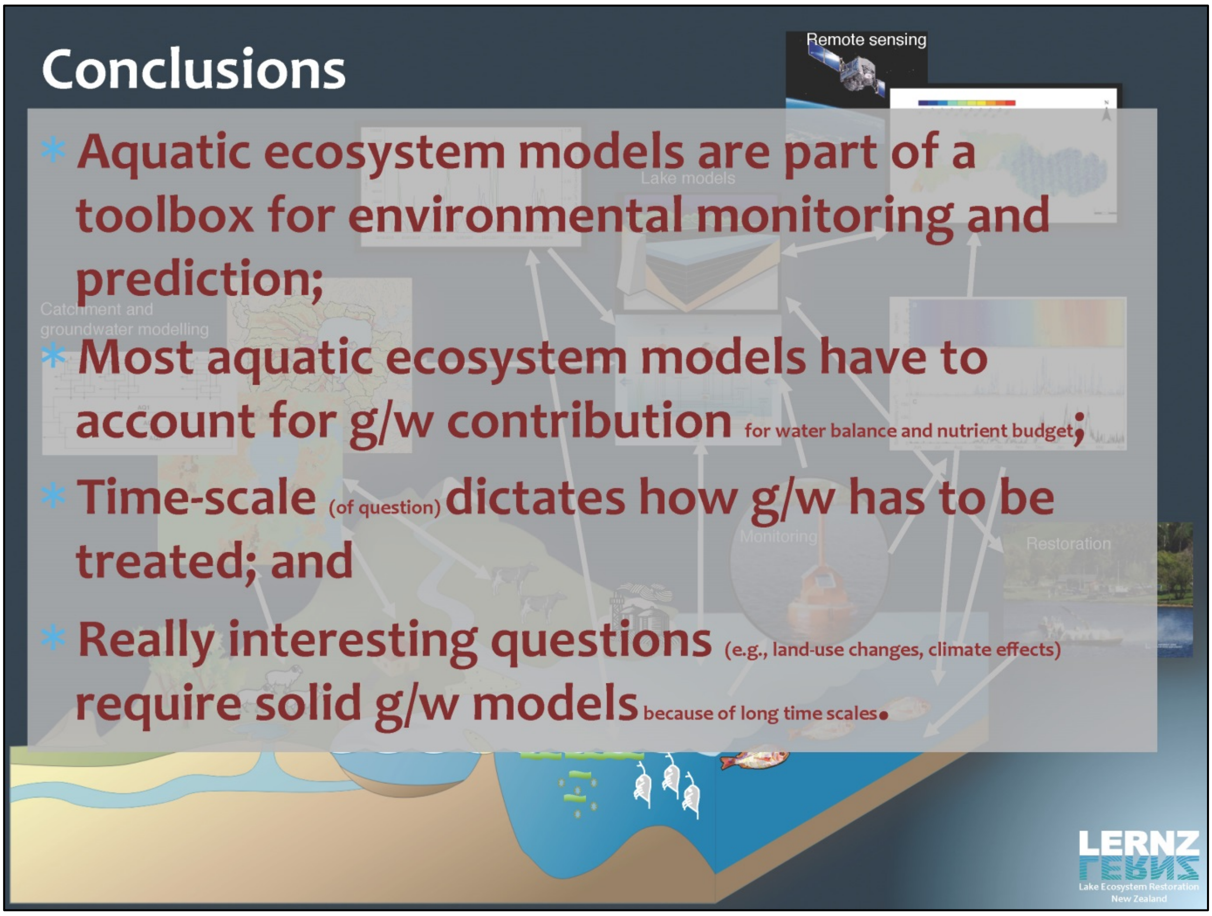
- Use Radium (Ra) as tracer (more isotopes with different λ);
- Spatial survey for g/w hotspots
- Combine with hydrodynamic modelling


Conclusion
Remote sensing
Lake models
Catchment and
groundwater modelling
Monitoring
Restoration
LERNZ
Lake Ecosystem Restoration
New Zealand


Conclusions
Aquatic ecosystem models are part of a toolbox for environmental monitoring and prediction;
Remote sensing
Lake models
Catchment and
groundwater modelling
Monitoring
Restoration
LERNZ
Lake Ecosystem Restoration
New Zealand


Conclusions
Remote sensing
Lake models
Catchment and groundwater modelling
Aquatic ecosystem models are part of a toolbox for environmental monitoring and prediction;
Most aquatic ecosystem models have to account for g/w contribution for water balance and nutrient budget;
Monitoring
Restoration
LERNZ
Lake Ecosystem Restoration New Zealand


Conclusions
Remote sensing
Lake models
Catchment and groundwater modelling
Aquatic ecosystem models are part of a toolbox for environmental monitoring and prediction;
Most aquatic ecosystem models have to account for g/w contribution for water balance and nutrient budget;
Time-scale (of question) dictates how g/w has to be treated; and
Monitoring
Restoration
LERNZ
Lake Ecosystem Restoration New Zealand


Conclusions
Remote sensing
Lake models
Catchment and groundwater modelling
Monitoring
Restoration
* Aquatic ecosystem models are part of a toolbox for environmental monitoring and prediction;
* Most aquatic ecosystem models have to account for g/w contribution for water balance and nutrient budget;
* Time-scale (of question) dictates how g/w has to be treated; and
* Really interesting questions (e.g., land-use changes, climate effects) require solid g/w models because of long time scales.
LERNZ
Lake Ecosystem Restoration New Zealand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Lake Ecosystem Restoration
New Zealand
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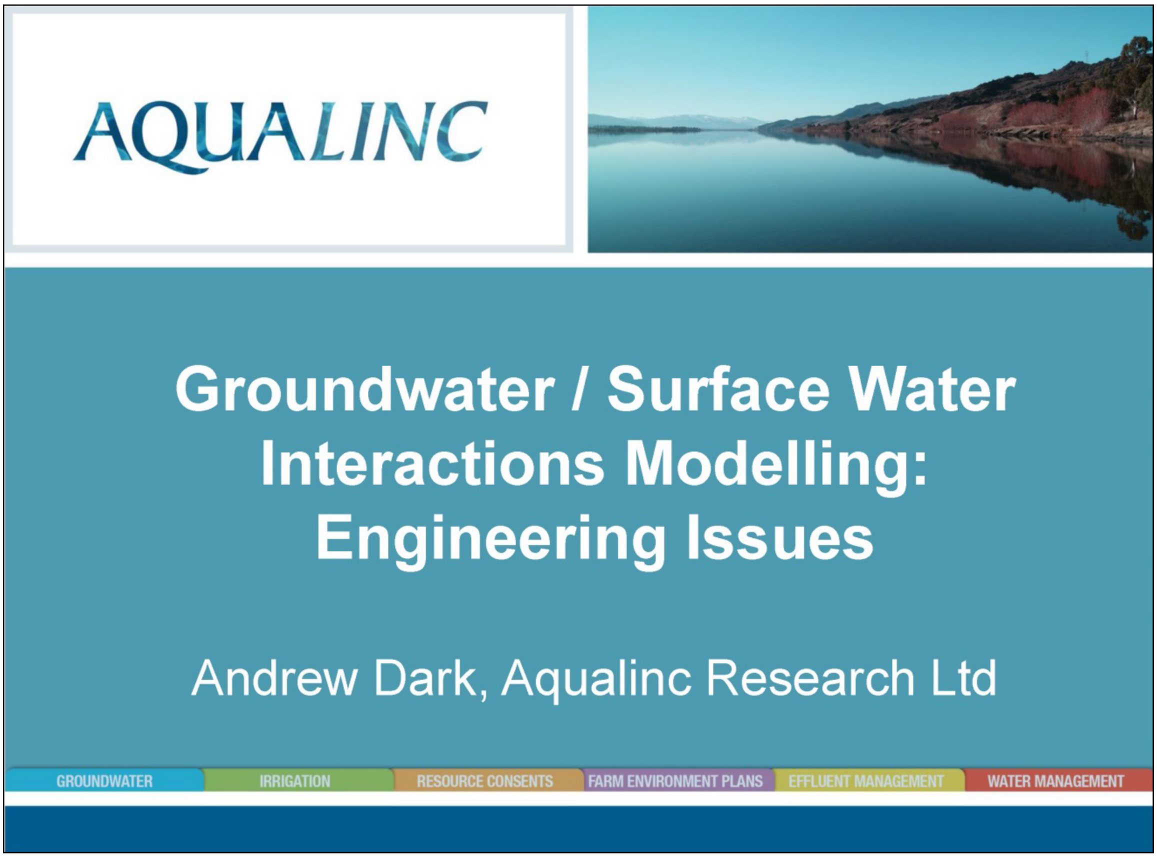
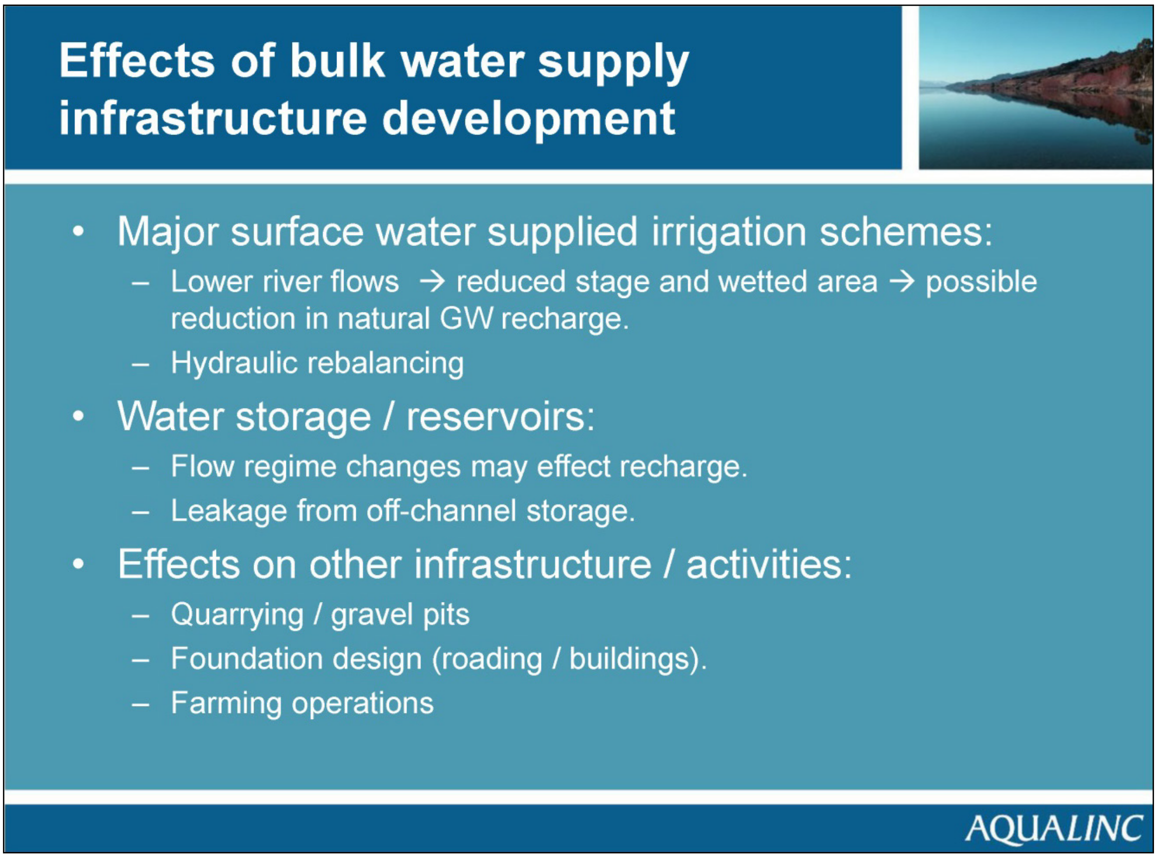
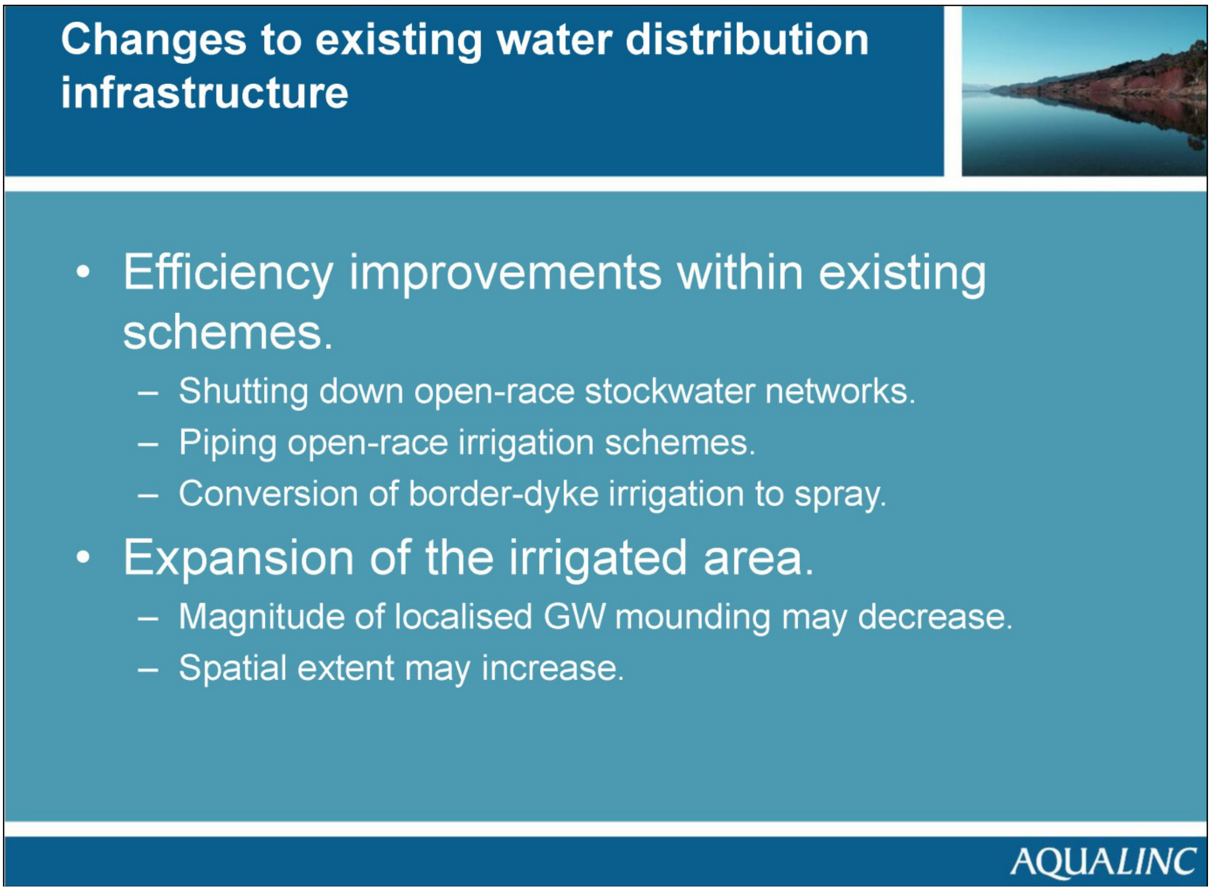
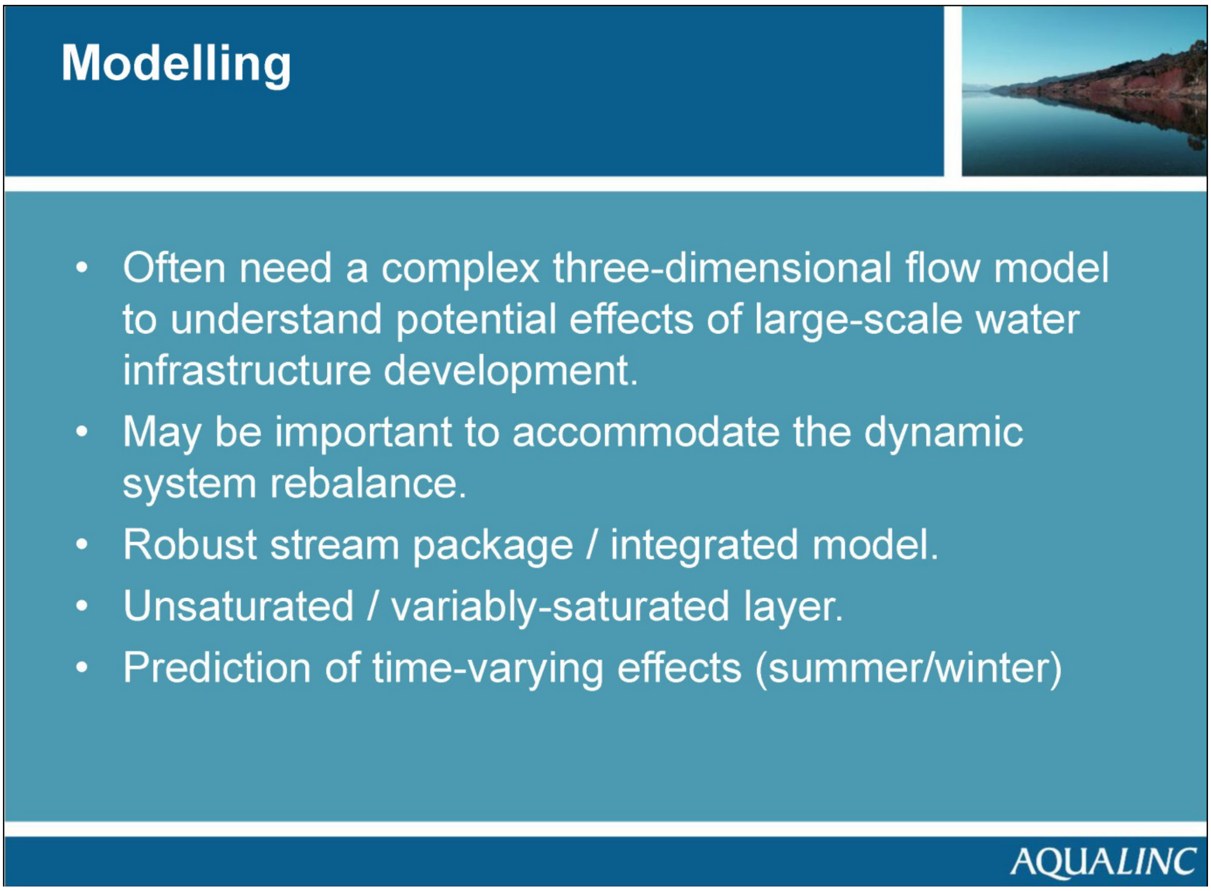
WAIKATO
Te Whare Wānanga o Waikato
Acknowledgements:
David Hamilton
Chris McBride*
Katie Noakes*
Karyn Bryan
*here today
Moritz Lehmann
(mlehmann@waikato.ac.nz)
Environmental Research Institute
University of Waikato
Thank You!

4.2.4 Groundwater-surface water interaction: engineering issues
Facilitator: Andrew Dark, Aqualinc Research Ltd






Changes to existing water distribution infrastructure
• Efficiency improvements within existing schemes.
– Shutting down open-race stockwater networks.
– Piping open-race irrigation schemes.
– Conversion of border-dyke irrigation to spray.
• Expansion of the irrigated area.
– Magnitude of localised GW mounding may decrease.
– Spatial extent may increase.
AQUALINC


Modelling
• Often need a complex three-dimensional flow model to understand potential effects of large-scale water infrastructure development.
• May be important to accommodate the dynamic system rebalance.
• Robust stream package / integrated model.
• Unsaturated / variably-saturated layer.
• Prediction of time-varying effects (summer/winter)
AQUALINC

Data Requirements

- Robust estimates of changes to land-surface recharge
  - Spatial coverage of irrigated area
  - Soil, land-use, climate and irrigation methods
  - Irrigation scheduling and soil-water balance model
- Modified river flows
  - Natural (naturalised?) flows
  - Allocation rules
  - Details of proposed abstraction
- Infrastructure
  - Points of take
  - Any likely leakage from distribution
  - Is receiving environment hydraulically connected to take water body?

AQUALINC

Feedbacks and re-balancing

- Potential feedback loops between modified river flows, irrigation water-use and effects on GW :
  - Temporary reduction in land-surface recharge due to low-flow restrictions
  - "Catch-up" irrigation following restrictions.
  - Does increased irrigation water use balance the effect of reduced river flows??
  - Judgement required on level of complexity incorporated in model.

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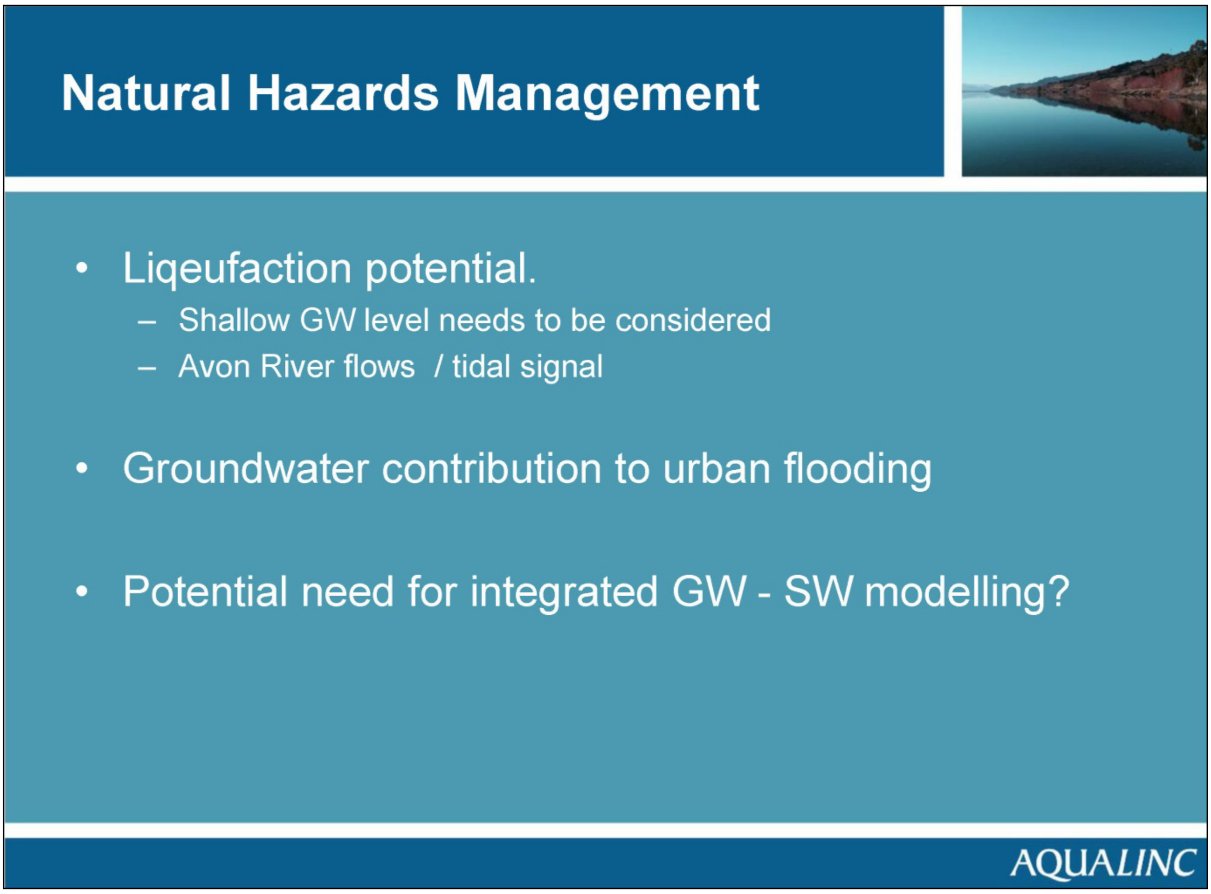

Natural Hazards Management
Liqeufaction potential.
Shallow GW level needs to be considered
Avon River flows / tidal signal
Groundwater contribution to urban flooding
Potential need for integrated GW - SW modelling?
AQUALINC

4.2.5 Water budgets and gravel-bed rivers
Facilitator: Paul White, GNS Science

WATER BUDGET MODELS

Paul White

GNS SCIENCE TE PŪ AO

INTRODUCTION

- **Water budget models are very useful:**
  - **in the assessment of gw-surface water interaction**
  - **setting up for groundwater flow models**

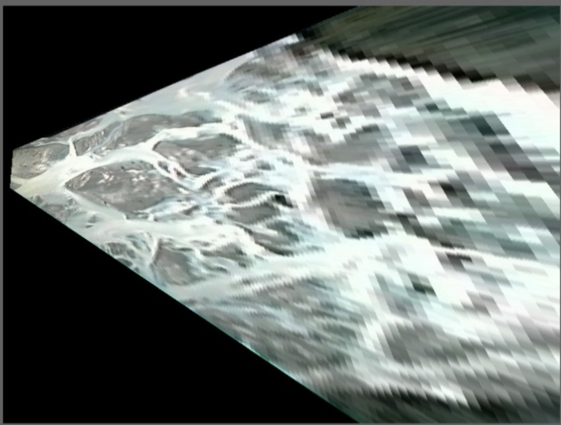
I'm going to describe a water budget for the Puka Glen River bed (i.e., groundwater and surface water)

- **This example will appear in the sessions on uncertainty and policy**

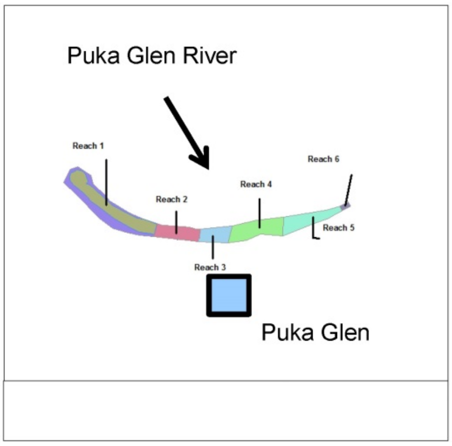
GNS Science

Broad scale groundwater – surface water interaction

The Puka Glen River:
- a braided gravel-bed river
- six reaches across the Plain



Thanks to Jeremy Walsh (NIWA) for the photo.



GNS Science

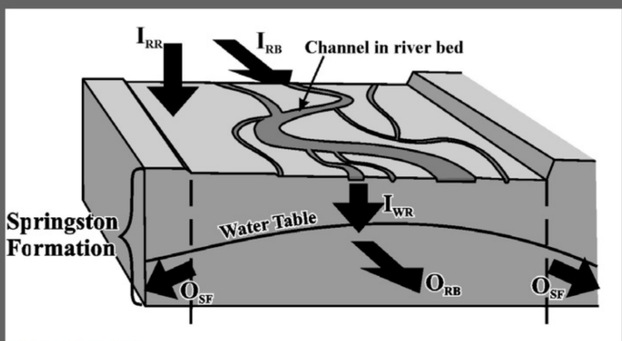
Groundwater budget

Steady-state groundwater budget of each reach

Groundwater budget equation:

Inflows = outflows

$I_{RR} + I_{WR} + I_{RB} = O_{RB} + O_{SF}$



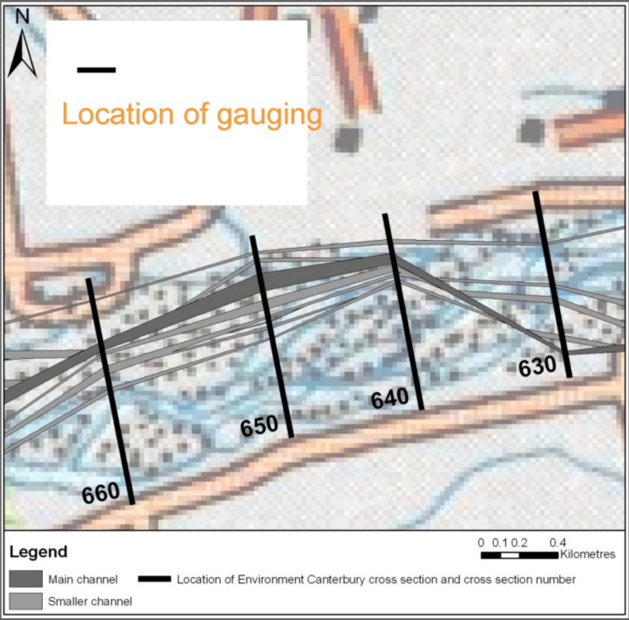
I_{RR} inflow of rainfall recharge through the dry river bed;
I_{WR} inflow of river recharge from Puka Glen River channels;
I_{RB} groundwater inflow from the upstream reach in Holocene river bed gravels;
O_{RB} groundwater outflow to the downstream reach in Holocene river bed gravels;
O_{SF} groundwater outflow to Holocene gravels beside the river bed.

GNS Science

I_{RR} : inflow from rainfall recharge on the river bed

Method

- estimate dry river bed area at average flow; by
- calculating channel area for average flow and estimated river flow – channel width relation; using
- Environment Canterbury river cross observations at low flow



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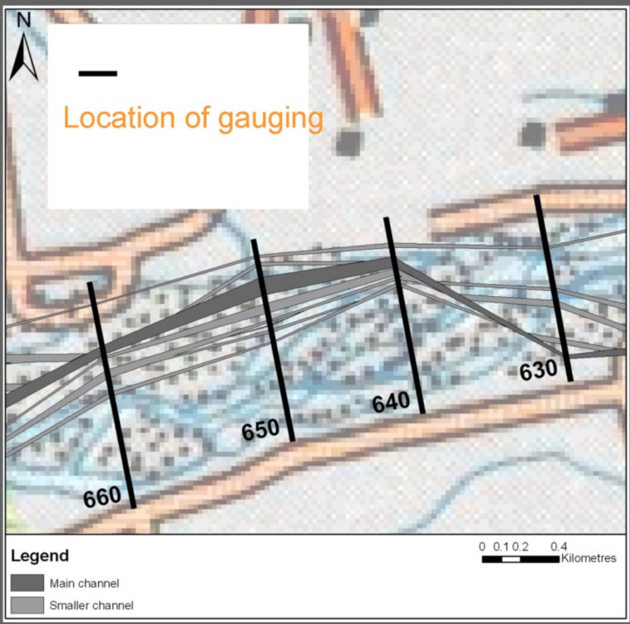
I_{WR}: inflow of river recharge to groundwater

- Calculates river gains and losses between pairs of gaugings measured between 1953 and 2015
  - 88 are 'concurrent' gaugings
  - calculate flow differences between all pairs of gaugings (flow less than 10 m^3/s) at the tops and bottoms of reaches



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I_{RB} (inflow) O_{RB} (outflow) in river bed

- calculated with Darcy equation
- Uses river bed properties and groundwater gradient

GNS Science

O_{SF}: outflow of groundwater to Holocene gravel beside the river bed

- calculated to balance the water budgets for each reach
- estimates groundwater recharge from the river to the groundwater in the bulk of the Waimakariri gravel fan

GNS Science

Steadу-state model: water budget

$I_{RR} + I_{WR} + I_{RB} + O_{RB} + O_{SF} = 0$

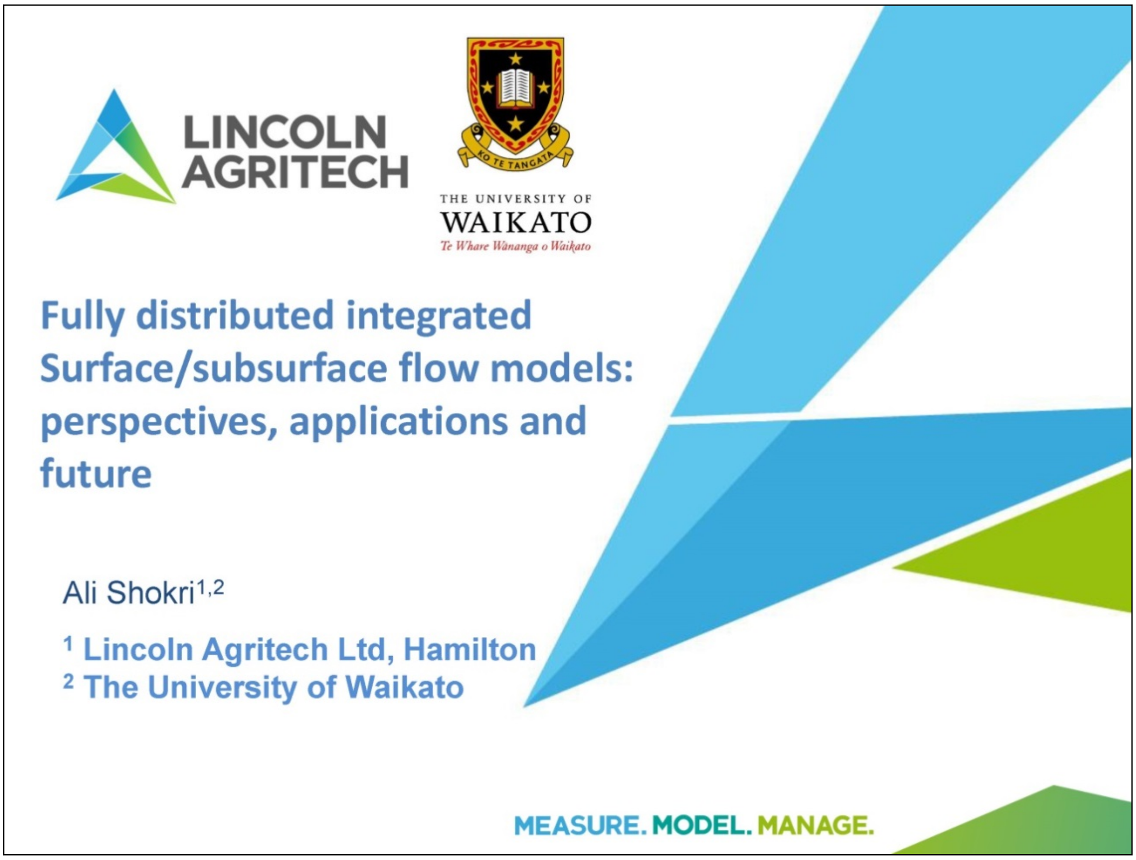
Puka Glen River reach	Inflow I_{RR} (m^3/s)	Inflow I_{WR} (m^3/s)	Inflow I_{RB} (m^3/s)	Outflow river bed O_{RB} (m^3/s)	Outflow Holocene gravel O_{SF} (m^3/s)
1	0.2	0.7	0	-0.4	-0.5
2	0.1	0.5	0.4	-0.5	-0.5
3	0.1	0.1	0.5	-0.4	-0.3
4	0.1	1	0.4	-0.4	-1.1
5	0	0	0.4	-0.2	-0.2
6	0	-0.2	0.2	0	0
Total	0.5	2.1	1.9	-1.9	-2.6

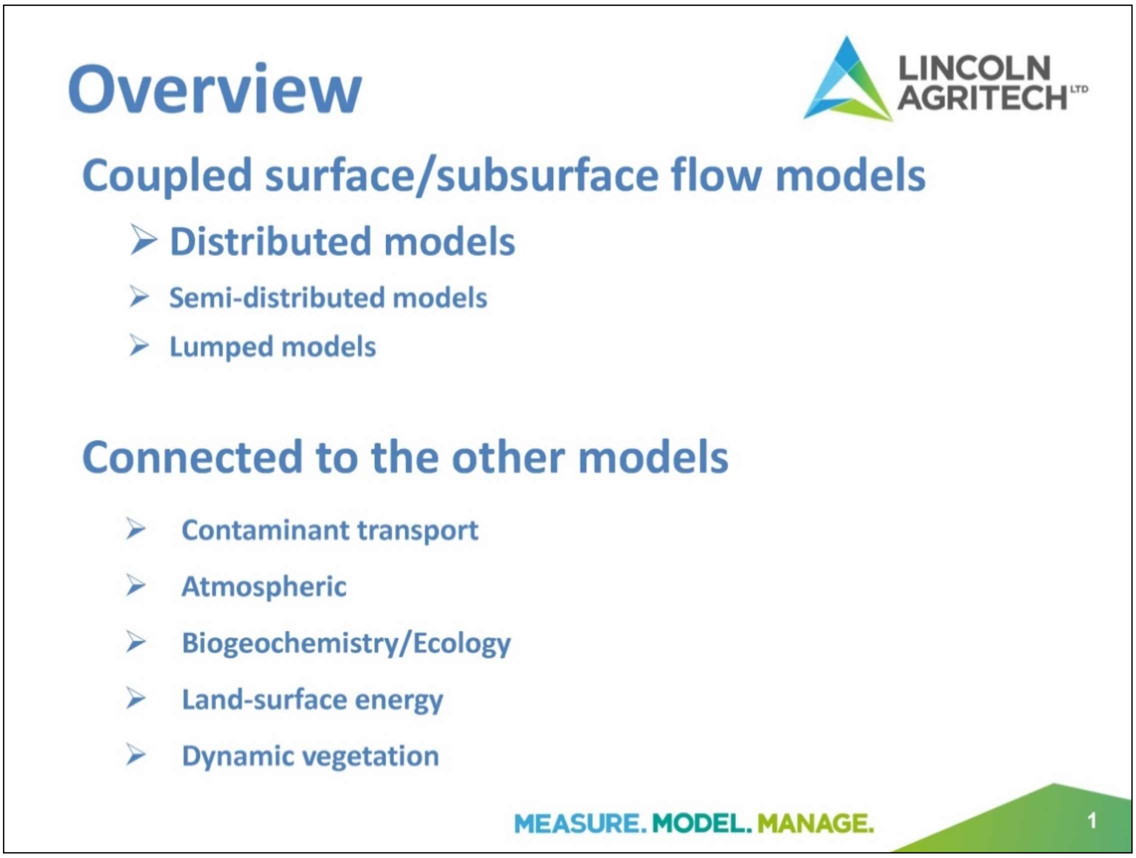
GNS Science

This example will be used in the sessions on uncertainty and policy

GNS Science

4.2.6 Fully distributed integrated surface/subsurface flow models
Facilitator: Ali Shokri, Lincoln Agritech.





Hydrological components in a hillslope

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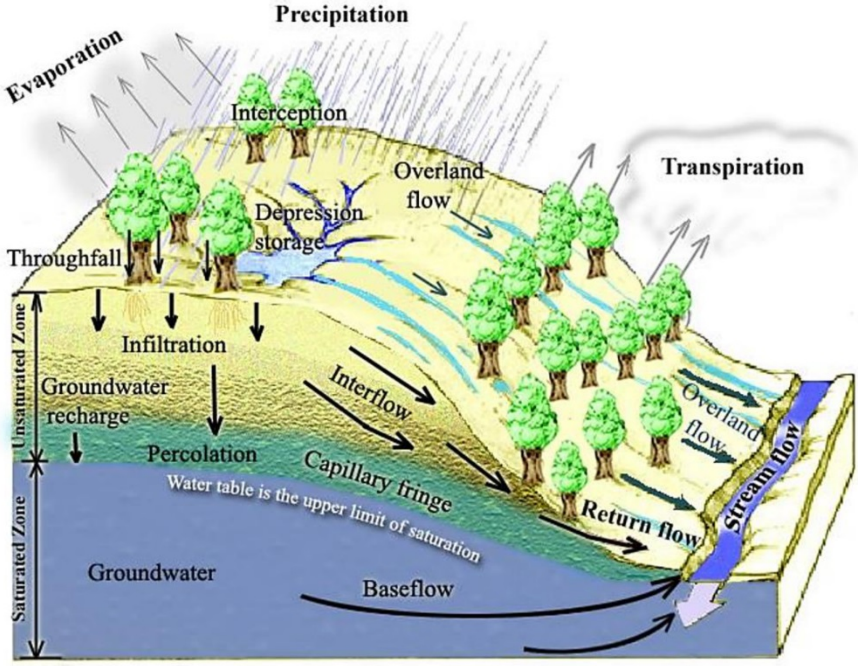

