NEW ZEALAND HYDROLOGICAL SOCIETY

60th Annual Conference

NZHS 2021

30 Nov – 3 Dec

Te Whanganui-a-Tara | Wellington

He kimihanga waiwaiā o te wai māori
An Essential Freshwater Odyssey

Conference Handbook

www.nzhsconference.co.nz

Contents

New Zealand Hydrological Society
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Welcome

Kia ora koutou! The NZ Hydrological Society warmly welcomes you to their annual conference to be held in Te Whanganui-a-Tara / Wellington and online from 30 Nov to 3 Dec 2021. It is the 60th anniversary conference and promises to be a memorable event in the capital. The national museum Te Papa Tongarewa is a superb venue in the heart of a city that has easy foot access to many attractions including the vibrant harbour front, the lively inner city café, bar and shopping scene and the diverse town belt trails.

The conference theme is He kimihanga waiwaiā o te wai māori | 2021: An Essential Freshwater Odyssey. This theme captures the idea of a water management/guardianship journey, from the past to the future, via the crossroads we currently find ourselves at with the government's Essential Freshwater reforms and the central concept of Te Mana o te Wai. In keeping with the anniversary event and theme, we encourage attendees to reflect on progress and their experiences to date as well as think about how future water research might best meet the kaitiakitanga and management challenges ahead.

Conference Committee

Richard Hawke (co-chair) – *Toitū Te Whenua Land Information New Zealand*
Mike Thompson (co-chair) – *Greater Wellington Regional Council*
Rebecca Morris – *Greater Wellington Regional Council*
Alasdair Keane – *Keane Associates*
Mike Stewart – *GNS Science*
Chris Daughney – *NIWA Taihoro Nukurangi*
Tim Baker – *SLR Consulting*

Exhibitors

VIRTUAL EXHIBITORS

Use the conference App to view the virtual exhibitors.

ON-SITE EXHIBITORS

OCEANIA ROOM FLOOR PLAN

1. GNS
2. RDCL
3. ESR
4. Aqualinc
5. NIWA
6. Scottech
7. Hydrometrics
8. Griffiths Drilling

Society Welcome

It is my pleasure to welcome everyone to Wellington for the 60th Annual conference of the New Zealand Hydrological Society. This is another milestone anniversary event for the Society, and it is a pleasure to have the 60th conference, like the 50th conference, in Wellington.

This has been an eventful year in New Zealand with the re-emergence of Covid-19 and with different parts of the country at different levels of restrictions. The Wellington organising committee despite the challenges have put a lot of effort into organising this conference under the current Level 2 requirements. The committee and the conference venue Te Papa are confident in the ability to run the conference safely with the protocols that have been established. We would like to welcome all attendees, both in person and virtual, and trust you will all take every opportunity to connect with each other on line or in person.

The conference theme this year is: He kimihanga waiwaiā o te wai māori | 2021: An Essential Freshwater Odyssey. This is an appropriate theme as it captures the idea of a water management/guardianship journey, from the past to the future, and at the stage we currently find ourselves at with the government's Essential Freshwater reforms and the central concept of Te Mana o te Wai. The conference offers a large and diverse range of papers (both in person and virtual) with an exciting range of keynote speakers. This conference also offers a great opportunity for learning and networking with a wide and varied range of colleagues involved in the water sciences.

It's also a pleasure for the Society to publish a special journal celebrating the 60th Anniversary of the Society. My appreciation to all the contributors and editor Richard Hawke and assistant editor Laura Keenan for making this happen. Well done!

I would like to thank all the sponsors and trade exhibitors for the ongoing support of our Society's conference and the Society itself. Congratulations organising committee who have done a brilliant job and On Cue who have put a lot of effort into this event. I wish everyone a great and safe conference and for those attending to be ever mindful of all health and safety protocols, notices and requirements. I sincerely hope all of you attending enjoy your stay in Wellington.

I look forward to the opportunity of meeting as many of you as possible.

Joseph Thomas
President NZHS

General Info

REGISTRATION DESK

If you require any assistance throughout the conference please see the conference organisers at the Registration Desk in the foyer of the Oceania Room.

Our registration area will be split into two, please follow the signage to register at your correct registration desk

NAME TAGS

Delegates are requested to wear their name tags to all sessions and social functions.

- Committee identified by the yellow strip.

On the back of your name tag – the coloured dots indicate what you are registered to attend.

CELL PHONES

Please ensure that cell phones are turned off or on silent, during all presentations.

CONFERENCE CONTACT

For assistance during the conference, please call Tracy Young from On-Cue Conferences on 021 164 7820

TAXIS & SHUTTLES

Wellington Combined Taxis 04-384 4444

Super Shuttle 09 522 5100

The Wellington airport is approximately 12 minutes' drive from the conference venue.

EXHIBITORS

Don't forget to visit and chat with the exhibitors. Check the app for more details about our exhibitors and don't forget to visit our virtual exhibitors this year.

MEALS

All catering will be in the Exhibition Area / Oceania Room.

If you have advised us of your special dietary requirements, these have been forwarded to the caterers and will be available on a separate table individually marked.

At the Conference Dinner, please make yourself known to the wait staff and they will make the necessary arrangements for your special meal.

If you have any dietary requirements that we are not aware of, please see the Conference Organisers at the Registration Desk on arrival at the conference.

As part of the Covid Safety Plan all meals will be served in individual packaging (brown paper bags) and there will be 2 main catering areas. Please follow the signage at each food break to minimise queuing. Packaging is non-plastic where possible and has been minimised as much as possible while ensuring minimum risk around food service.

You can take your pack outside or find a seat in the Oceania space to sit and eat.

You can remove your mask while seated and eating and drinking, however you are encouraged to put the your mask back on prior to moving around the exhibitor space.

Please note, no food can be eaten in Te Papa outside of the conference rooms.

LOADING PRESENTATIONS

Please take your presentation on a USB stick to the AV desk – this should be done at the start of the day that you are scheduled to present.

POSTER PRESENTATIONS

Poster session will be on Wed 1st Dec during lunch, 12:40 –2:10pm. Posters are located in the Oceania Room.

Please put your poster up on arrival. Posters should remain up all week and be removed at lunchtime Thursday. Any posters remaining will be considered unwanted.

SESSION CHAIRS

Please can all session chairs be in their room at least 5 minutes prior to the start of the session. Please introduce yourself to the AV tech in the room. There will be a student assistant in each room, to help with Q&A. It is very important that presentations do not run over their allocated time so please ensure presenters start and finish on time.

JUDGES

If you are judging presentations please collect judging forms from the registration desk. Once complete, please return judging forms to the box on the registration desk.

CONFERENCE APP

You can access all of your conference information, including presenter abstracts on the conference app.

Your login information was sent to you last week, if you haven't downloaded the app yet, just follow these instructions:

1. Go to the app/play store and search for eventsair, download the app
2. Once downloaded, enter the event code: 2021wellington
3. Login: your email address (used for conference registration)
4. PIN: check the back of your name tag for your PIN

You are now set up to see the latest conference programme and receive alerts.

COVID-19

The health and wellbeing of our members, attendees, speakers and sponsors are at the forefront of all decision making and we want to ensure that you are confident that we have taken all appropriate steps to keep you as safe as possible whilst encouraging you to enjoy, network and make the most of the 2021 conference.

The Conference Organisers are following the principles outlined in the "Event Sector Voluntary Code during NZ COVID-19 Level 2", as well as putting in place additional CovidSafe planning procedures, which includes:

- Registrants should stay home if they're sick
- Should an attendee arrive at an event looking unwell or presenting any symptoms of cold or flu, we will respectfully request that they do not attend in order to protect others
- Mandatory use of the NZ COVID Tracer app or manual sign in
- Social distancing is required, only 2 people in the lifts at any one time. Please maintain at least 2m distance between other visitors around the museum and 1m between other delegates and function staff inside the venue space.
- Mask wearing is mandatory when visiting the museum and if physical distancing is difficult, unless exempt for health reasons.
- Hand sanitiser/soap will be available on arrival and through-out the Conference
- Good hygiene principles will be reinforced, including hand washing and covering coughs and sneezes
- Adequate equipment and facilities will be available to support good hygiene practices, e.g. soap/hand sanitizer, tissues, rubbish bins and some face masks (face masks will be available at the registration desk)
- Caterers will be encouraged to be extra vigilant with hand hygiene and they will not work if they feel unwell, all food and beverage services are to operate under level 2 rules: Seated and separated.
- Our registration staff will be behind a Perspex screen during registration. Our registration area will be split into two, please follow the signage to register at your correct registration desk.
- Delegate name tags will be laid out in advance for delegates to collect and registration will be separated into two areas.
- There will be signage about Covid19 protocols
- There will be Covid health and safety announcements throughout the Conference and reminders via the Conference App

NZHS and the Conference Organisers have implemented plans to help minimise the risk for those in attendance, however you are reminded that all individuals are responsible for their own personal hygiene and decision to attend.

Thank you for helping us stay safe.

Venue Information

VENUE INFORMATION

The Conference Venue is
Te Papa | Tongarewa Museum of New Zealand

55 Cable Street, Te Aro, Wellington
Phone 04-381 7000

INTERNET

Wireless internet is provided free to conference delegates. After accepting the terms and conditions you have a maximum of 2GB per 24 hours.

WiFi: Te Papa Events

Password: events

PARKING

Te Papa offers a special day function attendees parking rate of $12.00 from 6am to 6pm. A small car parking validator machine is available at registration where the guests need to bring their parking ticket from the barrier arm to the validator and pass it through the machine, then they will need to go to a pay station on departure and the special function attendees rate will apply.

NO SMOKING

Te Papa Museum is a non-smoking environment. Smoking is only permitted outside the confines of the building and away from the main entrance doors.

All types of electronic smoking devices are also not permitted inside the museum building.

VENUE EMERGENCY INFORMATION

Fire: Continuous alarms will be activated throughout the building and all occupants should leave the building immediately. The assembly points are either in front of Te Papa Museum near Circa Theatre or on Barnett Street corner Cable Street, next to Waitangi Park.
Earthquake: In the event of an earthquake, stop, drop and cover. When the shaking stops, follow the instructions of the emergency wardens and make your way out of the building to the assembly point.

This information will be covered each day in conference housekeeping, preceding the Keynote presentation.

MEDICAL & EMERGENCY INFO

NEW ZEALAND EMERGENCY SERVICES

Ambulance, Fire and Police. Dial 111 from any public, private telephone or mobile phone in New Zealand.

WELLINGTON POLICE

Phone 04-381 2000 from within Wellington. The police station is located at 41 Victoria Street, Wellington Central

WELLINGTON REGIONAL HOSPITAL

49 Riddiford Street, Newtown

Phone 04-385 5999

AFTER HOURS MEDICAL CENTRE

17 Adelaide Road, Newtown

Phone 04-384 4944

CHEMIST/PHARMACY

Unichem Pharmacy - Plimmer Steps

354 Lambton Quay, Wellington Central

04-555 3540

Hours Mon-Fri 8:30am - 5:30pm

Venue Map

LEVEL
2

Te Papa o Pōneke, Te Taiao, Karipori
Wellington Foyer, Nature, Gallipoli

Taupaepae
Information Desk

Te Taiao | Nature

Te Ika Whenua
Unique NZ

Whakarūamoko
Active Land

Te Kōhanga
Nest

Ngā Kaitiaki
Guardians

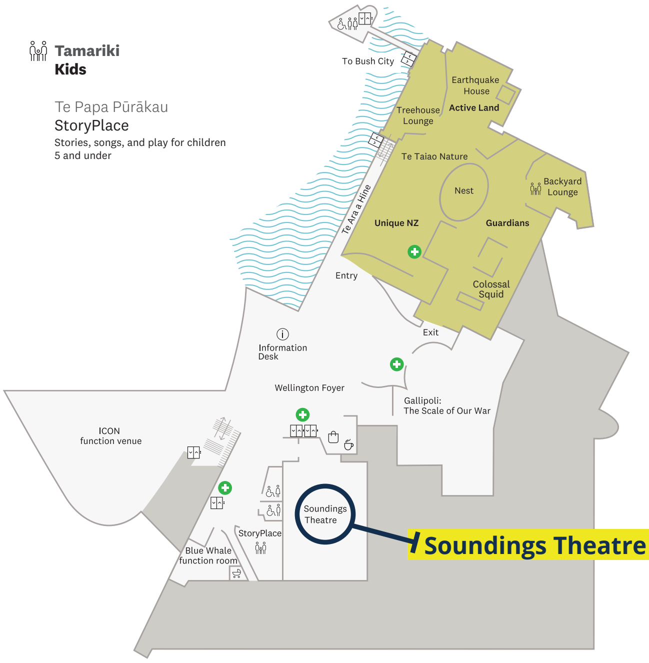
Karipori: Te Pakanga Nui
Gallipoli: The Scale of Our War
New Zealanders in the World War I campaign

Toa Tamariki
Our store for kids

Toa Kawhe
Coffee kiosk

Tamariki
Kids

Te Papa Pūrākau
StoryPlace
Stories, songs, and play for children 5 and under



LEVEL
3

Te hua a te tangata, a te whenua
People's impact on the land

Blood Earth Fire | Whāngai Whenua Ahi Kā
The transformation of Aotearoa New Zealand

Kei te Kairauhī: 21 Taonga
Curators' Choice: 21 Things
Explore new collection items

LEVEL
4

Kōrero pāpori & Toi Art
Social history & Toi Art

Toi Art
Art exhibitions

Mana Whenua
The world of Māori

Ko Rongowhakaata: Ruku i te Pō, Ruku i te Ao
Ko Rongowhakaata: The Story of Light and Shadow
Iwi (tribal) gallery

Rongomaraeroa
Te Marae
Te Papa's contemporary meeting place

Te Tiriti o Waitangi: Ngā Tohu Kotahitanga
Treaty of Waitangi: Signs of a Nation
Aotearoa New Zealand's founding document

Rātana: Te Kaiwhakaora
Rātana: The Healing Faith
100 years of the Rātana Church

Tangata o le Moana
Pacific peoples in New Zealand

Uruwhenua
Passports
Immigrants' stories

Ngā Manene
The Mixing Room
Stories from young refugees in New Zealand

Kawhe Kutētē
Espresso

Motupaika Hautipua
Britten Bike
The record-breaking Britten V1000 motorbike

Phar Lap
The legendary racehorse

Tamariki
Kids

Te Papa Moana
PlaNet Pasifika
Pacific Discovery Centre

Te Huka ā Tai
Māori Discovery Centre

Welcome to Wellington

Haere mai ki Pōneke

ATTRACTIONS

- A Nairn Street Cottage
- B Pukeahu National War Memorial Park & Carillon
- C Sky Stadium
- D Mount Victoria Lookout
- E Toi Pōneke Arts Centre
- F Embassy Theatre
- G BATS Theatre
- H Hannah Playhouse
- I St James Theatre
- J St Gerard's Monastery
- K Freyberg Swimming Pool
- L Wellington Convention and Exhibition Centre
- M Museum of New Zealand Te Papa Tongarewa
- N Circa Theatre
- O The Opera House
- P Department of Conservation Visitor Centre
- Q Arapaki Manners Library
- R Michael Fowler Centre
- S Te Wharewaka o Pōneke
- T City Gallery Wellington
- U Old Bank Shopping Arcade
- V Wellington Museum
- W Capital E
- X TSB Arena
- Y Shed 6
- Z Wellington Cable Car Museum
- A1 Wellington Cable Car
- A2 New Zealand Academy of Fine Arts
- A3 The New Zealand Portrait Gallery, Shed 11
- A4 Space Place at Carter Observatory
- A5 Wellington Botanic Garden
- A6 Thorndon Summer Pool
- A7 Old Government Buildings
- A8 Reserve Bank Museum
- A9 Beehive and Parliament Buildings
- B1 Wellington Cathedral of St Paul
- B2 He Matapihi Molesworth Library
- B3 Ngā Taonga Sound & Vision
- B4 National Library of New Zealand
- B5 Old St Paul's
- B6 Katherine Mansfield Birthplace
- B7 Te Awe Library

ACCOMMODATION

		STARS / ROOMS
1	Brentwood Hotel	3.5 / 116
2	Grand Mercure Wellington	5 / 111
3	Liberty Apartment Hotel	4.5 / 43
4	Oaks Wellington Hotel	4.5 / 226
5	Courtenay Village	3.5 / 10
6	QT Wellington	5 / 180
7	Bay Plaza Hotel	3 / 76
8	Ohtel	4.5 / 10
9	Copthorne Hotel Wellington Oriental Bay	4 / 118
10	Rydges Wellington Airport	4.5 / 134
11	Mercure Wellington Abel Tasman	3.5 / 73
12	Mercure Central City Apartments	3.5 / 54
13	Astelia Apartment Hotel	4 / 75
14	Willis Village Urban Garden Apartments	3.5 / 21
15	West Plaza Hotel	4 / 102
16	Boulcott Suites	5 / 114
17	CityLife Wellington	4 / 70
18	James Cook Hotel Grand Chancellor	4.5 / 260
19	DoubleTree by Hilton Wellington	4 / 106
20	InterContinental Wellington	5 / 231
21	Ibis Wellington	3.5 / 200
22	Novotel Wellington	4.5 / 139
23	Aspect Apartments	3.5 / 21
24	Quest on Johnston	4.5 / 62
25	Park Hotel Lambton Quay	4 / 136
26	Sofitel Wellington	5 / 129
27	Rydges Wellington	4.5 / 280
28	Thorndon by Rydges	3.5 / 108

Social Functions

ENVCO NETWORKING SPONSOR

This year due to Covid restirctions Envco can't make it to the Conference, but they would still like to support your networking efforts!