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2

Coupled SW-GW models

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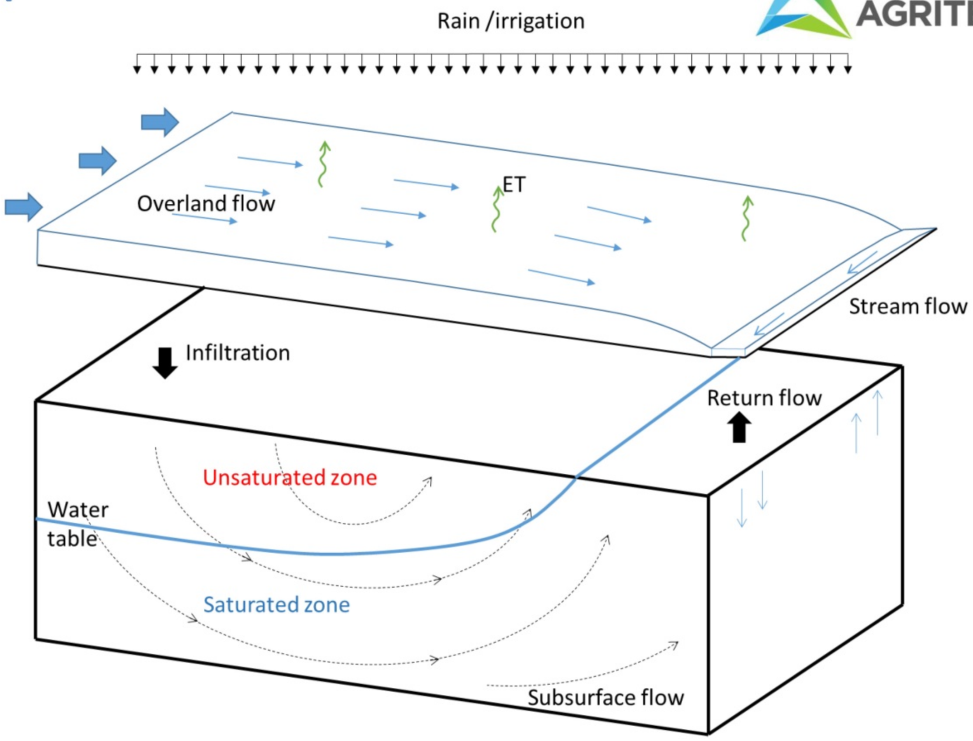

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3

Coupled GW-SW applications

- Atmosphere-subsurface water and energy fluxes
- Runoff generation
- Stream-aquifer exchange
- Solute transport
- Sediment transport
- Dam removal
- Groundwater recharge
- Climate change impacts
- Urban systems
- Groundwater-lake interaction
- Hydrograph separation
- Pore-water pressure development
- slope stability
- Irrigation drainage network
- Tile drainage network

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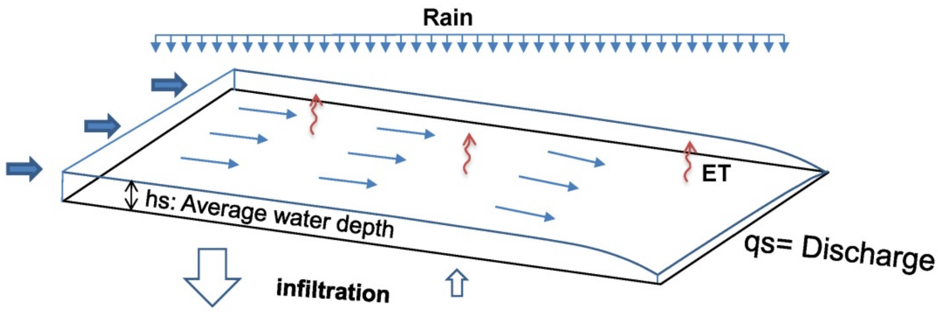
Overland flow

Saint-Venant or shallow water equations



$$\frac{\partial H_s}{\partial t} - \frac{\partial}{\partial x}\left(\frac{hs^{5/3}}{n_x(1+S_{0x}^2)^{2/3}}\frac{1}{\sqrt{\left|\frac{\partial H_s}{\partial x}\right|}}\frac{\partial H_s}{\partial x}\right) - \left(\frac{hs^{5/3}}{n_y(1+S_{0y}^2)^{2/3}}\frac{1}{\sqrt{\left|\frac{\partial H_s}{\partial y}\right|}}\frac{\partial H_s}{\partial y}\right) = qe$$

Diffusive wave approach

$$\frac{\partial H_s}{\partial t} - \frac{\partial}{\partial x}\left(\frac{hs^{5/3}}{n_x(1+S_{0x}^2)^{2/3}}\frac{1}{\sqrt{|S_{0x}|}}\frac{\partial H_s}{\partial x}\right) - \left(\frac{hs^{5/3}}{n_y\left(1+S_{0y}^2\right)^{2/3}}\frac{1}{\sqrt{|S_{0y}|}}\frac{\partial H_s}{\partial y}\right) = qe$$

Semi-diffusive wave approach

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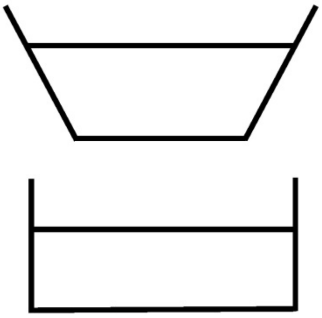
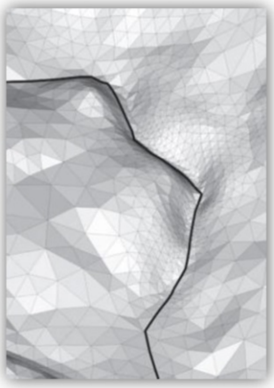
Flow in channels





$$\frac{\partial H_c}{\partial t} - \frac{\partial}{\partial x}\left(\frac{hc^{\frac{5}{3}}}{n_c(1+S_{0c}^2)^{\frac{2}{3}}}\frac{1}{\sqrt{\left|\frac{\partial H_c}{\partial x}\right|}}\frac{\partial H_c}{\partial x}\right) = qe_c$$

Diffusive wave approach

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Subsurface flow (SSM)

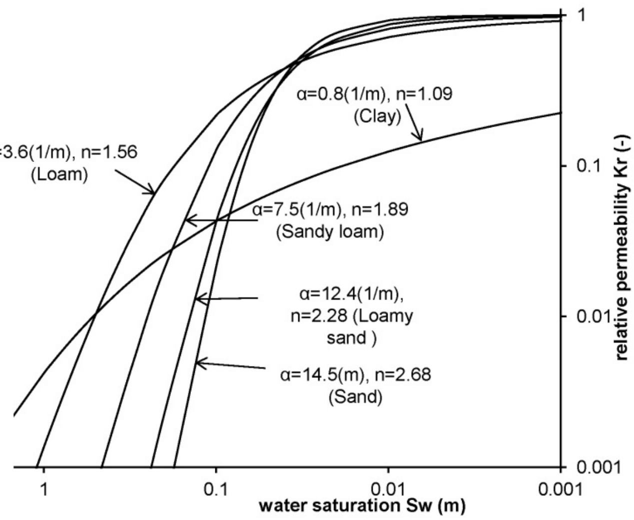
- **Richards Eq:**

$$\nabla.(\boldsymbol{K_s} K_r \nabla H) = S_s S_w \frac{\partial h_p}{\partial t} + \varphi \frac{\partial S_w}{\partial t}$$

- **Van Genuchten analytical expression**

$$K_r = S_e^{\,l}(1-(1-S_e^{\,1/M})^M)^2$$

$$S_e = \begin{cases} (1+|\alpha h_p|^n)^{-M} & if\, h_p < 0 \\ 1 & if\, h_p \geq 0 \end{cases}$$



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Coupling method

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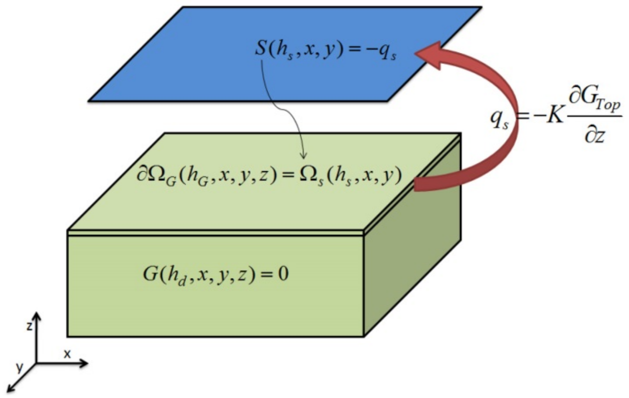
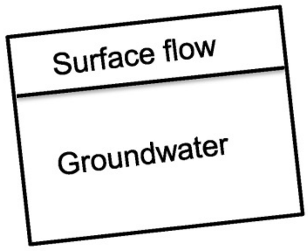
- Boundary condition coupling concept



- Using a general purpose equation for both surface and Groundwater domains



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Distributed Surface Subsurface flow models

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- CATHY
- Mike SHE
- Cast3m
- HydroGeoSphere (HGS)
- OpenGeoSys (OGS)
- ParFlow
- PAWS
- PIHM
- tRIBS + VEGGIE.
- **DrainFlow**

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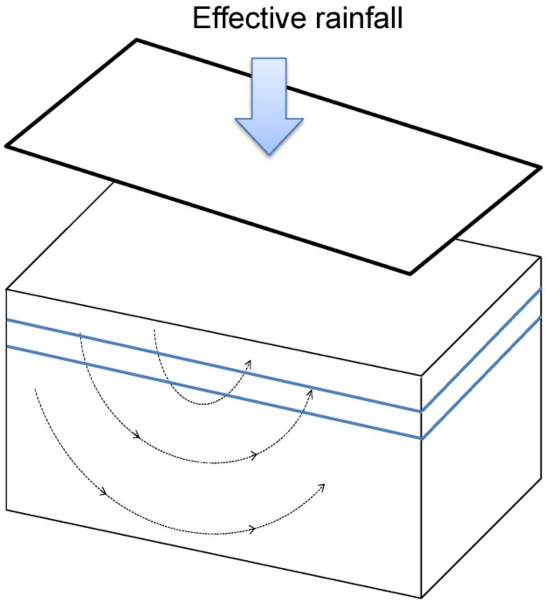
9

Saturation Excess Runoff

- Hydraulic conductivity > Effective rainfall

1st Scenario: IWT= 0.5m
2nd Scenario: IWT= 1m

- **IWT**: Initial Water Table Depth
- **Effective Rain** = Rain - ET



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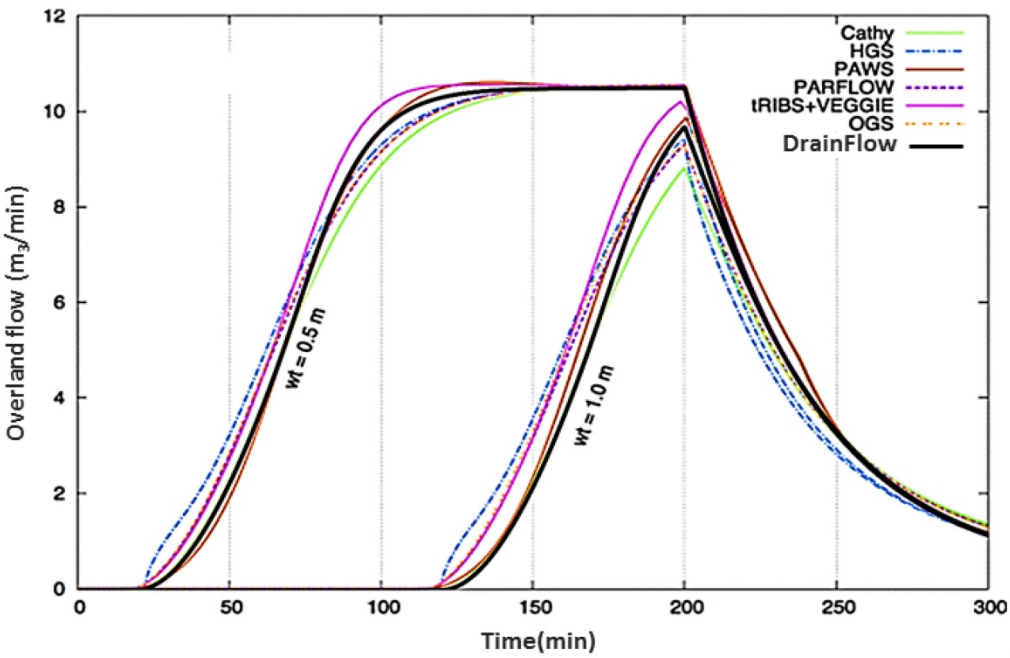
10

Simulated Hydrographs



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11

Conclusion

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➢ Advantages

1. Improving the infiltration estimation
2. Enhancing the SW and GW models calibration/validation process
3. The effect of any changes in the surface water condition can directly be predicted in the groundwater flow condition
4. Similarly, any changes in the groundwater condition can be seen directly on the surface water predictions

➢ Disadvantages

1. Solving convergence problems because of dry and wet boundary conditions
2. Long calculation time, especially for large scale models
3. More sensitivity to physically based parameters like Manning roughness coefficients and soil -water retention curve

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12

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DrainFlow: Fully-distributed surface subsurface flow model for tile drainage study

Ali Shokri[1,2]

[1] Lincoln Agritech Ltd, Hamilton
[2] The University of Waikato

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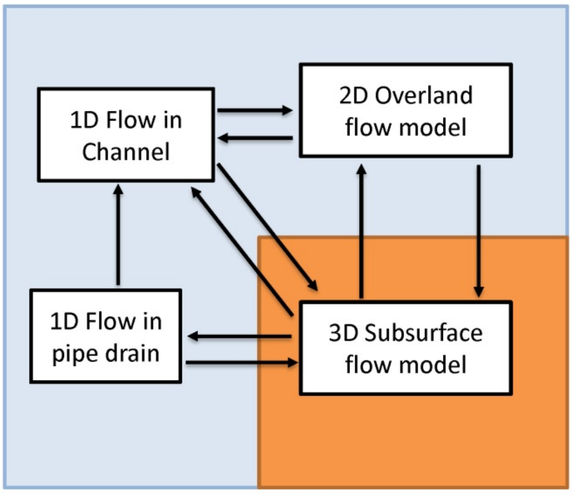
DrainFlow

- What is the DrainFlow?
- What does make DrainFlow different from the other coupled models?
- What is the advantage of drain flow to the previous drainage models?



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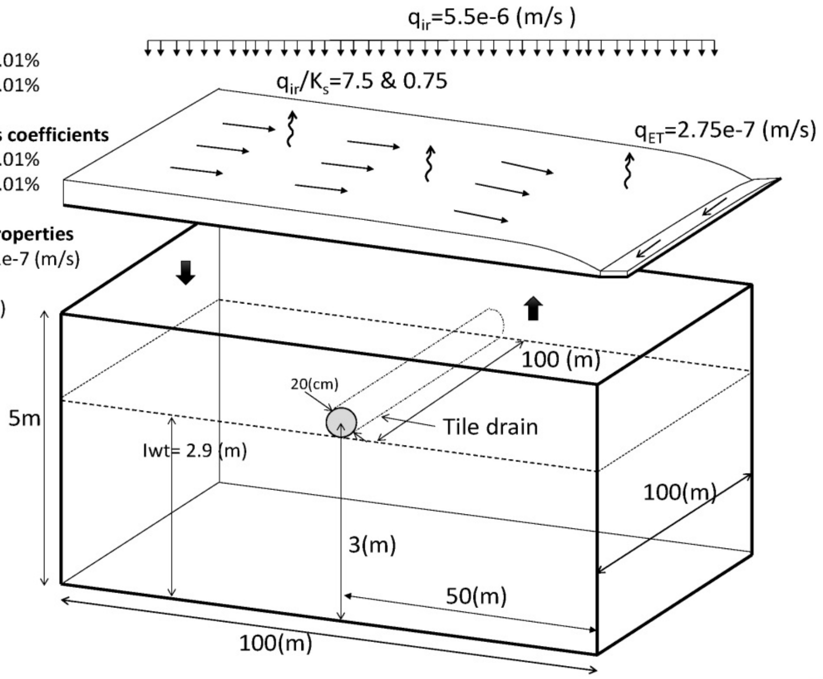
14

Example 1

Slopes
Ground surface: 0.01%
Tile drain: 0.01%

Manning's roughness coefficients
Ground surface: 0.01%
Tile drain: 0.01%

Soil hydrodynamic properties
K_s= 7.71e-6 and 7.71e-7 (m/s)
S_s =5e-4m^{-1} & φ=40%
n_{van}=0.2 & α = 1 (m^{-1})
S_{res}= 0.2 & S_{sat}=1



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DrainFlow results

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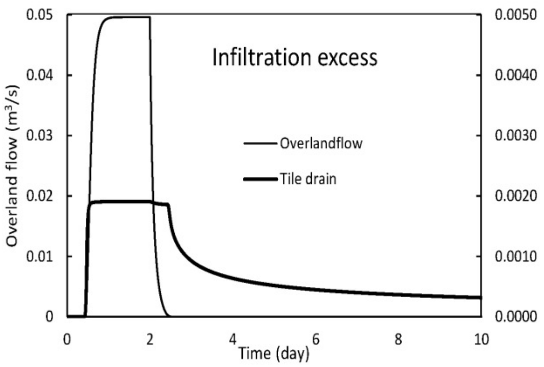

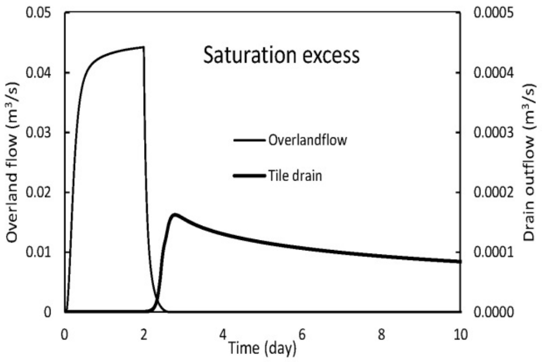

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16

Example 2

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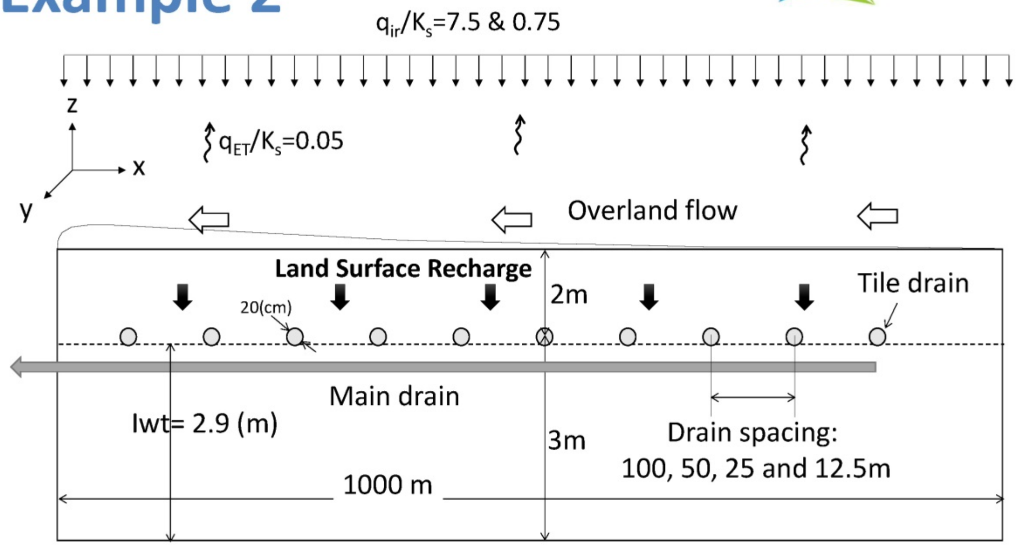

Slopes

Ground surface: 0.01%

Tile drain: 0.01%

Manning's roughness coefficients

Ground surface: 0.01%

Tile drain: 0.01%

Soil hydrodynamic properties

K_s= 7.71e-6 and 7.71e-7 (m/s)

S_s =5e-4m^{-1} & φ=40%

n_{van}=0.2 & α = 1 (m^{-1})

S_{res}= 0.2 & S_{sat}=1

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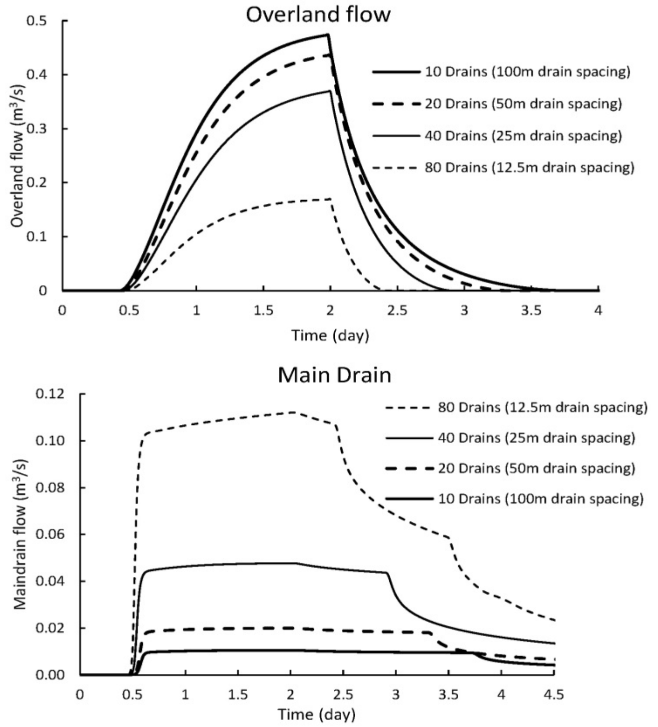
18



Overland flow and maindrain hydrographs for 10, 20, 40 and 80 tile drains

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20

conclusion

- A comprehensive surface/subsurface interaction flow model specialized in drainage study is developed. The model tested against some well-known published benchmarks.

- Model utilized in some simple drainage studies. Results shows the developed model could gives a better understanding of drainage study process like:
  - Tile drain and main drain discharge
  - Land Surface Recharge (LSR)
  - The lag time
  - Runoff
  - water table

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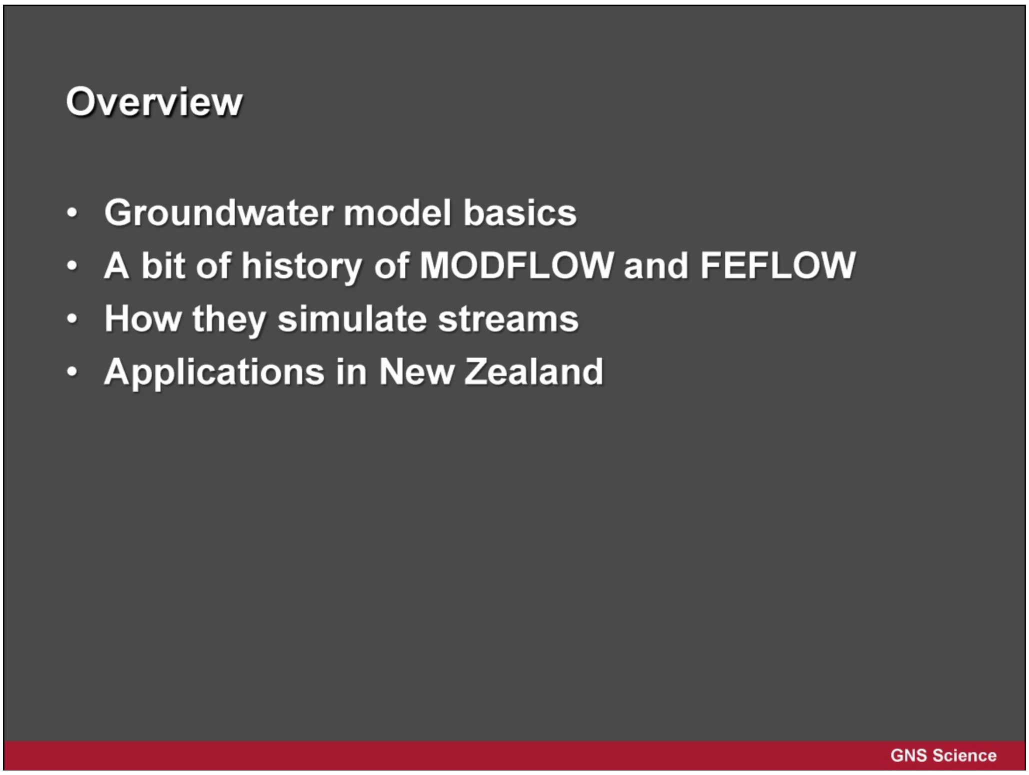
21

4.2.7 MODFLOW applications
Facilitator: Mike Toews, GNS Science

Refer to Section 4.2.8 for copy of presentation.

4.2.8 FEFLOW applications
Facilitator: Mike Toews, GNS Science



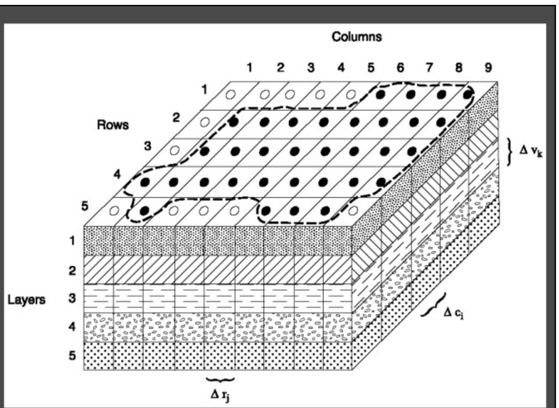
Groundwater Models

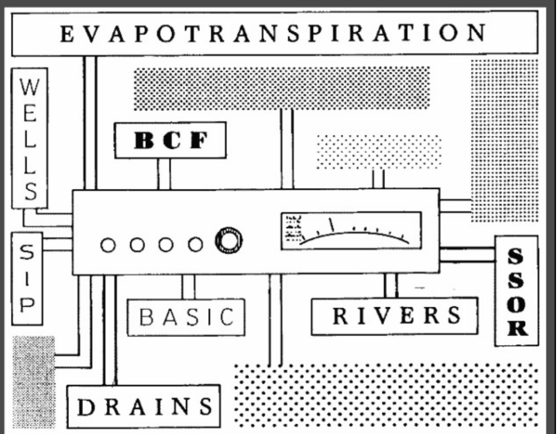
- **Groundwater flow equation**
  - Basically groundwater flows from high to low
  - Partial differential *diffusion equation*
  - *Solved* to determine flow in the domain
- **Types of groundwater models**
  - **Space**: Spatial 2D vs. 3D aquifer geometry
  - **Time:** Steady state (1 time), transient (many times)
  - **Method:**
    - Finite difference: **MODFLOW**
    - Finite element: **FEFLOW**

GNS Science

MODFLOW History

- **U.S. Geological Survey**
- **In the 1970s, individual GW models programmed directly in FORTRAN**
- **In the 1980s, a *modular* approach was developed for any general purpose GW model**
- **Different Packages can be plugged in**
- **Reads formatted text files**





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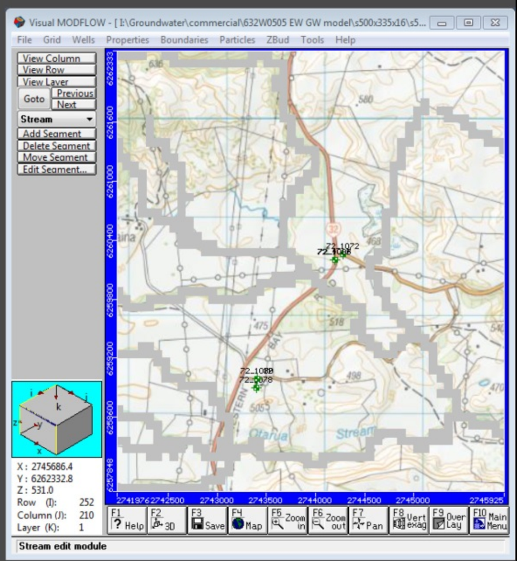
MODFLOW Packages for GW–SW Interaction

- **River Package (RIV): flow in/out**
  - Does not route flow, use only for large rivers
- **Drain Package (DRN): flow only out of aquifer**
  - Useful for gaining (only) ephemeral streams
- **Stream Package (STR)**
  - Instantaneously routes flow, uses Manning's *n*
- **Streamflow-Routing Package (SFR)**
  - Routes flow using kinematic wave equation
  - Supports advanced processes, such as unsaturated flow beneath streams

GNS Science

MODFLOW Software

- **Several graphical programs to use MODFLOW**
  - GMS
  - Groundwater Vistas
  - ModelMuse – USGS
  - Visual MODFLOW [Flex]
- **Wide range of variants**
  - MODFLOW-88, 96, 2000, 2005, NWT, LGR, USG
  - SEAWAT – seawater intrusion
  - Related: MODPATH, MT3DMS



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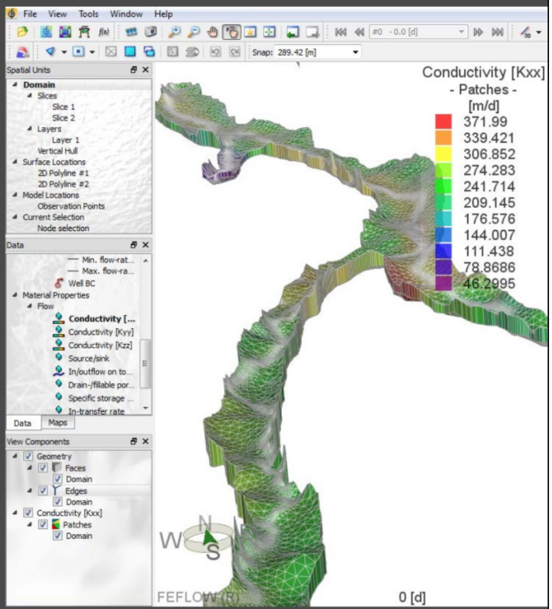
FEFLOW

- Finite Element groundwater Flow simulator
- Also couples mass and heat transport
- First developed in Berlin, East Germany, 1979
- Has a built-in GUI
- Triangles (2D) or wedge (3D) elements created with nodes
- Can have flexible geometry
- Advanced methods, like age



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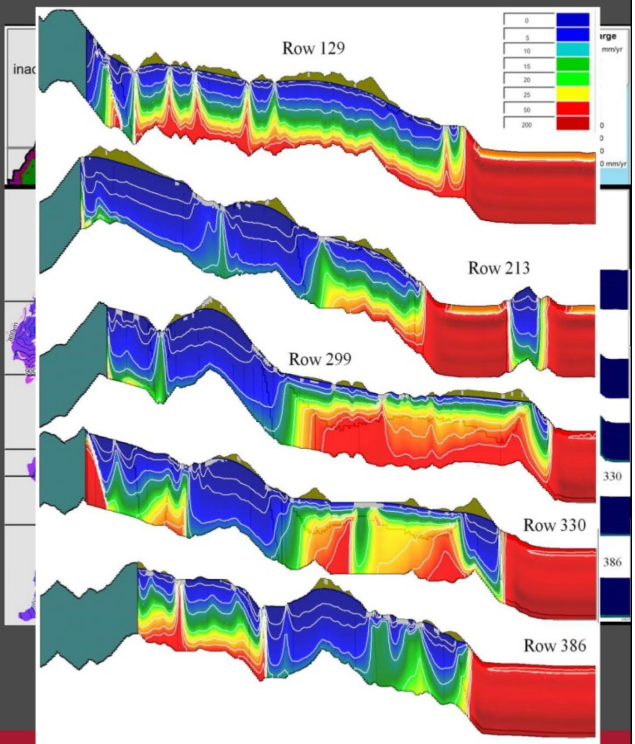
Applications in NZ: MODFLOW

- Western Lake Taupo
- Uses 3D geologic model of TVZ
- Flow simulated in streams using drains
- ³H measured in streams
- Used to calibrate transport model to simulate mean age
- See Gusyev et al. 2013