Come to the registration desk to get a voucher to use anytime during conference.

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CONFERENCE DINNER

Date: Thursday 2 Dec From 7:30pm until late
Venue: Te Papa - Conference venue
Dinner Theme: A Sixties Odyssey
Tickets: Not included with your registration

This event is a wonderful opportunity to celebrate the year with your colleagues. The evening will be held at Te Papa and will feature the Conference Awards.

Dress to impress with the dinner theme: A Sixties Odyssey. Think dress for the era: anything from formal/black tie to casual/flower power to space characters: the options are only limited by your imagination!

Covid-19: Remember to maintain social distancing throughout the dinner, unfortunately this means no dancing. And please wear your mask when moving around between tables.

Field Trip:

DRINKING FROM THE HOBBIT'S WELL

HUTT VALLEY CATCHMENT / KAITOKE FIELD TRIP

Trip Leader: Rebecca Morris, GWRC

Date: Friday 3 December

Departure time: 8.30 am from Te Papa

Return: approx. 3.00 pm to Te Papa, then on to Wellington Airport by 3.30pm

The Hutt Valley Catchment is the main source of potable water supply to Upper Hutt, Lower Hutt, Porirua and Wellington. The Waiwhetu gravel aquifer, located in Lower Hutt, supplies up to 70% of Wellington's potable supply water in the summer. The high transmissive nature of the aquifer requires a delicate balance for management with minimum flow from Hutt River and saline intrusion from the Wellington Harbour. The first stop will be McEwan Park, to discuss the hydrology/hydrogeology of Lower Hutt and the saline intrusions monitoring network that is managed by Greater Wellington Regional Council and Wellington Water Ltd. We will then stop at the artesian water fountain. Hydrate yourself with fresh water straight from the Waiwhetu aquifer (UV treated, no chlorination). From there we will drive along the Hutt River explaining the hydrological complexities and the recharge mechanisms to the aquifer before stopping at Te Marua Water Treatment Plant. Here we will tour the water treatment plant and storage lakes before heading to Kaitoke Regional Park to view the Kaitoke weir - where it all begins. Plenty of free time has been allocated for lunch where you can don your elf ears or hobbit feet for lunch at Rivendell, Lord of the Rings Movie Site and take a short walk with Ranger Steve to hear memorable stories of our native forest.

Please wear good walking shoes and bring a rain jacket, just in case it's needed. Remember to fill and bring your water bottle.

Field Trip:

MATIU / SOMES ISLAND - DAYS BAY FIELD TRIP

Trip Leader: Mike Stewart, GNS

Date: Friday 3 December

Departure time: 9:00 am from Te Papa

Return: approx. 4.00 pm to Te Papa - Airport transfer not included

The trip will start with a short walk around the wharves to the East By West ferry terminal at Queen's Wharf. From there, the new electric ferry will take us to Matiu /Somes Island.

Matiu/Somes Island is a predator-free scientific reserve. It is also a historic reserve with a rich multicultural history. A guided walk will cover the fascinating multi-layered history of the island as well as the historic and biodiversity conservation which is taking place now. The walk will also increase our chance of finding some of the rare and shy wildlife.

From Matiu/Somes Island, the ferry will take us to Days Bay where we will have lunch at the Days Bay Pavilion.

After lunch we will visit Northern Forest, East Harbour Regional Park, where a park ranger will point out features of interest in the forest. Northern Forest lies between Eastbourne and Wainuiomata, and is held as a scenic reserve. It consists of steep hill country with beech/rata forest, and podocarp/broadleaf forest on the valley floors. Lower Hutt Forest & Bird and the general Wellington community are very active in preserving the ecology of the Northern Forest and controlling pests.

We will then catch the 3.15pm ferry back to Queens Wharf.

Sturdy shoes and a rain jacket are advised but the walking will be easy grade.
Remember to fill and bring your water bottle.

Please note: This trip does NOT include an airport transfer, however, it is easy to catch a taxi from Te Papa to the airport.

Keynote Speakers

Gillian Blythe WATER NEW ZEALAND
& Troy Brockbank PDP

Gillian is Chief Executive of Water New Zealand, a not-for-profit member organisation promoting and enabling the sustainable management and development of the water environment. She previously worked as head of strategy and regulatory affairs over a 20 year period for Meridian Energy.

Gillian has a BSc Economics and MSc in Natural Resource & Environmental Economics from University College London. Gillian is a Chartered Member of the Institute of Directors.

Troy Brockbank (Te Rarawa, Ngāti Hine, Ngāpuhi) is a civil engineer, Māori Advisory lead with PDP, Board member of Water NZ and Taumata Arowai, 2018's New Zealand Young Water Professional of the year, and 2020's Engineering NZ President's Fulton-Down Silver medal winner. He has over 15 years professional experience across engineering consultancies, civil contractors & suppliers. He considers himself an intermediary, having the advantage of seeing aspects from both an engineering and an indigenous Te Ao Māori world view. He is passionate about the widespread adoption of a holistic culturally enhanced design approaches and will continue working towards raising awareness as a leader in this field both nationally and internationally.

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THREE WATERS REFORMS AND TE MANA O TE WAI

The past, can be described through the whakapapa of Te Mana o te Wai and the historical delivery of three waters in Aotearoa New Zealand.

The reform of the three waters including the establishment of Taumata Arowai, the proposed establishment of four new water service entities, and the requirement to give effect to Te Mana o te Wai is the present.

What does the future bring for the three waters sector? One water, where through collaboration the strengths of Te ao Maori and Te ao Pakeha are leveraged.

Titiro whakamuri Haere whakamua – Look to the past to inform the future

WEDNESDAY 1 DEC | 8:30 AM

Mahina-a-rangi Baker

TE KŌNAE

Dr. Mahina-a-rangi Baker (Ātiawa, Ngāti Raukawa, Ngāti Toa) runs Te Kōnae, a Māori environmental consultancy that supports iwi and hapū all over the country, and also works providing advice to government on environmental issues. Currently she is reviewing the governments proposed reform of the Resource Management Act. The work that takes up most of her time is working as the Environment Manager for Āti Awa ki Whakarongotai. She is a lecturer in Kaitiakitanga Pūtaiao (Māori Science) at Te Wānanga o Raukawa. Her PhD is in Environmental Planning and her thesis was focused on mātauranga Māori (Māori knowledge) tools for modelling water catchments. She has also been closely involved in the development of the National Policy Statement for Freshwater Management 2020 in her role on the Kāhui Wai Māori.

A MĀORI KNOWLEDGE ODYSSEY: COMING HOME TO MĀORI METHODS OF CATCHMENT MODELLING

'The Odyssey' is great way to think about the long and challenging journey for Māori to return the nation's way of thinking about water back to the knowledge system that is indigenous to our home, to Aotearoa. We have finally arrived at 'Te Mana o te Wai'; a Māori conceptualisation of the principles of practice in caring for water and managing the impact of human activities on it.

The embedding of Te Mana o te Wai in our statutory framework includes the requirement to 'enable the application of a diversity of systems of values and knowledge, such as mātauranga Māori, to the management of freshwater.' But in a context where New Zealand academics have continued to marginalise or reject Māori knowledge and science, the eurocentric scientific tradition's myths about the supremacy of their knowledge system clearly needs busting.

I will share a local example of Māori science and knowledge being applied through catchment scenario modelling that is being used to support the implementation of the national objectives framework of the National Policy Statement for Freshwater Management, whilst examining some key questions such as:

• What is mātauranga Māori and science?

• How can mātauranga Māori incorporate western scientific modelling approaches and methods such as systems thinking and Bayesian statistics?

• What is the contribution that mātauranga Māori can make to key scientific challenges in water modelling, such as integrating ecological and social considerations, or handling uncertainty?

Professor Martin Manning

VICTORIA UNIVERSITY OF WELLINGTON

Professor Martin Manning, has worked across several areas of science including: theoretical nuclear physics, the carbon cycle, atmospheric chemistry, and climate change science more broadly. From 2002 to 2007, Martin was Director of the Working Group I Technical Support Unit for the Fourth Assessment Report on Climate Change by the IPCC that won the Nobel Peace Prize with Al Gore. He has been author of more than seventy peer reviewed publications, two this year, and more than twenty chapters in books on climate change, four of which were major IPCC reports to governments. As the inaugural Director of Victoria University of Wellington's Climate Change Research Institute, he led the first interdisciplinary study of New Zealand's capacity to adapt to climate change. His current work includes: analysis of 30 years of 14CO data to determine changes in atmospheric oxidation rates, and being on an experts panel, led by Jim Bolger, ONZ, to establish a community-led coastal adaptation plan for Kapiti.

HYDROLOGY, OR LIVING WITH WATER IN TIMES THEY ARE A-CHANGIN'

Talking of climate change in degrees celsius is the devil's way to make it sound simple. And as the impacts of change emerge more clearly, its hydrological aspects are becoming dominant. Extremes in rainfall are now going beyond what is seen in climate models and show that a Clausius-Clapeyron link between temperature and water vapour is not the full story. Recognising atmospheric rivers, and new challenges for predicting them, are part of a steep learning curve.

Vulnerability to drought is well recognised, but the extent of fires across Australia, Siberia and North America, etc is now breaking records every year and raising concerns for sustainability at a biome level. The fact that some major decreases in groundwater were first identified from satellite gravitational data also shows large gaps in the way that we are tracking changes, and so our ability to anticipate.

Then there is sea level rise. This year's IPCC Working Group I report has a reasonable match between observations and climate models together with projections out to 2150 and a first look at where the sea can be in 2300. This shows it's not just about keeping warming below 2°C. It's whether we can keep sea level rise below 3 m and avoid crossing thresholds that mean 7 m or more.

Hydrology sits in the middle of all this. There is more water coming down from above, more coming up from the beach, and growing disparities between where it actually is versus where it is needed. Urgency in dealing with these changes is becoming recognised. For example, Jim Bolger is leading a Takutai Kāpiti Community Assessment Panel that has to develop and recommend medium to long term coastal adaptation options to the council.

I've been pulled in to be part of this, so I have a list of questions for experts in hydrology, such as: What happens to groundwater levels and flood extent on coastal land when we get to a 1 m sea level rise? To what extent are hydrological models already covering 2 m or 3 m rises in sea level? Can restoring wetlands to what they were 150 years ago set up buffer zones to reduce salinisation of groundwater? And then there are the tricky ones like: how do we use science to get the timing right for carefully relocating a steadily increasing number of families and their homes?


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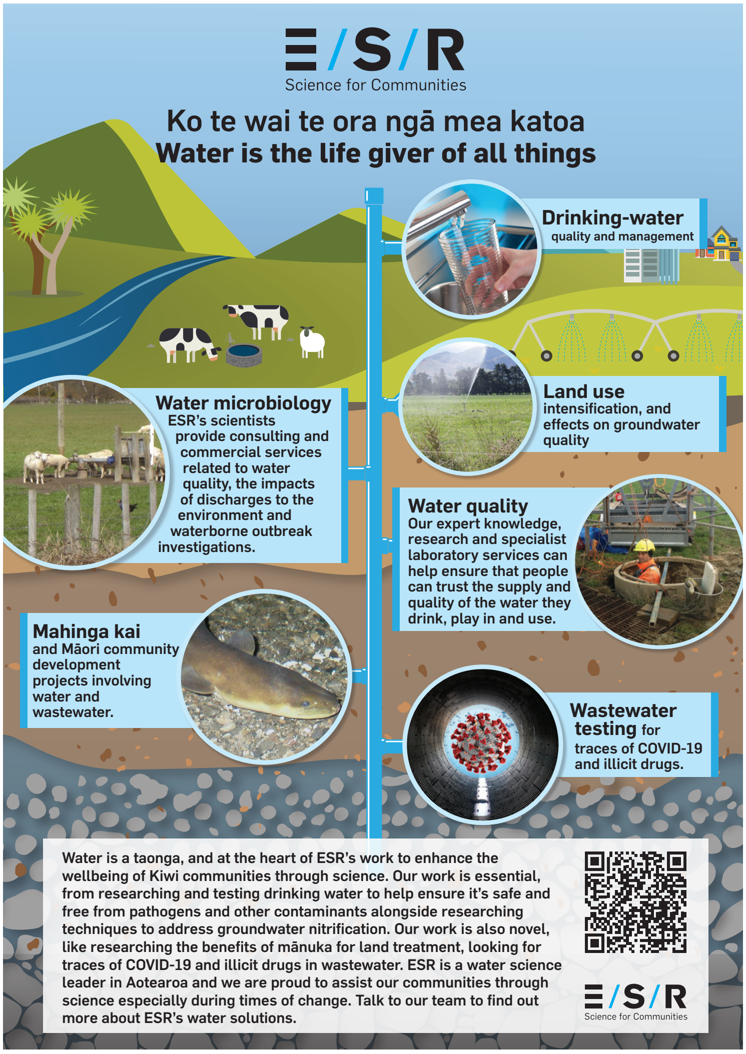
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ESR's scientists provide consulting and commercial services related to water quality, the impacts of discharges to the environment and waterborne outbreak investigations.
Water quality
Our expert knowledge, research and specialist laboratory services can help ensure that people can trust the supply and quality of the water they drink, play in and use.
Mahinga kai
and Māori community development projects involving water and wastewater.
Wastewater testing for traces of COVID-19 and illicit drugs.
Water is a taonga, and at the heart of ESR's work to enhance the wellbeing of Kiwi communities through science. Our work is essential, from researching and testing drinking water to help ensure it's safe and free from pathogens and other contaminants alongside researching techniques to address groundwater nitrification. Our work is also novel, like researching the benefits of mānuka for land treatment, looking for traces of COVID-19 and illicit drugs in wastewater. ESR is a water science leader in Aotearoa and we are proud to assist our communities through science especially during times of change. Talk to our team to find out more about ESR's water solutions.
ESR
Science for Communities

Modelling Workshop

THURSDAY 2 DECEMBER

Session Theme: Modelling for Water Management and Limit Setting Workshop

Session Chair: Andrew Fenemor

1.40pm-4.50pm

Introduction and overview of NPSFM - Andrew Fenemor

Te Mana o Te Wai – Rehabilitating Waterways, Working with Councils, and Thinking About Governance
Betsan Martin, *Victoria University & Response Trust*
Thompson Hokianga, *Haukūnui Solutions (Takitimu), Ngāti Kahungunu*

Case study 1: Catchment Scale Models: Which Ones and Why
Carl Hanson, *Environment Canterbury*

Case study 2: Wairau Aquifer Groundwater Model
Peter Davidson, *Marlborough District Council*
Thomas Wohling, *Lincoln Agritech - Technical University of Dresden*

Case study 3: Community Limit-Setting Processes
Mike Thompson, *Greater Wellington Regional Council*
John Bright, *Aqualinc*

Short Break / Afternoon Tea

Case study 4: Motueka-Riwaka Groundwater Model
Joseph Thomas, *Tasman District Council*
Julian Weir, *Aqualinc*

Case study 5: Integrated Modelling for Limit Setting
John Hadfield, *Waikato Regional Council*

Panel discussion: lessons learned, common pitfalls and future plans for knowledge sharing

Poster List

POSTER SESSION WED 1 DEC - 12:40PM - 2:10PM

Poster	Presenting Author First Name	Presenting Author Last Name	Organisation	Paper Title
1	Morgan	Bennet	University Of Otago	Development of an Extreme Hydrometeorological Event Index
2	Rob	Davies-Colley	NIWA	Turbidity is a flawed metric – that should be replaced by light beam attenuation
3	Matt	Hanson	Komanawa Solutions Ltd	Climate-shock resilience and adaptation for North Canterbury farms
4	Mohammed	Majeed (V)	Manukau Institute Of Technology	Toward evaluation of energy storage capacity
5	John	Montgomery	NIWA	Too many rocks: modelling the influence of river confinement on aggradation in the Waiho River
6	Andrew	Raj (V)	Environment Canterbury	Waimakariri deep monitoring well
7	Helen	Rutter	Aqualinc Research Ltd	Estimating section 14(3)(b) groundwater takes in Auckland
8	Maria Estefania	Santamaria Cerrutti	GNS Science	Dealing with changing best-practice within a long-term monitoring programme: comparison of ammonia-nitrogen measurements between unpreserved and acid-sulfuric preserved groundwater samples
9	Shailesh	Singh	NIWA	Spatio-temporal distribution of flood event types in New Zealand
10	Shailesh	Singh	NIWA	Strategic planning for dynamic water supply system
11	Shailesh	Singh	NIWA	Streamflow recession curves in gauges and ungauged basin
12	Jennifer	Tregurtha (V)	Environment Canterbury	Spatial and Temporal Analysis of Well Depths Over Time in Canterbury, New Zealand
13	Simon	Vale	Manaaki Whenua Landcare Research	Evaluating the impact of erosion process on sediment related water quality
14	Sam	Yeo	Otago Regional Council	Groundwater-surface water interactions in the Kauru River and implications to the lowland longjaw galaxias

V=Virtual Poster

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Oral Abstracts

IN ORDER OF PRESENTERS LAST NAME

SPECIAL THEMED SESSION: MODELLING FOR WATER MANAGEMENT AND LIMIT SETTING

Organisers: Rajanayaka, C.,[1] Thomas, J.,[2] Srinivasan, MS.,[1] Weir, J. [3]
[1] NIWA, Christchurch
[2] Tasman District Council
[3] Aqualinc Research Limited, Christchurch

Aim

Freshwater resources of Aotearoa-New Zealand are facing increasing pressures from farming, industrial uses, population growth and climate change. There is an increasing awareness for a need to sustainably manage and maintain our river systems and groundwater aquifers, for the benefit of the entire society. Water resource managers therefore face a major challenge to balance the allocation of water for societal needs and to generate important economic benefits whilst ensuring the environmental needs for today and into the future are provided for. The National Policy Statement for Freshwater Management 2020 (NPSFM 2020) also requires regional councils to set freshwater objectives and limits for freshwater resource use in their regional plans by 2024. Due to the above stated challenges and requirements, regional councils across New Zealand are in the process of identifying a range of appropriate tools, methods and approaches for managing water resources under diverse hydrological conditions and for limit setting. The main methods used for water resource management are: (1) measurements, (2) estimations and (3) modelling (or a combination of all three).

Models are used for a diverse range of freshwater planning, management and operation including hydrological, engineering, ecological, and policy development. Applications of models to real systems have improved our understanding of these systems, and hence have often contributed to their improved design, management, and operation. There are numerous types of models and identifying the most appropriate model(s) and modelling approach(es) for a given purpose is a challenge. Modellers also need to take into account new policies, rules and sociocultural values (e.g. Te Mana o Te Wai, TMoTW) when applying modelling approaches.

The aim of this special themed session is to provide a platform to bring together scientists, practitioners and policy experts to enable open conversation between diverse stakeholders, and in doing so enable collaborations by sharing resources, knowledge, expertise and experience for water resources management in New Zealand. This is the first of its kind in New Zealand. Enabling an opportunity to better understand how TMoTW principles can be included in modelling, and using real world case studies from diverse regions of the country, the session aims to explore the benefits and limitations of existing models and potential future directions.

This special session will also seek interest in organising a special issue on topic of *Modelling for limit setting and water management* for the Journal of Hydrology (NZ).

Programme

The agenda of the session is:

- Introduction and overview of NPSFM
- Guidance for incorporation of TMoTW principles in water management and limit setting
- Five case studies on the use of models for limit setting
- Moderated panel discussion: lessons learned, opportunities for collaboration, common pitfalls and future plans for knowledge sharing

Abstracts of talks

Te Mana o Te Wai – Rehabilitating Waterways, Working with Councils, and Thinking About Governance
Betsan Martin PhD, Victoria University & Response Trust and Thompson Hokianga, Takitimu

Sponsored by NIWA, Aqualinc and Conference organising committee

TMoTW is central to the rangatiratanga framework of governance, which provides stewardship and care for our waterways. The concept seeks pathways and partnerships that lifts the standards of our waterways, benefiting Aotearoa-New Zealand's environmental, economic, cultural and social values. Presenters Betsan Martin and Thompson Hokianga will explore two critical aspects of TMoTW that pertains to its successful implementation: a practitioner aspect considered within the context of the Ka Māpuna and researcher aspect focussing on the governance of waterways. Thompson Hokianga brings a legacy of a fourth generation 'Water Carter' and knowledge of looking after rivers and water resources. On the face of diminishing wetlands, drying rivers, and declining aquifers, the survival of cultural values and economic well-being of his community is challenged. Dr Betsan Martin will discuss matters of governance in respect of Te Mana o Te Taiao.

Environment Canterbury (ECan): Catchment Scale Models: Which ones and Why
Carl Hanson

Over the past ten years, ECan has used catchment-scale models to evaluate the effects of land use change on water quality, groundwater levels and stream flows in eight zones across the region. The work was completed to support the development of sub-regional plans that would set limits on water use, nutrient losses and water quality in the catchments. Models were built in sequence, working our way through the region zone by zone and learning from each model along the way. The models ranged from simple spreadsheet-based models to complex numerical models. Water quality modelling focussed on nitrates, and was heavily dependent on land-use mapping and models, particularly OVERSEER, that estimated nitrate leaching rates from different land uses. A common approach was to develop a lookup table that assigned nitrate leaching rates to different combinations of mapped land use, soil types and rainfall amounts. In most zones, uncertainty in model results was expressed qualitatively, with generalised descriptions of the sources of uncertainty and the potential impacts on limit-setting decisions. In one zone, stochastic analyses were used to quantify uncertainty in the model, and an expert panel approach was used to describe the uncertainty in nitrate leaching inputs. Model uncertainty was a difficult concept to communicate to public audiences. Generally, limits were set based on the model results that scientists presented as their best estimates, and uncertainty was accommodated through provisions for ongoing monitoring in the catchment.

Marlborough District Council (MDC): Wairau Aquifer Groundwater Model
Peter Davidson and Thomas Wohling Lincoln Agritech - Technical University of Dresden

The Wairau Aquifer underlies the northern half of the Wairau Plain (approximately 14,500 ha), and supplies most of the crop irrigation water and all of the drinking water for Blenheim, Renwick and Woodbourne. A series of regional scale numerical flow models of the Wairau Aquifer have been developed since 1988 to improve hydrological understanding of the resource and for limit setting by MDC. A declining trend in well levels since at least 1974 has forced MDC to review its limit setting approach to seasonal low groundwater levels, as hard cutoffs in wells would eventually be transgressed. Instead, a management-by-volume approach was tested using the model. The sustainable storage volume was defined as the net difference between river recharge and spring discharge. This annual volume is significantly less than the current annualised volumetric limit in the Marlborough Environment Plan, meaning it will manage short term seasonal problems and more accurately reflect actual water use. The numerical model was also used to investigate the potential for intra-seasonal effects relative to different abstraction rates, and found that carryover effects corresponding with current actual rates of abstraction were unlikely.

Greater Wellington Regional Council (GWRC): Community Limit-Setting Processes
Mike Thompson and John Bright - Aqualinc

GWRC has had community limit-setting processes underway in several whaitua (catchments). All are informed to an extent by hydrology and water quality models. The Ruamāhanga whaitua process started in 2015, and a large multi-component 'Collaborative Modelling Project' was developed to inform future scenario predictions for water quality and allocation. Primary model platforms included MODFLOW with MT3D (including stream flow routing), TopNet, EFSAP, eSource, 3D hydrodynamic lake modelling, representative farm modelling and associated economic analyses. A similar model framework and approach was developed for Te Awarua-o-Porirua whaitua but with a focus on a harbour receiving environment and no substantive groundwater modelling. The third whaitua process, Te Whanganui-a-Tara (Wellington/Hutt). has taken a simpler modelling approach by extrapolating from other areas where appropriate, and as such relied more on spreadsheets, lookup tables and Expert Panels (rather than site-specific complex numerical models) to predict scenario outcomes. We will summarise and contrast some features of the modelling approaches taken, but not in great technical detail. Instead, the focus will be on our perception of the value and challenges models have brought to limit setting discussions, decision making and policy development.

Tasman District Council (TDC): Motueka-Riwaka Groundwater Model
Joseph Thomas and Julian Weir - Aqualinc

The Motueka-Riuwaka Plains cover an area of approximately 40 km^2, and the underlying groundwater system supports intensive horticulture and associated industry, and the communities of Motueka, Riuwaka and the adjacent Kaiteriteri area. A numerical flow model of the aquifer system underlying the plains has been progressively developed (over multiple stages) since 1999 to assist TDC with management of the groundwater system. The most recent component of work incorporated the design, optimisation and effects-assessment from a proposed community water supply well field located adjacent to the Motueka River. Allocation criteria were defined based on the risk of saltwater intrusion, as indicated by modelled coastal groundwater levels and an absence of landward flow along the sea boundary. Under historical patterns of climate (and subsequent river flows and land surface drainage) and sea level, groundwater abstraction of over 30,000 m^3/day is predicted to be sustainable from the well field without breaching any decision criteria. However, a lesser rate may be needed if management of coastal drain/spring flows is important to the Council and community.

Waikato Regional Council (WRC): Integrated Modelling for Limit Setting
John Hadfield

WRC is interested in utilising integrated surface water and groundwater modelling in the process of limit setting and management of water resources more generally. There have been groundwater / surface water models developed in response to management issues in several areas. These have generally been used to provide context and understanding to underpin decision making. Examples include demonstration of nitrogen load-to-come scenarios in Lake Taupo. Similar substantial lags have been revealed in the Upper Waikato, again with uncertainties related to the extent of denitrification. Other modelling work in the Hauraki and Pukekawa areas have already been useful in showing the connection between groundwater and surface waters for allocation management. Further contaminant transport modelling in these areas will inform land-use loading and likely concentration limits. These models have not been used directly in limit setting to date. This in part reflects the recognition of inherent uncertainties and related current limitations in calibration data. It also indicates the involvement of larger political processes.

AN EXAMINATION OF THE SURFACE ENERGETICS CONTROLLING THE RECENT AND DRAMATIC LOSS OF ICE ON BREWSTER GLACIER

Abrahim, B.N.,[1] Conway, J.P.,[1] Cullen, N.J.,[2] Sirguey, P.[3]
[1] School of Geography, University of Otago
[2] National Institute of Water and Atmospheric Research
[3] School of Surverying, University of Otago

Aims

Changes in glacier extent affects seasonal flow rates in some catchments – particularly, summer low flows used for irrigation.To better understand glacier behavior and changes (such as variations in length, area and mass), the surface energy and mass balance is an important tool. Mass balance measurements and monitoring stations on the Southern Alps are still relatively scarce, with Brewster Glacier and Rollenston Glacier being the only two to be included in the World Glacier Monitoring Progrmamme. Brewster Glacier is a benchmark glacier in the Southern Alps for observational data collection and modelling studies relating to atmospheric forcing and glacier changes (Anderson et al., 2010; Gillett and Cullen, 2011; Conway *et al*., 2015; Cullen and Conway, 2015; Cullen *et al*., 2017).

The mass balance of Brewster Glacier has been reconstructed using several approaches, including the glaciological method (Cullen *et al*., 2017) and the albedo method that uses MODIS and the End of Summer Snowline (Sirguey *et al*., 2016). Recently, a geodetic survey allowed the reconstructed series to be calibrated and validated on the basis of observed mass loss over the period 1986-2006-2018. This produced a revised mass balance, which revealed a shift to significant mass loss on Brewster Glacier since 2008. The ablation has been widespread and has led to changes in the mass balance gradient, compromising the glacier's ability to store mass. This provides a unique opportunity to assess in detail what components of the surface energy balance have been responsible for the dramatic shift towards negative mass balance. The full causality chain of the controlling physical processes and environmental significance of this drastic change in glacier mass balance is unresolved. The aim of this research is to determine the multi-scale atmospheric processes governing the significant mass loss on Brewster Glacier. Specific focus is given to the surface energy balance and the partitioning of the energy fluxes to the energy available for melt in a temporal and spatial context and how this affects the mass balance of Brewster Glacier.

Method

A physically-based surface energy and mass balance model run in a fully spatially distributed mode is used in this study. The model computes the mass balance as the sum of solid precipitation, melt, sublimation, surface deposition and englacial accumulation due to refreezing of meltwater. The surface energy balance calculates melt energy when surface temperature = 273.15 K as a sum of net radiation, turbulent heat fluxes, heat flux from rain and conductive heat flux. Automatic weather station meteorological data and glaciological mass balance measurements are used to construct and evaluate the mass balance model. The meteorological data used in this study is a 10-year record (March 2010 to April 2020) collected from an AWS located next to the terminus of Brewster Glacier (Abrahim ***et al***., 2021).The glaciological mass balance of Brewster Glacier extends over a decade, making it the most extensive in situ glacier mass balance record for the Southern Alps. The model uses a detailed climatology of the study site to provide important details about the variations and magnitude of each energy flux and their influence on the seasonal spatial and temporal mass balance.

The fully distributed surface energy and mass balance model requires two inputs: digital elevation model (which includes slope, aspect, altitude and sky-view factor for each grid cell) and meteorological data (air temperature, wind speed, precipitation, cloud cover, relative humidity and atmospheric pressure) at 30 minutes timestep, which is used to force the model over a specified time period.

Results

The fully distributed surface energy and mass balance model allows for the examination of glacier-wide surface energy and mass balance variations. Over the 10-year study period, net radiation is the largest contributor to melt energy followed by the turbulent sensible and latent heat fluxes.This finding confirms the results from previous point-based studies conducted on Brewster Glacier (Gillet and Cullen, 2011; Cullen and Conway, 2015). The relative contributions of the energy fluxes to the surface energy balance varies slightly with alitude with net radiation becoming more dominant at higher elevations. Topographic controls on incoming solar radiation can lead to spatial variations in melt energy and is key factor in understanding the spatial complexity of glacier surface energy balance (Hock and Holgrem, 2005).

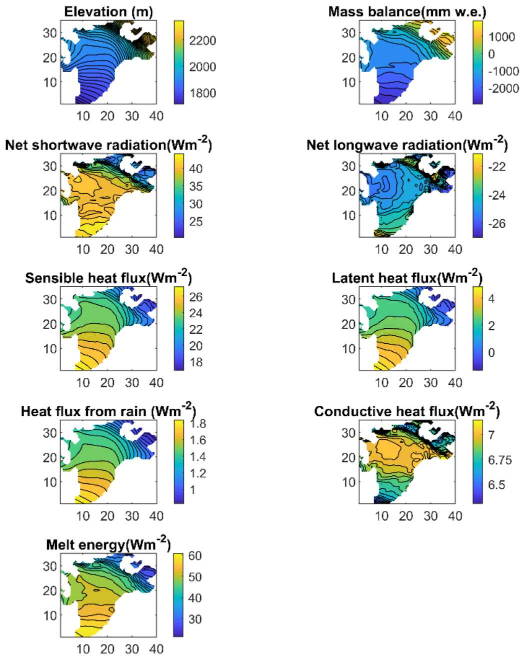

Figure 1: Spatial patterns of average mass balance and energy fluxes over the study period

References

Abrahim BN, Cullen NC and Conway JC. (2021). A decade of surface meteorology and radiation fluxes at Brewster Glacier in the Southern Alps of New Zealand. ***International Journal of Climatology***.