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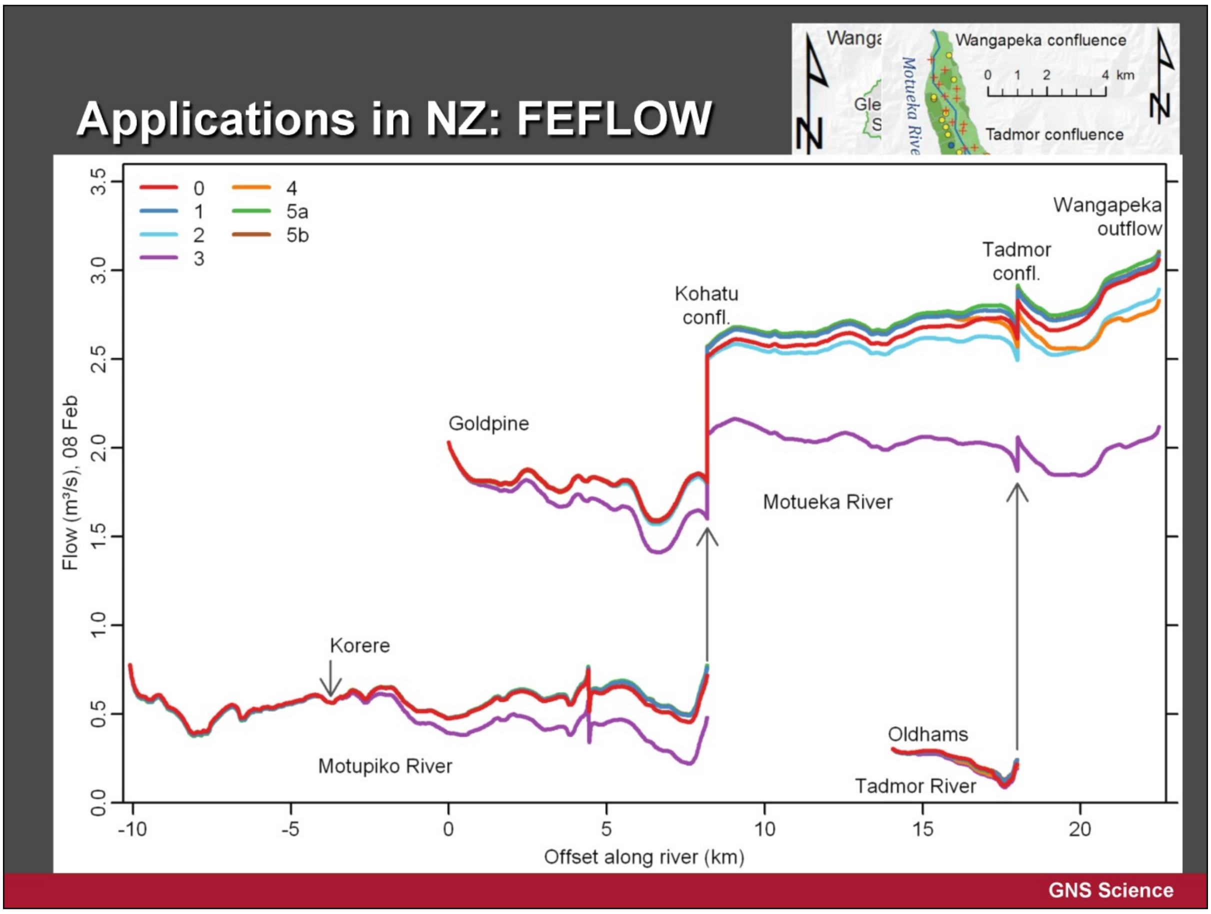
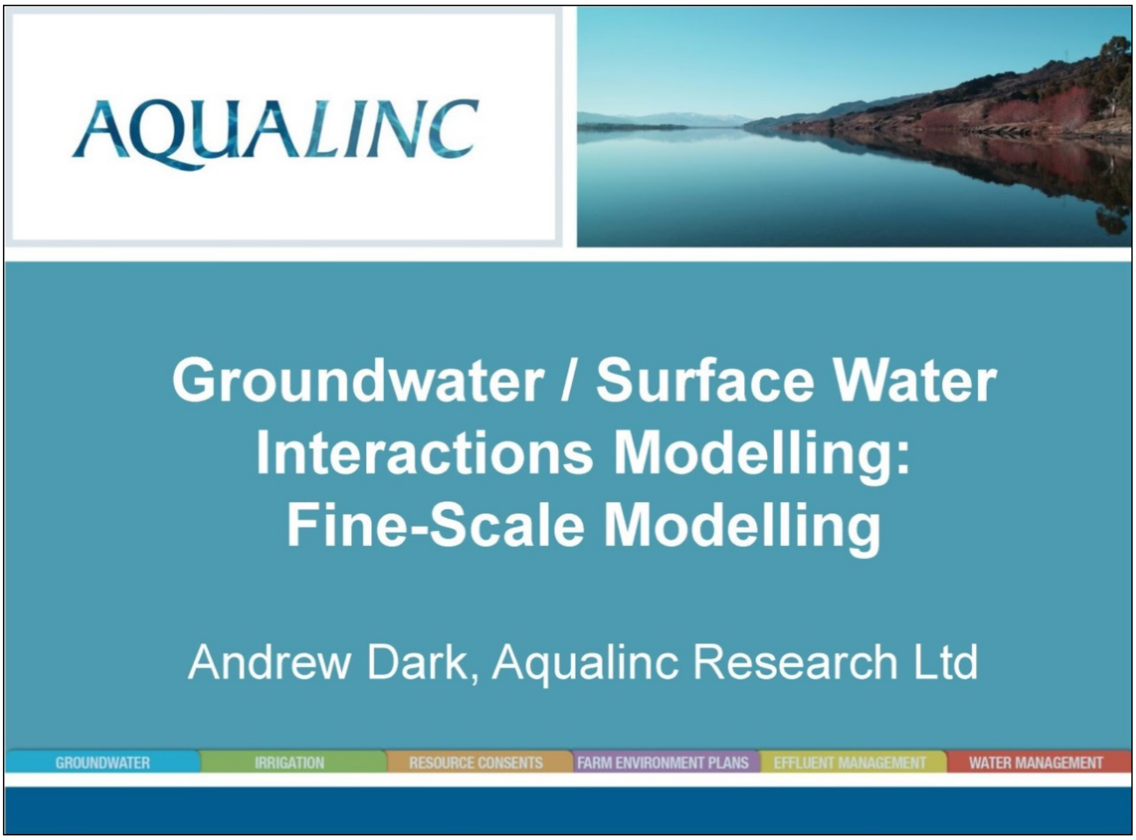
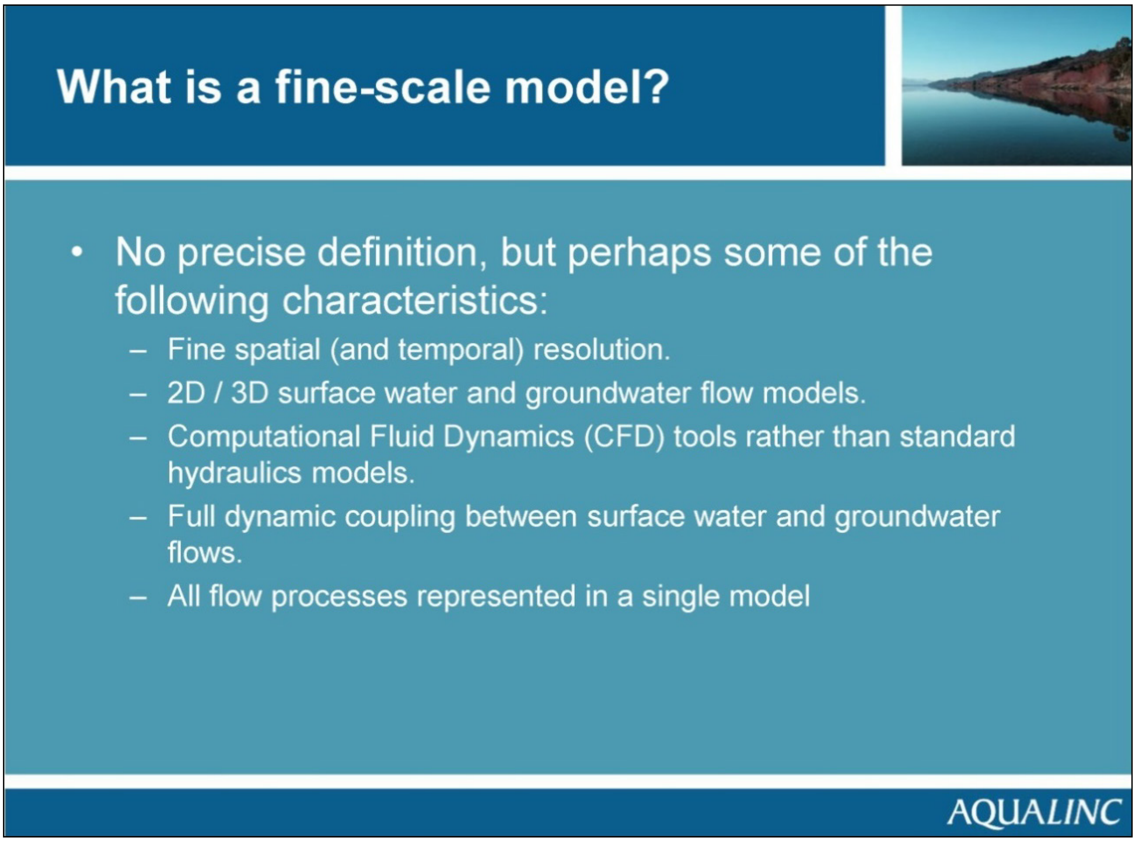


Applications in NZ: FEFLOW
Wanga
Gle
S
Motueka Rive
Wangapeka confluence
0 1 2 4 km
Tadmor confluence
0
1
2
3
4
5a
5b
Flow (m³/s), 08 Feb
Offset along river (km)
Goldpine
Kohatu confl.
Tadmor confl.
Wangapeka outflow
Motueka River
Korere
Motupiko River
Oldhams
Tadmor River
GNS Science

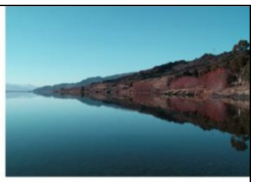
4.2.9 Fine scale understanding of surface water groundwater interaction along river beds

Facilitator: Andrew Dark, Aqualinc Research Ltd





Potential applications of fine-scale models



- Understanding how flow in the hyporheic zone is affected by changes in stream-bed geometry.
- Detailed design of stream restoration works.
- Design / effects assessment for infiltration galleries (esp. where riverbank filtration is being relied on for water treatment)

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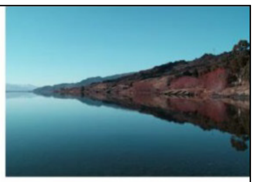
A few examples from literature



- Cardenas and Wilson (2007). Exchange flows between surface flow and bed sediments with an irregular interface surface (i.e. dunes / bed-forms).
- Sawyer *et al* (2011) Hyporheic exchange due to woody debris (i.e. logs) in the stream channel.
- Tonina and Buffington (2007) Hyporheic exchange in rivers with pool / riffle morphology.
- Derx *et al* (2010) Flow in a gravel bar in the Danube River.

- **These examples all employ fine-scale modelling for surface and / or subsurface flow, but none of them appear to handle coupling of the two domains very robustly.**

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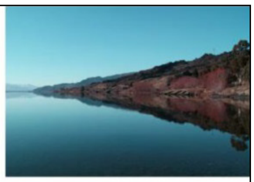
Why develop a single-domain flow modelling approach?



- Assumptions in standard models may not be valid – e.g. :
  - Shallow water / Saint Venant equations (and simplifications such as kinematic wave) assume an impermeable bed with a no-slip boundary condition, and no vertical flow.
  - Groundwater models typically assume that flow is laminar and Darcian.
- Numerically coupling two models may not accurately capture the physics of the overall flow.
- Possible mass-balance errors at the interface.
- A riverbed can be conceptualised as a form of porous medium (e.g. Lane and Hardy, 2002)
- Small-scale examples in literature (flow through heat-exchangers, oil filters, etc)

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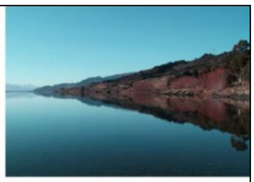
Basis of the current research (Waterscape programme)



- All water flows can be described by the Navier-Stokes equations (NSE).
- Typically not practical to do this for a porous medium.
- Standard equations for both GW and SW flow can be derived from the NSE.
- Averaging in time and over a volume that contains both fluid and solid phases gives the Double-Averaged Navier Stokes Equations (Nikora *et al*, 2007), which can describe both surface and subsurface flows.

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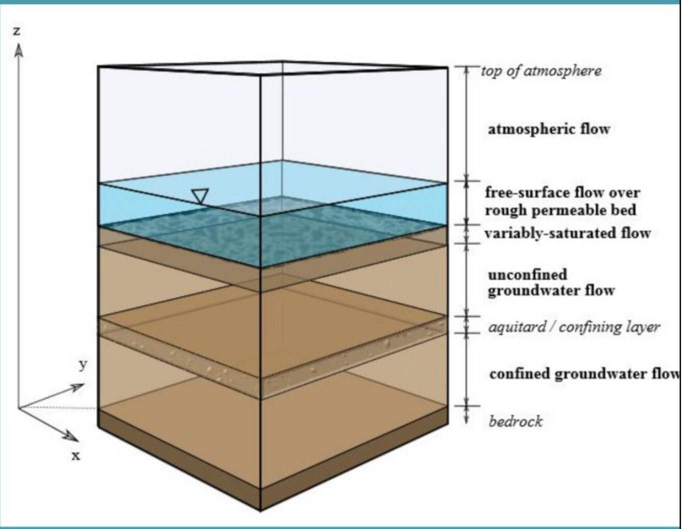
Current research (continued)

- Single model can be applied across porous and clear fluid sub-domains.
- Surface flow can be treated as a special case of porous media flow.
- Model parameters are a continuum (conductivity, porosity)



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Challenges to resolve

- Transition between laminar and turbulent flows.
- Extension to 3D
- Unsaturated flow
- Confined flow

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Laboratory Investigations

- 2-layer flume experiments
- Transparent porous medium – optically matched to water
- Particle tracking velocimetry

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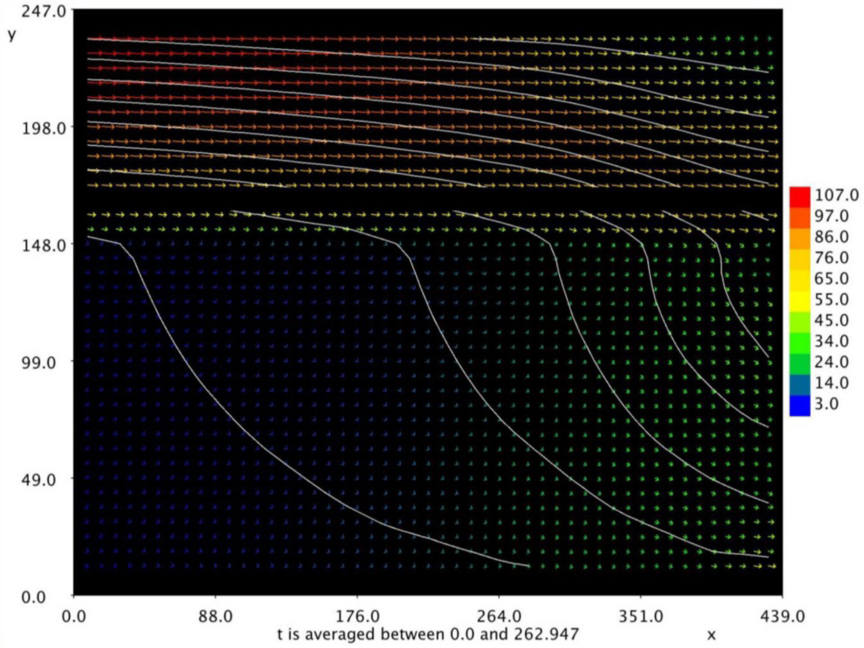
2D Velocity Fields



8/03/2016

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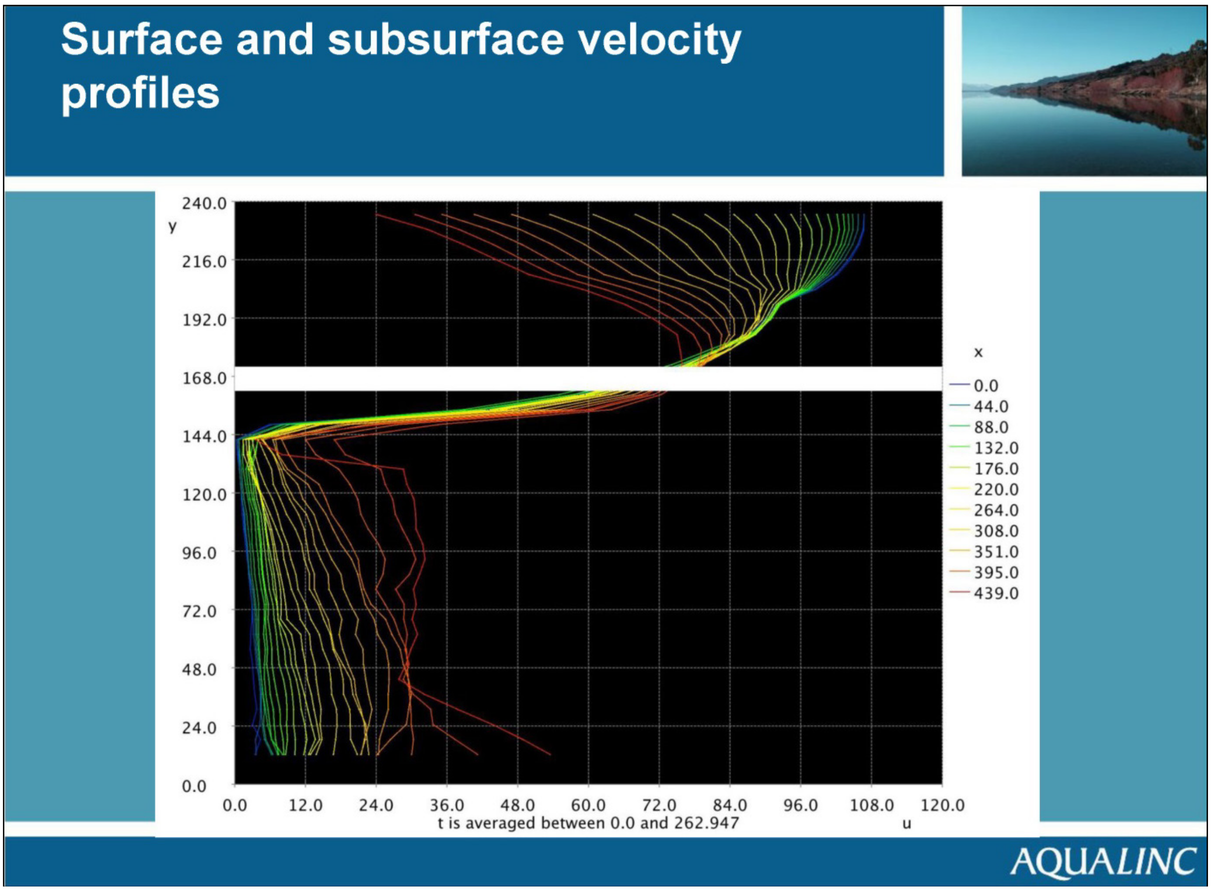
Surface and subsurface velocity profiles
240.0
y
216.0
192.0
168.0
144.0
120.0
96.0
72.0
48.0
24.0
0.0
0.0 12.0 24.0 36.0 48.0 60.0 72.0 84.0 96.0 108.0 120.0
t is averaged between 0.0 and 262.947
u
x
0.0
44.0
88.0
132.0
176.0
220.0
264.0
308.0
351.0
395.0
439.0
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4.2.10 Eigen model

Facilitator: Lee Burbery, ESR

Evaluating SW-GW interactions from hydrodynamic analysis of groundwater levels: application of the 'Eigen-model'

Lee Burbery

SW-GW workshop, Wellington

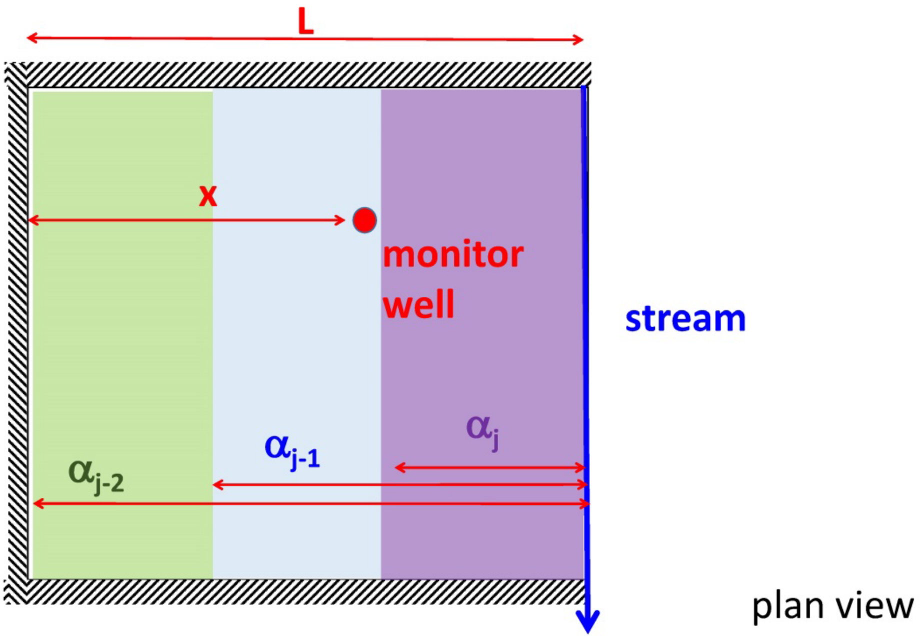
1/09/2015

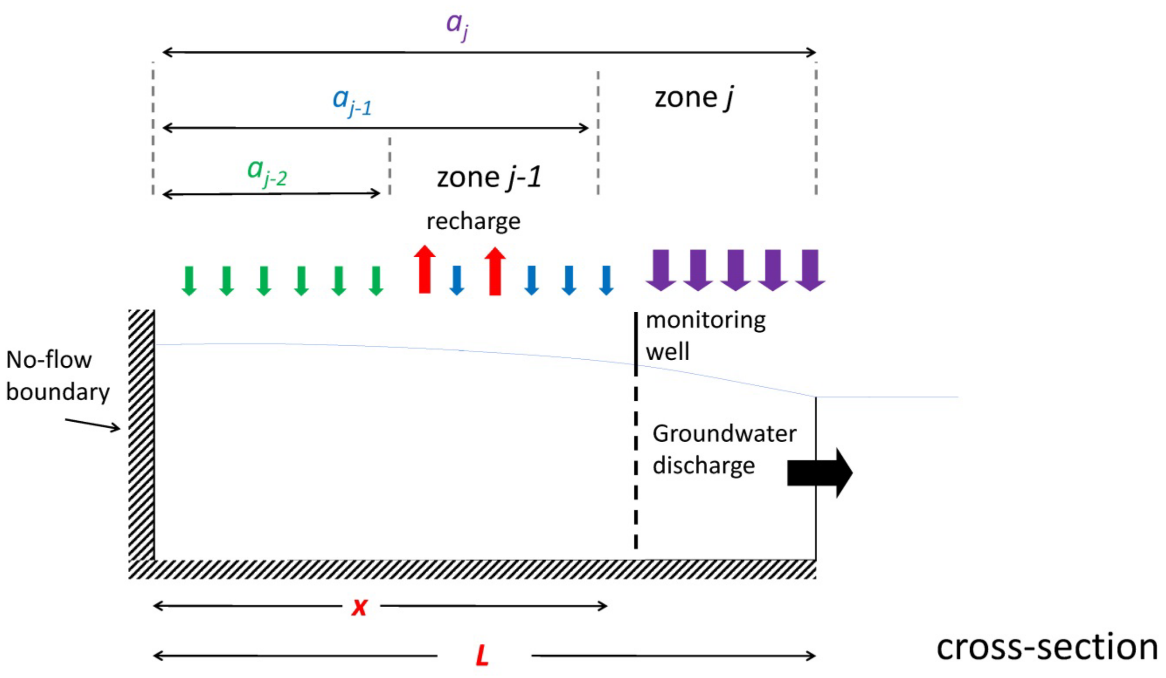
Topics

- Groundwater hydrodynamics; interpreting groundwater level monitoring data
- Baseflow separation concept for aquifers
- 'Eigen-model' **analytical** solution to transient GW flow eqtn.
- Groundwater Data Analysis tool (GDA-tool)
- Mathematical concepts
- Application in Riversdale 'riparian' aquifer, Southland

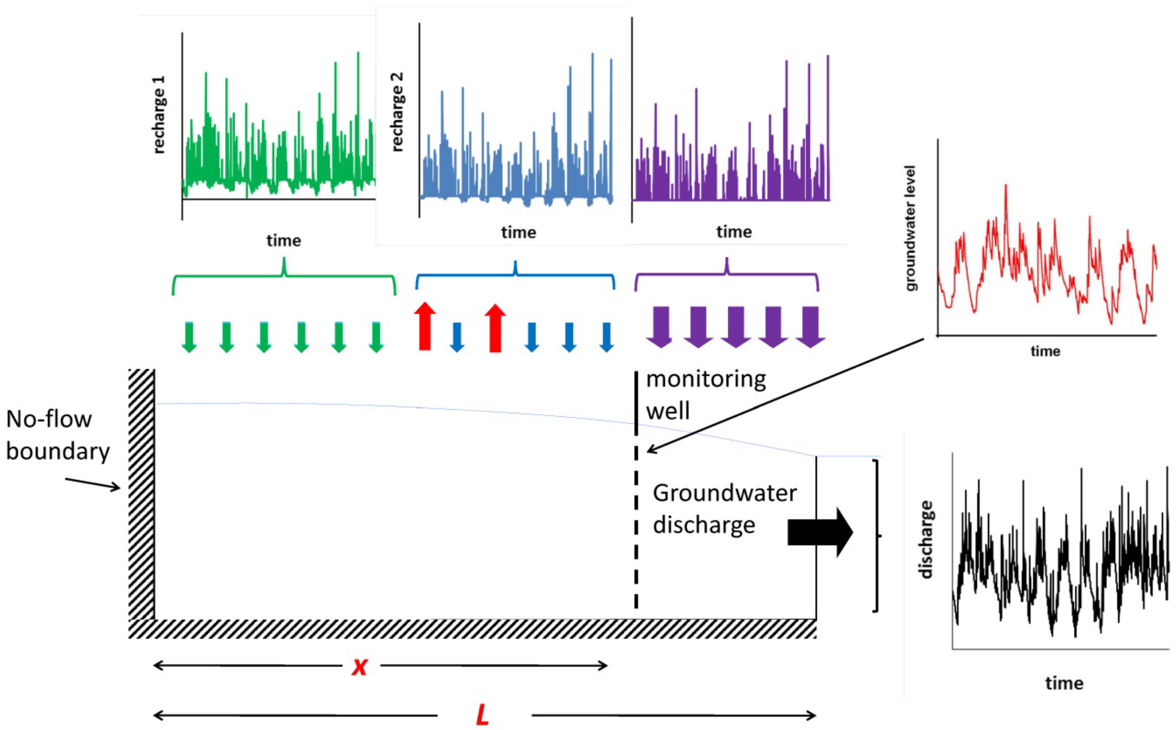
2

- Conceptual model: aquifer w/ distributed recharge/discharge, connected to a stream
- Instrumented with a monitoring well

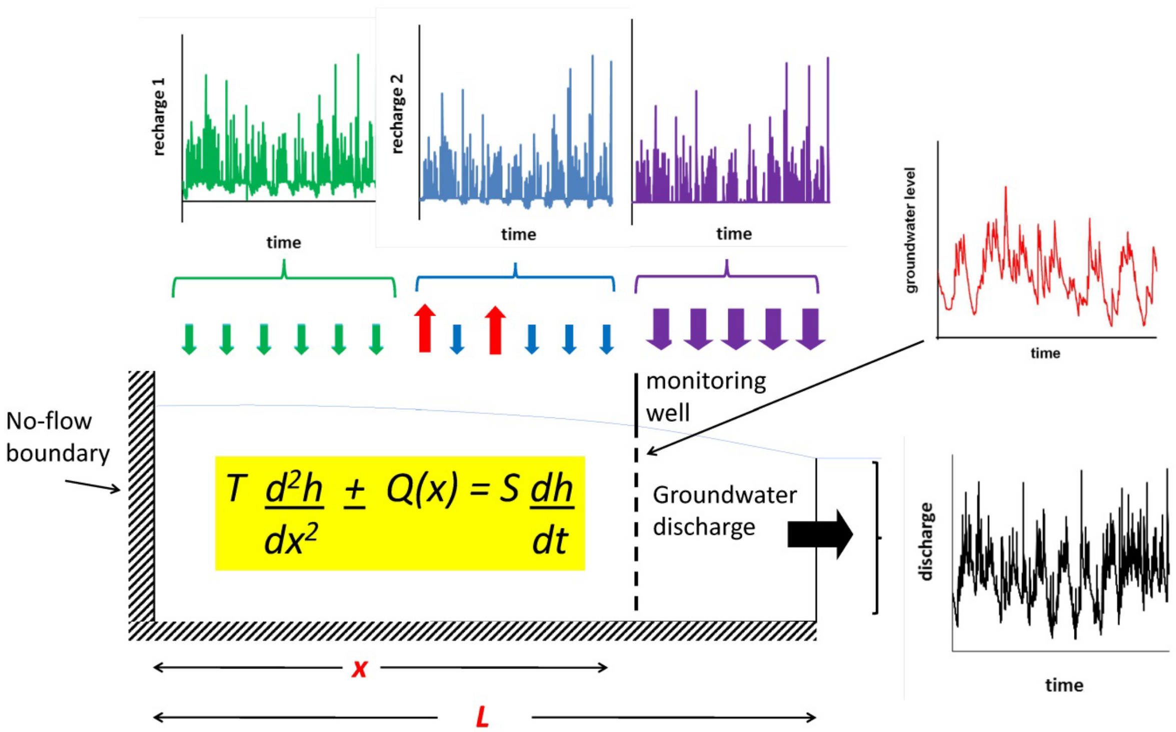




Hydrodynamics



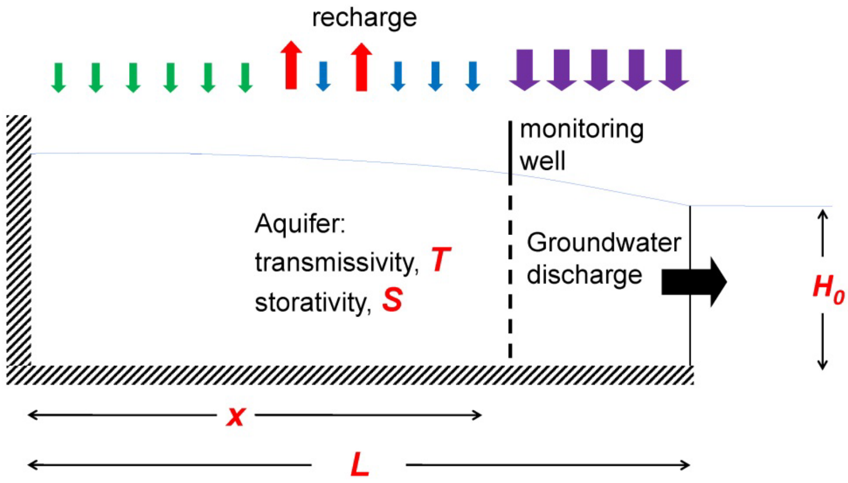
Transient groundwater flow equation



Four governing parameters:

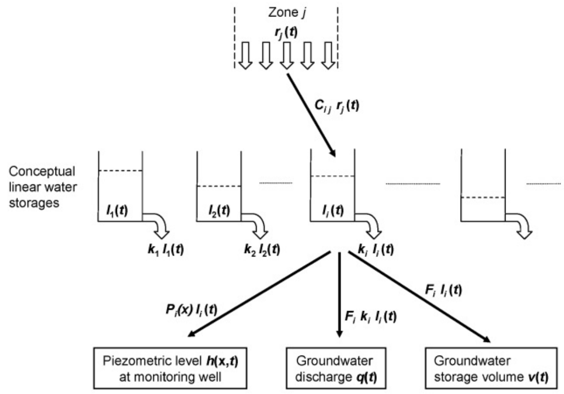
1. Effective diffusivity, T/SL^2 [T^{-1}]
2. Aquifer storage coefficient, S [-]
3. Observation point, x/L [-]
4. Base level groundwater datum, H_0 [L]

$$T \frac{d^2h}{dx^2} \pm Q(x) = S \frac{dh}{dt}$$



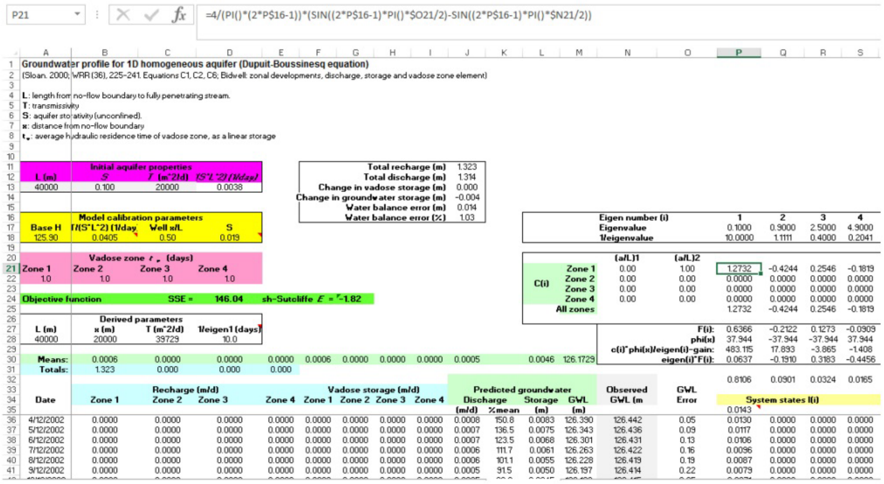
The 'Eigen-model' or Embedded Multi-Reservoir Model (Pulido-Velazquez, 2005)

- Very efficient analytical soln. to Dupuit-Boussinesq Eqtn.
- Characterises dynamics for infinite number of conceptual linear storage reservoirs, each of which drains at some exponential rate (the Eigen-values)
- Eigen-functions represent state of physical aquifer system, i.e. encapsulate spatial heterogeneity
- Linearity assumption



- Formulated as a set of difference equations
- Simple; can solve in a spreadsheet
- Tool for evaluating cumulative effects of pumped abstraction on stream depletion

$$\textbf{eigenvalue,}\ \varepsilon_m = \left[\frac{(2m-1)\pi}{2}\right]^2 \frac{T}{SL^2}$$



E/S/R THE SCIENCE BEHIND THE TRUTH

9

Groundwater Data Analysis (GDA)-Tool

- Envirolink tools project (2010); developer Vince Bidwell; publically available
- Eigen-model groundwater model foundation
- Time-series analysis of groundwater level data = signal processing
- Filter various recharge process signals
- Characterise hydrodynamic properties of aquifer; evaluate aquifer hydraulic residence times
- Assess environmental effects:
  - Cumulative effects of groundwater use on water levels / discharge to streams
  - Climate change effects
  - Impact of increased recharge (e.g. irrigation schemes) etc.

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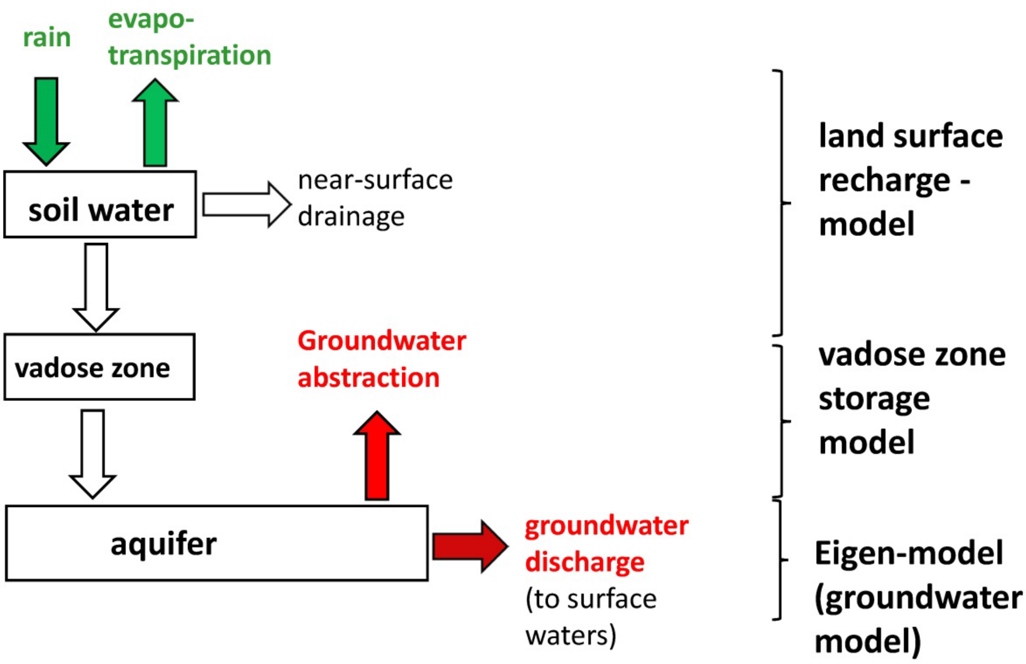
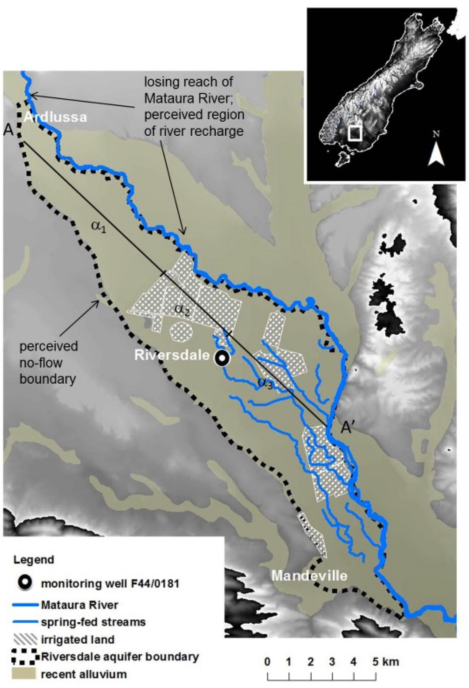
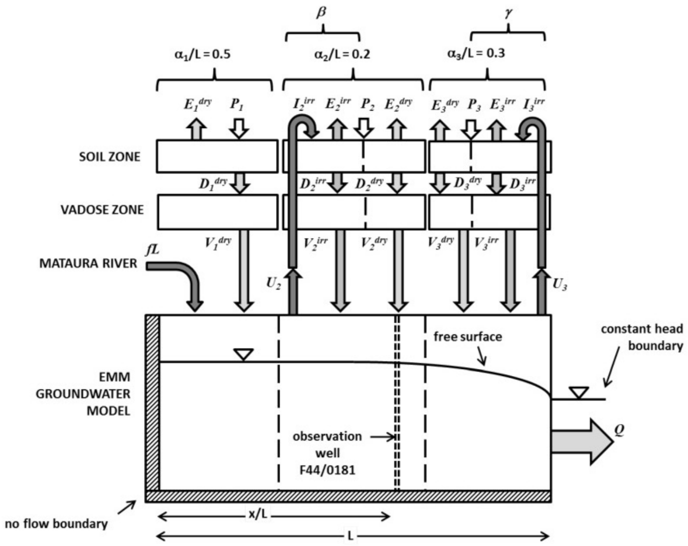
10

3 systems components to GDA-tool:



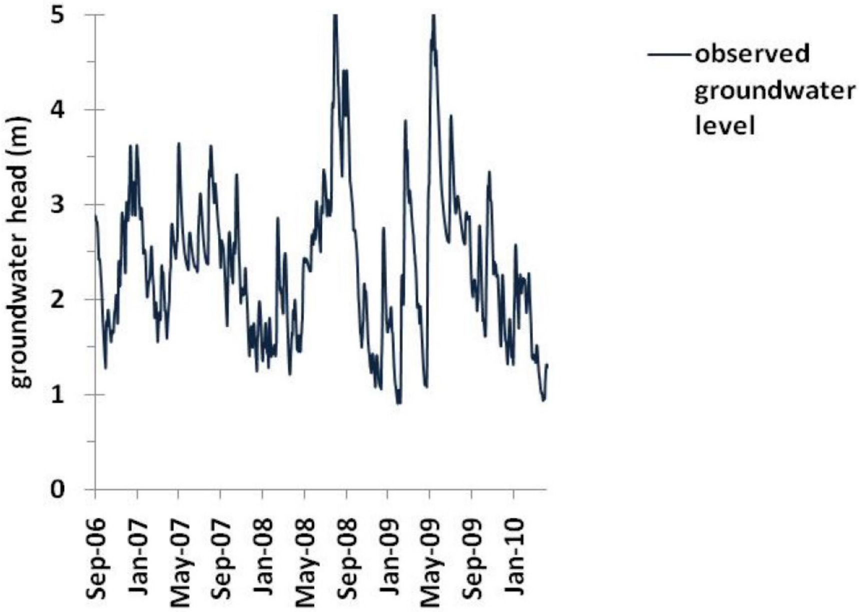
Example: Riversdale aquifer, Southland

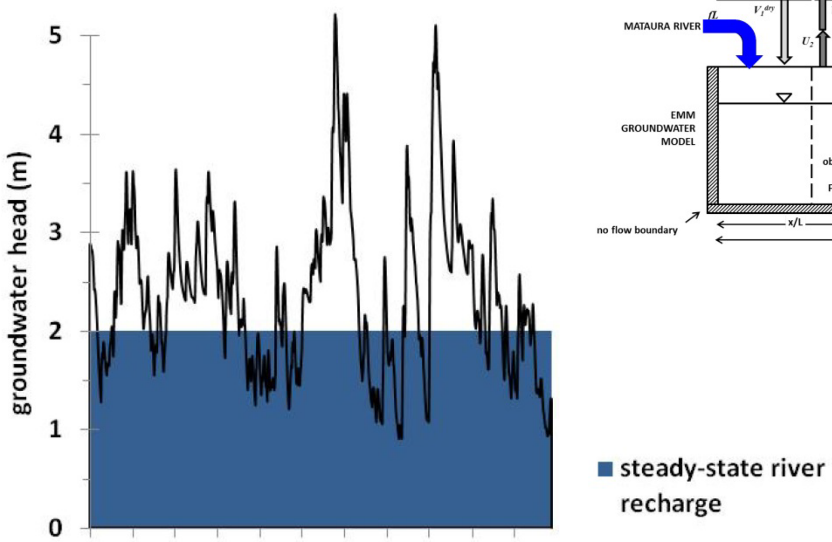


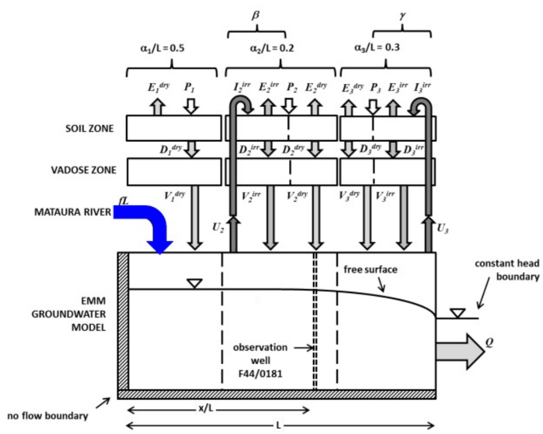


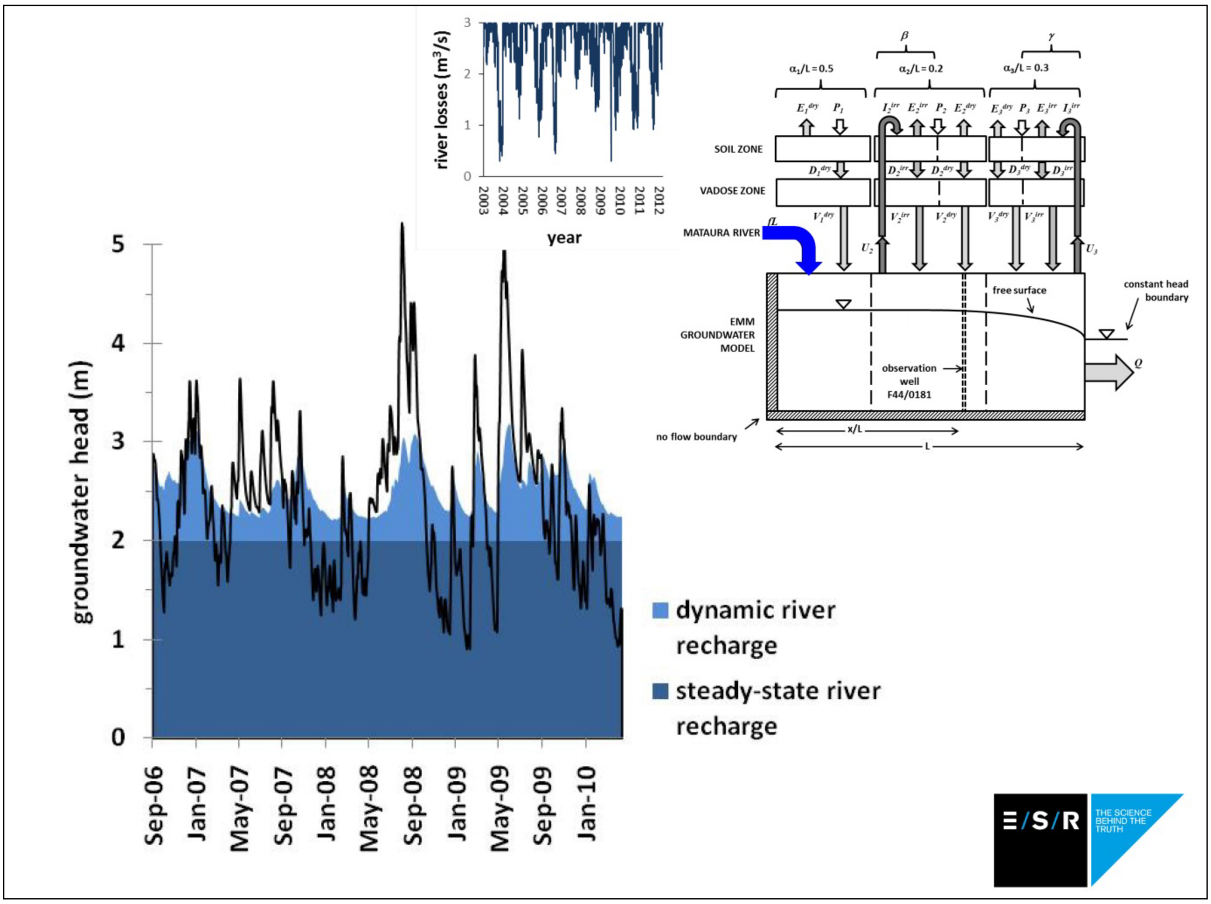
12

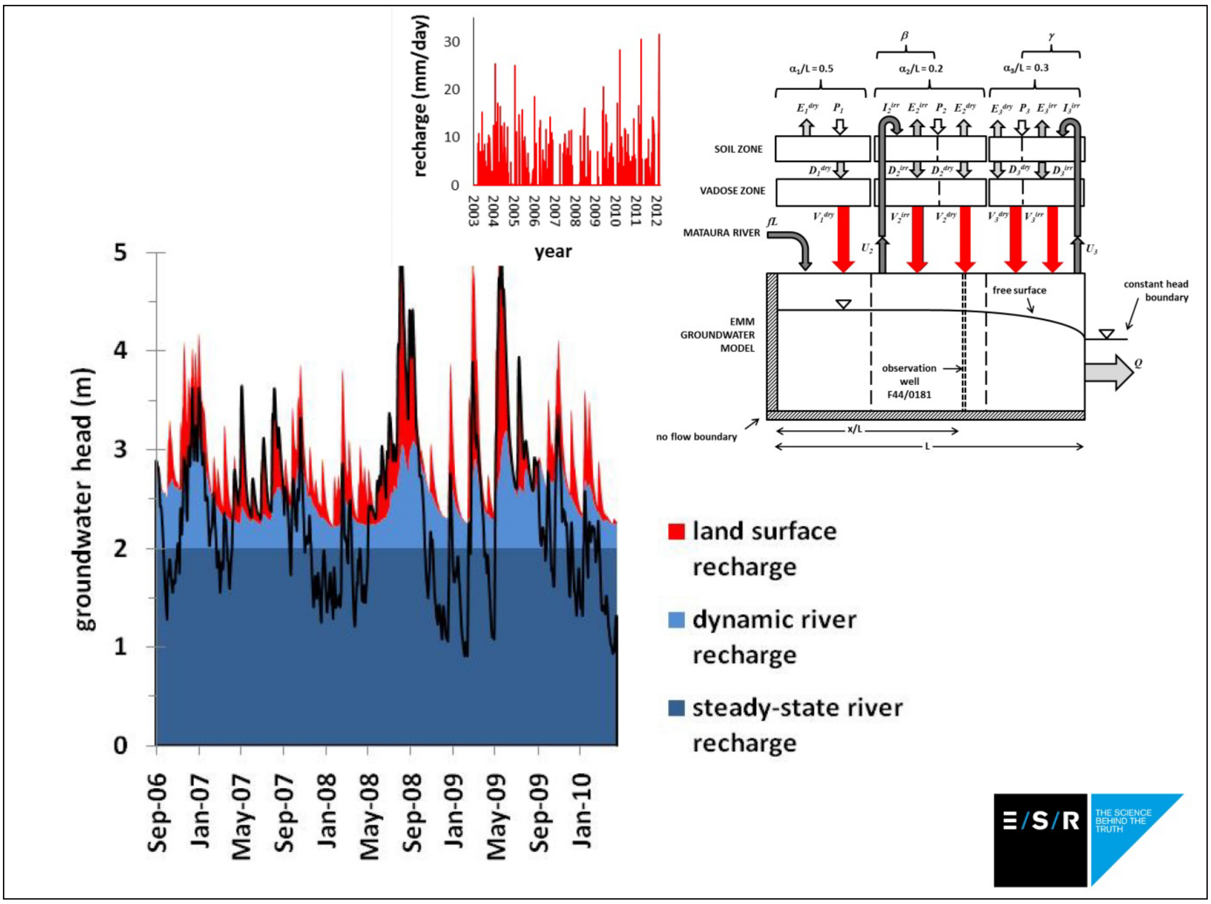
Continuous groundwater level data well F44/0181

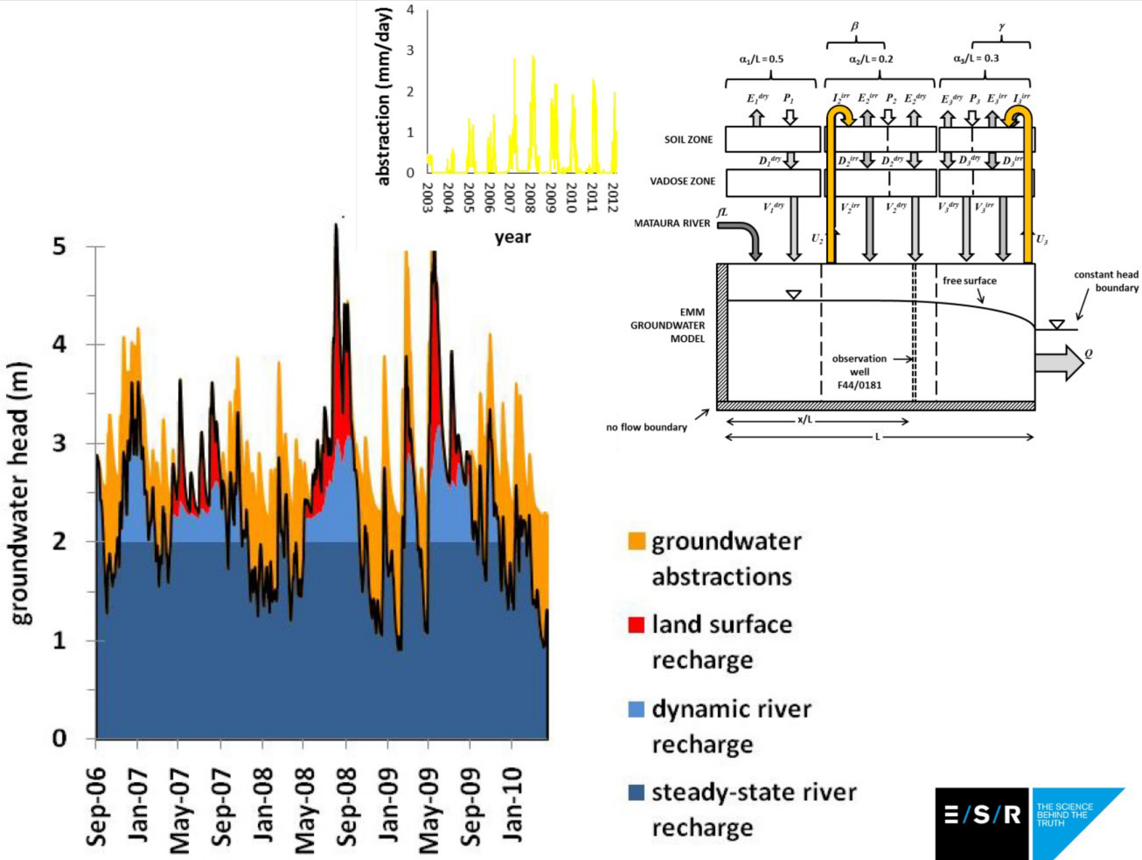




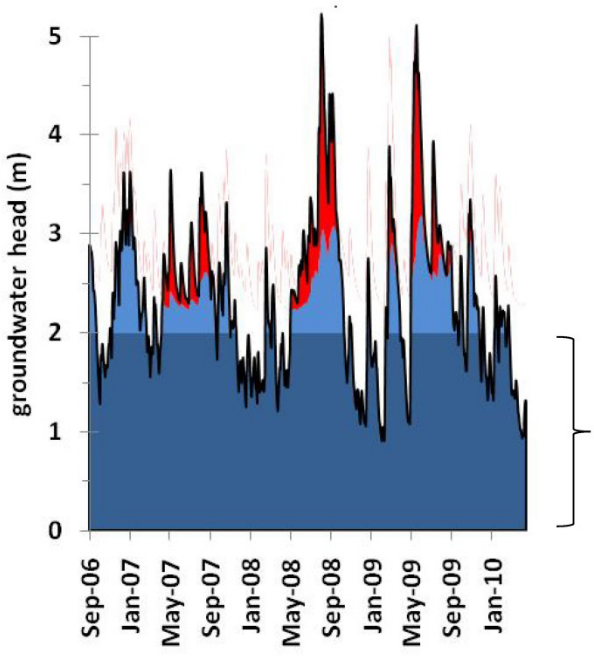



river losses (m³/s)
year
groundwater head (m)
SOIL ZONE
VADOSE ZONE
MATAURA RIVER
EMM GROUNDWATER MODEL
free surface
constant head boundary
observation well F44/0181
no flow boundary
dynamic river recharge
steady-state river recharge
E/S/R
THE SCIENCE BEHIND THE TRUTH


recharge (mm/day)
year
groundwater head (m)
SOIL ZONE
VADOSE ZONE
MATAURA RIVER
EMM GROUNDWATER MODEL
free surface
constant head boundary
observation well F44/0181
no flow boundary
land surface recharge
dynamic river recharge
steady-state river recharge
E/S/R
THE SCIENCE BEHIND THE TRUTH



Concept of groundwater base-level H_0



Estimated parameter values:

H_0 = 125.73m asl

S = 0.16

T/SL^2 = 0.009

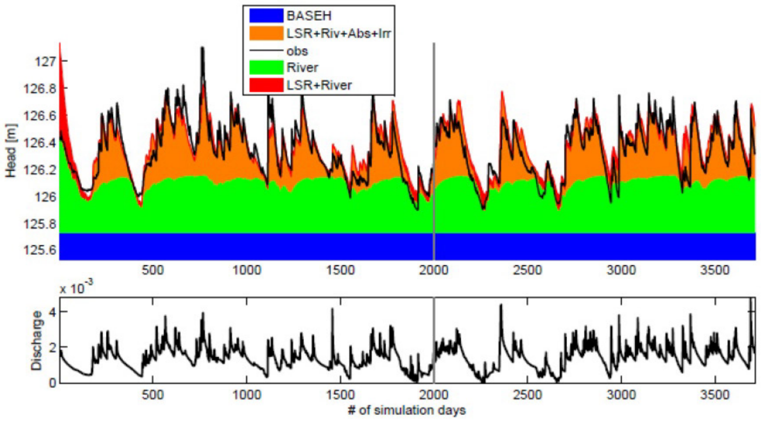
x/L = 0.12

Aquifer residence time = $1/\varepsilon(1)$ = approx. 48 days

[steady-state] base-level, H_0

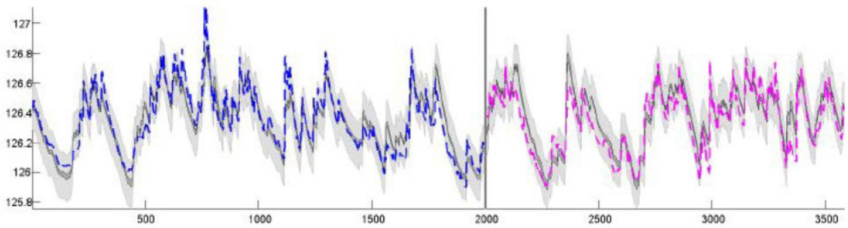
Head; well F44/0181

aquifer discharge



Nash-Sutcliffe model efficiency index, N = 0.87

95% confidence limits in modelled groundwater levels



calibration period **prediction period**

19

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Rupp DE, Schmidt J, Woods RA, Bidwell VJ (2007). Analytical assessment and parameter estimation of a low-dimensional groundwater model. Journal of Hydrology 143-154.

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Sloan, W.T., 2000. A Physics-Based Function for Modeling Transient Groundwater Discharge at the Watershed Scale. Water Resources Research 36 (1): 225–241.

20

Eigenvalues

$$\varepsilon_m = \left[\frac{(2m-1)\pi}{2}\right]^2 \frac{T}{SL^2}$$

Difference equation describing state in conceptual linear storage reservoir (*k* is time integer):

$$l_m(k) = l_m(k-1)e^{-\varepsilon_m} + \frac{[1-e^{-\varepsilon_m}]}{\varepsilon_m}\sum_{j=1}^{3} B_{mj}R_j(k)$$

distributed recharge

Groundwater level:

$$h(x,k) = \sum_{m=1}^{n} A_m(x)l_m(k)$$

Eigenfunctions

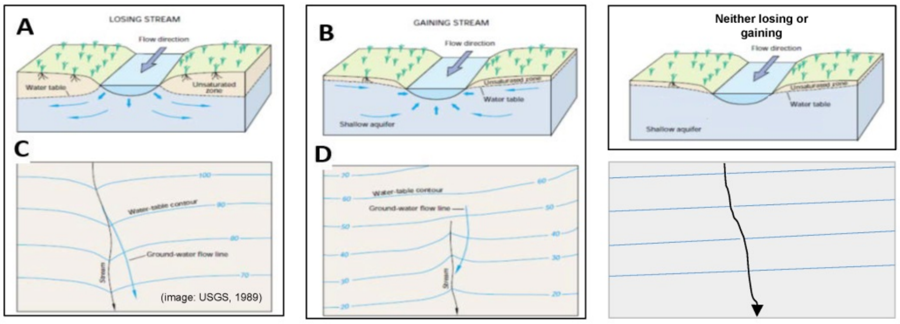
$$A_m(x) = \frac{cos\left[\left(2m-1\right)\frac{\pi}{2}\left(\frac{x}{L}\right)\right]}{S}$$

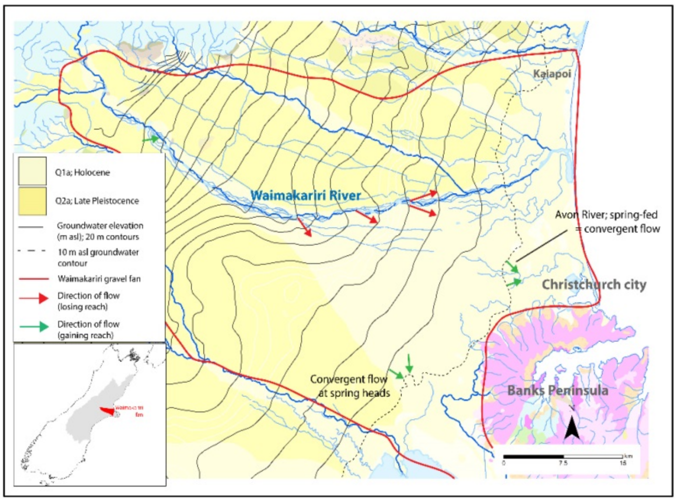
Aquifer discharge:

$$Q_{aq}(k) = \sum_{m=1}^{20} F_m\, \varepsilon_m l_m(k) \qquad F_m = \frac{2(-1)^{m+1}}{(2m-1)\pi}$$

21

Piezometric contours as an indicator of SW-GW interaction

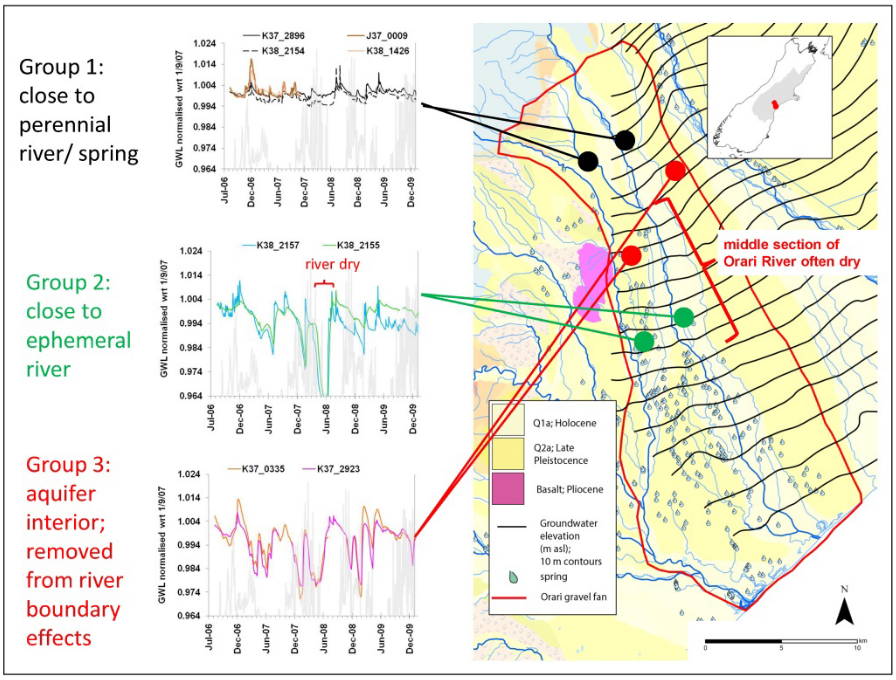




Wamakariri River and spring-fed streams about Christchurch city example

22

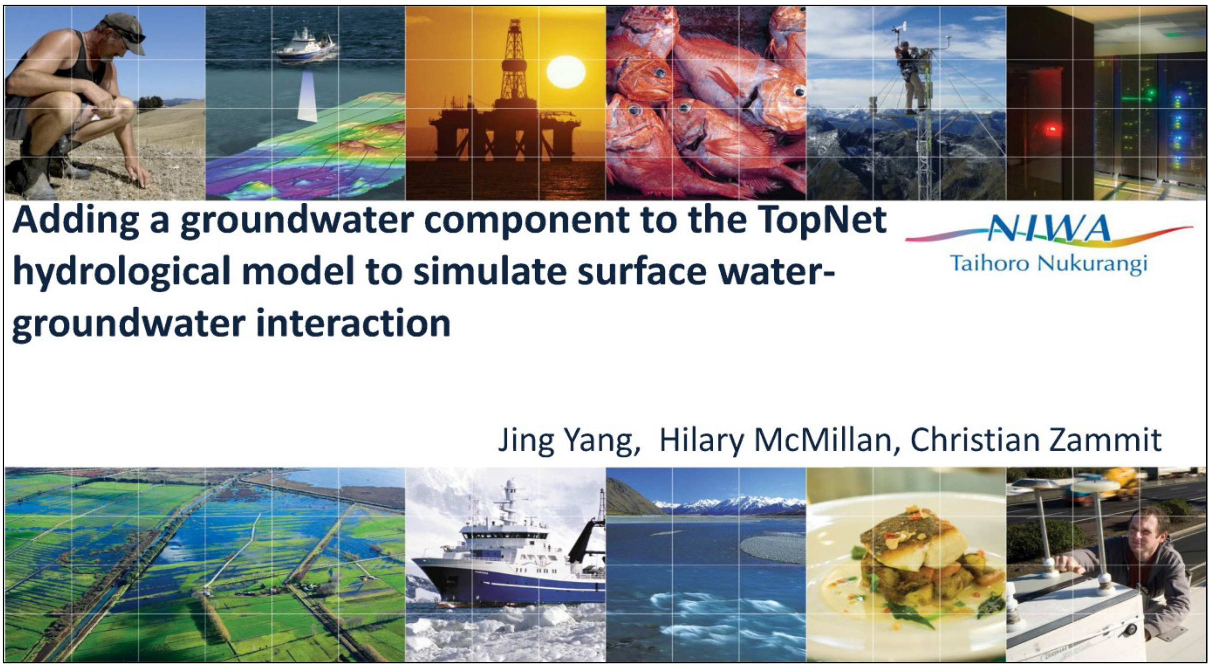
- **Geological and hydrological controls on flow direction.**
- **Piezometric contours as an indicator of gains/losses.**
- **Dynamics of groundwater levels symbolic of relationship with surface water.**

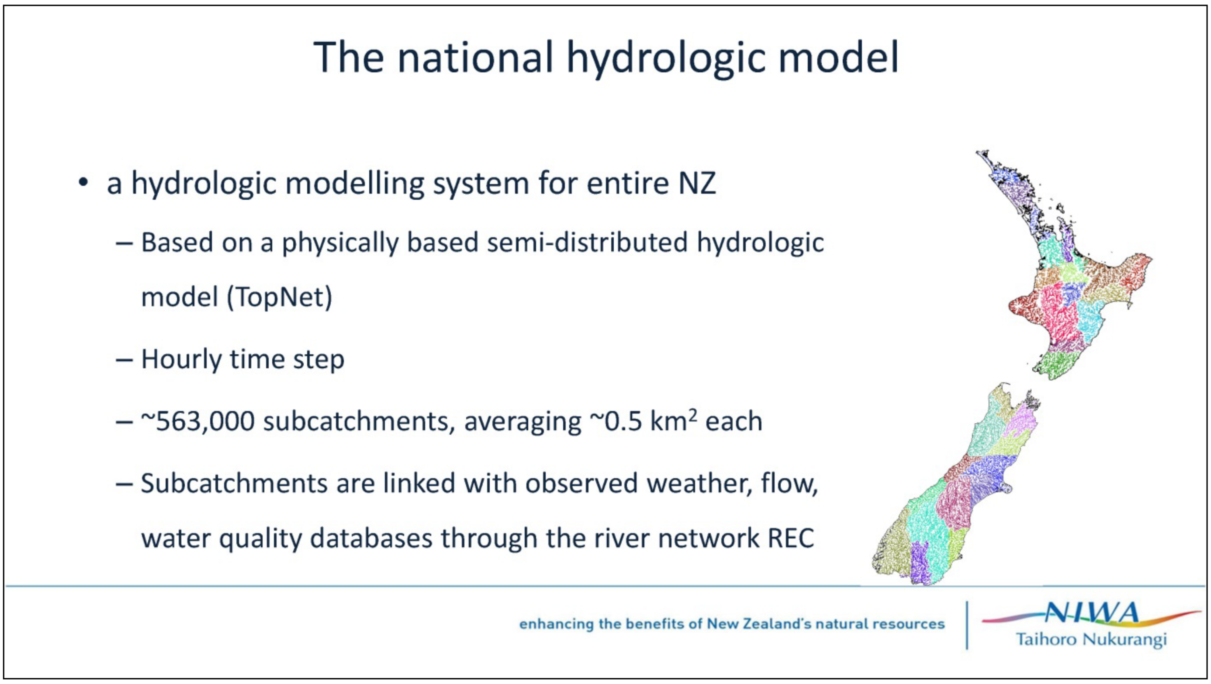


Orari River, South Canterbury. New Zealand's youngest river?

23

4.2.11 TopNet hydrological model
Facilitator: Jing Yang, NIWA





- Main problem:

fail to simulate river flow in some plains where there are losing and gaining rivers

  – Groundwater system is simulated as individual reservoirs

  – It does not consider surface water-groundwater interaction

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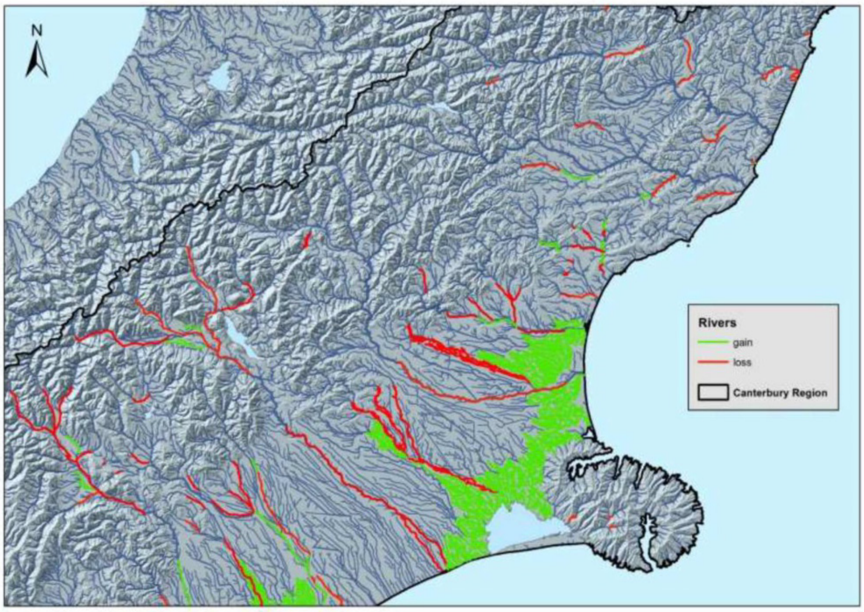

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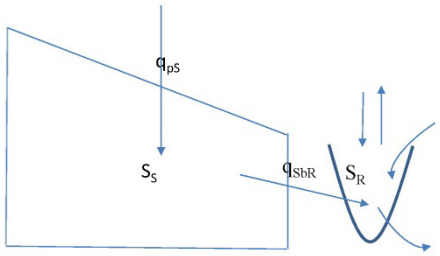
Gaining and losing reaches in Central Canterbury (Horrell et al., 2014**)**

Original TopNet groundwater and river system



– Groundwater stores are independent (corresponding to subbasins)
– No river losing/gaining
– River always accumulates water

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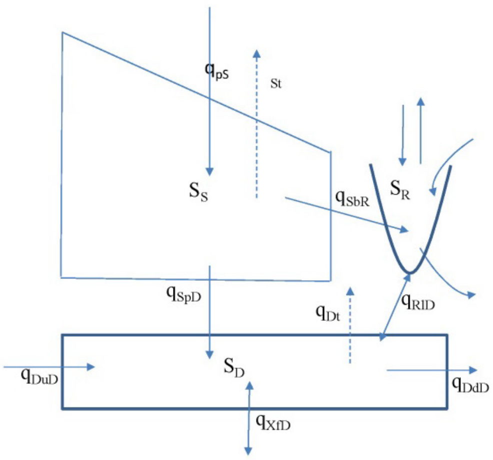
- Our approach

S_S –shallow aquifer
S_R - stream
S_D –deep aquifer



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- Features
  - Based on the built-up national TopNet
  - Predefined groundwater flow direction
  - Conceptual
  - But combine local information
    - Incorporate local losing/gaining information based on survey/measurements (empirical and statistical)
    - Establish the relationship between storage and groundwater indicators (e.g. groundwater table)
    - Make use of previous groundwater researches (e.g. ELFMOD)
  - less time-consuming for computation

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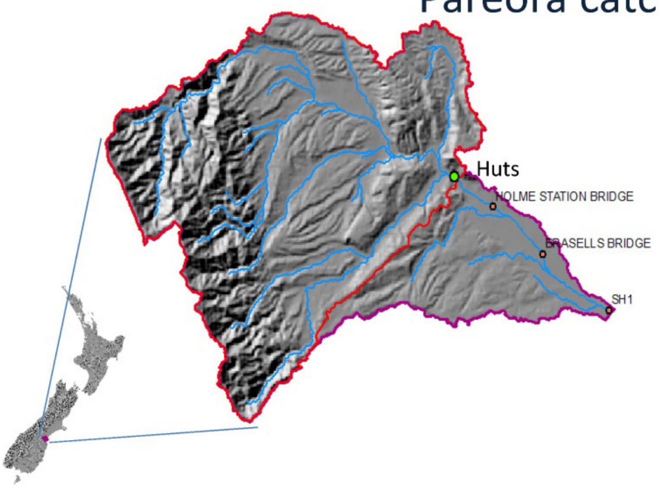
Pareora catchment



- Size: 539 km2
- Precipitation: 698 mm/year
- Flow station: Huts and SH1 (State Highway 1)
- Concurrent gaugings: Holme Station Bridge, Brasells Bridge, and SH1

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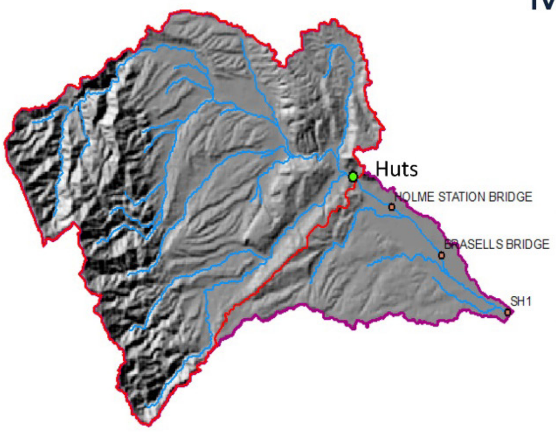

Model Assumptions

- Streams above Huts: no losing & no gaining (Groundwater is inactive)
- Groundwater flow direction in the lower Pareora: same as river system
- Streams
  - Huts ~ BB : losing
  - BB ~ SH1 : gaining
- Groundwater at the outlet: returns to stream and flows to sea

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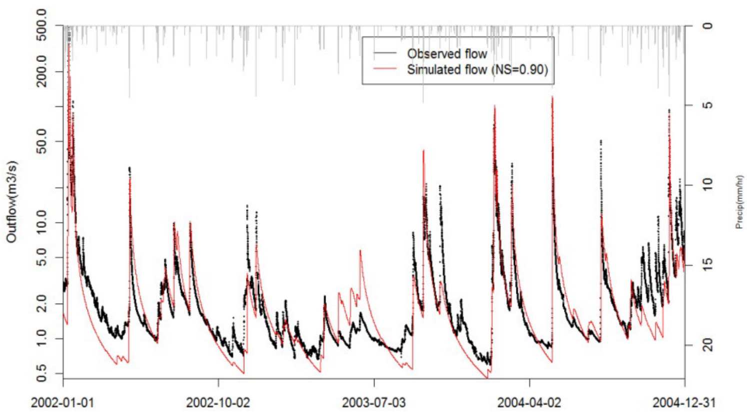
Calibration at Huts



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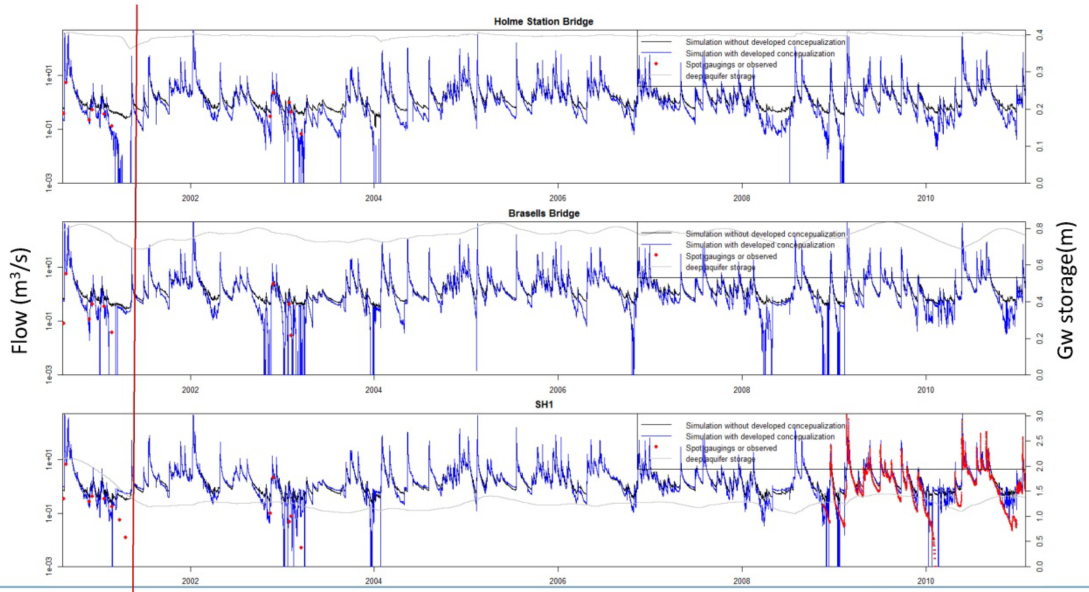

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Conclusion and outlook

- A general surface water-groundwater interaction is realized within the national hydrological model
  - Conceptual but aims to incorporate the local hydrological information
- Initial simulation results are promising
- Further development and test in several watersheds with losing/gaining rivers, & comparison with existing groundwater studies (e.g. MODFLOW)
- Collaboration with other research institutes / regional councils
- Long term aim is to apply this to the national model

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Acknowledgement

- This work is Funded by New Zealand’s Ministry for Business Innovation and Enterprise via the **Waterscape** programme (C01X1006) and NIWA Freshwater core funded activities.
- Thanks Ecan for providing all the data
- Thank Philippa and Graeme for discussion

enhancing the benefits of New Zealand's natural resources

NIWA
Taihoro Nukurangi

4.2.12 Participatory exercise

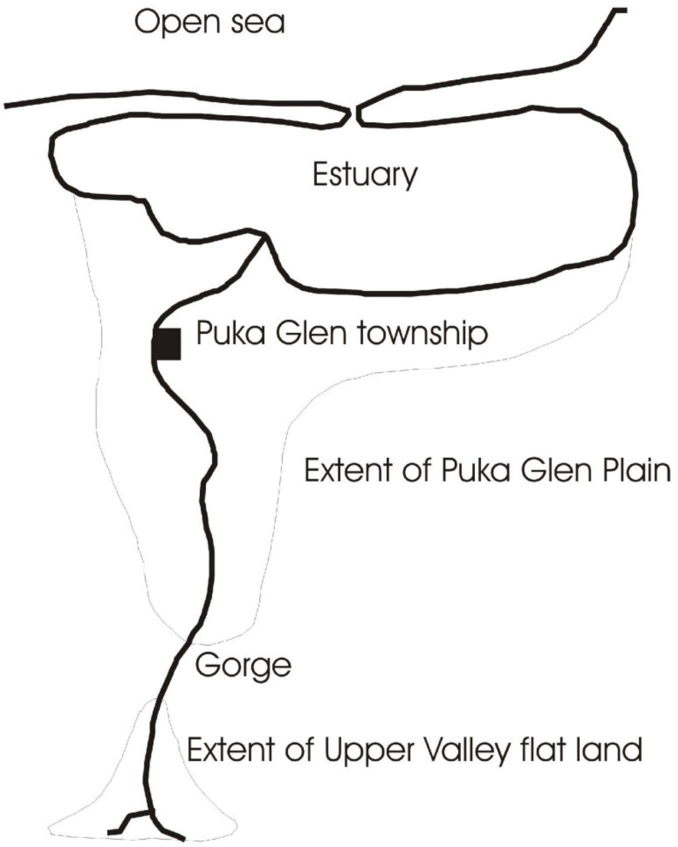
4.2.12.1 Exercise modelling

GROUNDWATER AND SURFACE WATER INTERACTION

Session: modelling
Workshop tutorial: characterisation

1

Exercise 1: Conceptual model of geology in the Puka Glen catchment

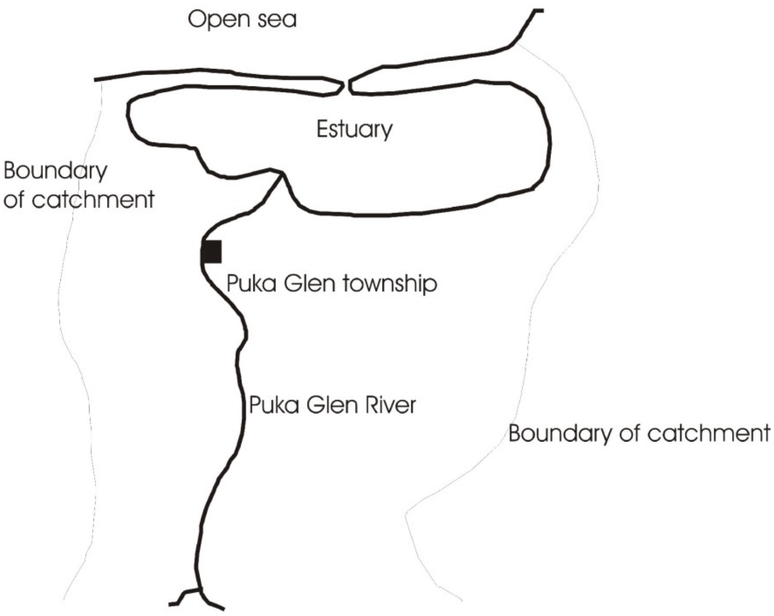


2

Exercise 1: Conceptual model of geology in the Puka Glen catchment

Puka Glen catchment. The catchment of Puka Glen includes:

- alluvial flats on the Puka Glen Plain and the upper valley;
- marine and estuarine sediments near the coast; and
- greywacke (basement) elsewhere



3

Exercise 1: Conceptual model of geology in the Puka Glen catchment.