Anderson B, Mackintosh A, Stumm D, George L, Kerr T, Winter-Billington A and Fitzsimons S. (2010). Climate sensitivity of a high-precipitation glacier in New Zealand. ***Journal of Glaciology***. 56(195): 114-128.

Chinn TJ. (2001). Distribution of the glacial water resources of New Zealand. ***Journal of Hydrology (NZ)***. 40: 139–187.

Conway JP, Cullen NJ, Spronken-Smith RA and Fitzsimons SJ. (2015). All-sky radiation over a glacier surface in the Southern Alps of New Zealand: characterizing cloud effects on incoming shortwave, longwave and net radiation. ***International Journal of Climatology***. 35: 699-713.

Cullen NJ and Conway JP. (2015). A 22 month record of surface meteorology and energy balance from the ablation zone of Brewster Glacier, New Zealand. ***Journal of Glaciology***. 61(229): 931-946.

Cullen NJ, Anderson B, Sirguey P, Stumm D, Mackintosh A, Conway JP, Horgan HJ, Dadic R, Fitzsimons SJ and Lorrey A. (2017). An 11-year record of mass balance of Brewster Glacier, New Zealand, determined using a geostatistical approach. ***Journal of Glaciology***. 63(238): 199-217.

Gillett S and Cullen NJ. (2011). Atmospheric controls on summer ablation over Brewster Glacier, New Zealand. ***International Journal of Climatology***. 31: 2033-2048.

Hock R and Holmgren B. (2005). A distributed surface energy-balance model for complex topography and its application to Storglaciären, Sweden. ***Journal of Glaciology***. 51(172): 25-36.

McKerchar AI, Pearson CP and Moss ME. (1996). Prediction of summer inflows to lakes in the Southern Alps, New Zealand, using the spring Southern Oscillation Index. ***Journal of Hydrology***. 184(3): 175-187.

Sirguey P, Still H, Cullen NJ, Dumont M, Arnaud Y and Conway JP. (2016). Reconstructing the mass balance of Brewster Glacier, New Zealand, using MODIS-derived glacier-wide albedo. ***The Cryosphere***. 10: 2465-248.

RESTORING LAKE HAYES PART 2 – PROGRESS AND ROADBLOCKS

Badenhop, A.,[1] Johnstone, S.,[1] Davis, G.,[1] Bloomberg, S.,[1] Hanff, M.,[2] Rewi, M.[3]
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[2] Friends of Lake Hayes Society
[3] Mana Tahuna Charitable Trust

Lake Hayes, near Arrowtown, is prized for its beautiful vistas and recreational value for locals and tourists alike and yet has been subject to algal blooms and poor water quality. Friends of Lake Hayes have campaigned and fundraised over many years to see real action in restoring the Lake, and e3Scientific has been working with FOLH to provide concrete conceptualisation of nutrient mitigation options using a suite of methods including riparian fencing and planting, sediment traps, wetland enhancement and construction of wetlands to reduce nutrients from Mill Creek prior to discharge. Last year we presented the vision for the catchment and outlined a constructed wetland design. In order to implement this vision, work has progressed on several fronts in 2021 – not just the practical implementation of works but also campaigning for policy change to make sure gains for Lake Hayes are long lasting. However, this road has not been without its challenges.

Whilst there are many engaged stakeholders ready to invest in enhancing their land to improve water quality outcomes, not all developers are so willing – thus the birth of Policy 24.2.4.2 in the proposed Queenstown Lakes District Plan "*Restrict subdivision, development and use of land in the Lake Hayes catchment, unless it can contribute to water quality improvement in the catchment commensurate with the nature, scale and location of the proposal*". This landmark policy decision was the result of days of expert conferencing and mediation with planners, lawyers, water quality specialists and lake experts. However, whilst incorporation the Policy into the Plan was a significant achievement, it is just the first step - the fight continues to hold developers accountable to doing more than just mitigating the impacts of their developments.

On the implementation front, Mana Tahuna Charitable Trust recently won a grant from the Department of Conservations Jobs for Nature fund to make the restoration vision a reality. Locals will be employed for willow removal, bank battering, riparian planting, pest control and maintenance. The contract requires achievement of goals that include employment, community engagement and training in conjunction with environmental outcomes and so will showcase best practice catchment restoration.

A SOURCE-TO-SINK CONTAMINANT RISK FRAMEWORK TO SUPPORT WATER QUALITY POLICY ACROSS SCALES

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[3] Land and Water Science
[4] Waterways Centre, University of Canterbury

Introduction

In the wrong place, or at excessive concentrations, nutrients (nitrogen and phosphorus) and sediment become contaminants. Along with pathogens, they require reduction to improve water quality. Our Land and Water National Science Challenge (OLW NSC) and Ministry for the Environment (MfE) have commissioned a research programme 'Mapping Contaminants from Source to Sink' to inform both national and local government policy and planning on the fate of freshwater contaminants, specifically nitrogen and phosphorus species, sediment, and microbes in our environment and will be used to support the implementation of the National Policy Statement for Freshwater Management (2020).

The overall objective of this project is to produce a national landscape classification for water quality to support contaminant risk assessment for policy option development. The classification units will describe contaminant processes within parcels of land, surface water and shallow groundwater (hydrologically connected to streams and rivers).

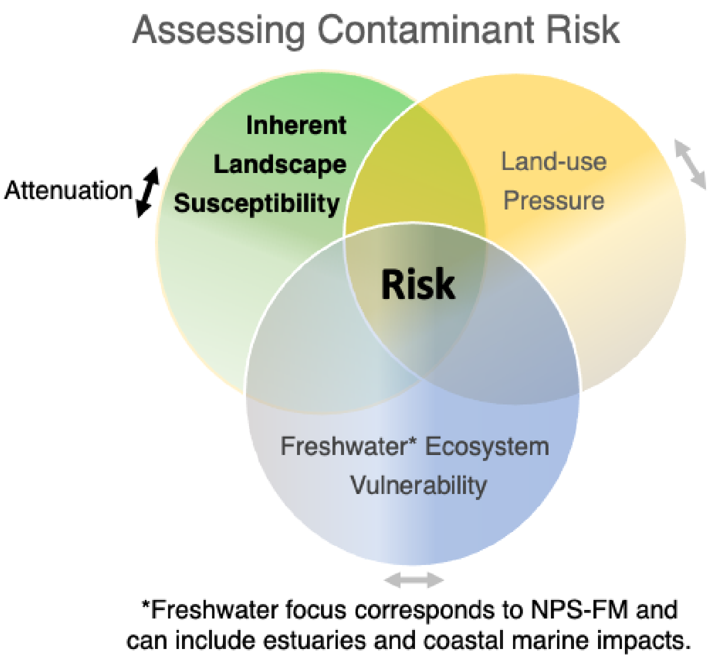

Figure 1. Contaminant risk is the intersection the inherent susceptibility of the landscape for contaminant loss, pressure from land uses, and the vulnerability of the receiving environment.

Framework

The landscape classification provides a system for identifying and grouping individual land parcels according to their risk for water quality, applied separately for nitrogen and phosphorus species, sediment, and microbial contaminants. The water quality risk describes the intersection of three factors:

1. the *pressure* from land use and management contributing to contaminant generation,
2. the *inherent susceptibility* of the landscape to contaminant mobilisation, and
3. the *vulnerability* of downstream receiving environments to contaminant loads.

The framework draws attention to the importance of mapping and classifying inherent susceptibility of the landscape to contaminant mobilisation and delivery. It supports problem identification as part of a multi-contaminant framework considering land-use pressure in landscape units, providing consistency across scales from national policy, through regional policies and rules, to land management activity – a span of up to ~10^5. Through landscape classification, the programme builds on previously successful work (Rissmann et al., 2018; 2019), identifying the dominant processes controlling risk to water quality for each contaminant.

The approach draws on the success of *Risk = Hazard x Exposure x Vulnerability* frameworks, and its application for climate change adaption related to land and water. Realistic support for national water policy appears to benefit strongly from focus on mesoscale water governance with locally relevant land assessment (Biswas et al., 2010; Scholten et al., 2020). A landscape classification framework provides a mechanism to identify dominant processes for the key contaminants, enabling comprehensible catchment-driven focus on attributes and the development and application of appropriate models within similar landscapes, ranging from internationally accepted tools, such as eSource and SWAT, and locally adapted accounting frameworks, such as ROTAN or the methods forming the foundation for this work (Rissmann et al., 2019).

Here, the final form is expected to yield risk as probability (*p*) given as $p\ [S \times P \times \prod (1\text{-}A)_i < V\ ]$, where: *S* is inherent susceptibility in units of contaminant load; ***P*** is land-use pressure, as a dimensionless multiplier (where 1 = reference); *A* is attenuation (as a fraction ≤ 1) and multiplicative in i locations along flowpaths using ∏ as the multiplicative version of summation (Σ). Notably *A* may occur within any of the three main compartments (Fig. 1). Finally, *V* = critical contaminant loading (e.g. limit). It is expected that the overall risk *(p)* can be evaluated with uncertainty by comparing the probability distribution function of the load, after attenuation, to the critical load estimated for the receiving environment. However, pragmatic assessment can be completed by setting ***V*** up as an additional multiplier.

The framework enables efforts to detail the role of the landscape in assessing responses to water quality issues, while retaining clear descriptions of land use pressure and vulnerability of receiving freshwater and coastal environments with a focus on ecosystem health. Focus within the project is on classification and map-based assessment of each contaminant's *inherent landscape susceptibility* to mobilisation and delivery, using a *dominant process* approach to characterise contaminant transport and attenuation to address multiple contaminants across a range of scales. The dominant processes known to drive spatial variation in water quality include climatic (e.g., orographic forcing), hydrologic (e.g., water source and pathways), redox (soil and aquifer), and physical weathering (erosion and mass wasting) categories. Other processes relevant to microbial transport and attenuation may also need to be developed. The assumption that a few dominant processes govern the response of environmental systems in any landscape is fundamental to the classification. The relationship between process response (e.g., percent overland flow of effective rainfall), and the landscape properties (e.g., slope, soil slaking and dispersion index) reduces unnecessary complexity and retains accuracy at national, catchment and farm scales.

The framework serves as a mechanism to guide, draw together, and prioritise previous work undertaken in OLW NSC and other aligned research that may be more appropriate locally, regionally or within land cases based on recognition of factors, such as dominant processes or data availability.

References

Biswas, A.K.; Tortajada, C. 2010. Future Water Governance: Problems and Perspectives. *International Journal of Water Resources Development 26(2):* 129-139.

Rissmann, C.W.F., Pearson, L.K., Beyer, M., Couldrey, M.A., Lindsay, J.L., Martin, A.P., Baisden, W.T., Clough, T.J., Horton, T.W., & Webster-Brown, J.G. (2019). A hydrochemically guided landscape classification system for modelling spatial variation in multiple water quality indices : process-attribute mapping. *Science of the Total Environment*, 672: 815-833; doi: 10.1016/j.scitotenv.2019.03.492

Rissmann, C., Pearson, L., Lindsay, J., Marapara, T., Badenhop, A., Couldrey, M., & Martin, A. (2018). Integrated landscape mapping of water quality controls for farm planning - applying a high resolution physiographic approach to the Waituna Catchment, Southland. In: *Farm environmental planning - Science, policy and practice*. Eds. L. D. Currie and C.L. Christensen, Fertiliser and Lime Research Centre, Massey University, Palmerston North, https://www.massey.ac.nz/~flrc/workshops/18/Manuscripts/Paper_Rissmann_2018.pdf

Rissmann, C., and Pearson, L. (2020). Physiographic Controls over Water Quality State for the Northland Region. Land and Water Science Report 2020/05. p120.

Scholten, T.; Hartmann, T.; Spit, T. 2019. The spatial component of integrative water resources management: differentiating integration of land and water governance. *International Journal of Water Resources Development 36(5):* 800-817.

QUANTIFYING THE POTENTIAL TO REDUCE EXCESS NITROGEN FLOWS FROM PASTURE CATCHMENTS: DESIGNING ISOTOPE TOOLS

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[2] Te Pūnaha Matatini Centre of Research Excellence, University of Auckland School of Environment
[3] Biogeosci.nz
[4] Lincoln University
[5] Independent farmer, DERRICK Team
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Introduction

High producing grazed pastures occupy almost one third of Aotearoa New Zealand (268,000 km2) and produce exported protein to feed more than 40 million people. Since 1990, trends within farming systems include increasing rates of urea fertiliser use and greater concentrations of nitrogen (N) via urine deposition, which contribute to increasing N_2O emissions and NO_3 losses.

We used natural isotope tracers to better pinpoint periods or locations of nitrogen excess that can be identified as control points, to target potential mitigation of nitrate losses. Focussing on N-sensitive lake catchments, we ask: how can isotope tools be applied to reduce uncertainties in the sources and magnitude of N losses, to quantify potential reductions in N excess, and to clarify rates of change in N budgets.

Results and Discussion

We combined widespread monthly, low flow, and targeted monitoring at many sites with operation of an event-based autosampler in the Lake Ōkaro catchment. This allowed us to augment the concentrations of N species and dual-isotope nitrate with water isotopes and $\Delta^{14}C$ in dissolved inorganic carbon (DIC).

Dual-isotope NO3 measurements continue to support previous interpretations and differentiate urine and urea-derived sources ($\delta^{15}N$ < 4 ‰) from mineralized soil organic N ($\delta^{15}N$ of 4–8 ‰). Nitrate in streams draining the Rotorua region's pumice soils and aquifers is dominated by urine and urea sources, compared to streams flowing from finer soils (e.g., Rotomahana mud) that only show these lower $\delta^{15}N$ values when large runoff events activate surface flow paths. We have confirmed that shifts in stream water $\delta^{2}H$ and $\delta^{18}O$ toward the values observed in the major rainfall events coincide with elevated NO_3 concentrations and low $\delta^{15}N$ representative of urine and urea-derived sources, across an event-size threshold. A combination of $\delta^{2}H$ and $\delta^{18}O$ and $\Delta^{14}C$ in dissolved inorganic carbon (DIC) largely confirmed tritium-based assessments, suggesting lag times of many decades in some aquifers, but rapid responses to recent N inputs elsewhere.

In the Southland region, where tile drainage enables effective pasture growth, we explored flow responses in a drainage tile where NO3 ($\delta^{15}N$ > 12 ‰) consistently showed an imprint of denitrification. In this location following major rainfall, NO3 concentrations remained stable but dissolved organic N concentrations increased, at times associated with stormwater $\delta^{2}H$ and $\delta^{18}O$ shifts. The $\Delta^{14}C$ in DIC yielded apparent ages of several hundred years during low-flow periods, suggesting ongoing breakdown of soil organic matter releases N, which should be considered in farm and catchment N budgets.

We conclude that monitoring N concentrations and multiple isotope species can resolve control points of N excess, which reveal targets in space and time for potential mitigation. Specifically, N content in clover-ryegrass pastures seasonally exceeds N demand in grazing animals, suggesting alternate species or feeds could reduce animal urinary N excretion, and therefore limit soil-derived NO_3 losses as well as N2O emissions. Other management decisions, including timing of fertilisation, grazing and cut-and-carry can all be considered for potential mitigation of excess N and associated N losses.

A DESIGN PROCESS FOR ACHIEVING NITRATE MITIGATION BENEFITS FROM WOODCHIP BIOREACTORS

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Aim

To gain benefit from a nutrient reduction measure against a farm nutrient discharge allowance, there is an onus to robustly demonstrate that the technique or activity can deliver, over the long-term, the claimed reduction in nutrient discharge. As the performance of mitigation measures is affected by the year-to-year variation in weather and agricultural management, achievable nutrient reductions should be estimated using a probability of performance approach over the long-term. For example, a bioreactor may be designed for a targeted nitrate (NO_3-N) export of 6 kg NO_3-N/ha/yr, with a probability of this performance target being met 70% of the time over the long-term, i.e., 30% of the time the nutrient target will be exceeded. This performance target should include an agreed confidence interval (e.g., 90 % CI), which represents the statistical confidence around the estimated targeted removal. Moreover, it is important that discussions of the uncertainties in the method and data used in making these estimations are provided.

This presentation initially examines the factors that affect the NO_3-N reduction in the Tatuanui woodchip bioreactor targeting artificial farm drainage. Subsequently, a design process is presented that demonstrates how a NO_3-N removal target maybe determined, including a probability level of performance, CI, and uncertainties. Such a design process could then provide regulators with the confidence required to take the implemented mitigation measure appropriately into account when farm-scale nutrient discharge limits are set.

Method

Woodchip bioreactors have been proven to be effective at reducing NO_3-N loads into waterways in a variety of applications. For two and a half drainage seasons we have monitored the N mass fluxes in and out of a 60 m^3 pilot-scale bioreactor, using flow-proportional sampling at the entry and exit. In addition, an optical sensor has provided NO_3-N concentrations at high temporal frequency and multiple locations within the bioreactor. This intensive sampling has enabled us to better understand the NO_3-N removal processes and functioning within the bioreactor under dynamic flow conditions and NO_3-N influx concentrations. This new information has allowed us to develop a robust design process for bioreactors to achieve targeted NO_3-N removal under the given conditions with an expected level of performance.

Results

The four critical variables that affect the NO_3-N removal capacity of a woodchip bioreactor are,

I. long term NO_3-N mass removal rate (NRR) of the substrate (i.e., woodchips),

II. the size of the installed bioreactor,

III. the operating temperature of the bioreactor, and

IV. the NO_3-N concentrations and flowrates in the influent delivered into the bioreactor.

Once a bioreactor is installed at a specific site the only operational variables that change substantially between seasons are the concentrations of NO_3-N and drainage fluxes delivered to the bioreactor (i.e., IV above). At the given site, due to climatic variations and land management between drainage seasons expressed in the contaminant delivery (N conc. and drainage flow) the mass of NO_3-N removed is **not** the same between seasons. For example, the annual masses of NO_3-N removed and efficiencies of N removal from the Tatuanui bioreactor over two and a half seasons are given in Table 1. The obvious variations in performance between season must be recognised in a design process.

Table 1: NO_3-N delivered into and removed from the Tatuanui bioreactor over 2 ½ drainage seasons.

Drainage season	Length of drainage season (days)	Average daily NO_3-N load (g NO_3-N /day)	Average daily NO_3-N removed (g NO_3-N /day)	Mass of NO_3-N delivered over season (kg NO_3-N)	Mass of NO_3-N removed over season (kg NO_3-N)	Eff. of NO_3-N removal (%)
Part 2017	94	20.7	20.5	2.0	1.9	99.0
2018	108	115.1	54.8	12.4	5.9	47.6
2019	40	174.6	50.3	7.0	2.0	28.8

This variation in NO_3-N removal between drainage seasons reflects the bioreactor NO_3-N removal capacity being essentially fixed, within temperature and nitrate limiting constraints. However, daily NO_3-N concentrations and fluxes delivered to the bioreactor will vary and can exceed the bioreactors removal capacity. These daily delivery variations are a function of site hydrology, nutrient management, and timing within the drainage season. As total annual mass of NO_3-N delivered in a year cannot reflect daily dynamics it is not feasible to use annualised data in a design process. Reflecting that the daily mass of NO_3-N (g N/day) is not a unique combination of flow and concentration, daily flow rates (m^3/day) and average daily NO_3-N concentrations (g N/m^3) over the drainage season are necessary inputs for the design process. This data is also required over enough years to reflect the variation in the long-term N delivery dynamics, e.g., probably greater than 15 years. While seemingly an onerous level of data required, there are methods available that can assist with estimating this data that will be discussed. The total annual NO_3-N loads are assumed to represent the population, which permits exceedance probability statistics to be assigned.

The carbon substrate is assumed capable of suppling sufficient available carbon, to sustain the long-term NRR, at a non-limiting rate over the practical life of the bioreactor. However, this is not the same for NO_3-N, with suboptimal NO_3-N concentrations limiting NRR being described using Michaelis-Menten (MM) enzyme kinetics. The temperature effect is incorporated using a Q_{10} temp. coefficient.

As the removal of NO_3-N by denitrification is a time-dependant relationship, the time of exposure of the NO_3-N to denitrification conditions created within the bioreactor impacts on the NO_3-N removal. The hydraulic retention time (HRT) within the bioreactor describes the time that a daily NO_3-N parcel is within the reducing conditions. The slower the flowrate, the longer the HRT, resulting in greater NO_3-N removal being achieved. Similarly, the larger the bioreactor, the longer the HRT, the greater the N removed. This demonstrates how flow rate (HRT) impacts on the NO_3-N removal achieved.

The long-term NRR of the substrate is determined from literature and an initial size assumed for a bioreactor. Using daily flow rates, the HRT of the NO_3-N parcels are determined from the estimated pore volume of the trialled bioreactor and daily flow rates. The NO_3-N limited NRR for the incoming daily NO_3-N parcel can be estimated from MM equation, and combined with the HRT, resolves an estimate of the daily mass of NO_3-N exported from the bioreactor. This daily simulation is repeated and summed over the drainage season to ascertain the annual NO_3-N mass discharged (or removed) for the bioreactor and season under consideration. Using all the seasonal drainage data, annual amounts of NO_3-N removed in each year are determined over the long time and exceedance probability assigned and graphed as shown in Figure 1. The targeted exported NO_3-N, and probability can then be selected from the graph for the two sizes of bioreactors considered. For example, the smaller sized bioreactor (shown in red), specifies exported NO_3-N will be less than 7.5 kg NO_3-N/ha/yr with a 70% probability of performance, the 90% CI range being 7.1 to 11.4 kg NO_3-N/ha/yr. Increasing the size of the bioreactor (in green) and decreasing the probability to 60%, results in an estimate of exported NO_3-N being less than 3.4 kg NO_3-N/ha/yr (90% CI range of 3.1-4.0). The desired level of exported NO_3-N targeted, and associated probability level can thus be iteratively determined by resizing the bioreactor size being considered.

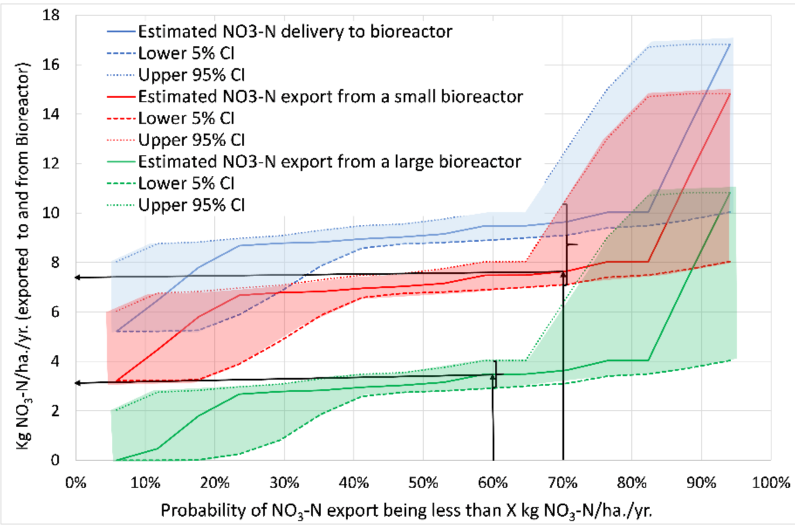

Figure 1: Design example of annual long term NO_3-N delivered to, and exported from, two different sized bioreactors including probabilities of exceedance and shaded 90% confidence intervals.

Information on mitigating initial start-up effects and discussion of any possible pollution swapping effects should also be included with the design information.

MODELLING, MONITORING AND MANAGING GROUNDWATER AT THE TE OREORE LANDSLIP, STATE HIGHWAY 4

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[3] Mt Messenger Alliance

The landslip on State Highway 4 (SH4) at Te Oreore, between Raetihi and Whanganui caused major disruption to transport links in the central North Island. The landslip was first noticed when, on 29 September 2019, cracks appeared in the pavement at the site. SH4 remained opened and was actively monitored. On 2 October 2019, the cracks widened, and Waka Kotahi closed the road due to the deterioration of the road and the development of a significant slip above the road. On 4 October 2019, the major landslip event occurred, removing a 250 m section of the State Highway (Figure 1).

Significant geotechnical investigations were commissioned by Waka Kotahi to better understand the triggers of the landslip, including site walkovers, drilling of geotechnical boreholes, installation of monitoring instrumentation (piezometers, surface/subsurface movement monitors), and unmanned aerial vehicle (UAV) surveys. These investigations indicated that it was elevated groundwater pressures within the landslip mass that are likely to have caused the failure of the slope.

Considerable effort has been made to understand the mechanics of the landslip, including the development of both conceptual and quantitative models of slope stability and groundwater flow. These models have provided insight into the site conditions and have helped to inform the selection of a permanent solution for slope movement at the site, namely dewatering of the landslip mass. It is anticipated that the proposed measures will protect this vital transport link as well as the health and safety of those who use it.

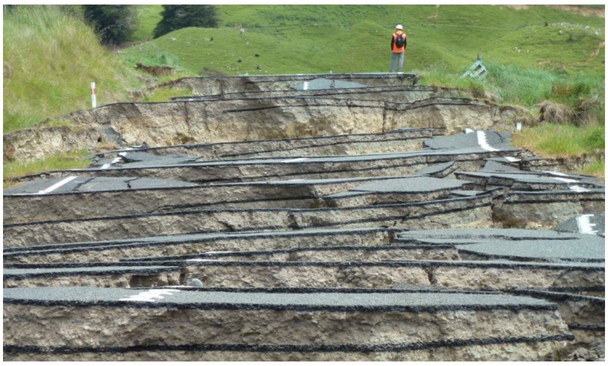

Figure 1: Tension cracks in road surface of SH4.

The hydrogeological conceptual model is presented in Figure 2 below. Groundwater recharge within the landslip is considered to be driven predominantly by rainfall events, both falling directly on the landslide as well as causing runoff from the upper valley area that then infiltrates into the landslip via surface and shallow subsurface flows. Groundwater seeps have been observed within the earthflow portion of the landslide, and this is considered to be the main groundwater discharge zone for the landslip. These seeps are likely to be driven by the topographical changes within the earthflow area.

The landslide acts as a leaky aquifer system. As the groundwater level observed at the basal shear surface is drawn down, groundwater from overlying layers begins to move downwards ('leak') towards the basal surface. A thick siltstone unit acts as an aquitard, inhibiting movement of groundwater between the landslip deposits and the underlying sandstone. Groundwater levels in the underlying sandstone are below the top of this formation and are considered unlikely to contribute to groundwater pressure changes within the landslip.

Rapid displacement of the landslide in early October 2019 is likely to have been caused by long-term (i.e., 10 to 15 weeks) increases in groundwater level caused by rainfall and low evapotranspiration (cf. Utiku landslip, Massey et al., 2013). Numerical back-analysis of slope stability using Plaxis 3D indicates that groundwater levels were around 1 m bgl at the time of the main displacement event. During and immediately following the main displacement, groundwater levels in the landslip close to a significant scarp that formed are likely to have dropped by at least 2 m, reducing groundwater pressures close to the scarp and throughout the landslide.

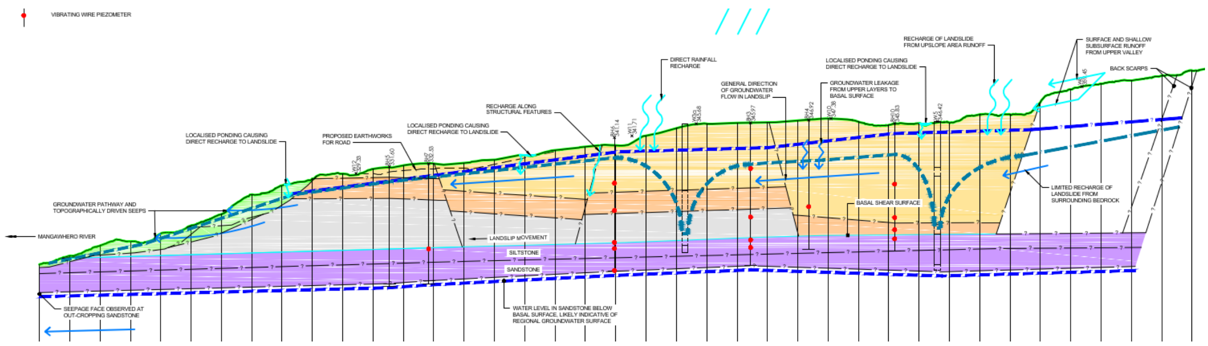

Figure 2: Hydrogeological conceptual model.

As elevated groundwater pressures were inferred to have triggered the initial landslip, the alleviation of these pressures in the landslip mass was the focus of stabilisation works at the site. Dewatering wells have been installed at the site in order to lower the groundwater pressure. This remedial option was evaluated through quantitative scenario analysis of potential dewatering configurations using numerical slope stability models and groundwater conditions based on analysis of extensive monitoring at the site.

Five dewatering wells were constructed at the site between June and August 2020. The purpose of these dewatering wells was twofold: (i) To obtain information on drawdown, zones of influence, pumping rates, transmissivity and flow rates within the landslip materials. (ii) To lower the groundwater in the landslip and provide more stability to the site over the winter period when groundwater levels are expected to rise without intervention.

Continuous monitoring of surface movement, pump volumes and groundwater drawdown is ongoing using telemetry and a customised data platform. The data can be easily accessed via the Geotechnics Solutions online platform (Figure 3), giving asset engineers and managers the information they need to make decisions about the management of this important transport corridor.

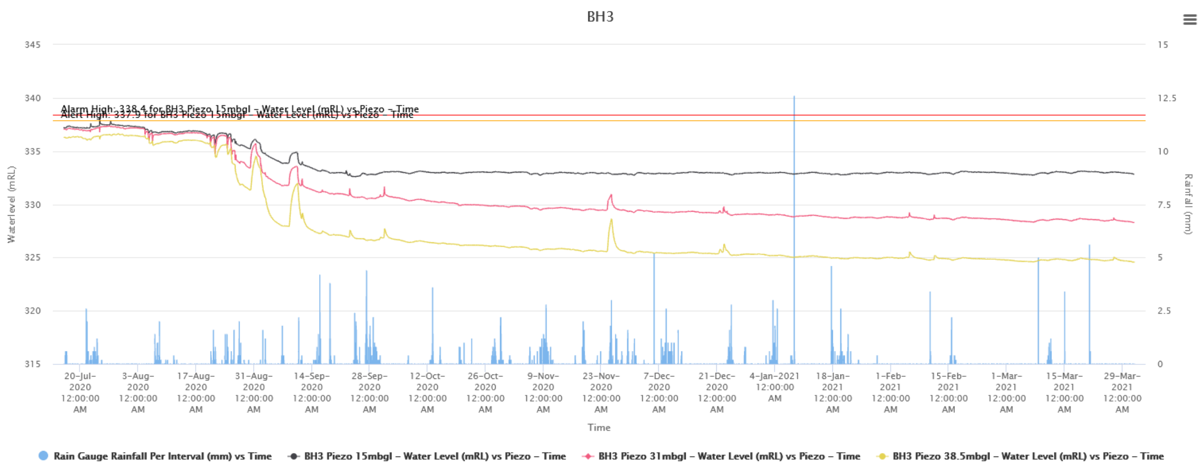

Figure 3: Groundwater response to dewatering accessed through the Geotechnics Solutions online platform.

References

Mount Messenger Alliance, November 2020. ***SH4 – Te Oreore Geotechnical Factual Report (SH4-DES-GEO-00-RPT-0010)***; ***SH4 – Te Oreore Geotechnical Interpretive Report (SH4-DES-GEO-00-RPT-0009); SH4 – Te Oreore Geotechnical Design Report for Stabilisation Works (SH4-DES-GEO-00-RPT-0008)***. Reports prepared for Waka Kotahi.

Massey, C.I., Petley, D.N., McSaveney, M.J., 2013. Patterns of movement in reactivated landslides. ***Engineering Geology***. Vol 159, pp. 1-19.