Only one well has been drilled in the area that we can find records for.

This well was drilled in the plain many years ago and has a moth-eaten geological log showing only:
- 'gravel, clay and sand to about 32 feet, with some water';
- 'hard rock below about 32 feet'

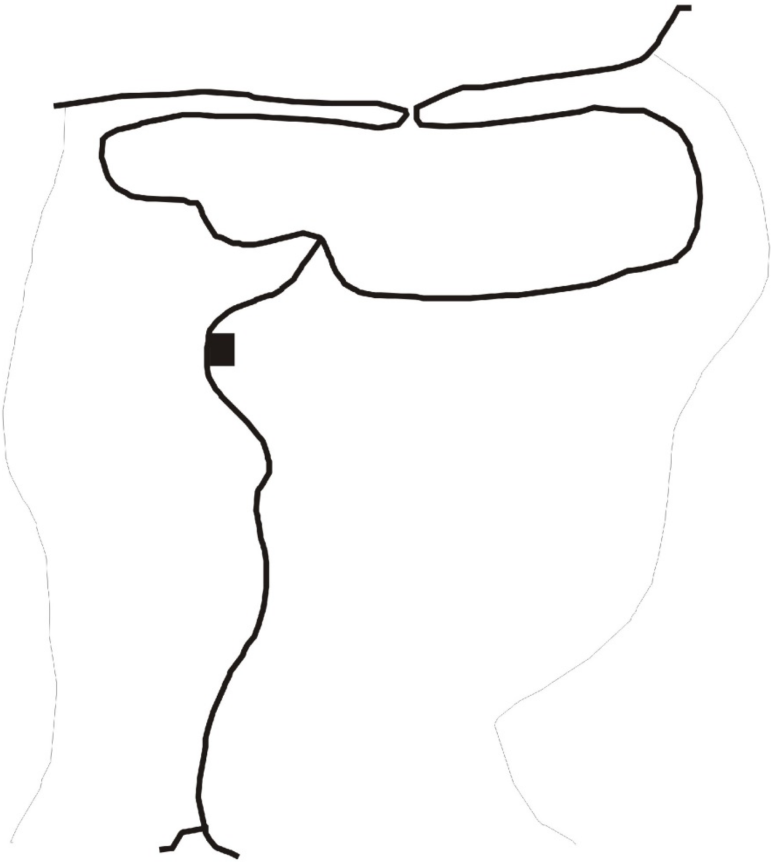
We are not sure about the location of the well as the well log indicated the property owners name, and nothing else.

The National Geological Survey plan to map the area properly in 5 years time.

4

Exercise 1: Conceptual model of geology in the Puka Glen catchment

Geological map



5

Exercise 1: Conceptual model of geology in the Puka Glen catchment

This page for:

- geological cross section across the catchment including the Puka Glen Plain
- geological cross section up the valley including the coast, estuary, Puka Glen Plain and Upper Valley.

6

Exercise 2: Water budget

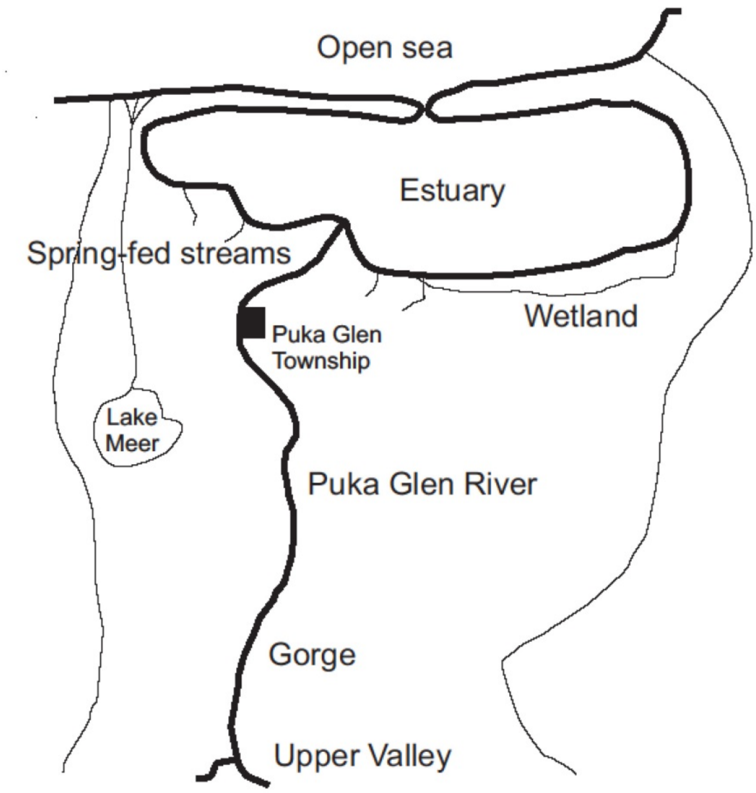
The town of Puka Glen takes water from a spring
- other springs occur in the catchment
- spring-fed streams, and a wetland, are located near the estuary

Puka Glen River discharges into the estuary

Lake Meer is in the hills, and discharges to a river that flows to the coast

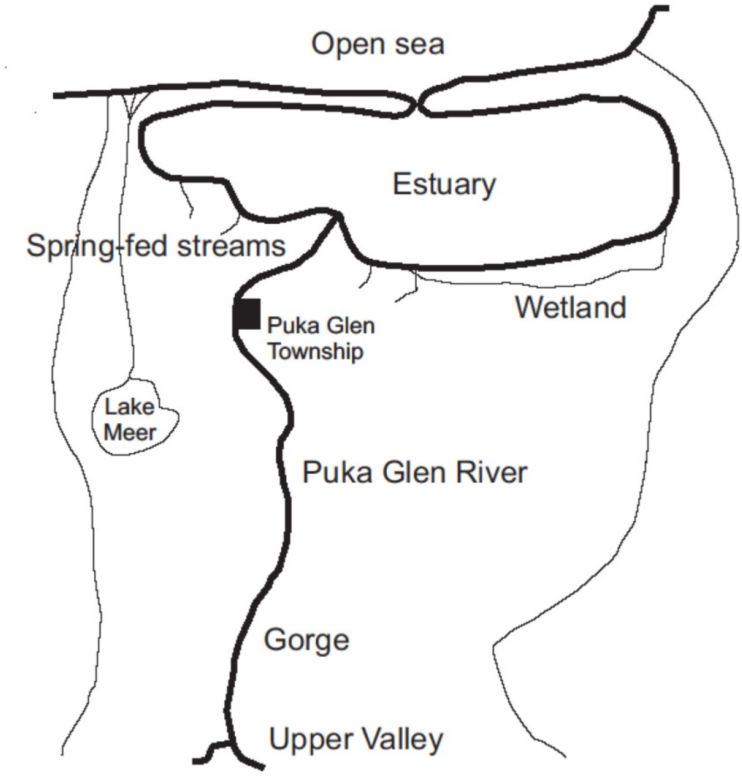
7

Exercise 2: Draw water budget components on this map



8

Exercise 2: Draw groundwater contours on this map



9

Exercise 3: calculate a water budget for Puka Glen Plain

- units for water budget: m^3/s
- please calculate a water budget that balances
- useful numbers include:

- water use by the town: 100,000 m^3/year
- rainfall on the Puka Glen catchment: 800 mm/yr
- evaporation from the plain: 550 mm/yr
- area of Puka Glen Plain: 7000 ha
- area of hills around the plain downstream of the gorge: 10,000 ha
- area of the Lake Meer catchment: 1,000 ha
- mean flow of river at gorge: 16.5 m^3/s
- mean flow of river at Puka Glen: 15.5 m^3/s
- flow in spring-fed streams near estuary: 3 m^3/s

- stream depletion calculation (Jenkins):

Pumped well-to-river distance (m)	Time (days)	Stream depletion, fraction of pumped well flow rate (%)
10	7	99
	30	99
	150	100
	365	100
100	7	87
	30	93
	150	97
	365	98
500	7	40
	30	68
	150	86
	365	91
1000	7	9
	30	41
	150	72
	365	81
5000	7	0
	30	0
	150	7
	365	24

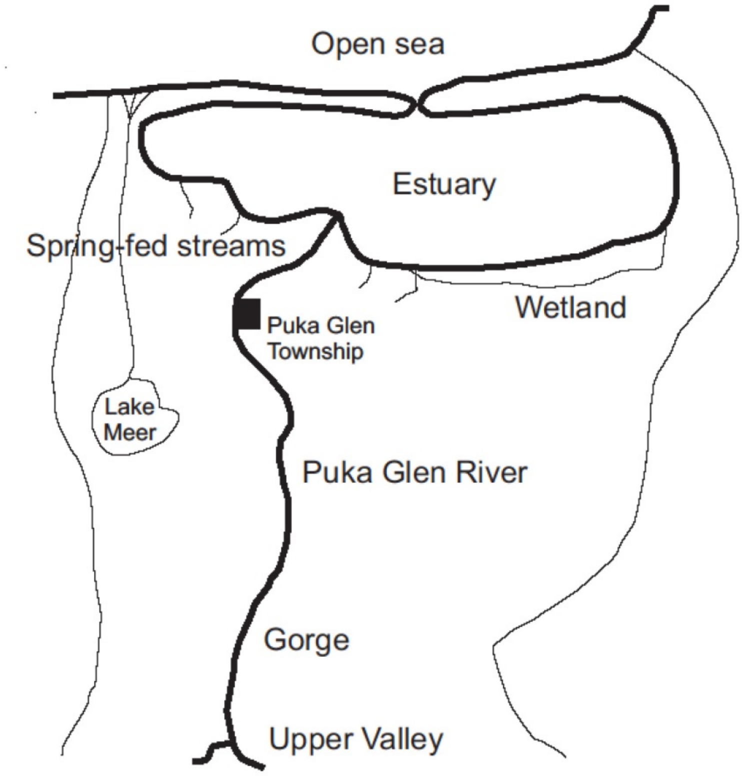
10

Exercise 3: Puka Glen Plain water budget

Page for water budget calculations

11

Exercise 3: Puka Glen Plain water budget
Write water budget components on this map



12

Exercise 4: Groundwater- surface water interaction and policy

The community's water management aims:

1) The community wishes to protect the summer low-flow in the Puka Glenn River and flow in spring-fed streams

2) The district council insists on security of supply for the town water supply

3) Central government have funding to develop agricultural irrigation

To do:

- List the key elements of a water management policy that addresses these aims
- The policy is to include "bright lines", therefore decide on the pumped well-to-river distance, from the stream depletion table above, and map the lines
- Please think about the modelling approach you would take to understand groundwater-surface water interaction.

13

Exercise 4: Groundwater- surface water interaction and policy

This page is for notes

14

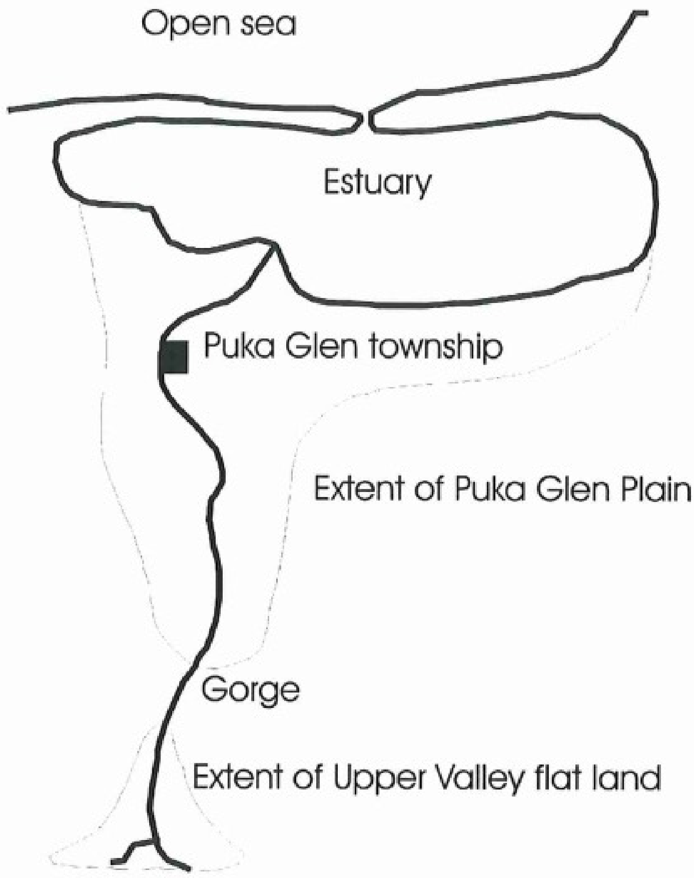
4.2.12.2 Example modelling

GROUNDWATER AND SURFACE WATER INTERACTION

Session: modelling
Workshop tutorial: characterisation

1

Exercise 1: Conceptual model of geology in the Puka Glen catchment

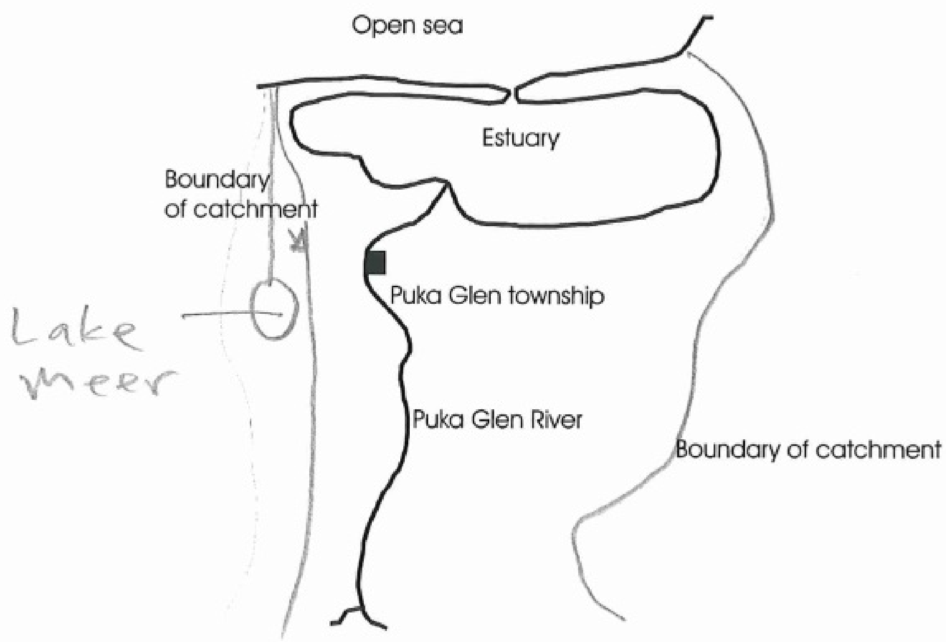


2

Exercise 1: Conceptual model of geology in the Puka Glen catchment

Puka Glen catchment. The catchment of Puka Glen includes:

- alluvial flats on the Puka Glen Plain and the upper valley;
- marine and estuarine sediments near the coast; and
- greywacke (basement) elsewhere



3

Exercise 1: Conceptual model of geology in the Puka Glen catchment.

Only one well has been drilled in the area that we can find records for.

This well was drilled in the plain many years ago and has a moth-eaten geological log showing only:
- 'gravel, clay and sand to about 32 feet, with some water';
- 'hard rock below about 32 feet'

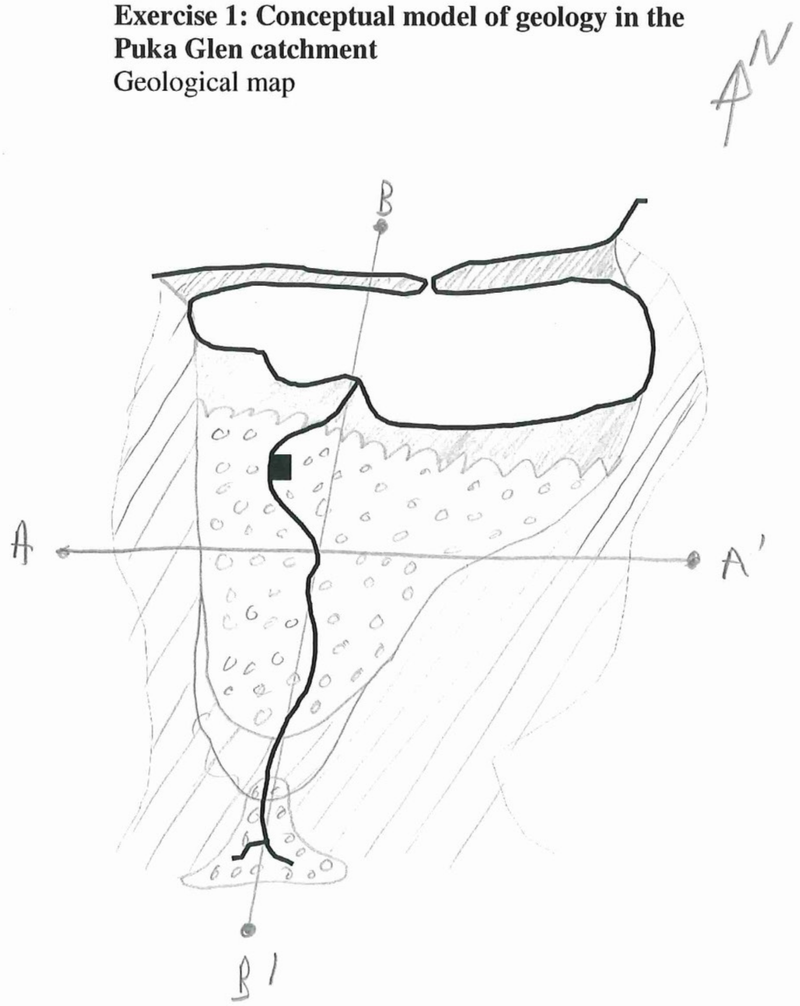
We are not sure about the location of the well as the well log indicated the property owners name, and nothing else.

The National Geological Survey plan to map the area properly in 5 years time.

4

Exercise 1: Conceptual model of geology in the Puka Glen catchment

Geological map



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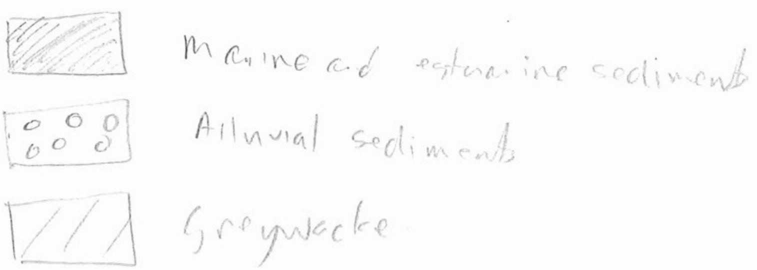

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- geological cross section across the catchment including the Puka Glen Plain
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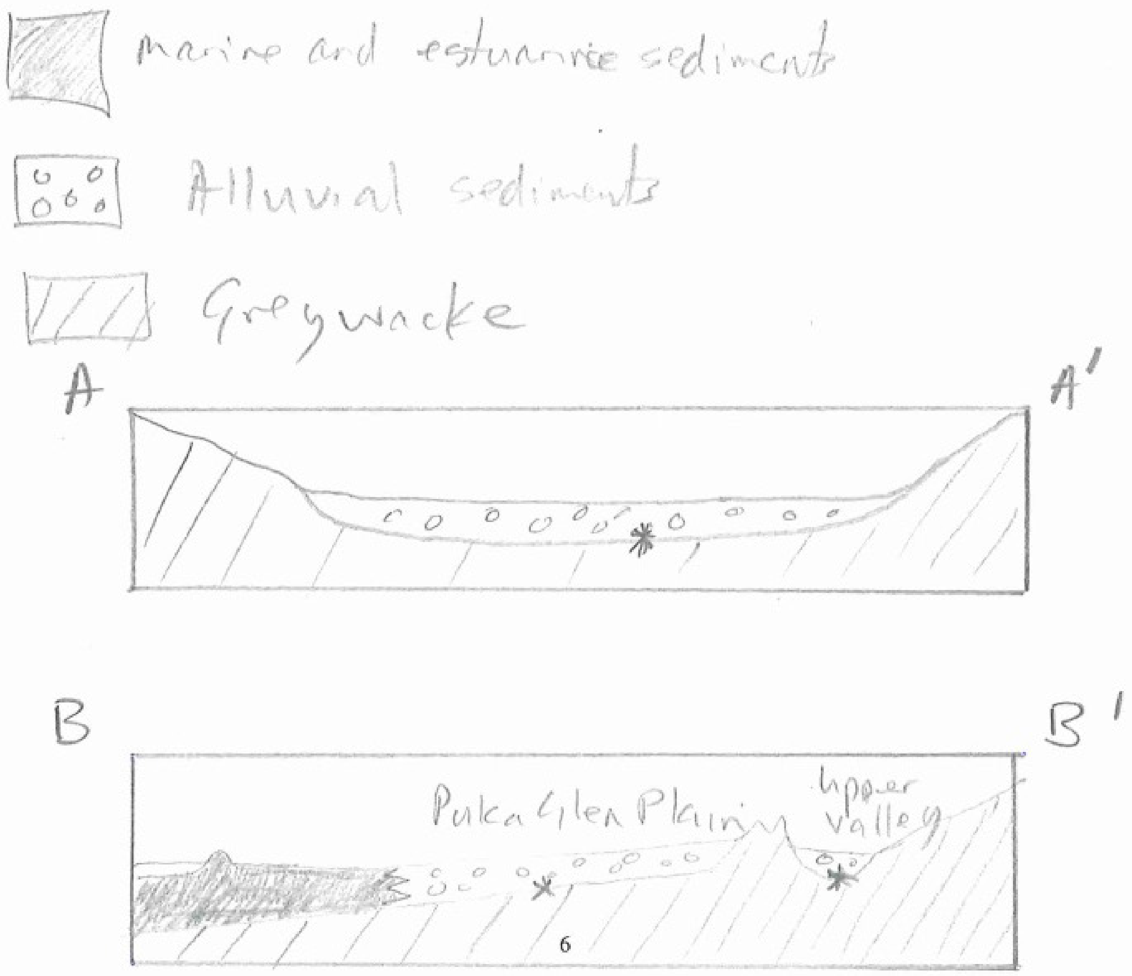

* Thickness of alluvial sediments unknown.

Exercise 2: Water budget

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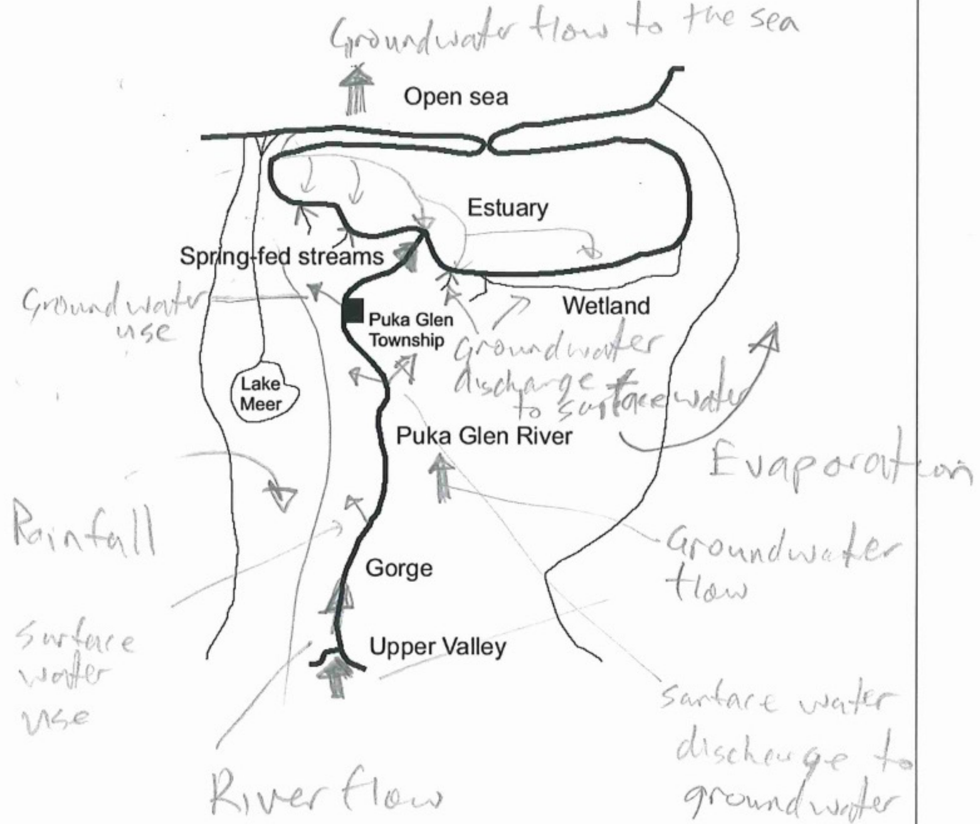
- spring-fed streams, and a wetland, are located near the estuary

Puka Glen River discharges into the estuary

Lake Meer is in the hills, and discharges to a river that flows to the coast

7

Exercise 2: Draw water budget components on this map

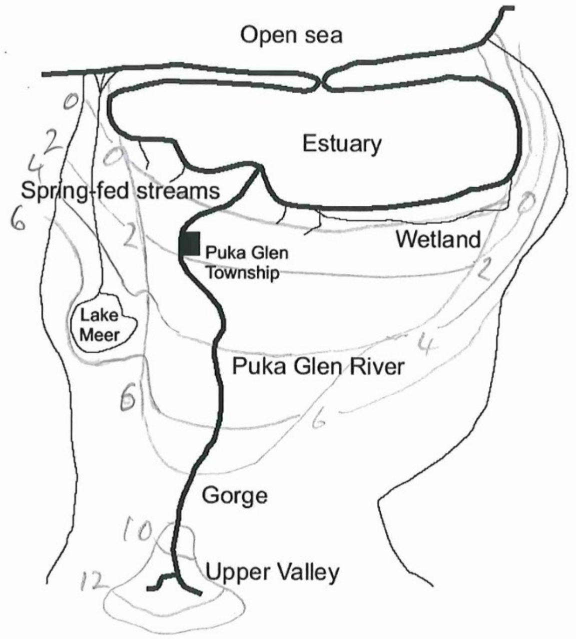


8

Water budget components of Puka Glenn

fix '0m contour'
fix 4m contour to show sea to gw (and wat label)

Exercise 2: Draw groundwater contours on this map



— Groundwater elevation (m)

9

Exercise 3: calculate a water budget for Puka Glen Plain

- units for water budget: m^3/s
- please calculate a water budget that balances
- useful numbers include:

- water use by the town: 100,000 m^3/year ✓
- rainfall on the Puka Glen catchment: 800 mm/yr
- evaporation from the plain: 550 mm/yr
- area of Puka Glen Plain: 7000 ha
- area of hills around the plain downstream of the gorge: 10,000 ha (i.e. in catchment of Puka Glen)
- area of the Lake Meer catchment: 1,000 ha
- mean flow of river at gorge: 16.5 m^3/s
- mean flow of river at Puka Glen: 15.5 m^3/s
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	30	41
	150	72
	365	81
5000	7	0
	30	0
	150	7
	365	24

10

Exercise 3: Puka Glen Plain water budget
Page for water budget calculations

water use by town = $\frac{1 \times 10^5 \text{ m}^3/\text{year}}{31.5 \times 10^6 \text{ secs/year}}$

$= 3 \times 10^{-3}$ m³/sec
$= 3$ l/sec

Rainfall on the Plain = 0.8 m/year * 7000 × 10^4 m²
= 5.6×10^7 m³/year
= 1.8 m³/sec

Evaporation from Plain = 0.55 m/year × 7000 × 10^4 m²
= 3.9×10^7 m³/year
= 1.2 m³/sec

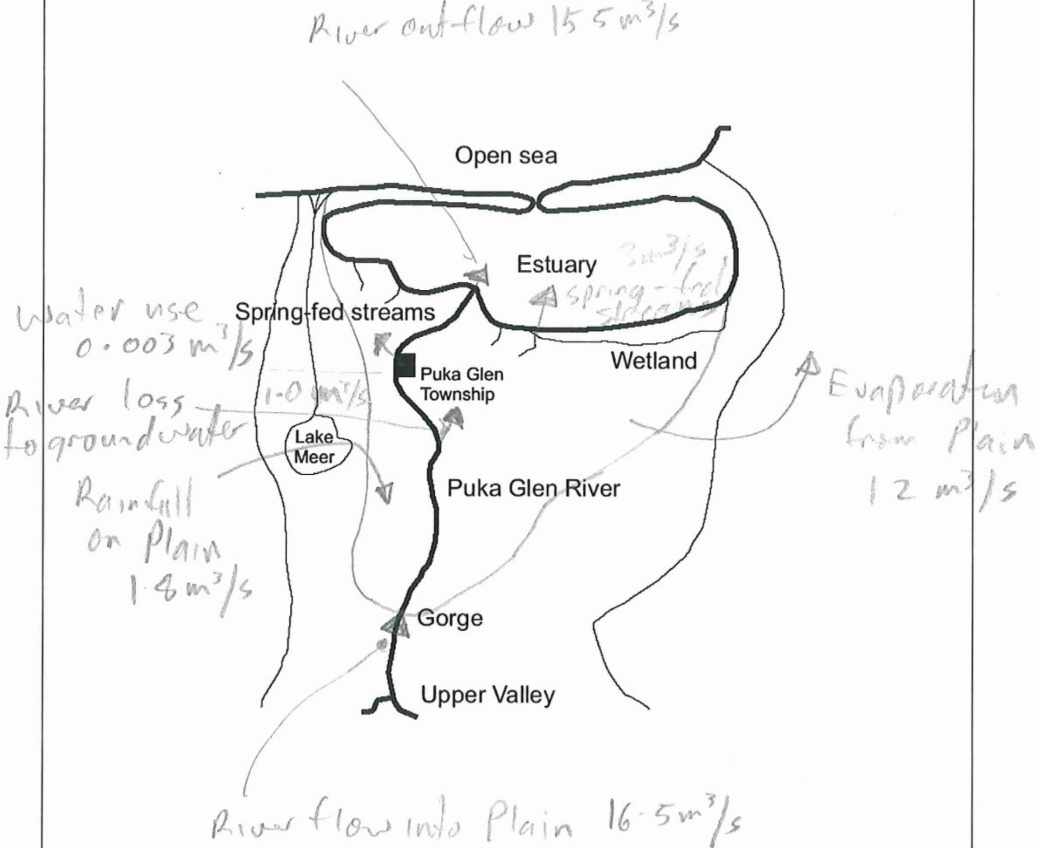
Rainfall on Puka Glen catchment d/s of gorge = 0.8 m/year * (7000 + 10000) * 10^4 m²
= 1.4×10^8 m³/year
= 4.3 m³/sec

11

The lake catchment is not part of the water budget

Exercise 3: Puka Glen Plain water budget

Write water budget components on this map



12

Exercise 4: Groundwater- surface water interaction and policy

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- Please think about the modelling approach you would take to understand groundwater-surface water interaction.

13

Exercise 4: Groundwater- surface water interaction and policy

This page is for notes

Some key elements of policy

Policy	Aims
A. surface water allocation policy – river and spring-fed streams	1. Preservation of groundwater recharge 2. Maintenance of spring flows 3. Preservation of town supply 4. Preservation of river flows and flow distribution 5. Preservation of ecology in surface water
B. Ground water allocation policy	2, 3, 5 above 6. Maintenance of groundwater volume

14

Policies (cont.)

	Aims
C. Surface and groundwater use policies	7. Water use efficiency 8. Water use monitoring 9. water use trading 10. Water-use clawback 11. water allocation clawback 12. water use effects assessment criteria 13. Groundwater - surface water interaction effects
D. water storage	14. Investigation criteria 15. Construction standards 16. Effects assessment criteria
E. Land use (urban, dry land and irrigated)	1, 2, 3, 4 5 17. Economic development 18. Assess of effects criteria - physical, biophysical, economic

15

'Bright lines' policy:

This policy requires a decision based on the table on page 10. Criteria for this decision include: the calculation, 'reasonableness' and practicality. For example the policy could be:

'Wells within 1000m of the river will be considered as surface water takes for the purposes of assessment of surface water allocation and surface water use'

16

SESSION 5: GW-SW INTERACTION UNCERTAINTY ANALYSIS FACILITATOR: CATHERINE MOORE, GNS SCIENCE

5.1 INTRODUCTION

- Objective 1: Understand why uncertainty analysis is important.
- Objective 2: Understand the strengths and weaknesses of uncertainty analysis.
- Objective 3: Understand how to communicate and use the uncertainty results.

5.2 PRESENTATIONS

5.2.1 Uncertainty analysis of flux calculation in GW-SW interaction
Facilitator: Catherine Moore, GNS Science

Session outline

- Presentations (25 mins)
  - Cath Moore
  - Paul White
- Participatory learning (25 mins)
- Reporting back (1-2 m per table) – provide a sentence which communicates uncertainty for a policy, risk based decision or a field monitoring program based on Puka Glen catchment.