THE ROLLING STONES PROJECT

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Aims

Sediment transport shapes the Earth's surface (Walling, 2009), with rivers redistributing rocks and floods forming fertile plains. Measuring, or accurately modelling, the movement of Earth's sediment is critical. However, sediment transport formulae are primarily empirical and "the physics of bed load transport remains incompletely analysed" (Gomez & Church, 1989). Rolling is currently ignored in sediment transport formulae, which results in a substantial underestimate of the total kinetic energy of rolling stones (among other issues). There is generally a lack of field data on bedload transport, with no high-resolution field data on particle dynamics (i.e. time series of linear accelerations and angular velocities). To date, field studies of linear stone motion have used radio-tracking (Habersack, 2001 and others) or GPS (Ryder & Mika, 2016) to quantify stone displacements, rest times, and average velocities. These techniques provide useful data on average stone motion and diffusion; however, they are unable to resolve fine scale stone dynamics and rolling. Progress has been made on the development of in situ sensors for sediment dynamics (Dwivedi *et al*., 2008; Gronz *et al*., 2016 and others), however none of these sensors have been suitable for field deployment and recovery.

To address these knowledge gaps, the 'Rolling Stones' project aims to develop in situ sensors to deploy inside stones (i.e. cobbles and boulders), then release them during floods to measure timeseries of angular velocities and accelerations. Herein we cover sensor development, recovery system development, and sensor deployment inside stones. The conference presentation will also cover the latest results from field deployments.

Methods

To achieve the project aims 'kinematic loggers' were developed (Figure 1A) to record stone motion during floods. These sensors consist of a CPU, 128 MB Flash Memory, 9-Axis Inertial Measurement Unit (IMU), 3-Axis high-g accelerometer, LoRa radio transmission module, real time clock, battery and power management components. The 9-Axis IMU logs at 400 Hz to record rotations and moderate accelerations, while the 3-Axis high-g accelerometer logs at 1000 Hz to record shocks from collisions during bedload transport. The loggers are configured to wake up and record data when movement commences, then sleep when not moving to conserve power. At the highest recording frequency, they can log ~4 hours of kinematic data. In the sleep/recovery mode they can be deployed for up to 6 months before being recovered. The 'kinematic loggers' are housed inside a waterproof chassis (Figure 1B), which is then screwed into a threaded sleeve (Figure 1D) that is glued into a rock. Ballast plugs (Figure 1C) filled with a distribution of Tungsten Carbide (ρ=15.63 g/cm^3) and mortar are placed at each end of the threaded sleeve, such that the mass and moments of inertia of the full 'kinematic logger' assembly matches that of the removed Greywacke core (as closely as possible).

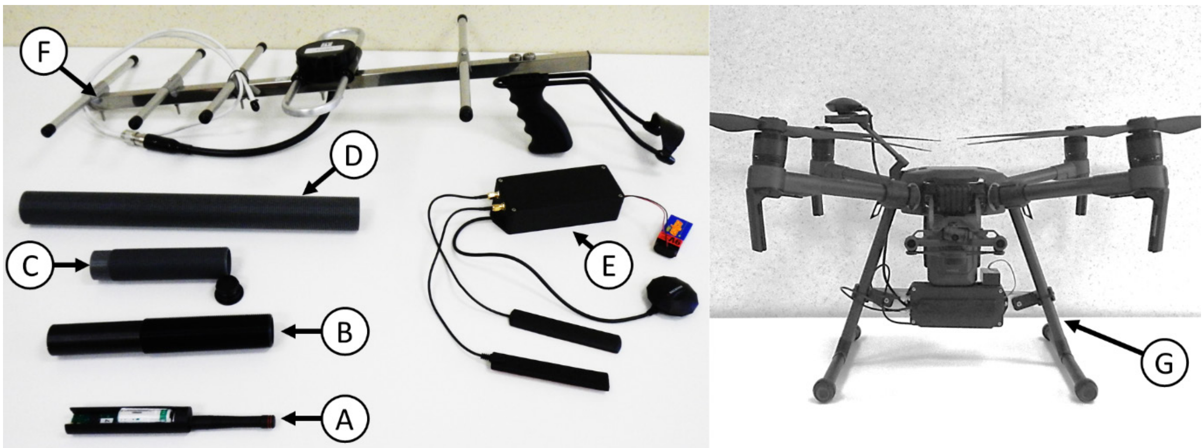

Figure 1: (A) Kinematic logger, (B) waterproof housing, (C) ballast plug, (D) threaded sleeve, (E) relay unit, (F) directional antenna, (G) DJI M210 drone with relay unit and GPS antenna attached.

Following deployment of the kinematic logger, it enters recovery mode, whereby it sends periodic radio signals (LoRa messages) stating its ID number. The timing and frequency of these messages are set to minimise power consumption (i.e. the real time clock is consulted, such that messages are only transmitted during daylight hours at times when recovery is feasible). A relay unit (Figure 1E) was developed that receives the LoRa messages at 433 MHz, then retransmits them at 915 MHz, along with GPS location of the relay unit, and RSSI (Relative Signal Strength Indicator) for the LoRa message. This message is then received by a 'base station' computer at 915 MHz and logged to a .csv file. The relay unit is mounted on a DJI M210 drone (Figure 1F) and flown in a zigzag pattern covering the study site for multiple kilometres downstream of where the stones were deployed. The data received by the base station computer is used to create a 'heat map' of the received signal strengths, and to triangulate 'kinematic logger' locations based on calibration curves of RSSI and distance. Team members are then deployed to the approximate location of each 'kinematic logger', where they pinpoint the exact location of the stone with a directional antenna (Figure 1F) and metal detector. 50 greywacke stones have been collected for field deployment, with holes drilled through them with a 40 mm diameter water cooled diamond hole saw (Figure 2A). Stones were 3D scanned (Figure 2B) using a structured light scanner (Einscan Pro HD) to assess surface abrasion and shape changes during the deployment. Stones were weighed using a high precision scale (Figure 2C), then threaded sleeves were glued into all the stones. The density of the stones was measured from their extracted cores, with core masses measured on a high precision lab scale, and their volume also measured on a high precision lab scale (Figure 2E) using Archimedes principle (i.e. from the mass of displaced water when hanging freely suspended).

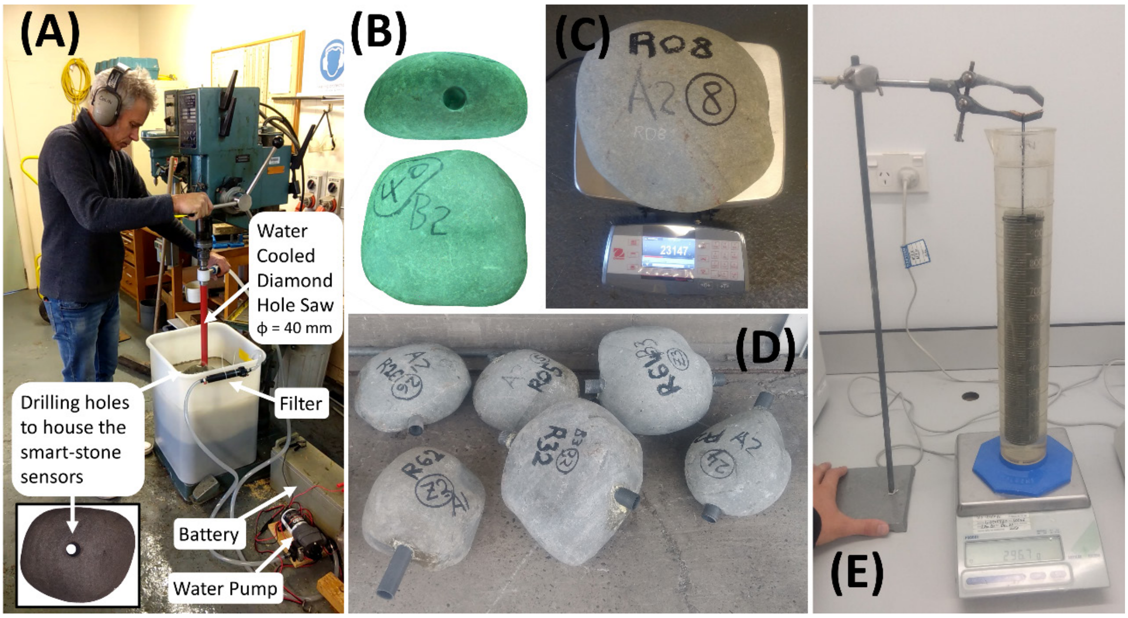

Figure 2: (A) Drilling stones, (B) 3D scanning stones, (C) weighing stones, (D) gluing sleeves, (E) measuring the volume of stone cores using Archimedes principal to calculate density.

Results

The collection and analysis of results is ongoing. Preliminary findings will be presented at NZHS.

References

Dwivedi, A., Melville, B., Akeila, E. and Salcic, Z. 2008. Design of 'Smart' pebble for sediment entrainment study. *Advances in Fluid Mechanics*, 7, 341-350.

Gronz, O., Hiller, P, Wirtz, S., Becker, K., Iserloh, T., Seeger, M., Brings, C., Aberle, J. and Ries, J. 2016. Smartstones: A small 9-axis sensor implanted in stones to track their movements. *Catena*, 142, 245-251.

Gomez, B. and Church, M. 1989. An assessment of bed load sediment transport formulae for gravel bed rivers. *Water Resources Research*, 25(6), 1161-1186.

Habersack, H. 2001. Radio-tracking gravel particles in a large braided river in New Zealand: A field test of the stochastic theory of bed load transport proposed by Einstein. *Hydrological Processes*, 15(3), 377-391.

Ryder, D., and Mika, S. 2016. Smart rocks and sand slugs: innovative methods for modelling sediment transport in rivers. in *Proceedings of 8th Australian Stream Management Conference*, Edited by Geoff Vietz, Alissa Flatley and Ian Rutherfurd. Leura, New South Wales. RBMS: 466-472.

Walling, D. (2009). *The impact of global change on erosion and sediment transport by rivers: current progress and future challenges.* UNESCO.

GROUNDWATER ECOSYSTEMS: A FIRST LOOK AT PROTOZOAN DIVERSITY IN GROUNDWATERS OF AOTEAROA

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Aims

To isolate and identify protozoa from groundwater as a first step in identifying their role in groundwater ecosystems.

Method

Meio-fauna are microscopic single and multicellular motile organisms. Within this grouping of organisms are acari (mites), copepods, oligochaetes and nematodes (worms), tardigrades (water bears) and rotifers. There is a lack of research on these potentially important group of fauna in groundwater systems. It is known that the abundance of meio-fauna is much greater than macrofauna and that they potentially play an important role in contaminant removal but more research is required in this area to fully understand their role. In this presentation we will show isolation and identification of one group of meio-fuana, the protozoa, collected from shallow alluvial aquifers and karstic aquifers in Aotearoa.

To collect protozoa from groundwater, we first purged the well/bore to ensure we were sampling from within the aquifer. Two 10L samples were collected via pumping into sterile buckets. Once collected a peristaltic pump was used to concentrate the sample onto polycarbonate 10 µM pore size membranes. The volume pumped through the filter was noted. The filters were then aseptically added to sterile pre-labelled containers with a 50:50 mix of groundwater and a hay and milk broth (Glaser and Coria (1930) and Altermatt et al (2015)) to maintain meiofauna prior to identification. Samples were stored at <10°C until arrival at the laboratory. On arrival in the laboratory samples were stored in the groundwater, hay and milk broth at 12(±2) °C for up to 25 days. Samples were identified under a light and differential interference microscope at x 400 magnification. Their grazing behaviour was also recorded.

Results

Live protozoan species were collected from groundwater samples and maintained in the laboratory. This has allowed us to visualise their behaviour over time and identify the dominant species present. We will present our findings on the presence of free-living protozoa and shed light on these overlooked taxa present in our groundwater. Their role in the groundwater ecosystem will be discussed, including seeing evidence of their bacteriovorous activity.

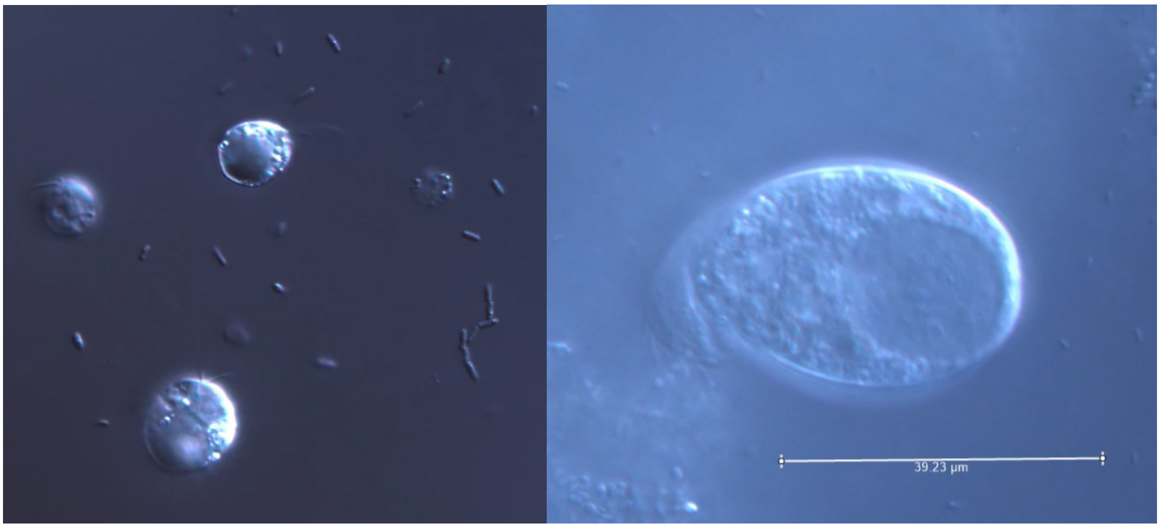

Figure 1 Examples of protozoa collected from groundwater samples and maintained in laboratory cultures.

References

Altermatt, F., Fronhofer, E.A., Garnier, A., et al. (2015). Big answers from small worlds: A user's guide for protist microcosms as a model system in ecology and evolution. Methods in Ecology and Evolution 6(2):218-23 DOI: 10.1111/2041-210X.12312

Glaser, R.W. and Coria, N.A. (1930) METHODS FOR THE PURE CULTURE OF CERTAIN PROTOZOA .Journal of Experimental Medicine 51 (5): 787–806. doi: https://doi.org/10.1084/jem.51.5.787

DEVELOPMENT OF A WETLAND DETECTION TOOL USING MACHINE LEARNING, HIGH RESOLUTION AIRBORNE LIDAR AND RGBI AERIAL IMAGERY

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[2] Lynker Analytics

Aims

The National Policy Statement for Freshwater Management 2020 as part of the essential freshwater reforms require Regional Councils to identify and map every natural inland wetland in their regions, outside of public conservation lands or waters, that is ≥0.05 ha by 2030. Furthermore, the policy statement provides direction that in doing so, regional councils should prioritise wetlands at risk of loss of extent or values. Given the risks to wetlands posed by the urban development plans for the Kapiti Coast District, the timing of work on the whaitua catchment committee plan in this district, and the spatial resources available, the Kapiti Coast District was selected to trial new predictive wetland detection techniques. Accordingly, this study is designed to provide an initial response to the need for wetland mapping in the Kapiti Coast District, Greater Wellington Regional Council. Specifically, we produced the first high-resolution wetland map of the Kapiti Coast using Machine Learning (ML), Light Detection and Ranging (LiDAR) and high resolution Red-Green-Blue-Infrared (RGBI) aerial imagery.

Method

Our method encompassed seven project phases (Figure 1) which are run in a serial process to generate all the output data. Several machine learning models were trialled with a Random Forest decision tree method chosen based on performance. Inference cycles were run using Python and Tensorflow/Keras with the mathematical ML models generating predictions using the patterns extracted from the training data sets. Active Learning was used to train the machine learning models, a methodology used to achieve high accuracy models using only the most essential training inputs. Vectorisation and comprehensive GIS post processing was completed after the final inferences were produced. The models were calibrated using a separate hold out set of ground truth data carefully selected and not used for training.

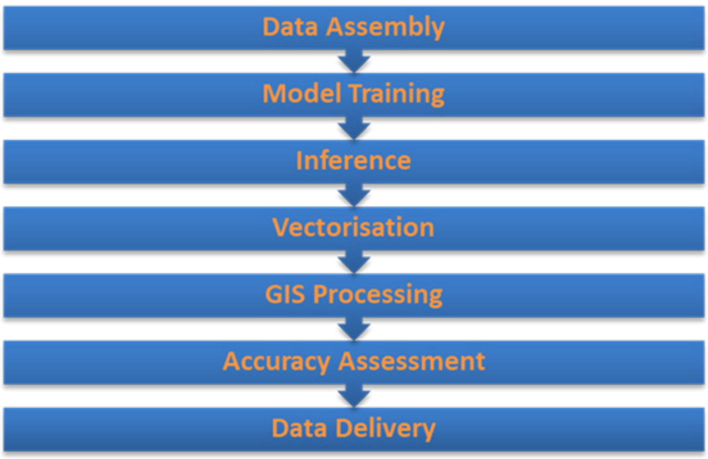

Figure 1: Flow diagram the project phases for the detection of wetlands in the Kapiti Coast.

Results

The final wetland prediction model reported an overall accuracy of 86%. The most influential data inputs in the modelling in this study area were LiDAR derivatives which explain landscape and geomorphic position. A multi-step vectorisation, GIS clean up and verification process produced candidate polygons based on model confidence thresholds. Using a confidence threshold of 0.8 (80%) to delineate wetlands across the area (Figure 3), 10,458 wetland polygons greater than 100 m2 in size were mapped. This equates to 1,148.61-ha or 2.98% of the 38,436-ha study area with the largest wetland being about 40 ha. The developed model achieves the project objectives of identifying and predictively mapping wetlands ≥0.05 ha in the project area (and also smaller wetlands) with an acceptable accuracy. An average delineation accuracy of 78.6% was achieved by comparing the wetland detection outputs with ground thruthed data (Figure 2). The method can be further developed and applied to predictively mapwetlands across New Zealand. This project has identified further improvements as being implementable, such as further refinement of threshold considering ecoregion and landscape, and potentially required when applying this method to a wider area.

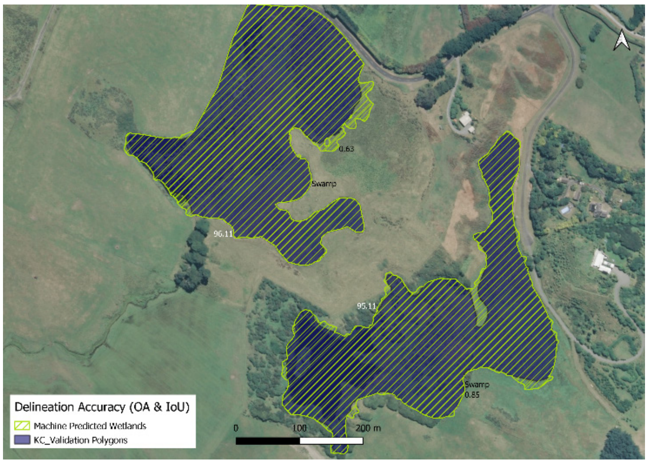

Figure 2: Wetland delineation accuracy representation of two swamp wetlands (Overlap Analysis and Intersection over Union)

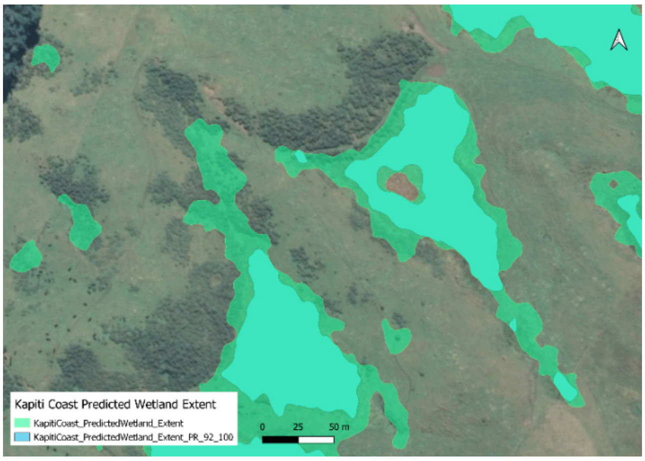

Figure 3: Wetland prediction output (80% confidence and 92%<)

References

Boon, M.A., Chapman, R., Lythe, M., Oulton, A and Stanley, M., June 2021. *Technical Report: Predictive Mapping of Wetlands on the Kapiti Coast 2021*. Wellington: Pattle Delamore Partners: 1-24.

IDENTIFYING THE VARIABILITY OF SHALLOW GROUNDWATER FROM WEST TO EAST IN URBAN CHRISTCHURCH

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Aims

Globally and in Aotearoa New Zealand water networks (wastewater, storm water and potable water) are aging (Su et al., 2020). The threat that this poses is exacerbated in coastal low-lying urban areas, such as Christchurch, where subsurface infrastructure is often collocated with shallow groundwater. Additionally, groundwater levels in coastal areas are expected to rise in response to sea-level rise and this will trigger flooding from below (Befus et al., 2020). In order to plan for these risks and improve the resilience of subsurface infrastructure it is critical, as a first step, that we understand the spatial distribution of depth to groundwater and the variability of the water table due to rainfall events.

This work presents a new depth to groundwater map for Christchurch using recent and continuous measurements from a dense network of monitoring sites. Additionally, we use a large dataset of groundwater hydrographs to represent fluctuations in depth to groundwater according to precipitation characteristics and hydrogeological settings, including the potential relationship with surrounding subsurface water-related infrastructure.

There are numerous challenges for urban coastal communities arising from a changing environment. This includes how to future-proof the current layout of subsurface infrastructure so it continues to function in the most efficient way under expected, unprecedented changes from climate. The current study is part of a broader work programme that aims to develop data analysis and modelling approaches that will enable prediction of where and how groundwater level rise will impact subsurface infrastructure, and how best to manage this risk.

Method

Depth to groundwater is recorded across Ōtautahi Christchurch and used to analyse shallow groundwater variations. The piezometer network (278 monitoring sites in total) extends north to Bottle Lake Forest and covers both catchments of the Avon River / Ōtakaro and the Heathcote River / Ōpāwaho to the Pacific Ocean coastline. In this study, we focused our assessment on variability of urban shallow groundwater along a transect dictated by the key arterial routes of Memorial Avenue, Bealey Avenue and Pages Road with a 500 m buffer on each side, from the west (Christchurch Airport) to east side of Christchurch (New Brighton), via the central city. This transect (Figure 1) is located primarily upon a flat and low-elevation alluvial and coastal landscape, in a suburban to medium-density built environment, and contains 55 monitoring sites; these were used to interpolate a surface representing the recent depth to groundwater in metres below ground level (m bgl), as a median value calculated with four years of continuous data. An example of groundwater hydrographs from a site in Bexley (ID number: BX24/2247 or APP159) is shown in Figure 2, and demonstrates fluctuations due to rainfall recharge at shallow depth, <1.5 m bgl.

Results

The calculated median depth to groundwater varies from a few centimetres below the ground surface to up to three meters at selected sites along the presented section. The interpolated surface (Figure 1) shows that in western urban Christchurch the water table sits >3 m bgl, and passing from the Burnside (2.5 m bgl) area to the Pacific Ocean (0 m bgl) becomes very shallow. Water levels are very shallow (0 - 0.5 m bgl) in three areas: Fendalton; between Merivale and Linwood; and near Bexley to New Brighton. The selected roads used for the study transect - Memorial Avenue, Bealey Avenue and Pages Road - are critical arteries across the city, provide access to essential services, and are tsunami evacuation routes.

Coastal cities each have unique hydrogeological settings that result in specific problems in assessing groundwater interactions with subsurface infrastructure. Mapping and identifying variability of water levels below the ground surface are necessary methods to forecast the response to future changes that affect water quality and quantity.

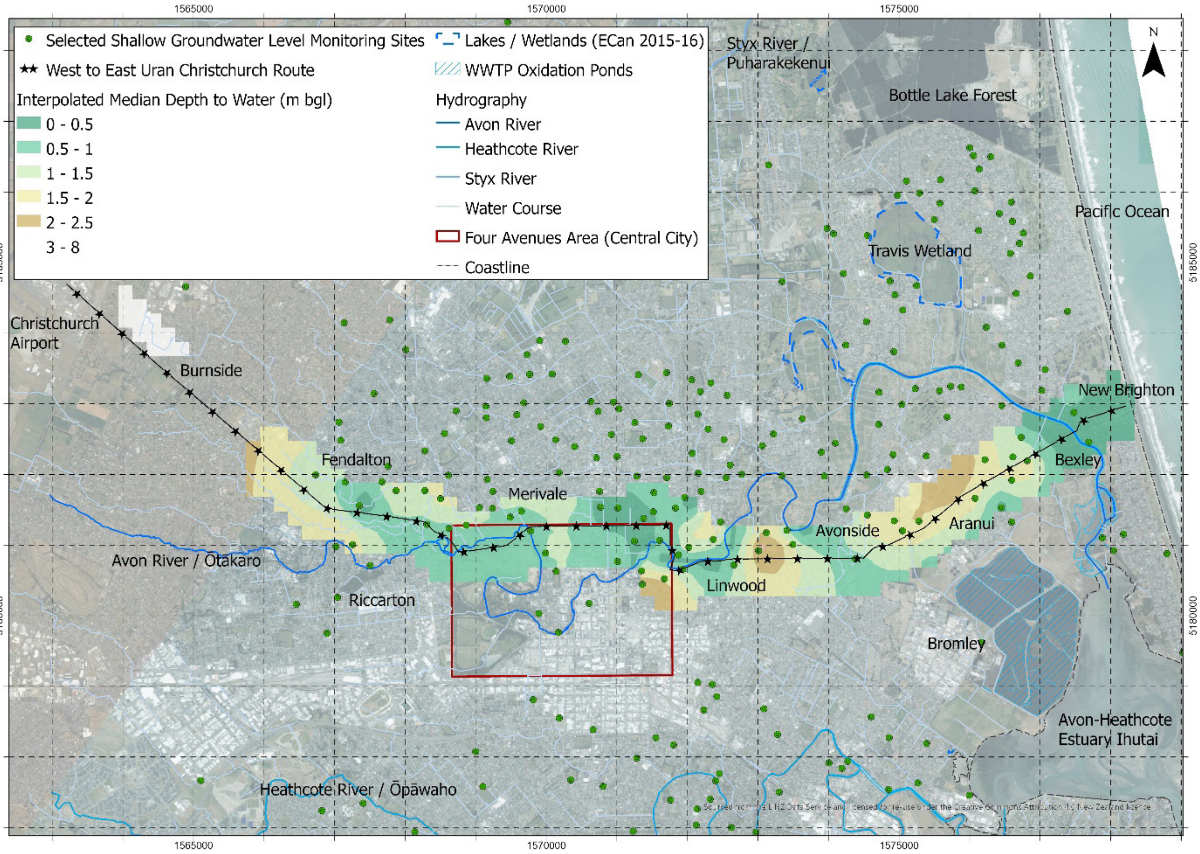

Figure 1. Study area map showing the interpolated depth to groundwater (median 2016-2020), the Christchurch shallow groundwater monitoring network, water courses and locations.

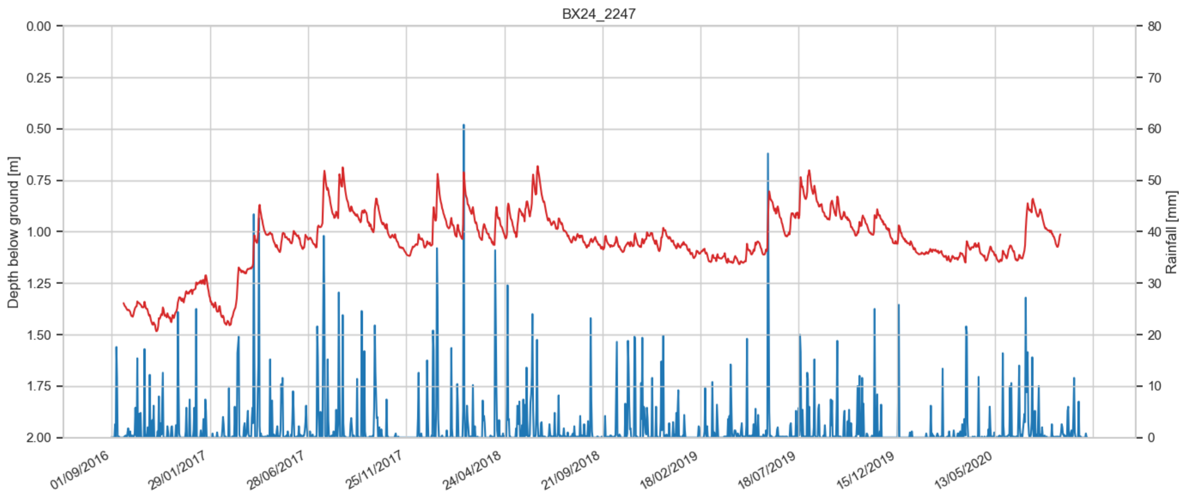

Figure 2. Hydrographs showing examples of time series available for shallow groundwater levels, daily rainfall for Christchurch Airport station for the period 2016-2020.

References

Befus, K. M., Barnard, P. L., Hoover, D. J., Finzi Hart, J. A., & Voss, C. I. 2020. Increasing threat of coastal groundwater hazards from sea-level rise in California. ***Nature Climate Change***, 10(10), 946-952.

Su, X., Liu, T., Beheshti, M., & Prigiobbe, V. 2020. Relationship between infiltration, sewer rehabilitation, and groundwater flooding in coastal urban areas. ***Environmental science and pollution research international***, 27(13), 14288–14298.

REMOVAL OF DISSOLVED HEAVY METALS FROM STORMWATER BY FILTRATION THROUGH RECYCLED MATERIAL; WITH AND WITHOUT MICROALGAE BIOFILM

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Aim
Stormwater treatment technologies are used routinely to reduce contaminant loads entering surface water and groundwater. However, in most cases, treatment is limited to particulate contaminants. Research into alternative filtration media for stormwater treatment is necessary to provide sustainable and environmentally friendly options for the removal of dissolved metals. While periphytic biofilms are known to develop on substrate materials, little is known of their effect on the sorption of dissolved metals.

Method
A laboratory study assessed the effectiveness of recycled glass, mussel shell, and freshwater periphytic biofilm to remove dissolved metals (copper, lead and zinc) from stormwater. Synthetic stormwater, containing typical concentrations of heavy metals (Cu, 154 g/L; Pb, 41 g/L; Zn, 280 g/L), was used for all experiments. The stormwater was recirculated through 1-L columns filled with granular recycled glass or mussel shell either colonised with periphytic biofilm (mainly microalgae) or not.

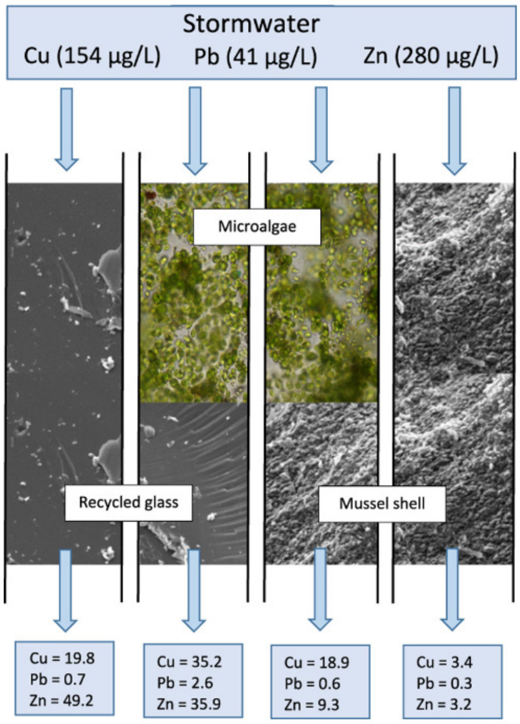

Figure 1: Schematic of treatment process.

Results
The biofilm absorbed high concentrations of the dissolved metals, but was less effective than using the substrates on their own. In some cases, the biofilm actually reduced the ability of the substrates to remove Cu and Pb, presumably by occupying potential adsorption sites on the filter media. The recirculation of a fixed volume of stormwater over a 48-hour period resulted in a constant removal efficiency for the three metals tested. The removal efficiency was lead (>97%) zinc (97%) > copper (89%) for mussel shell, and lead (96%) > zinc (86%) > copper (73%) for recycled glass. Both the composition and surface texture of the substrate affect the removal of dissolved heavy metals from aqueous solutions. The use of waste products, such as recycled glass and mussel shells, for stormwater treatment might contribute to waste minimisation and increase the value associated with the extended lifecycle of these materials.