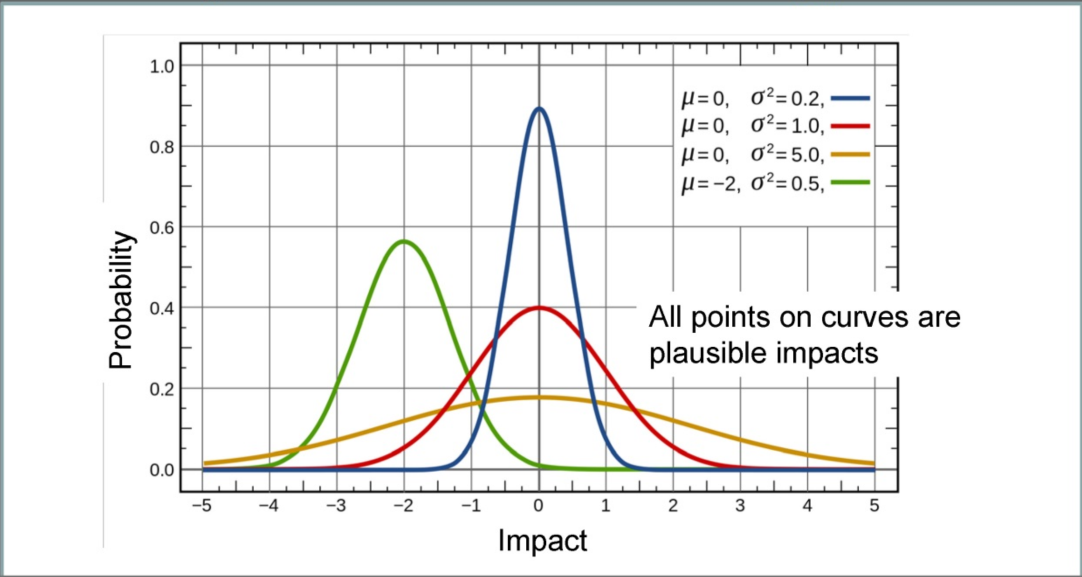
GNS Science

Why analyse uncertainty

- Models cannot tell us what will happen, but they can tell us what won't happen.
- Models with uncertainty analysis can tell us what won't happen.
- Can also tell us which data reduces uncertainty the most.

GNS Science

Models cannot tell us what will happen, but if correct they can tell us what won't happen.



Model outputs give distribution of predicted impacts. This distribution is consistent with available data and system knowledge, and provides bounds on what we do not know, i.e. "**Models with uncertainty analysis can tell us what won't happen**".

What is a correct model?

- **The model will not give a type II statistical error, i.e. it will not fail to detect an effect that is present, e.g.**
  - **failure to predict stream eutrophication;**
  - **failure to predict long term drying up of streams.**
- **Avoided if sufficient parameter detail to which a prediction is sensitive is included in the model (or at least accounted for in a model simplification correction). Superficially this may seem to increase uncertainty.**

GNS Science

Objectives

- When uncertainty analysis is important in gw-sw problems?
- Causes of uncertainty in gw-sw models.
- Uncertainty analysis strengths and weaknesses for sw-gw problems.
- How to communicate and use the uncertainty results for gw-sw problems.

GNS Science

At end of session be able to

- Identify when uncertainty quantification is required.
- Name the three main causes of uncertainty in gw-sw problems.
- Name three widely used uncertainty analysis methods, the main strength and weakness of each, plus the most common failing when applying these methods.
- Calculate uncertainty for an analytical model.
- Write a sentence communicating the uncertainty of a gw-sw flux estimate and how this informs either: (i) a risk based decision, (ii) a groundwater allocation policy and (iii) a field measurement and monitoring program.

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Main causes of uncertainty

- Measurement error
- Model simplification of real world complexity
- Insufficient data to support unique parameter estimate solution

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Measurement error

Usually the **smallest** component of uncertainty, and more measurements will **not** reduce this component of uncertainty

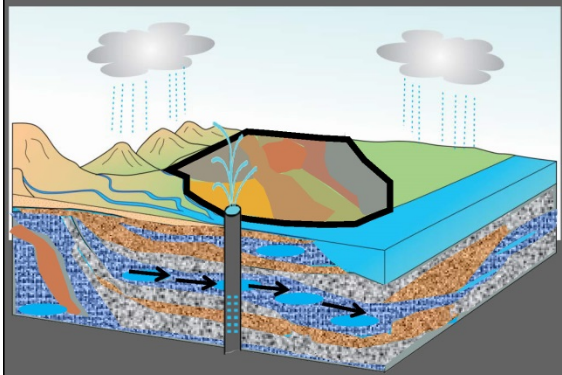


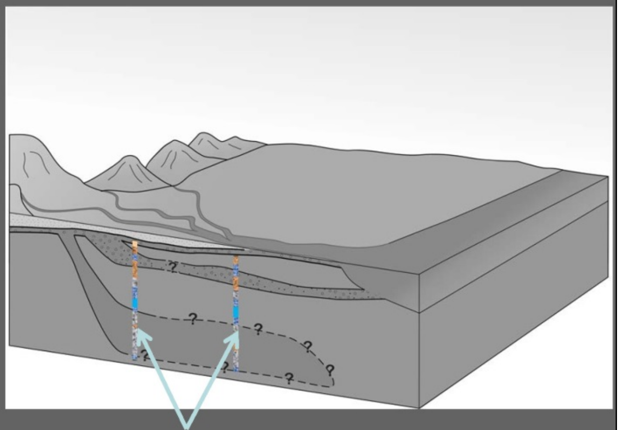


GNS Science

Data scarcity

Often a **big** source of uncertainty. **More measurements** significantly **reduce** this component of uncertainty. The larger the heterogeneity, the more this is important.



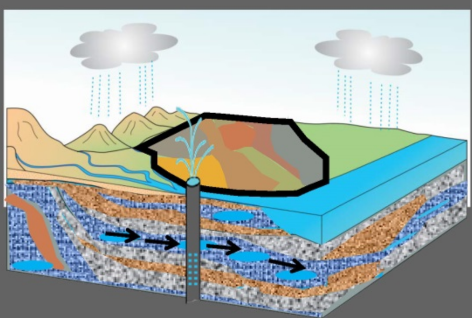


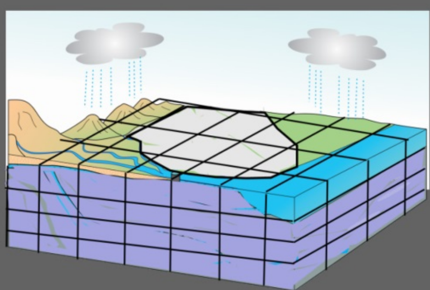
Two wells used to determine aquifer extents, flov and disposition of coastal boundary.

GNS Science

Model simplification of complex real world

May also be a **big** component of uncertainty, sometimes the **biggest**. Can create bias, undermining uncertainty quantification methods. More measurements will **not** reduce this component of uncertainty. Need to compare **complex** and **simple** model equivalents to quantify errors.

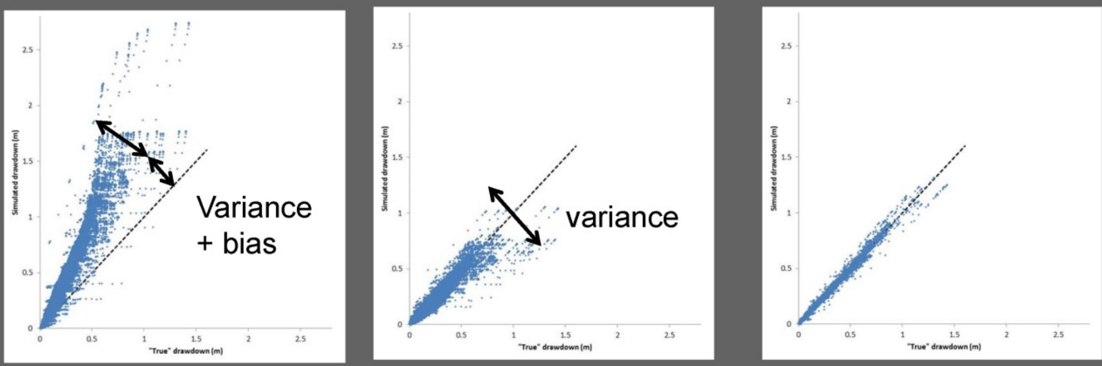




GNS Science 11

Calculating model simplification error

- Compare predictions made by simple and complex model for a stochastic sampling of model parameters to calculate error variance and any bias incurred by simplification.



GNS Science

When should we analyse uncertainty for gw-sw

- The cost of being wrong is not acceptable.
- Uncertainty is confounding environment court or stakeholder consultation on allocation planning.
- Model outputs closely scrutinised in public forum.
- Adaptive management, requiring risk based decisions.
- Need to maximise information from a field investigation budget -'data worth' method.
- ….can you add others?

GNS Science

When do we not need to analyse uncertainty for gw-sw

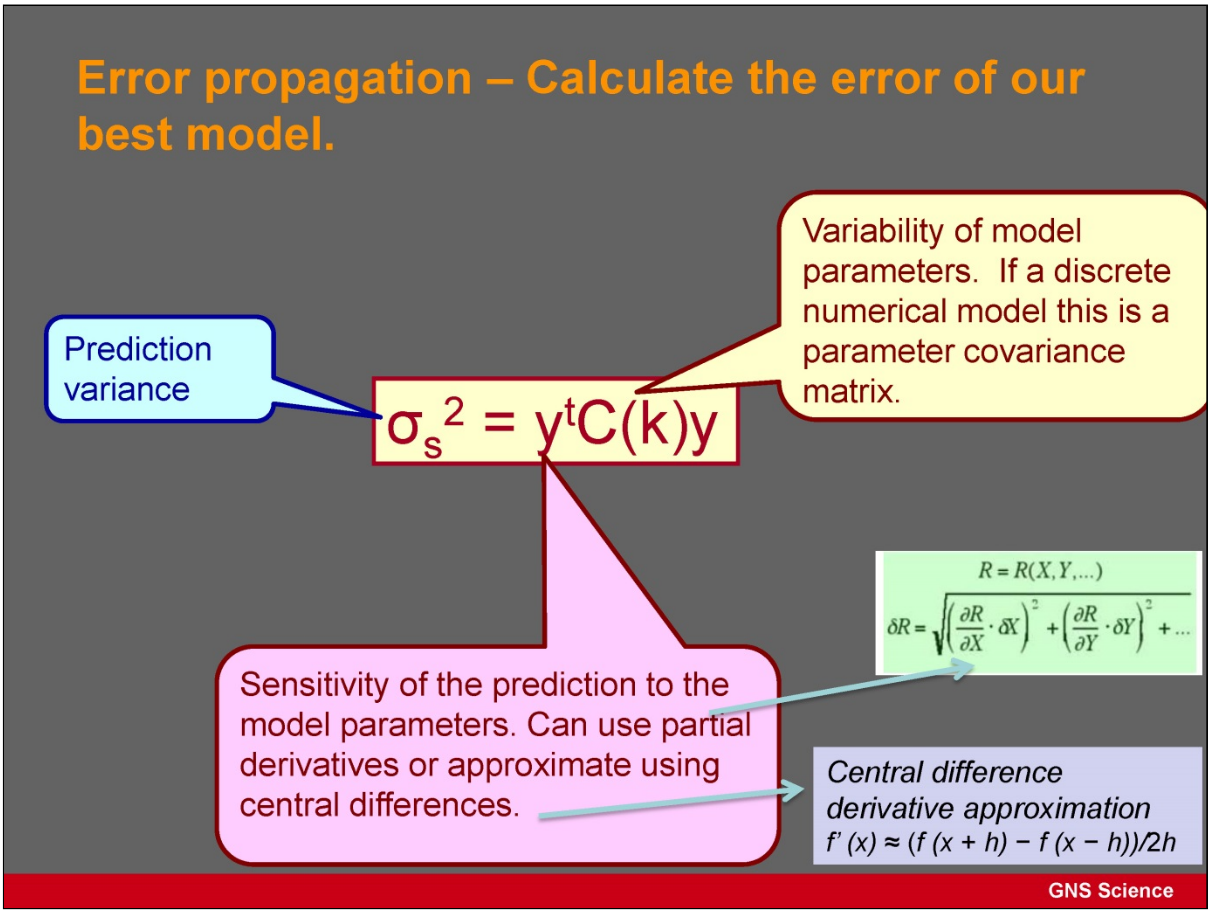
- Ranking of relative impacts are sought.
- Consequences of impact are insignificant.
- Most preliminary assessments (unless uncertainty is very significant and impacts feasibility).
- …can you add others?

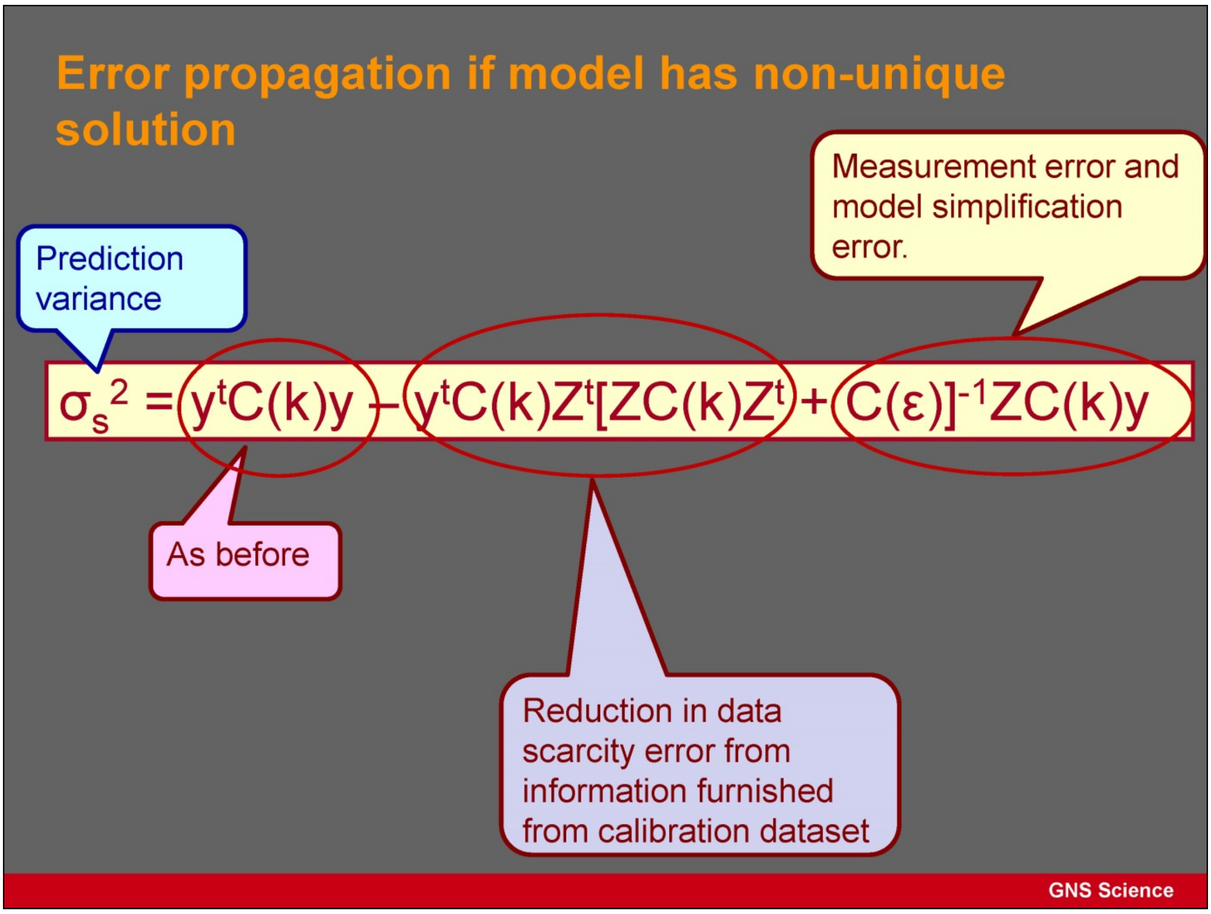
GNS Science

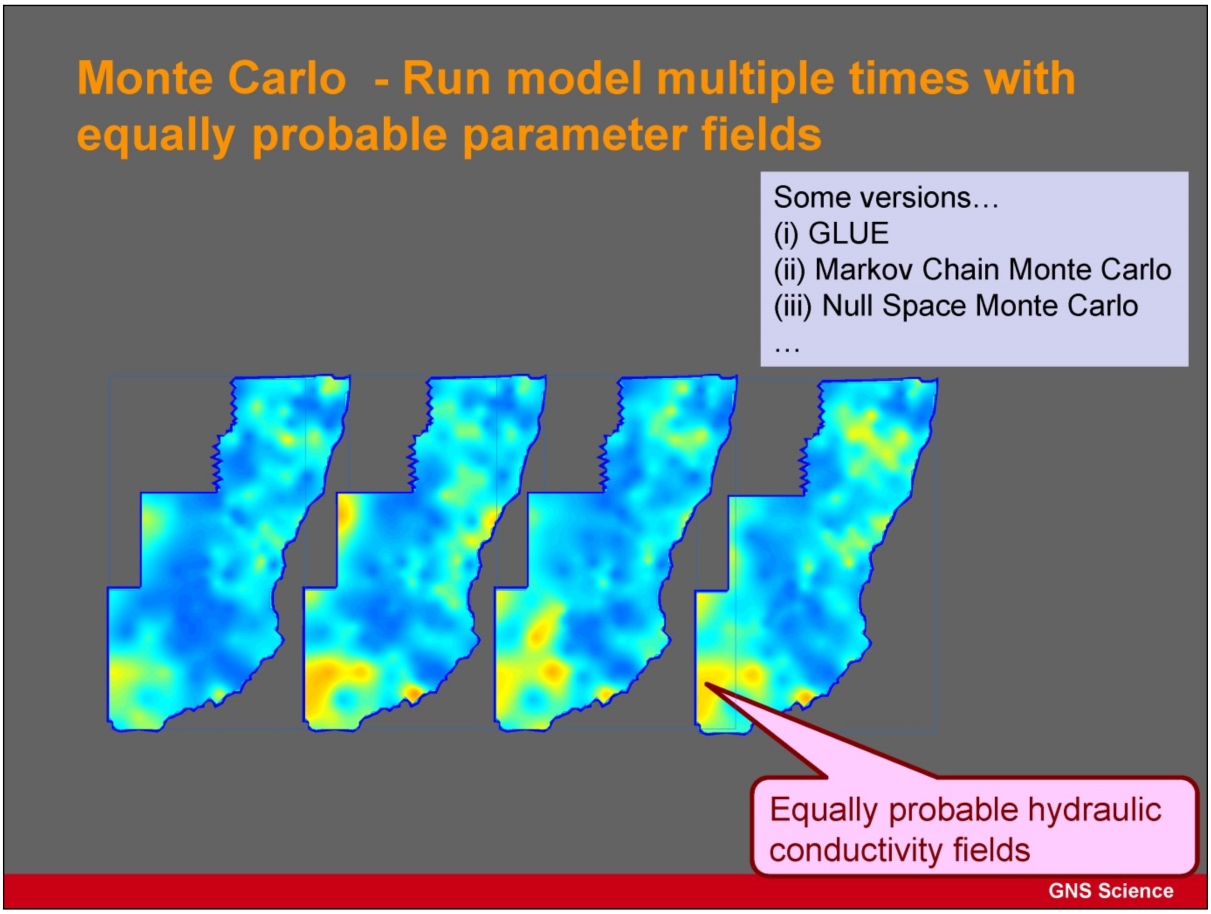
Methods for analysing gw-sw uncertainty

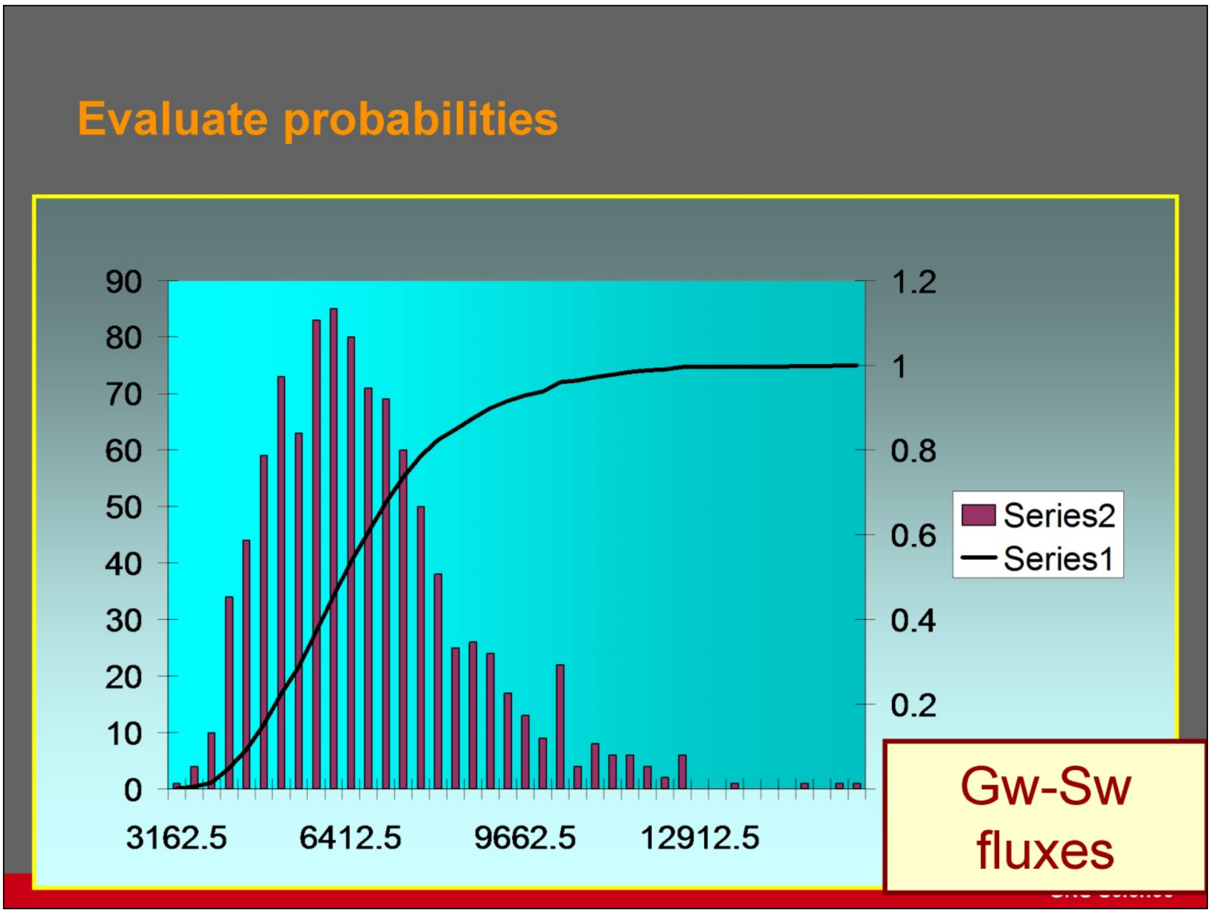
- Error propagation
- Monte Carlo (plus hybrid methods)
- Hypothesis testing

GNS Science


Error propagation – Calculate the error of our best model.
Prediction variance
$\sigma_s^2 = y^t C(k) y$
Variability of model parameters. If a discrete numerical model this is a parameter covariance matrix.
$R = R(X, Y, \ldots)$
$\delta R = \sqrt{\left(\frac{\partial R}{\partial X}\cdot \delta X\right)^2 + \left(\frac{\partial R}{\partial Y}\cdot \delta Y\right)^2 + \ldots}$
Sensitivity of the prediction to the model parameters. Can use partial derivatives or approximate using central differences.
Central difference derivative approximation
$f'(x) \approx (f(x+h) - f(x-h))/2h$
GNS Science


Error propagation if model has non-unique solution
Measurement error and model simplification error.
Prediction variance
$\sigma_s^2 = y^t C(k) y - y^t C(k) Z^t [Z C(k) Z^t + C(\varepsilon)]^{-1} Z C(k) y$
As before
Reduction in data scarcity error from information furnished from calibration dataset
GNS Science


Monte Carlo - Run model multiple times with equally probable parameter fields
Some versions…
(i) GLUE
(ii) Markov Chain Monte Carlo
(iii) Null Space Monte Carlo
…
Equally probable hydraulic conductivity fields
GNS Science


Evaluate probabilities
90
80
70
60
50
40
30
20
10
0
1.2
1
0.8
0.6
0.4
0.2
3162.5
6412.5
9662.5
12912.5
Series2
Series1
Gw-Sw fluxes

Hypothesis testing – include 'hypothesised' prediction in calibration data set and assess likelihood of parameters which allow that prediction to occur.

- Propose a hypothesis
- Test it against observations using an experiment
- Reject if doesn't fit data

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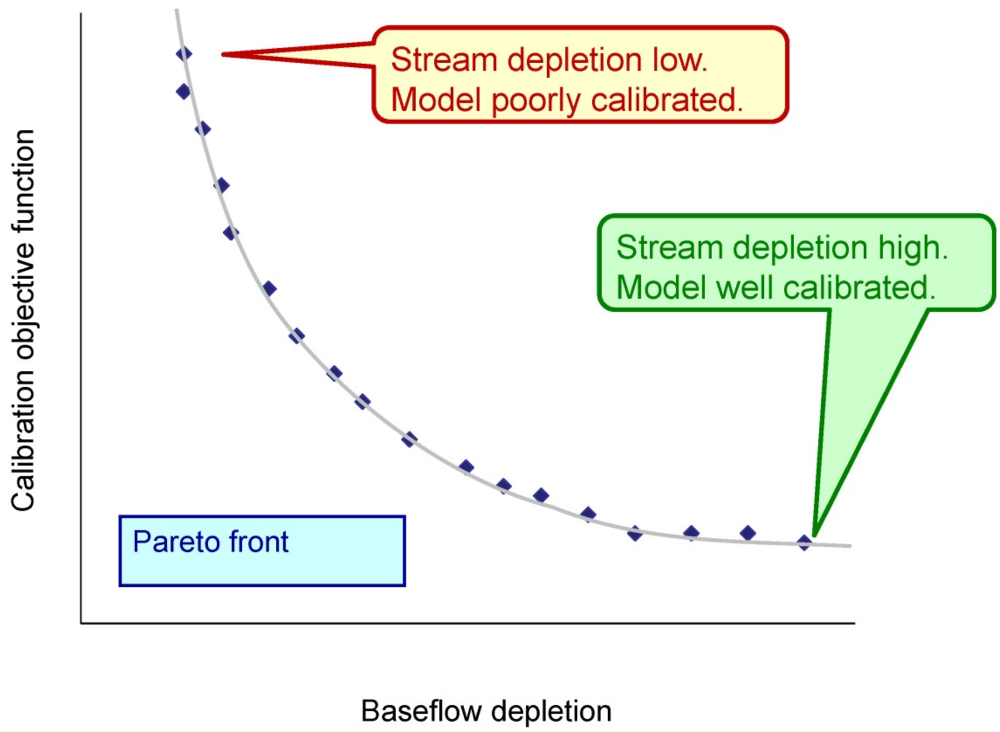

Hypothesis testing using Pareto Front based methods

Recipe for uncertainty analyses for gw-sw problems

1) Define:
   - Uncertainty in parameters
   - Sensitivity of prediction to parameters (e.g. partial derivaties or central difference approximation)
   - Model

2) Use either Monte Carlo, Error propagation methods or hypothesis testing methods.

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Some issues and mistakes…

Issues	Error propagation	Monte Carlo	Hypothesis testing
Computational effort	Low	Very High	Moderate
Accuracy	Low-Moderate Better used for comparing errors rather than exact magnitude of error.	Very High – and can run multiple predictions at one time	Very High – but for a single prediction only
Most common mistake	Not accounting for parameter null space	Not accounting for model simplification	Not accounting for parameter null space or model simplification

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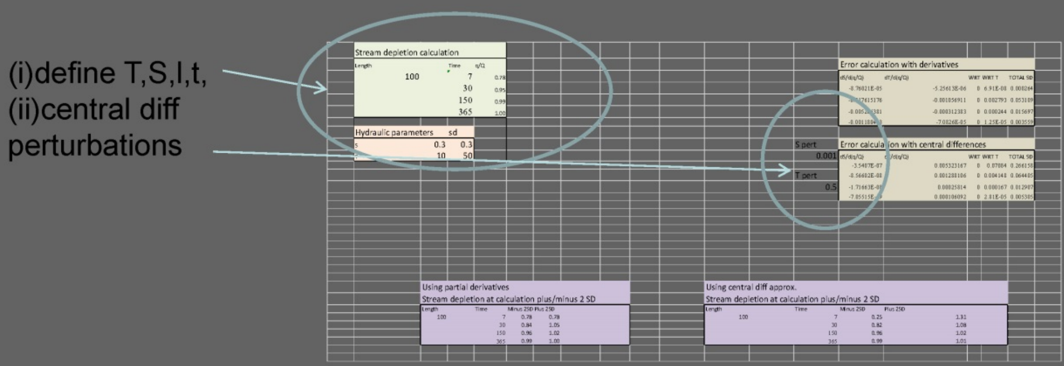
Participatory learning module

- **Calculate uncertainty of stream depletion estimate using Jenkins equation and spreadsheet.**
- **Write sentence that uses your calculation in a risk based decision or a policy rule.**



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Maths in spreadsheet

- *Glover and Balmer* (1954)
- $\frac{q}{Q} = erfc\left(\sqrt{\frac{Sl^2}{4Tt}}\right)$
- $\frac{q}{Q} = f(y), where\ y = \left(\sqrt{\frac{Sl^2}{4Tt}}\right)$
- **f(y) = erfc(y)**

GNS Science

Partial derivative wrt S

- $\frac{d}{dS}\left(erfc\left(\sqrt{\frac{Sl^2}{4Tt}}\right)\right) = \frac{dy}{dS} * \frac{d(erfc(y))}{dy}$
- $= -\left(\frac{Sl^2}{4Tt}\right)^{-\frac{1}{2}} * \left(\frac{l^2}{4Tt}\right) * \left(\frac{e^{-\frac{Sl^2}{4Tt}}}{\sqrt{\pi}}\right)$

GNS Science

Partial derivative wrt T

- $\frac{d}{dT}\left(erfc\left(\sqrt{\frac{Sl^2}{4Tt}}\right)\right) = \frac{dy}{dT} * \frac{d(erfc(y))}{dy}$
- $= \left(\frac{Sl^2}{4Tt}\right)^{-\frac{1}{2}} * \left(\frac{Sl^2}{4T^2t}\right) * \left(\frac{e^{-\frac{Sl^2}{4Tt}}}{\sqrt{\pi}}\right)$

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Quiz

- If $T=10m^3/d, S=0.01, l=1000m$, $t=3$ days, what is the upper 95% q/Q value when using:
  - Partial derivatives
  - Central differences
- What sources of error missing from the Jenkins spreadsheet?
- Give an example for when we do not need an uncertainty analysis accompanying our model results.
- Give an example for when we should do an uncertainty analysis accompanying our model.

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Quiz

- Write a sentence that communicates the uncertainty in a stream depletion calculation and the consequences of this in terms of making a risk based decision.

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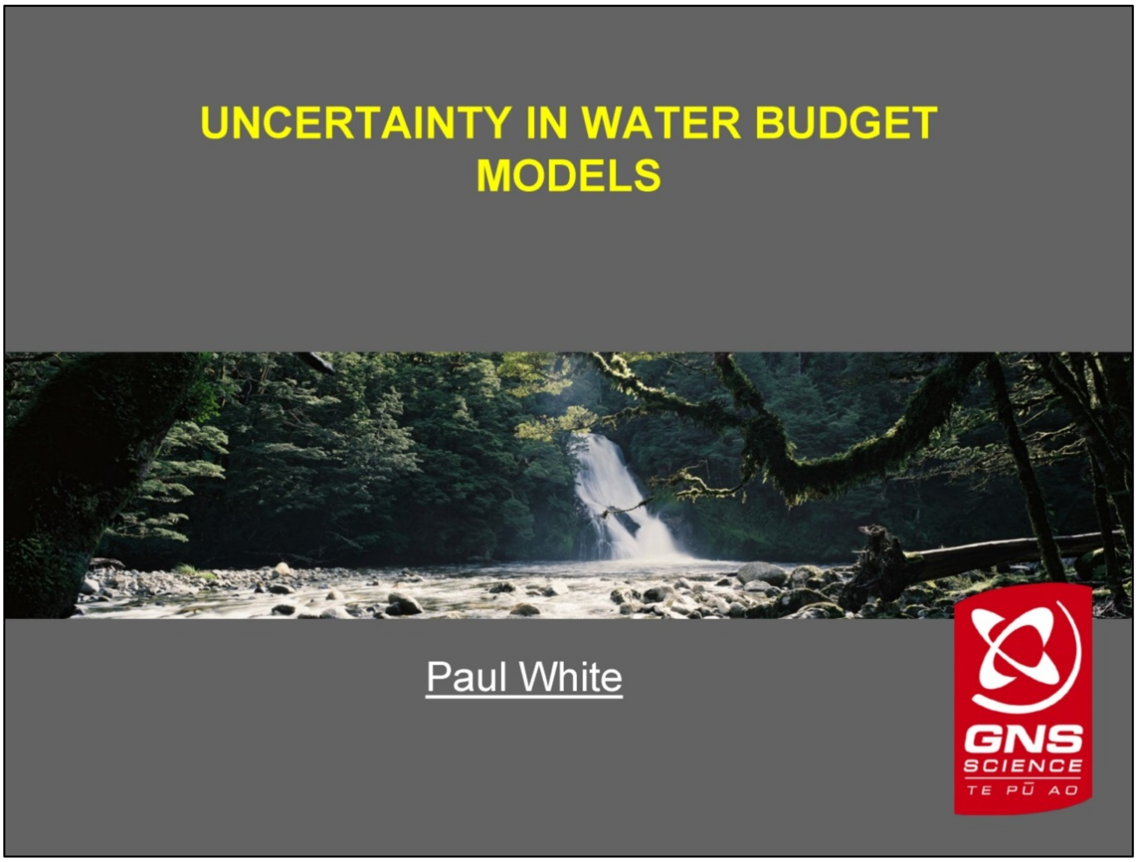
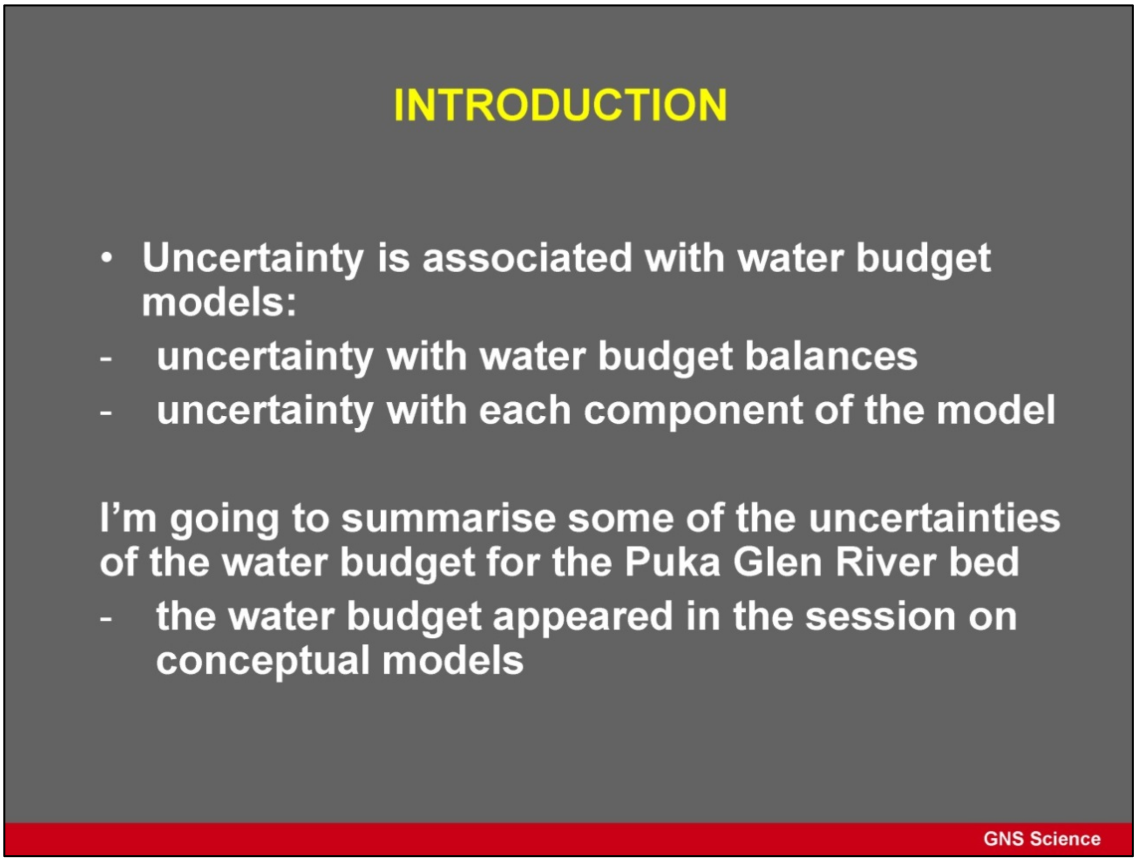
Uncertainty analysis to support risk based decisions in the limit setting process – possible topics
• Communicating uncertainty for different audiences – how to pitch it?
• Uncertainty in policy.
• Uncertainty communication with the public.
• Uncertainty analysis in models (multiple models, which analysis method?, strengths and weaknesses of these methods).
• Formats for displaying uncertainty graphically.
• Develop tools for simple quantification of uncertainty.
• Use a participatory or conference format?
GNS Science

5.2.2 Uncertainty and groundwater recharge from rivers
Facilitator: Paul White, GNS Science





Key message 1: uncertainty is 'magnified' by any equation that has uncertain components

E.g. A – B = C

100 (+/- 10)
– 90 (+/- 9)

10 (+/-19)

GNS Science

Groundwater budget

Steady-state groundwater budget of each reach

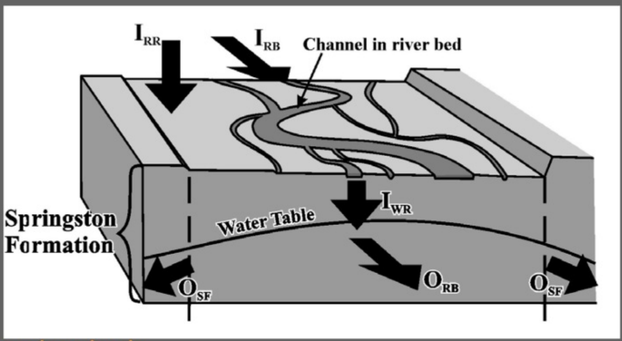
Groundwater budget equation:

Inflows = outflows

$I_{RR} + I_{WR} + I_{RB} = O_{RB} + O_{SF}$

Or

$I_{RR} + I_{WR} + I_{RB} = O_{RB} + O_{SF}$



I_{RR} inflow of rainfall recharge through the dry river bed;
I_{WR} inflow of river recharge from Puka Glen River channels;
I_{RB} groundwater inflow from the upstream reach in Holocene river bed gravels;
O_{RB} groundwater outflow to the downstream reach in Holocene river bed gravels;
O_{SF} groundwater outflow to Holocene gravels beside the river bed.

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Reach 3: Steady-state model: water budget

$I_{RR} + I_{WR} + I_{RB} + O_{RB} + O_{SF} = 0$

Puka Glen River reach	Inflow I_{RR} (m^3/s)	Inflow I_{WR} (m^3/s)	Inflow I_{RB} (m^3/s)	Outflow river bed O_{RB} (m^3/s)	Outflow Holocene gravel O_{SF} (m^3/s)
3	0.1	0.1	0.5	-0.4	-0.3

Reach 3: O_{SF} is calculated by the equation to balance the water budget

Question: what is the uncertainty in O_{SF}?

GNS Science

Uncertainty in O_{SF} calculated by the equation is greater than individual components

E.g., variable uncertainty in: I_{RR} I_{WR} I_{RB} O_{RB}

Puka Glen River reach uncertainty	Inflow I_{RR} (m^3/s)	Inflow I_{WR} (m^3/s)	Inflow I_{RB} (m^3/s)	Outflow river bed O_{RB} (m^3/s)
0	0.1	0.1	0.5	-0.4
10 %	0.01	0.01	0.05	0.04
100%	0.1	0.1	0.5	0.4

O_{SF} (m^3/s)	Uncertainty (approx.)
-0.3	0
0.11	30 %
1.1	300%

GNS Science

Key message 2: uncertainty is associated with each water budget component

A list of some of the data that is used in the water budget is as follows:

- **I_{RR}: inflow of rainfall recharge to groundwater**
  - calculation uses river bed dry area and rainfall recharge measurements
- **I_{WR}: inflow of river recharge to groundwater**
  - calculation uses gaugings and river bed engineering sections
- **I_{RB} (inflow) O_{RB} (outflow) in river bed**
  - uses aquifer thickness, groundwater gradients and hydraulic conductivity

GNS Science

For example I_{WR}: inflow of river recharge to groundwater

I_{WR}: inflow of river recharge to groundwater
- calculation uses gaugings and river bed engineering sections

Gaugings have uncertainties: each gauging is +/- 8%

Say we have flows of:
Top of reach: 24 (+/- 2)
Bottom of reach:12 (+/-1) m^3/s

Then the flow loss across the reach is: 12 (+/-3) m^3/s

- i.e. the uncertainty is increased by this calculation.

GNS Science

Reduce I_{WR} uncertainty with multiple gaugings

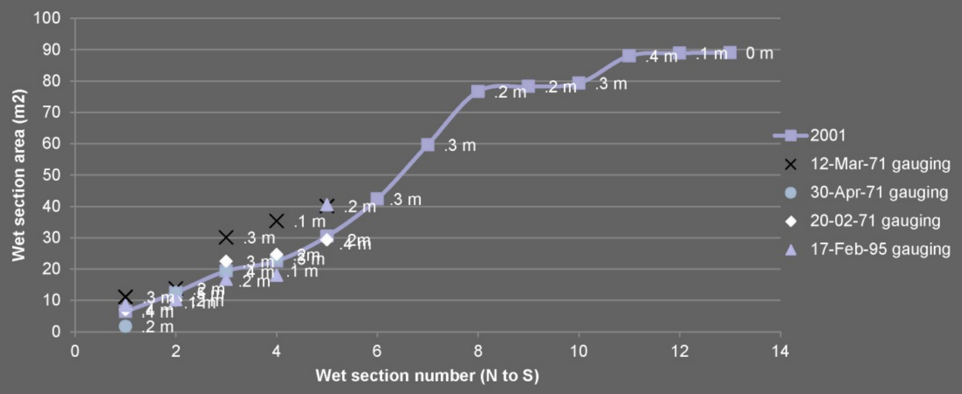
River reach	1	2	3	4	5
1	na	-0.7	-1.2	-1.3	-2.3
2	2	na		-1.0	-0.5
3	4	0	na	-3	
4	1	2	6	na	1.5
5	2	1	0	1	na

Yellow = average of flow differences across reach (m^3/s)
Blue = number of gauging pairs

GNS Science

Understand some I_{WR} uncertainty with additional information: e.g., do historic gaugings measure all river channels on a cross section?

Cumulative wet area on cross section



GNS Science

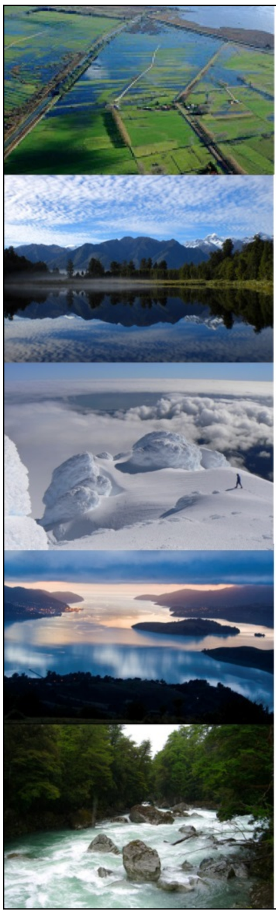
SESSION 6: GW-SW INTERACTION MANAGEMENT AND POLICY FACILITATOR: LAWRENCE KEES, ENVIRONMENT SOUTHLAND

6.1 INTRODUCTION

- Objectives?

6.2 PRESENTATIONS

6.2.1 Groundwater-surface water science (particularly national modelling) for MfE Facilitator: Doug Booker, NIWA



Outline

1. Need for national models
2. Current methods
   a) Input data
   b) Modelling
3. Results
   a) Pressures
   b) States
   c) Impacts
4. Science needs

2

1. Need for national models

- MfE have a need for nationwide information on river flows
- Nationally consistent methods
- Consistent pressure-state-impact philosophy

What **influences** the state of the environment?

Irrigation,
domestic supply,
power generation

How do the **characteristics** vary over time?

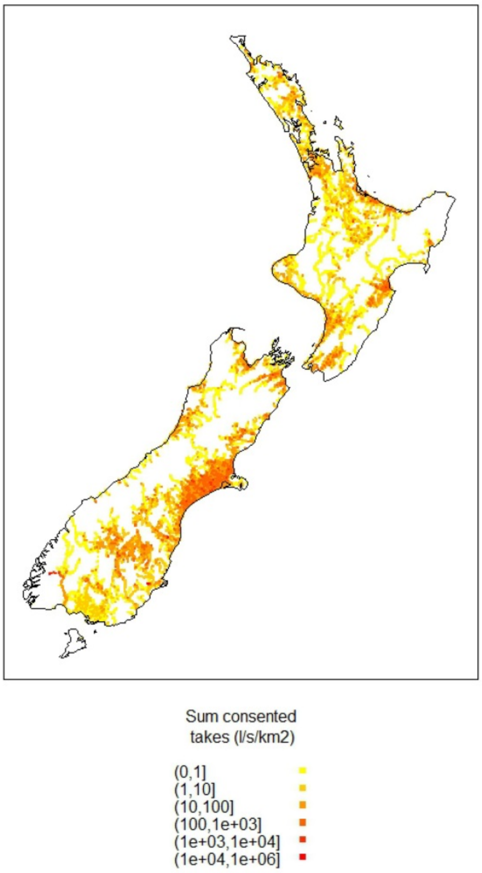
River flows

Consequences to environment, economy, society and culture?

In-stream values
Out-of-stream values

- National-level pressure-state-impact model for freshwater flows.

- Phase I, completed
  - Data collation procedures
  - Model developed
  - Applied to Canterbury for 2013/14
- Phase II, starting
  - Collate national data
  - Improve and apply model
  - Report national for 2013/14

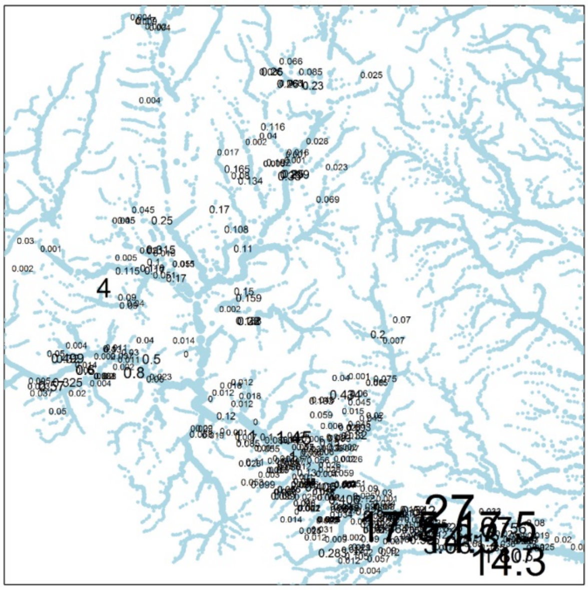


Collate data on:

- consent conditions
- Recorded takes
- flows & levels
- limits in plans
- permitted activities?
- HEP operation?

Calculate:

- Reliability of supply
- Compliance = Consented - Recorded
- Available = limit - consented - permitted
- Ecosystem health (e.g., flow regime, wetted width, hydraulic fish habitat…)

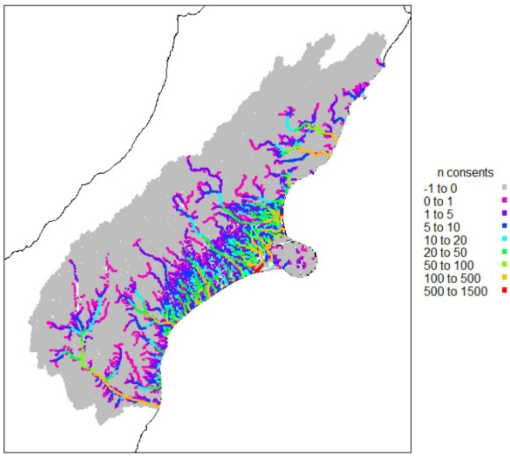


Max consented take in the Waitaki (m^3s^{-1})

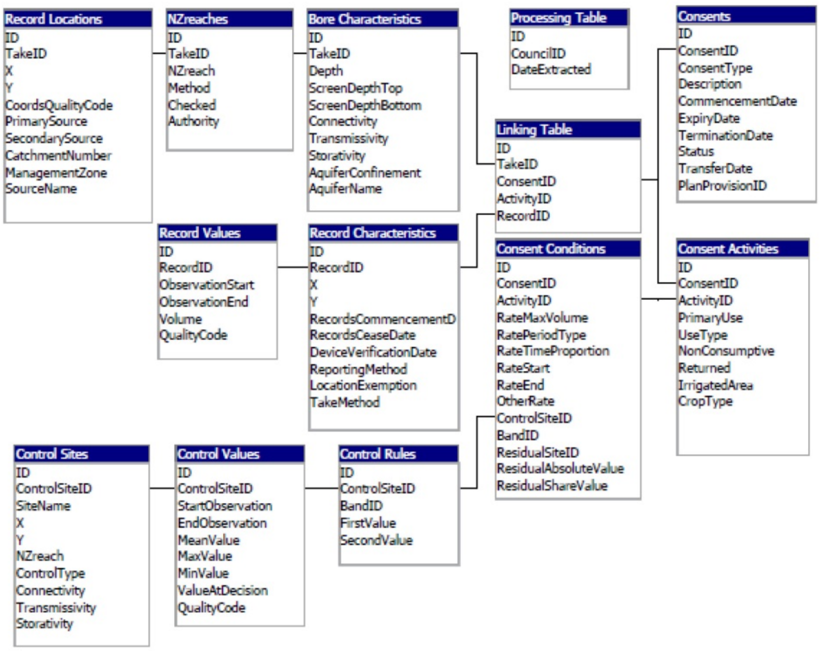
2. Current methods

Currently we are:

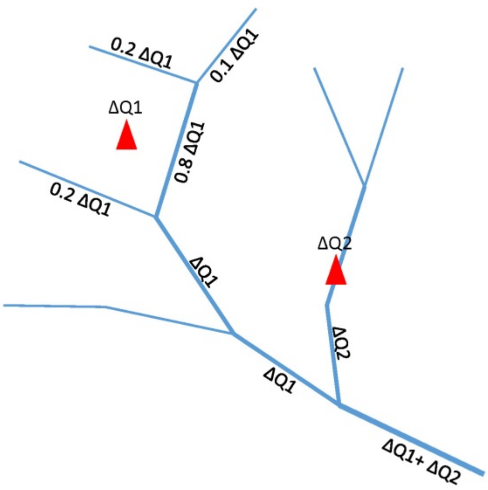
- Analysing particular years (e.g. 2013-14).
- Using REC v1 (can move to v2).
- Using daily data.
- Using an national rainfall-runoff model to estimate naturalised flow.
- Including influence of groundwater takes on rivers flows using stream depletion method.
- Not including influence of re-charge.
- Not including nutrients or any aspect of water quality.

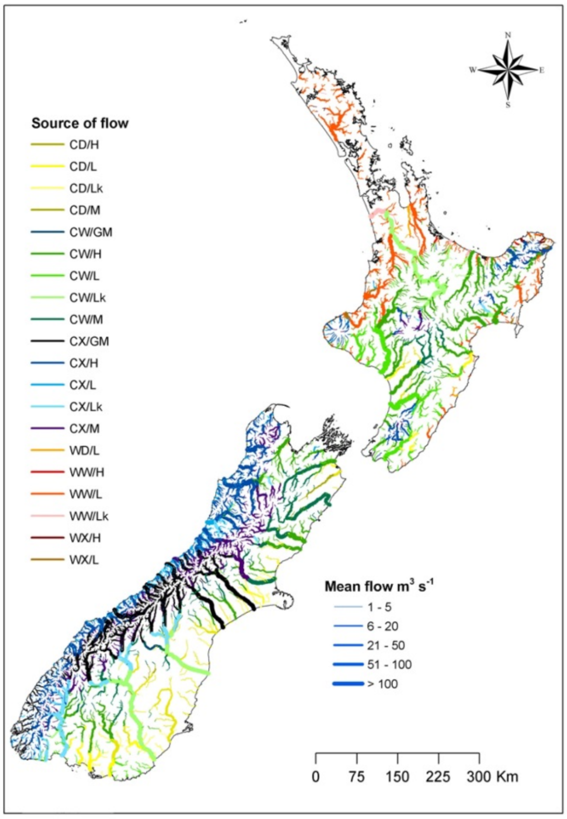


Input data schema



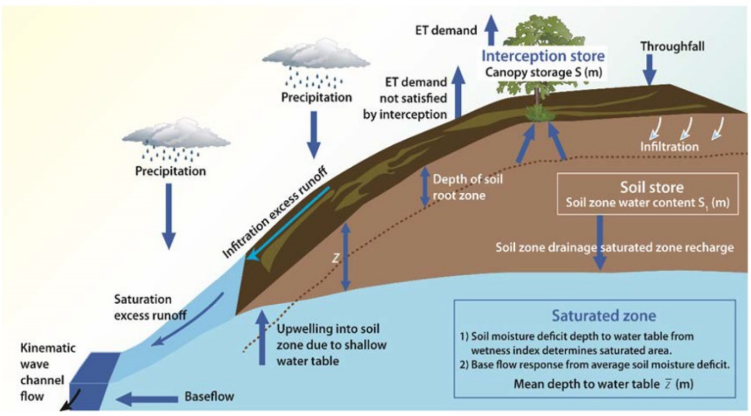
River Network

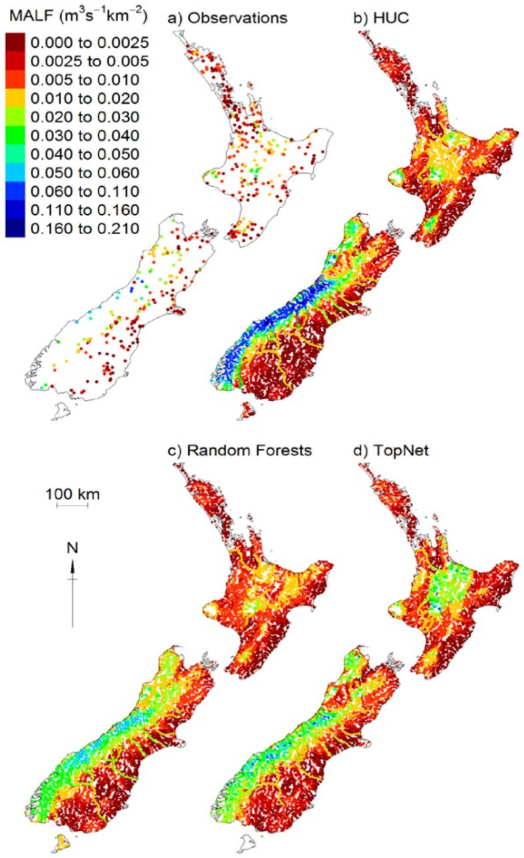




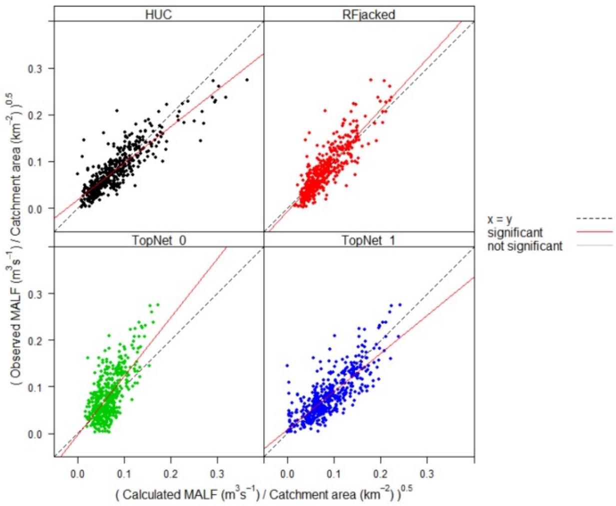
Naturalised flow estimates

- National TopNet rainfall runoff-model
- Correction procedure using FDCs (Booker and Woods, 2014)
- Testing various aspects:
  - Within site daily series (Q_t)
  - Within site annual series (ALF, mean flow, annual flood)
  - Site summary statistics (MALF, mean flow, mean annual flood)



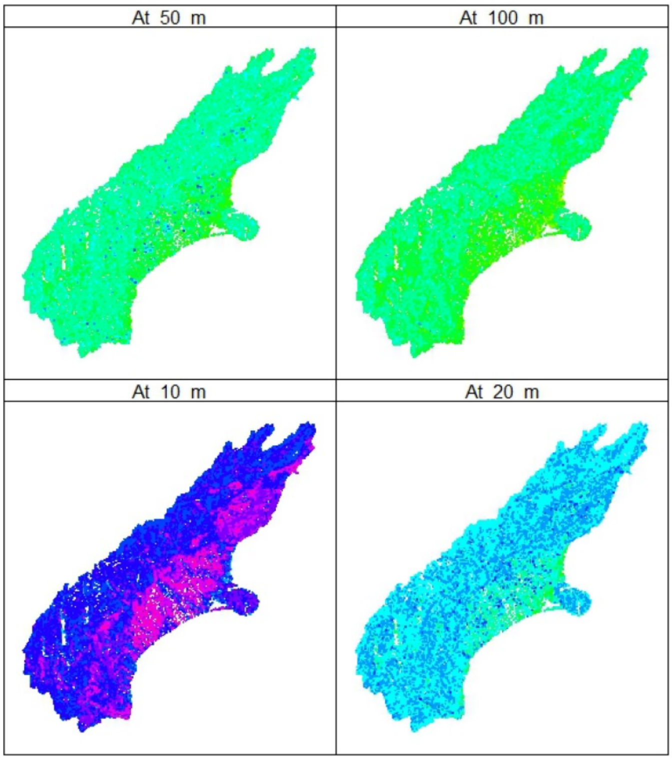


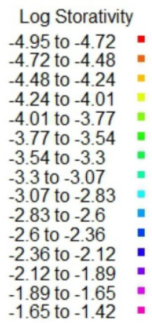
Testing flow estimates



Booker, D.J., Woods, R.A. (2014) Comparing and combining physically-based and empirically-based approaches for estimating the hydrology of ungauged catchments. Journal of Hydrology, 508, 227–239.

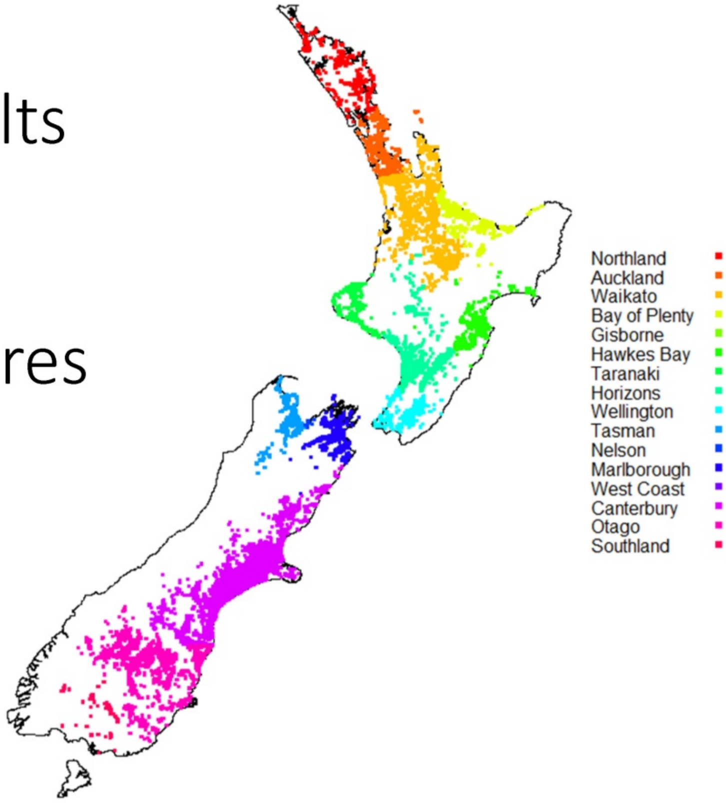
Maps of Storativity and transmissivity



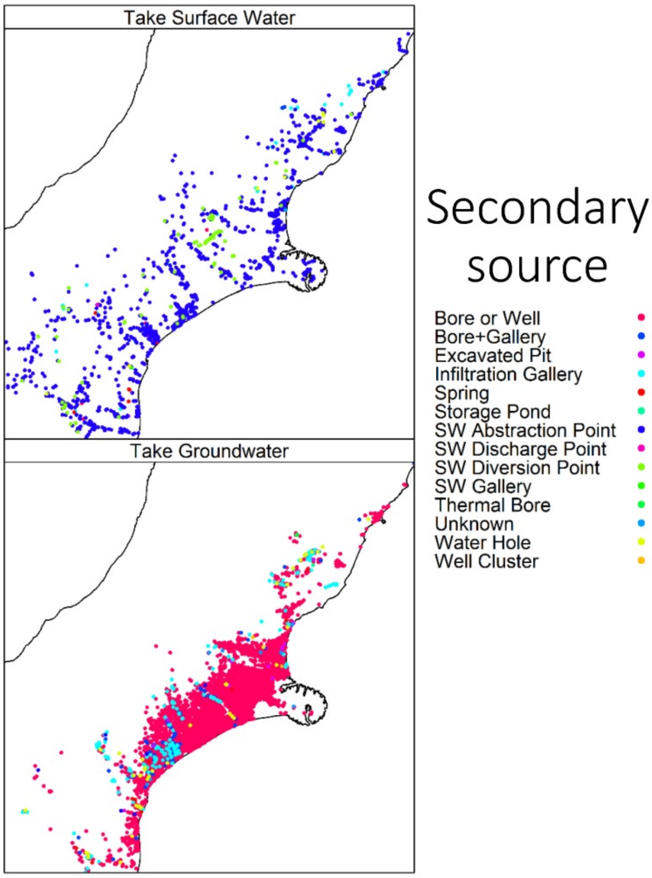


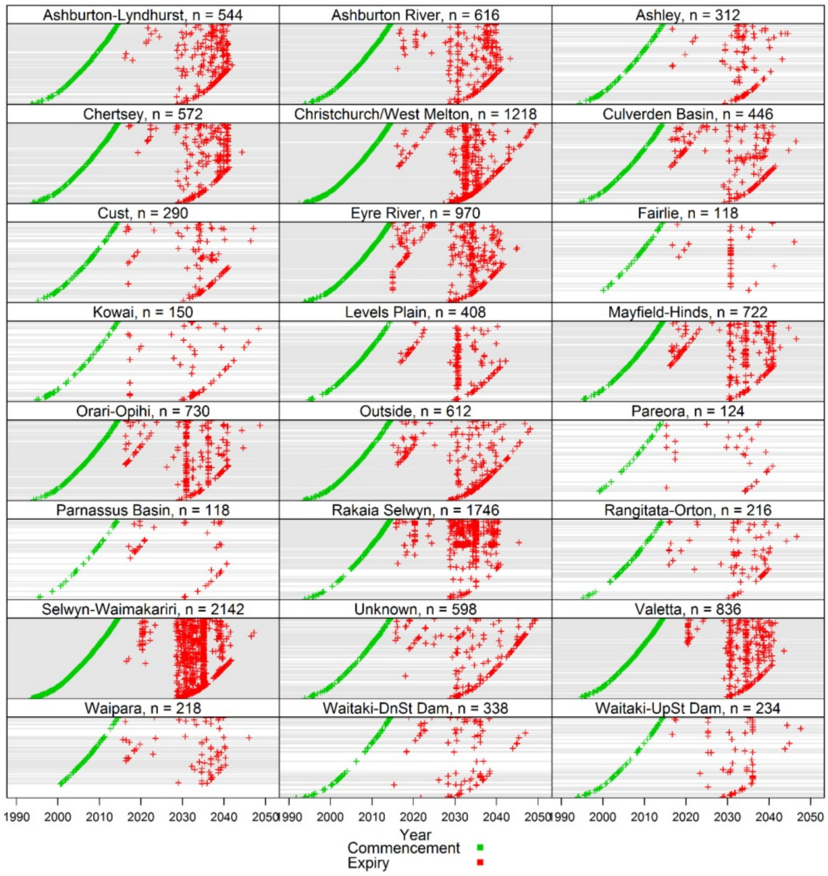
4. Results

a) Pressures



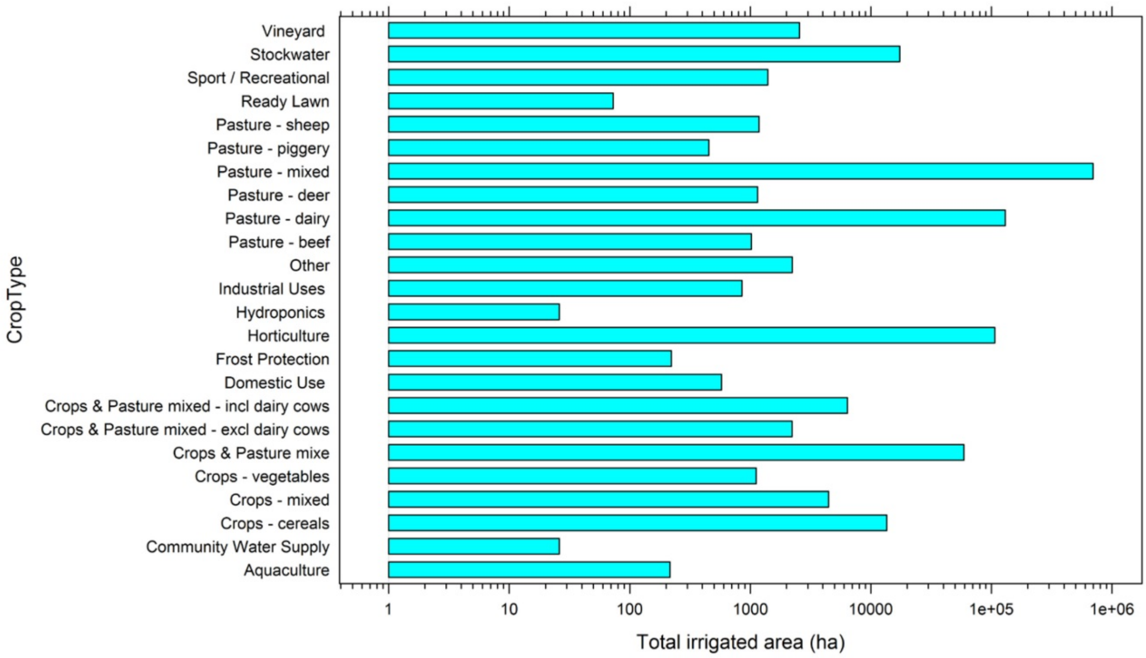
Secondary source

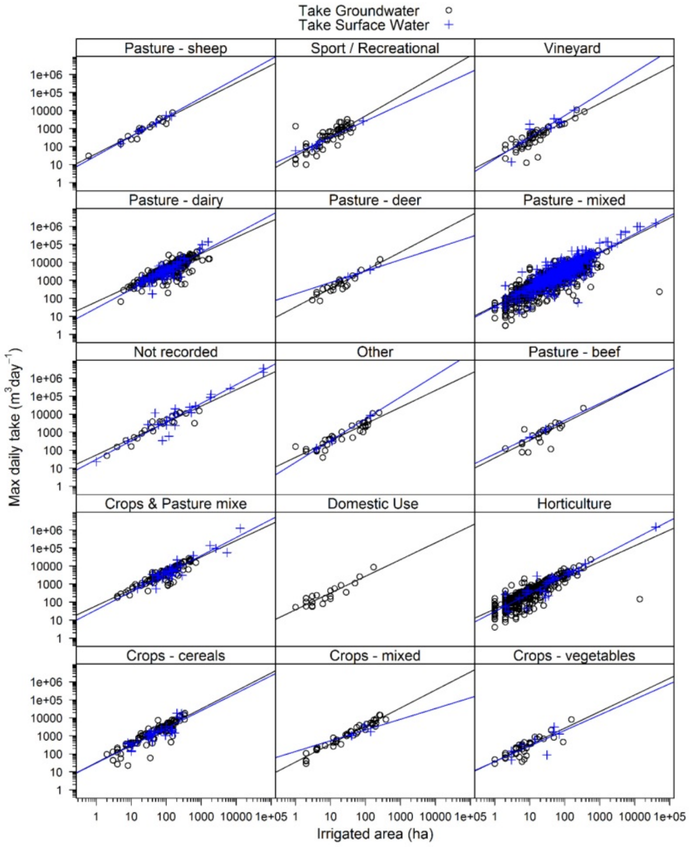




Consent timing

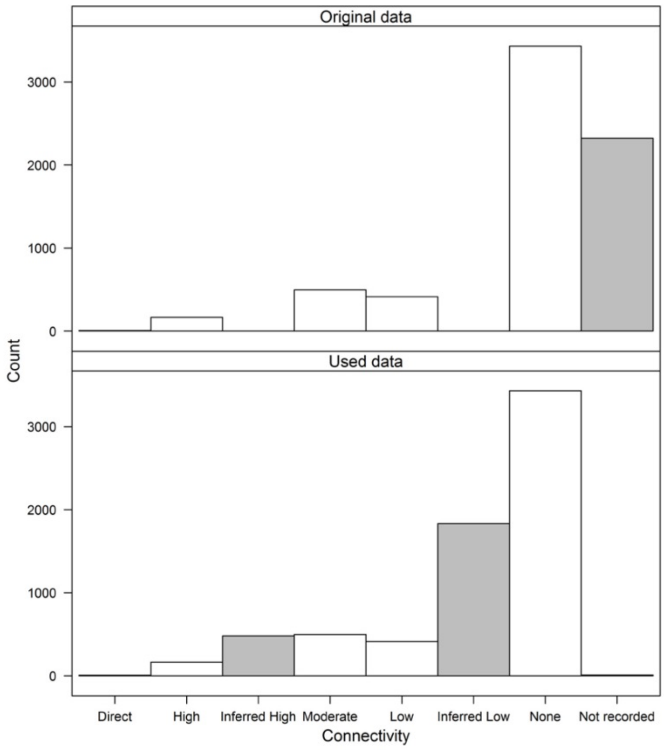
Total irrigated area, Canterbury





Consented rate
vs
irrigated area,

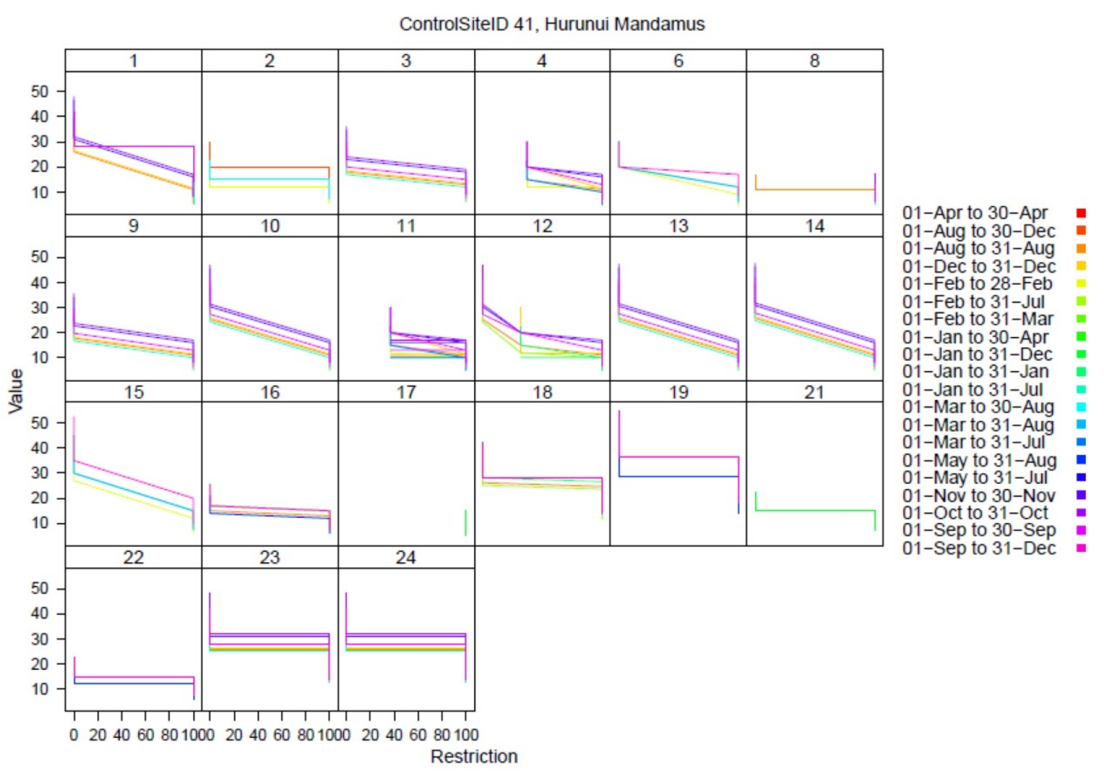
Canterbury



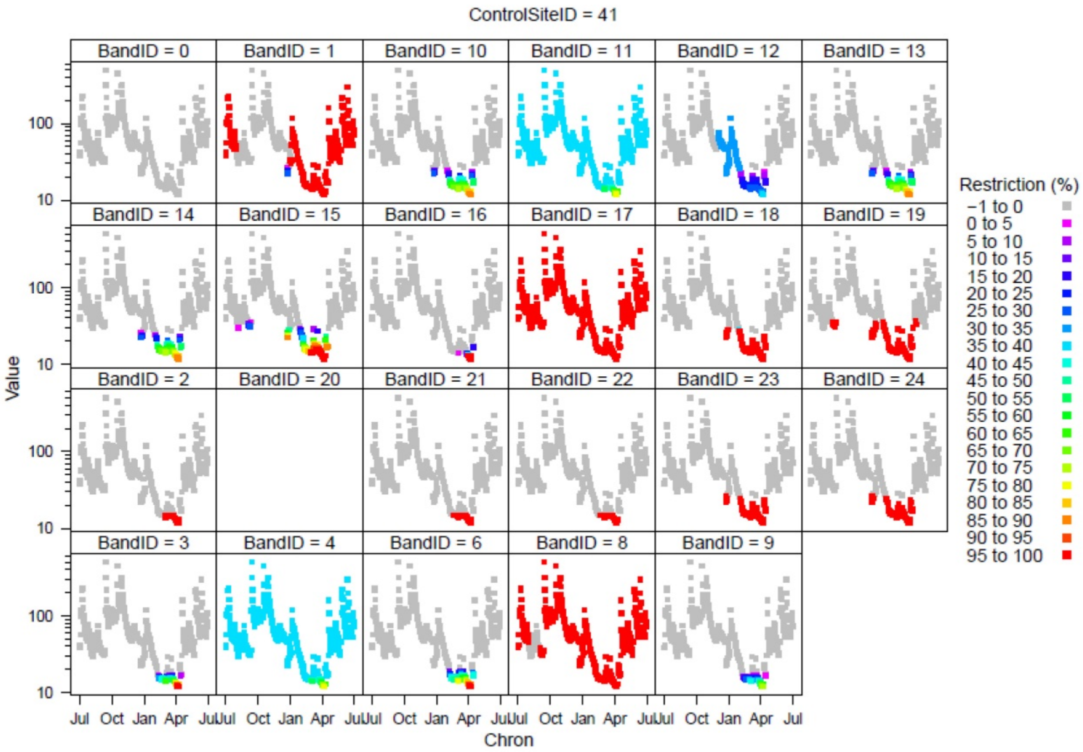
Groundwater
connectivity,

Canterbury

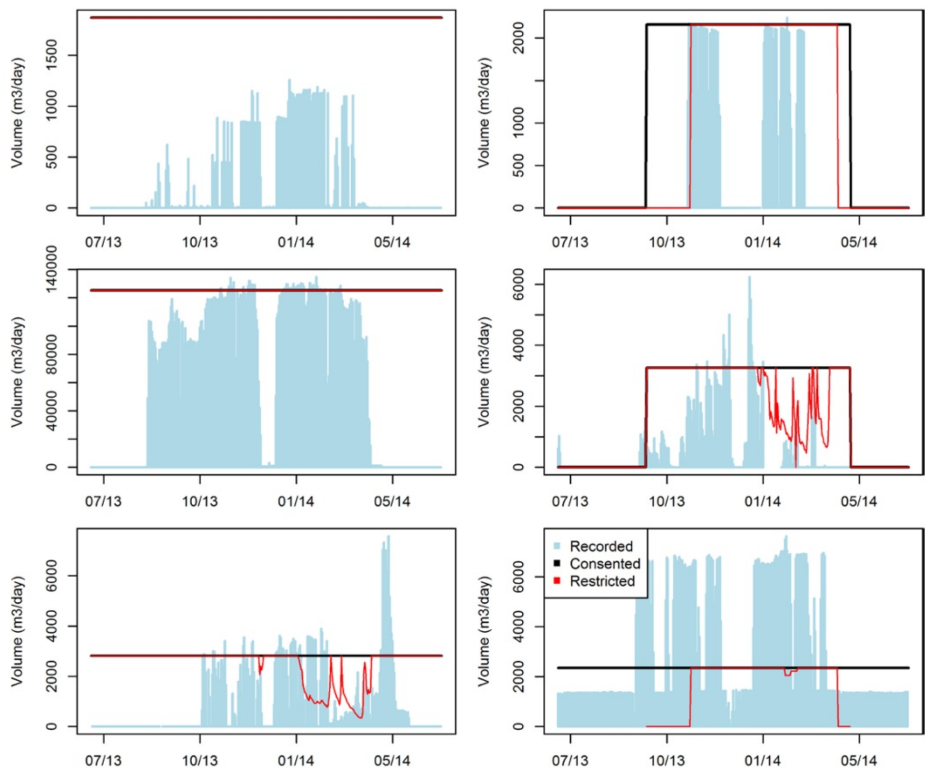
b) States

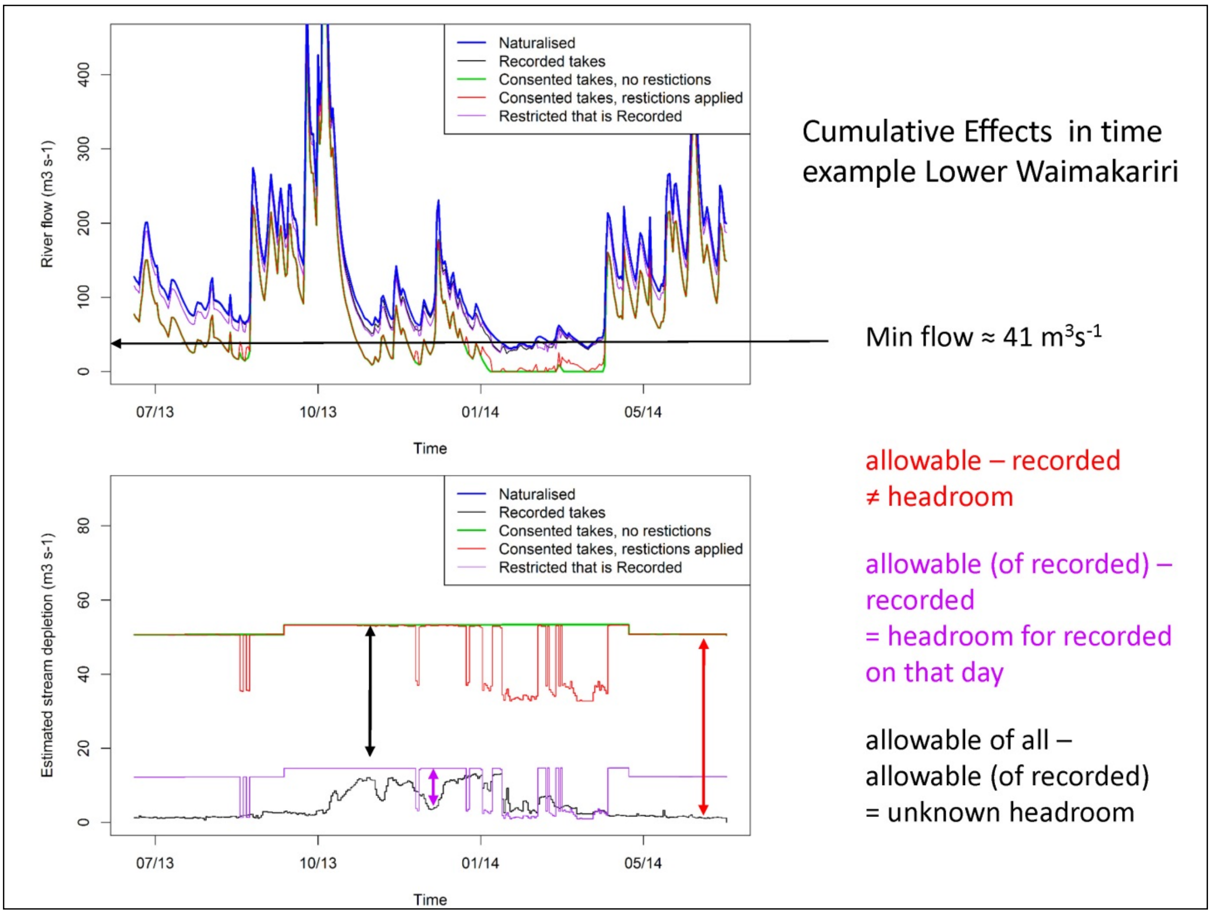


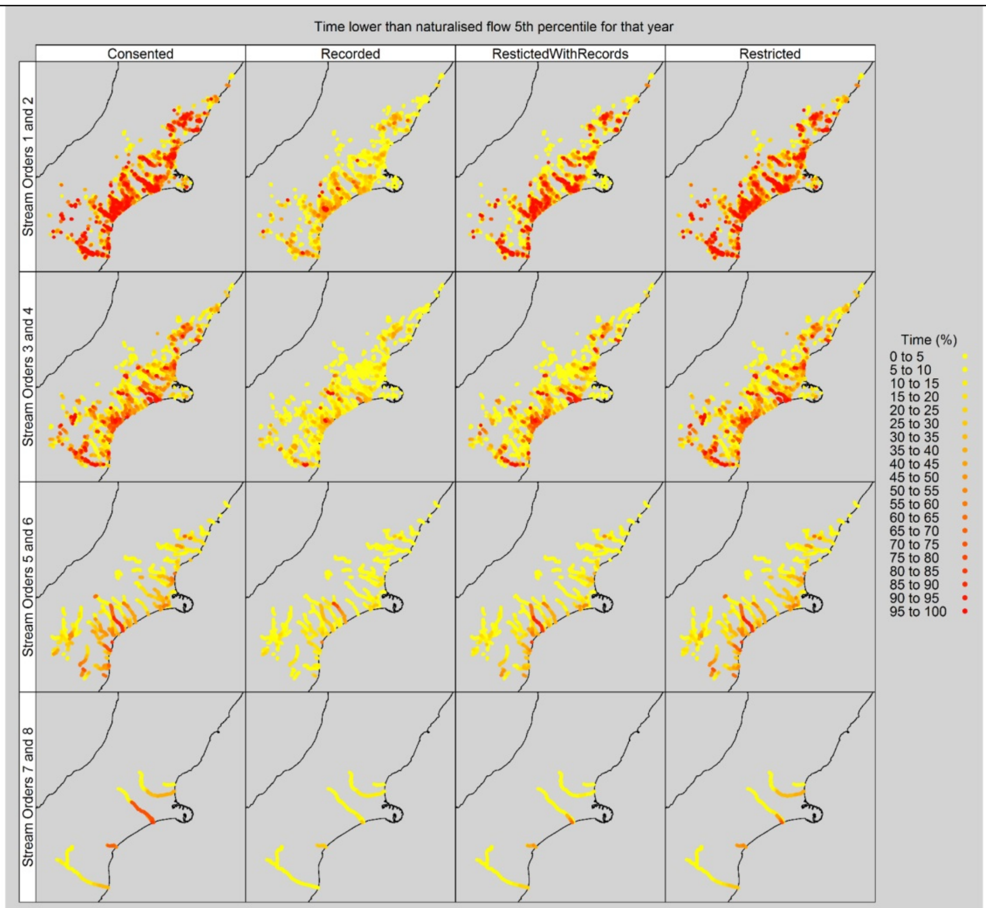
ControlSiteID 41, Hurunui Mandamus
1
2
3
4
6
8
9
10
11
12
13
14
15
16
17
18
19
21
22
23
24
Value
Restriction
01−Apr to 30−Apr
01−Aug to 30−Dec
01−Aug to 31−Aug
01−Dec to 31−Dec
01−Feb to 28−Feb
01−Feb to 31−Jul
01−Feb to 31−Mar
01−Jan to 30−Apr
01−Jan to 31−Dec
01−Jan to 31−Jan
01−Jan to 31−Jul
01−Mar to 30−Aug
01−Mar to 31−Aug
01−Mar to 31−Jul
01−May to 31−Aug
01−May to 31−Jul
01−Nov to 30−Nov
01−Oct to 31−Oct
01−Sep to 30−Sep
01−Sep to 31−Dec



Recorded takes




Cumulative Effects in time
example Lower Waimakariri
Min flow ≈ 41 m³s⁻¹
allowable – recorded
≠ headroom
allowable (of recorded) – recorded
= headroom for recorded on that day
allowable of all – allowable (of recorded)
= unknown headroom
Naturalised
Recorded takes
Consented takes, no restictions
Consented takes, restictions applied
Restricted that is Recorded
River flow (m3 s-1)
Estimated stream depletion (m3 s-1)
Time
07/13
10/13
01/14
05/14


Time lower than naturalised flow 5th percentile for that year
Consented
Recorded
RestictedWithRecords
Restricted
Stream Orders 1 and 2
Stream Orders 3 and 4
Stream Orders 5 and 6
Stream Orders 7 and 8
Time (%)
0 to 5
5 to 10
10 to 15
15 to 20
20 to 25
25 to 30
30 to 35
35 to 40
40 to 45
45 to 50
50 to 55
55 to 60
60 to 65
65 to 70
70 to 75
75 to 80
80 to 85
85 to 90
90 to 95
95 to 100

4. Science needs

- PSI relies on outside science input on:
  - Nationwide naturalised flow estimation
  - Treatment of dams and diversions
  - Stream depletion estimation
    - Algorithm
    - Unknown Storativity and transmissivity
    - Testing and verification
  - Flow augmentation estimation
  - Methods for in-stream values
  - Methods for out-of-stream values

Thanks
&
Questions

6.2.2 Conjunctive allocation of water in groundwater-river systems
Facilitator: Paul White, GNS Science

POLICY AND WATER BUDGET MODELS

Paul White

GNS SCIENCE TE PŪ AO

INTRODUCTION

Water budgets can be used for policies:

- they can clarify policy issues around water budget components
- they can be used to set policies
- they link characterisation and more complex modelling
- they can clarify the knowledge base (what we know, where we know it, what is the plan for further work?)

GNS Science

THIS TALK

1) One slide each on a few policies I have worked on and note the link between science and policy:
- national environmental standard of environmental flows and levels
- WRC's Variation 5 (Lake Taupo Protection)
- WRC's Variation 6 (water allocation)

2) I thought I would also mention an approach to conjunctive allocation of groundwater and surface water based on water budgets

3) "Bright lines" and policy

GNS Science

National environmental standard of environmental flows and levels

Link between science and policy: "Expert panel"

Outcome: a draft policy that allows application of methods that are appropriate to use and values

Method selection		Value		
		low	moderate	high
Use	low	Water budget	Water budget	SS model
	moderate	Water budget	SS model	SS model
	high	Water budget	Transient model	Transient model

Reference:
Cooke, J., Jowett, I., Hayes, J., Howard-Williams, C., Sorrell, B., White, P., Heller, T., Death, R., Hickey, M., Kelly, D., Smaill, A., Biggs, B., 2007. Scientific input to a proposed national environmental standard of environmental flows and levels. Beca Infrastructure Ltd report to Ministry for the Environment.

GNS Science

WRC's Variation 5 (Lake Taupo Protection)

Links between science and policy:

- groundwater outflow to streams and lakes developed with water budgets
- Land use effects on water quality (nitrogen) assessments including water dating
- Future projections of nitrogen loadings included water quality and dating

Outcomes:

- V5 made it through Environment Court and is now policy
- Project established (approx $160 M) to protect Lake Taupo
- Improvements in waste water treatment (TDC)
- Three weeks ago the Lake Taupo Protection Trust announced it had done the deals to remove 20% of the N from agricultural land use

GNS Science

WRC's Variation 6 (water allocation)

Link between science and policy:

- water budgets were used to establish that groundwater interacts with surface water in the Upper Waikato
- Surface flow is totally dominated by baseflow (i.e. groundwater recharge) in the Upper Waikato
- V6 aims to manage surface water and groundwater together

Outcome:

- Surface and groundwater policies cross-reference each other
- e.g., groundwater allocation has to comply with relevant Q5 flows

GNS Science

An approach to conjunctive allocation of groundwater and surface water based on water budgets

- can be used for catchment allocation limits
- can easily be implemented in XL
- demonstration example

GNS Science

An approach to conjunctive allocation of groundwater and surface water based on water budgets

WAA = GAA + SAA

Where:

WAA groundwater available for allocation

GAA groundwater available for allocation

SAA surface water available for allocation

GNS Science

An approach to conjunctive allocation of groundwater and surface water based on water budgets

$GAA = R - MFL^{GW}$

where R (recharge) $= P + Q^{GW}_{IN} - ET - Q^{SW}_{QF}$

MFL^{GW} from NZ's interim groundwater allocation limits:

- in coastal aquifers 85% of R (i.e., the minimum groundwater flow equivalent to an allocation of 15% of R);
- in non-coastal aquifers the greater of 65% of R (i.e., the minimum groundwater flow equivalent to an allocation of 35% of R) or MFL^{SW}.

GNS Science

An approach to conjunctive allocation of groundwater and surface water based on water budgets

- SAA was estimated from the groundwater budget as:

  $SAA = R - GAA - MFL^{SW}$,

  - MFL^{SW} various approaches to this across NZ
  - where $Q^{SW}_{BF} > 0$ and $MFL^{GW} > MFL^{SW}$,

    otherwise, SAA = 0.

GNS Science

An approach to conjunctive allocation of groundwater and surface water based on water budgets

Aquifer type	Water budget				
	P (L/s)	Q^{GW}_{IN} (L/s)	ET (L/s)	Q^{SW}_{QF} (L/s)	Q^{SW}_{BF} (L/s)
Coastal	200	0	150	0	0
Other	1000	0	500	375	125

Aquifer type	Water allocation				
	MFL^{GW} (L/s)	MFL_{SW} (L/s)	GAA (L/s)	SAA (L/s)	WAA (L/s)
Coastal	43	0	7	0	7
Other	81	54	44	27	71

GNS Science

"Bright lines"

- Denotes geographic boundaries of policy application
- Developed in the US (Hermann Bouwer, etc)
- Used to define boundaries between surface water policies and groundwater policies

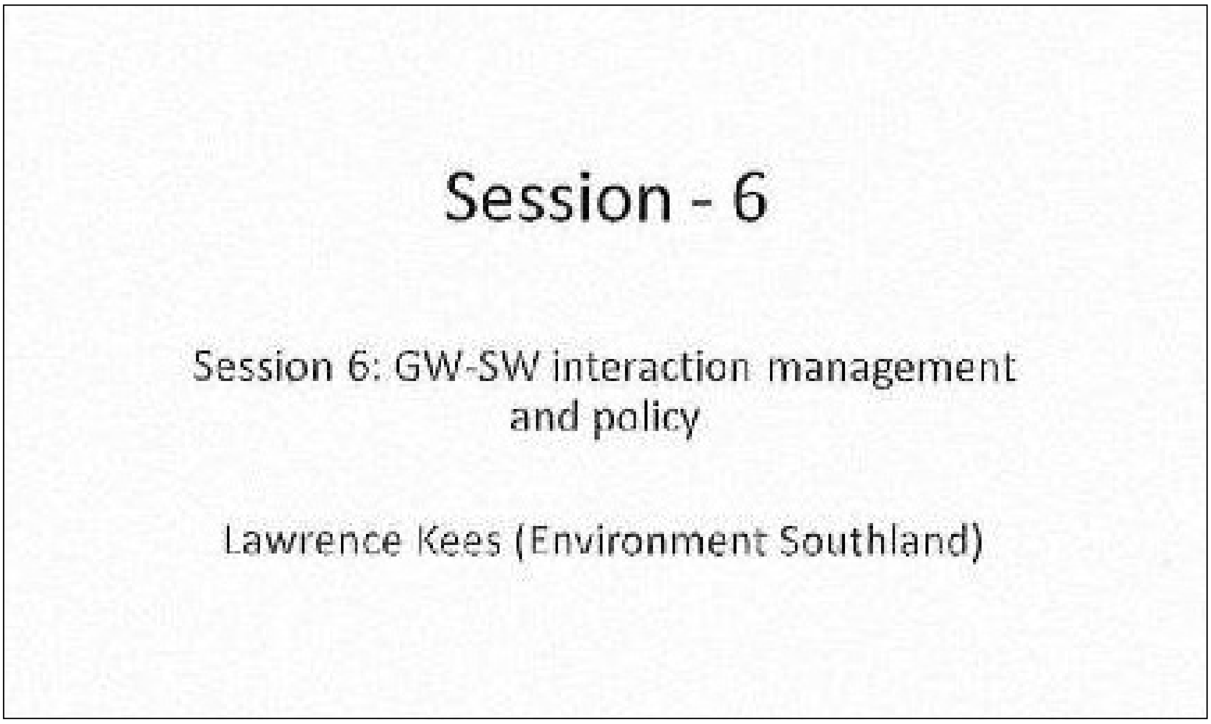
GNS Science

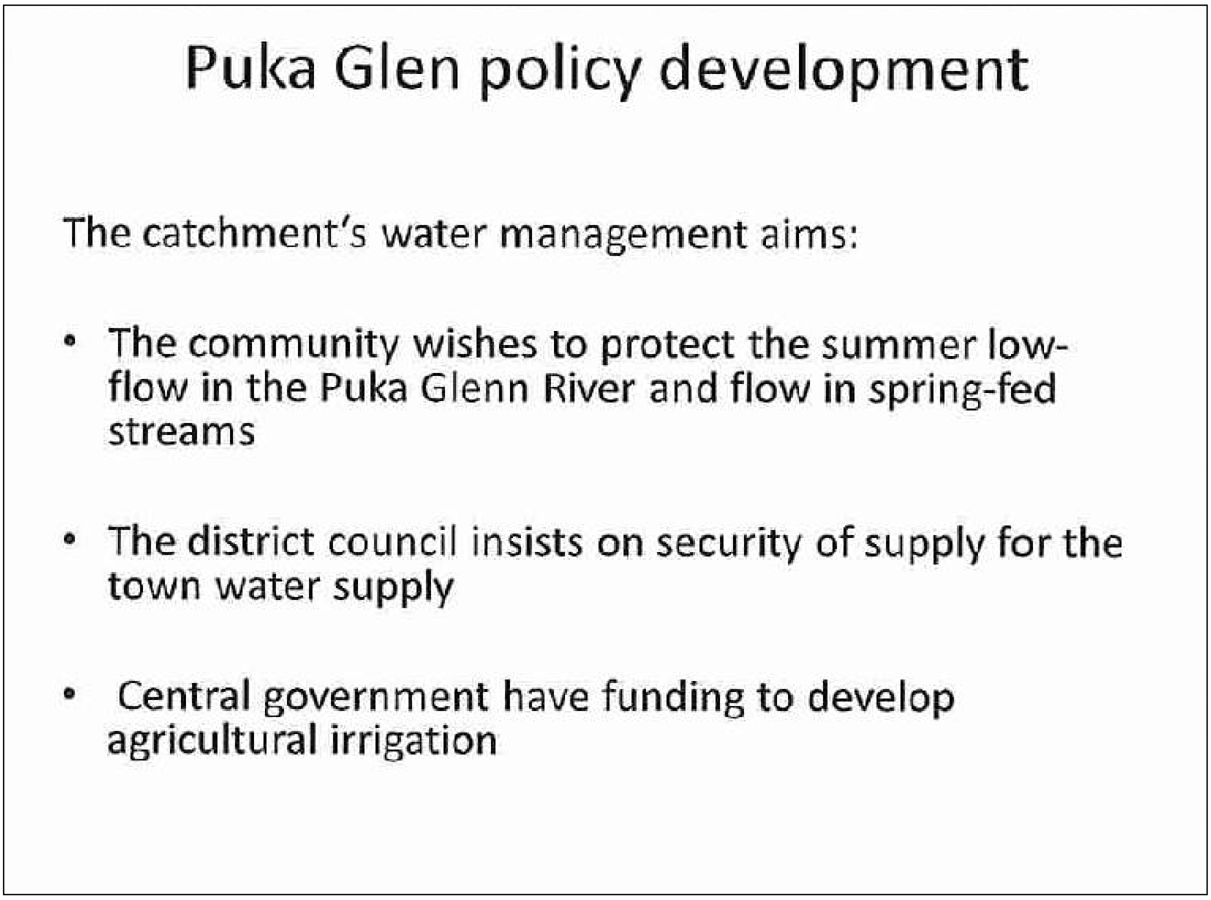
“Bright lines”

- Denotes what is in the focus area of policies, e.g., “Ensure it is safe before manoeuvring”:

GNS Science

6.2.3 Summary of previous sessions on policy
Facilitator: Lawrence Kees, Environment Southland





Puka Glen policy development

The catchment's water management aims:

- The community wishes to protect the summer low-flow in the Puka Glenn River and flow in spring-fed streams
- The district council insists on security of supply for the town water supply
- Central government have funding to develop agricultural irrigation

Puka Glen policy development

The catchment's water management aims:

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You will:

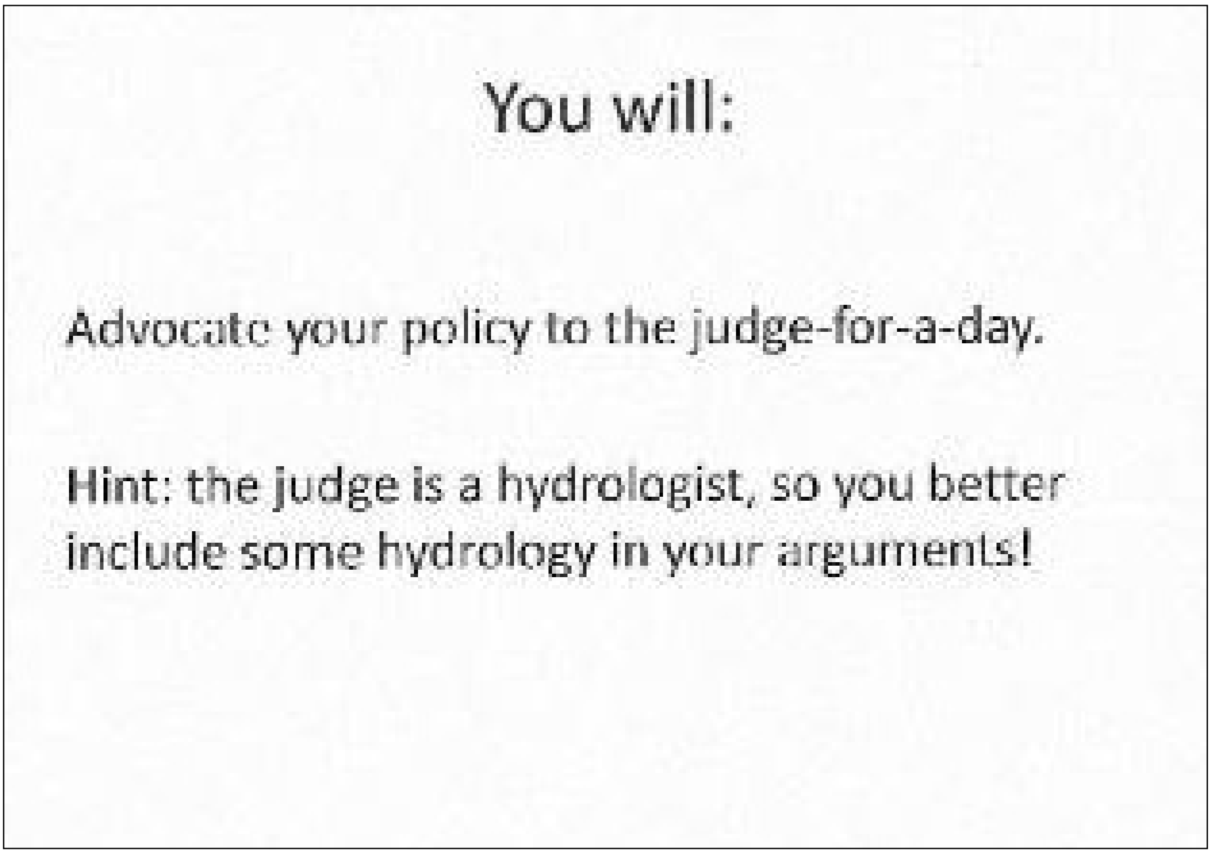
Develop policies that are:

- Sustainable
- Equitable
- Represent your sector's needs

You will:

Develop policies that are:

- Sustainable
- Equitable
- Represent your sector's needs


You will:
Advocate your policy to the judge-for-a-day.
Hint: the judge is a hydrologist, so you better include some hydrology in your arguments!

SUMMARY

GROUP EXERCISE

At the end of the workshop, attendees were split into groups of 5-6 people. As a group, they were asked to discuss the most important topics regarding GW-SW interaction in New Zealand, and to identify the top three to share. The results of the top three topics put forward by each group are summarised below (Figure 1).

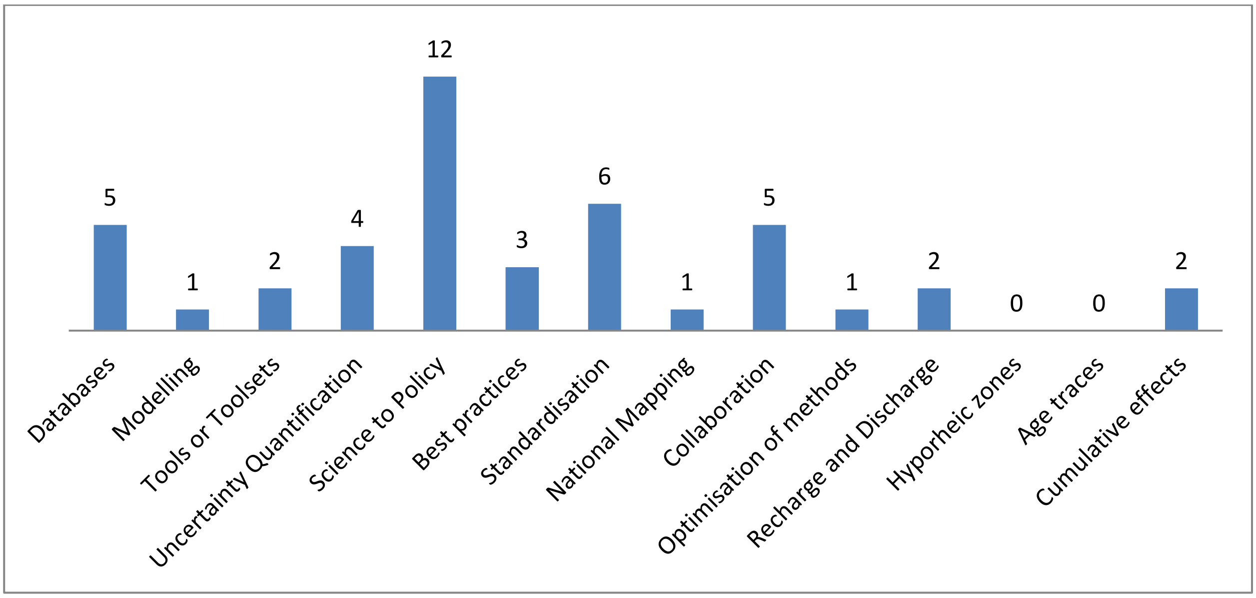


Figure 1: Summary of important topics in GW-SW interaction work, collated at the end of the workshop.

QUESTIONNAIRE

A questionnaire was distributed at the start of the workshop for participants to fill in. The questionnaire asked four high level questions to gauge the perception of attendees who had a range of experience and involvement in GW-SW interaction throughout New Zealand. The questions and answers have been detailed below:

Q1. What are the most important lessons/information you hope to learn from the workshop?

1. Range of methods available for meeting interactions.
2. The current methods involved in analysing GW and SW discharge and fluctuations.
3. Application of GW-SW policies methods of measuring GW.
4. Information about databases, techniques and tools.
5. Who and what organisations are doing what.
6. Tools and techniques for investigating SW/GW interaction. Pros and cons of these. Costs and benefits of these (costs-time/resourcing/SS).
7. GW/surface water interaction between locally confined aquifers and surface waters in zones where the aquifer becomes unconfined.
8. Methods available – Policy needs.
9. What practical solutions can come from research in GS-SW interactions? What do Regional Councils need to know about GS-SW interactions, either qualitative or quantitative?
10. How to quantify low land stream flow coming from the various aquifers.

11. What are variable methods for GW-SW1, where to find data, where to find resources.
12. Methods and tech used in GW-SW research;
13. Tools and ideas for implementation. Learning how other councils do things. Gaining knowledge.
14. Different techniques for assessing SW-GW interaction.
15. How to collaborate with competitors.
16. Fundamental/basic understanding of GW/SW interaction, specifically monitoring and modelling techniques.
17. A little bit about modelling.
18. I know very little about GW Envis and potential interactions so any info is a bonus.
19. How SW/GW interaction can be characterised (best practise) in a local setting. How to critique our upcoming research and monitoring plans. I am not convinced we have the right approach. I want to learn more and get a set of tools our Regional Council can use to progress our knowledge (in a meaningful way). Our research seems haphazard and the resulting uncertainty is still too high to convince planners/councillors of tough consent conditions that are desperately needed to protect our water resources and water bodies.
20. Better understanding of state and issues especially with respect to Regional policy setting.
21. Clear conceptual framework. Tools for Regional Councils.
22. How to integrate GW-SW interactions into policies.
23. Uncertainty analysis. Numerical and analytical solutions to assist with setting allocation limits.
24. What databases (regional) are available -geochem/isotopes – physical – aquifer characterisation data/models, in NZ that can be pulled together to form a better idea of those factors affecting stream depletion; health of the hyporheic zone and 'downstream' USERS – GDE's. Where are the high risk area on a catchment scale and what data is needed to inform policy makers.
25. Modelling technique to characterise GW-SW interaction.
26. What are the latest advances in surface water – groundwater interaction and tools.
27. How to quantify the uncertainties around surface water groundwater interaction.
28. Methods to determine SW-GW interaction.
29. Current state of GW-SW knowledge in NZ.
30. The ideas and knowledge that already exists and the gaps that need to be filled in regards to GW-SW interaction.

Q2. What do you consider to be the most important way forward/ aspect for future research on GW-SW interaction?

1. Methods that enable high resolution of interactions, also methods that quantify the interactions too.
2. Large scale river, stream bed techniques.
3. Identify gaps in knowledge. Standardisation. Mapping. New Models.
4. Development of new ideas. Trial of new ideas at same sites to enable comparisons and assessments of different methods. Also assess where 2 or 3 methods work better together.

5. Cost effective methods for limited budgets. Tools to analyse uncertainty. Integrations of science and policy. Improved communication of outputs. (public friendly).
6. Current research endeavours are excellent. Scientific/modellers should be encouraged and resolved to carry on.
7. Interaction quality. Quality surface water/groundwater national database.
8. Funding!
9. The correct tool box to solve quantitative issues: radon, temp, photo-satellite, chemistry.
10. Someone doing some fundamental work on it. That means funding commitment – that means some political commitment.
11. Combined/Integrated research. More information available on a public forum.
12. Standardised data collection. Data collection.
13. General data collection to assist resource managers, e.g., hydraulic parameters.
14. Collaboration between Institutes.
15. National spatial coverage and understanding. Improved understanding of aquifer process and impacts on water quality, i.e., between the land phase and receiving water body.
16. Finding suitable multi-face approaches.
17. Funding for university students to develop data sets, methods for monitoring and recommendations.
18. Everything!! The monitoring data collected is not in the right location (need finer scale resolution data to be useful). I'm not well placed to talk about research gaps but in terms of Council needs, we need convincing/reliable ways to enforce tougher consent conditions when we suspect an effect on SW → "uncertainty: always puts doubt on the need for touch conditions. Our regions recharge zones → this would benefit out land use policy and intensification.
19. Collaboration.
20. How it relates/impacts the NPS-FM.
21. Fully integrated models.
22. Addressing uncertainty.
23. Identify knowledge and data/info gaps. Apply funding to those who collect this info on a regional basis. Put this info/data into a national transparent data repository for all to use. Really need good old fashioned integrated catchment studies GW/SW to occur and develop computer tools to help inform policy and GW mgmt.
24. Don't know enough about it to answer this question.
25. Standardisation – Collaboration – catchment approach. National tool-box. Chemically conservative parameters/tracers to track water through all phases of flow cycle.
26. Development of a regional scale demand model for accuracy.
27. New modelling approaches.
28. GW location, quantity, flow paths, flow rates.
29. Improving technologies/using a range of technologies to understand GW-SW interaction.

Q3. What is biggest information gap regarding GW-SW interaction for yourself and/or your organisation?

1. Interaction data only based on a single method – flow gauging.
2. Tools and resources for GW-SW interaction open source resources, articles.
3. Access to data. Improved spatial coverage of sites.
4. Who is carrying out research in the area; what progress have people made.
5. Effect of land use on water quality. Sustainable GW allocation limits to protect SW flows/values. Climate change impacts. Quantification of uncertainty in existing models.
6. Stream depletion assessments.
7. Scale issue. Time issues related to timelag for integration assessment and appropriate life cycle.
8. Basic hydrological and biogeochemical processes.
9. How does upstream/plains abstraction cumulatively affect low land stream flows.
10. Mapping of discharge/recharge zones and relation (if any) between deeper, leaky aquifers and rivers.
11. Quantifying the flux @ the GW-SW interaction and relating that to low flow over seasons. Predictive capability.
12. Level of connection. Standardising approach.
13. Hydraulic parameters to go into analytical solutions, part stream bed clogging/conductivity.
14. Losing Reaches.
15. Lag times. GW/SW boundary alignment. Processes e.g., attenuation.
16. Hyporheic zone.
17. How to recognise, sample and model for future climate change.
18. Eventually a guidance document. Presentations → even video's emailed around. Emailing of recent journal articles (e.g., as public access if difficult). Email list for people interested in SW-GW interaction (i.e., we need more than just the GW scientists involved, SW scientists need this knowledge too).
19. What the capacity/capability of Councils is.
20. How to explain its importance to policy/decision makers.
21. Significance at regional scale.
22. Addressing uncertainty and communication of limitations to general public. Accounting for regional impacts on GW/SW interactions.
23. DATA! I want to be able to access research orgs and Regional Council databases so that I have all the data and knowledge of data gaps so that I can do my job as a hydrogeologist managing G/W users and protecting GDE's.
24. See Q1.
25. Recognition of interconnectedness.
26. Continuous flow data at multiple points along a river. Long term water use data.
27. Data.
28. Standard GW-SW modelling techniques.
29. How pathways taken from surface through the vadose to groundwater – what influences this? e.g., physical properties of soil, electrical conductivity.

Q4. What do you consider to be the most informative way for research results on GW-SW interaction to be disseminated?

1. Publish results in a report, journal or available by council etc.
2. Unsure.
3. Workshops. Papers.
4. Copies of presentations to be distributed.
5. Workshops. Guidance documentation on accepted tools, techniques and how/when to apply them. Webinars – web based presentation of case studies. Directory of providers – who does what.
6. Publications that are accessible to all users.
7. Papers – workshop.
8. Workshops to stakeholders, especially Ministries, Councils and sector groups.
9. Maybe LAWA science web page – where CRI papers/finding can be found.
10. Maybe using an internet portal – like USGS?
11. Public forum – web based and user group.
12. Presentations and workshops.
13. Register of research studies in individual rivers so that data can be accessed.
14. Visualisations. Repositories of data.
15. Smaller group discussions.
16. Through national guidelines.
17. Best practise guidelines for Council to use to address localised issues. E.g., characterise the pathways and likely effects on water bodies in X setting using X method, for X objective. Prior to local consenting issues/WQ issues/declining water levels happening, what should we be monitoring (at least).
18. Workshop/Webinar.
19. CRI-Wiki?
20. International journals (open access).
21. Geo database sets for results of investigations.
22. Onto a national, transparent, data repository. This data repository could be managed on a national basis by, say, the Dept. of Env., or Planning or something similar.
23. Workshops, refereed papers.
24. Workshops like this one and free software like ECAN provide – XL based tools.
25. Workshops.
26. Public access journals.
27. Discussion amongst organisations.

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