HYDROCLIMATOLOGY OF FOG AT SWAMPY SUMMIT, DUNEDIN

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Aims

Tussock grassland catchments in Otago are known to have greater water yield than catchments with other vegetation cover (Davie et al. 2006; Ingraham *et al*. 2008). One theory for this is the potentially significant role of fog deposition in augmenting water yield, facilitated by indigenous tussock vegetation. Previous research has largely focused on processes at the plant scale that result in the addition, or lack of hydrological inputs from fog. However, there has been less focus on the impact of weather and climate on fog formation and incidence, as well as its resultant impact on the quantity of fog deposited to tussock grasslands. This research seeks to establish the climatology and significance of fog at Swampy Summit, Dunedin. By incorporating climatic and hydrological investigations, it is hoped that this research will allow for a holistic view of the fog-tussock system to be created, resulting in better insights into the controls of fog incidence and deposition in Otago's indigenous tussock grasslands.

Methods

Over a study period of 405 days, hydrological inputs via fog and rain were recorded. Two passive harp-style fog collectors connected to tipping bucket rain gauges, as seen in Mager *et al*. (2016), were installed at Swampy Summit. These two fog collectors had different lid sizes (0.7 m and 1.2 m diameter), in order to understand the effects that lid size has on collection of fog water vs. limiting the inadvertent collection of rain water. A additional tipping bucket rain gauge was installed adjacent to the fog collectors to collect rainfall. Wind speed and direction, relative humidity and air temperature were also recorded.

For an initial classficaiton of synoptic-scale weather conditions associated with fog, Kidson weather types during fog events were determined, as well as the time-steps immediately before and after. A more detailed analysis of synoptic-scale conditions was undertaken by exploring individual geopotential height, u and v component of wind, wind vector and total column water for each fog event, using data from the ERA5 reanalysis.

Results

Depending on the configuration of the fog collector, and after accounting for accidental by-catch of rain, 1524-1736 mm of fog was recorded over the 405 day study period, compared to 940 mm of rain. The greatest monthly input to both fog collectors was during December 2018 with 413.3 mm recorded by the 0.7 m lid collector and 535.5 mm in the 1.2 m lid collector, compared to 109.4 mm of rain (Figure 1). The greatest monthly rain input was recorded in January 2019 with 123.3 mm, during which 107-115 mm of fog was also deposited (Figure 1). 192 events in total were observed, constituting 101 fog events, 42 rain events and 49 fog+rain events. Of all fog events, 66% had a modal wind direction of NE, with a further 21% being from the SW.

Analysis of Kidson weather type frequency revealed differing patterns between event types. Fog and NE fog events both showed HSE and Blocking being the most frequent cluster and regime types, respectively (Table 1). Both rain and fog+rain events saw trough as the most frequent regime, before, during and after events, with variation in the most frequent cluster types. SW fog events showed a different pattern to that of fog events in general, with the zonal regime most frequent before, during and after the event, with variation in cluster type frequency. The results of this study have shown that fog provides a substantial hydrological input to Swampy Summit. This is an important indication that facilitation of fog water deposition by indigenous tussock grasslands is something that warrants further investigation to better understand the inputs and use of water by tussock grasslands in Otago.

Table 1: Most frequent Kidson weather type clusters and regimes for event type

Event Type	12 hours before		During		12 hours after	
	Cluster	Regime	Cluster	Regime	Cluster	Regime
Fog	HSE	Blocking	HSE	Blocking	HSE	Blocking
Rain	SW	Trough	T	Trough	T/SW	Trough
Fog+rain	T/TNW	Trough	SW	Trough	SW	Trough
NE fog	HSE	Blocking	HSE	Blocking	HSE	Blocking
SW fog	SW	Zonal	HNW	Zonal	SW/HNW	Zonal

References

Davie, T., Fahey, B. and Stewart, M. 2006. Tussock grasslands and high water yield: A review of the evidence. *Journal of Hydrology (NZ)*, 35(1): 85-102.

Ingraham, N., Mark, A. and Frew, R. 2008. Fog deposition by snow tussock grassland on the Otago uplands: Response to a recent review of the evidence. *Journal of Hydrology (NZ),* 47(2): 107-122.

Mager, S.M., Trevelyan, A.M., Wilson, P.G. and Kingston, D.G. 2016. Quantifying the amount and incidence of fog at a mid-altitude site in the Saint Marys Range, Otago, New Zealand. *Journal of Hydrology (NZ)*, 55(2): 107-120.

WOODCHIP DENITRIFICATION WALL TRIAL IN A GRAVEL AQUIFER: RESULTS UPTO YEAR 3

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Aims

Woodchip denitrification walls have been demonstrated as a nitrate-mitigation practice for agricultural pollution impacting sandy aquifer systems, i.e., where groundwater is slow-moving (e.g., Schipper and Vojvodić-Vuković, 1998; Schmidt and Clark, 2012; Manca et al., 2020). They have never before been trialled in fast-flowing, highly permeable gravel aquifer settings, such as are distributed throughout New Zealand. We aimed to assess through a practical field trial whether woodchip denitrification walls might be a viable, edge-of-field, nitrate-mitigation method for shallow gravel aquifer settings, worth including in the suite of options available for reducing N-loads in freshwater catchments. The purpose of this presentation is to provide an updated report on the woodchip denitrification wall trial we have made at Silverstream Reserve, North Canterbury, and for which we published some of the first-year's results in Burbery et al. (2000). The specific discharge of the shallow gravel aquifer at Silverstream is 2.6 m/d, which is around 12-times greater than the discharge of the sandy aquifer at Hautapu, Waikato region that is the site of historic woodchip denitrification wall trials in New Zealand (Schipper and Vojvodić-Vuković, 1998).

Here, we collate results from three-years of study following emplacement of the 5 m-wide, permeable reactive wall in the shallow gravel aquifer at the north-end of the Canterbury Plains. Because of the fast groundwater flow at the study site, despite the denitrification wall being only 3-years old, we estimate it to have filtered more groundwater than the woodchip wall example at Hautapu that has been operating for almost 25 years, and from which prognoses about the longevity of woodchip denitrification walls have historically been evaluated.

Method

Over the course of our field study, a range of practical methods have been employed to examine the hydraulic performance and treatment efficiency of the woodchip wall, as it has aged. These have included water chemistry monitoring, saline tracer tests with time-lapse electrical resistivity measurement, geotechnical tests and pumping-tests. Pollution-swapping phenomena associated with adding carbon to the aquifer and altering its redox state have been examined as a matter of course. These have included mobilisation of arsenic from aquifer sediments and greenhouse gas (GHG) production.

Results

As anticipated, initially the woodchip wall exported dissolved organic carbon (DOC), phosphorus and ammonium, and generated a plume with a very low redox condition that we suspect went methanogenic early on. Maximum concentrations were 28 mg C/L, 1.6 mg P/L and 0.18 mg NH_4-N/L (e.g. Figure 1). For a time, concentrations of dissolved iron, manganese and arsenic all increased to above acceptable values prescribed the New Zealand Drinking Water Standards (MoH, 2018). Maximum concentrations were 4.8 mg Fe/L, 2.4 mg Mn/L and 22 ug As/L.

The woodchip wall has proved very efficient at removing groundwater nitrate. At the start, it provided more than 98% nitrate removal, reducing nitrate concentrations by more than 7.5 mg N/L (see Figure 1). Within a period of 9 months the labile organic carbon had effectively all leached from the woodchip, the system became carbon-limited and nitrate reduction the terminal electron acceptor process. At this stage the N-removal efficiency declined to ~89% ($\Delta N\Delta O_3$-N = -6.7 mg/L) and this condition was sustained for a further 11 months.

When the wall was 20 months old we conducted a set of salt tracer experiments with time-lapse electrical resistivity tomography (ERT) at the site, from which we have been able to successfully map solute transport pathways in the subsurface, including through the woodchip wall. We suspect however that use of NaCl in the field tracer tests inadvertently negatively impacted on the treatment performance of the woodchip wall, since we witnessed an obvious step-change in redox state and N-removal efficiencies coincidentally dropped down to ~55%. That is the wall now reduces groundwater nitrate concentrations by ~3 mg N/L (Figure 1).

Whilst we have determined that the structural integrity and permeability of the woodchip wall has not changed significantly over the three years, it appears that some clogging effect has been realised in the aquifer immediately down-gradient of the wall. The exact nature of the clogging and what its effect translates to in terms of impact on treated groundwater flux is the subject of ongoing research.

Since the denitrification wall became carbon-limited, we have detected a small trending increase in dissolved N_2O concentrations in the treated groundwater. Nonetheless, at under 0.1 mg N_2O-N/L absolute concentrations remain low. Also, the aqueous GHG concentrations we have measured do not reconcile with GHG emission measurements we have made at the land surface - atop of the woodchip wall and plume of treated groundwater. The soil flux measurements we have made at the site tend to show that the woodchip denitrification wall is not a significant emittor of GHG, which is consistent with the findings of another woodchip denitrificaton wall field trial being made in Queensland, Australia (Manca et al., 2020).

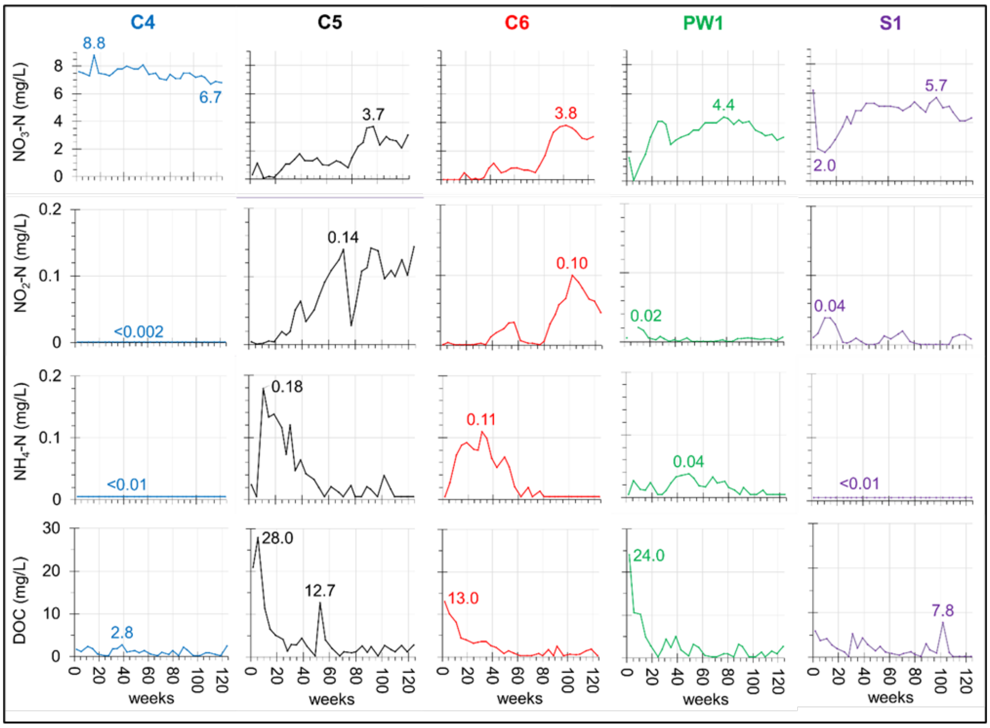

Figure 1: Time-series plots for reactive nitrogen species and dissolved organic carbon, measured for a transect of monitoring wells (C4:S1) aligned along a conceptualised flowpath that disects the woodchip denitrification wall at Silverstream. Well C4 is positioned 10 m up-gradient of the wall; C5 screens the wall itself. Wells C6, PW1 and S1 are positioned 10 m, 40 m, and 60 m down-gradient of the wall, respectively. The time axis is weeks since installation of the woodchip wall (8th November 2018).

References

Burbery, L.F., Sarris, T., Mellis, R., Abraham, P., Sutton, R., Finnemore, M., Close, M.E. 2020. Woodchip denitrification wall technology trialled in a shallow alluvial gravel aquifer. *Ecological Engineering* 157: 105996.

Manca F. et al. 2020. Nitrate removal and greenhouse gas production of woodchip denitrificaton walls under humid subtropical climate. *Ecological Engineering* 156: 105988.

Ministry of Health. 2018. Drinking-water Standards for New Zealand 2005 (revised 2018). Wellington: Ministry of Health.

Schipper, L., Vojvodić-Vuković, M. (1998). Nitrate removal from ground water using a denitrification wall amended with sawdust: field trial. *Journal of Environmental Quality* 27: 664–668.

Schmidt, C.A. and Clark, M.W. (2012). Evaluation of a denitrification wall to reduce surface water nitrogen loads. *Journal of Environmental Quality* 41: 724–731.

FLOOD FORECASTING USING CONVECTIVE-SCALE ENSEMBLES IN NEW ZEALAND

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Aims

Flooding is New Zealand's most frequent natural disaster, with an average annual cost of approximately NZ$51 million. Accurate forecasts can help mitigate impact and improve preparedness, however, accurately forecasting convective and orographically enhanced precipitation for hydrometeorological ensemble prediction systems is challenging in New Zealand's complex topographic, steep and fast responsive catchments. Globally, the design of river forecasting systems using convection-permitting ensembles is an active area of research, but a trade-off is often required between system configurations (model resolution, ensemble size, frequency of forecast issue times and model initialisation) and operational and computational constraints. The aim of this study is to design an optimal convective-scale ensemble system for operational flood forecasting by considering scientific performance and computational constraints. We aim to address the following questions:

- What is the most efficient and affordable operational flood ensemble system configuration in terms of both scientific and computational performance?
- How do ensemble strategies (size, resolution, frequency) impact forecast accuracy, reliability and uncertainty representation during flood events?
- How much skill do hydrometeorological forecasts have out to 5 days?
- Can a lagged ensemble strategy (combining older and most recent forecasts) add value to flood predictions?

Method

The Numerical Weather Prediction (NWP) models used are a local implementation of the UK Met Office-developed Unified Model. The New Zealand Convective-Scale Model (NZCSM) is NIWA's 1.5km resolution operational forecast model, issued four times a day and configured such that convective processes develop explicitly. The New Zealand Ensemble (NZENS) is configured with similar convection-permitting model physics but operates with a 4.5km horizontal resolution and features up to 18 members, available twice a day. Flood forecasts were produced by coupling several NWP configurations with the semi-distributed hydrological New Zealand Water Model (NZWaM) and its built-in statistical ensemble generation tool (Cattoën et al., 2016; Clark et al., 2008; McMillan et al., 2016). The hydrological model is based on TOPMODEL concepts of runoff generation controlled by sub-surface water storage (Beven et al., 1995; Goring, 1994).

We evaluate multiple ensemble strategies for flood forecasting over a 6-month period for the Buller catchment. Additionally, we illustrate the performance of the strategies during the recent Westport flood event on 17th July 2021, estimated to a 50 – 100 yr ARI event. No flow data assimilation is used in this experiment as we wish to assess the impact of weather ensemble configurations forced through the hydrological model. Using statistical scores, we compare the accuracy, bias and discrimination of rainfall and streamflow forecasts when i) increasing the NWP ensemble size from 6-18 members from the same issue time (a dynamical ensemble), ii) combining NWP ensemble forecasts from older issue times (a lagged super-ensemble), and iii) statistically perturbing a deterministic NWP forecast (a statistical ensemble). The members of a dynamical NWP ensemble have different initial conditions but are issued at the same forecast cycle. The members of a statistical ensemble are constructed by spatially and temporally perturbing a single NWP forecast realisation. Requirements of an ensemble prediction is that the spread between members is large enough to cover uncertainties in the prediction. For a well-calibrated ensemble, the spread should be the same magnitude as the RMSE (Wilks, 2011).

Results

Dynamical NWP ensembles outperform statistical ensembles in terms of accuracy, reliability and discrimination for high flow regime (80% threshold of ROC area score) (Figure 1). All ensemble strategies are under-dispersed, that is, the ensemble spread is too narrow which is a common problem with NWP ensembles (Porson et al., 2020). Forecasts show strong diurnal patterns with little dependency on lead time between lead time hours 24 to 80. Increasing ensemble size improves reliability and event discrimination more than accuracy, however performance between 9 and 18 members from the same issue time are similar (A and B in Figure 1). Using a lagged super-ensemble improves event discrimination for high flows (ROC area close to 1) with a trade-off of forecast accuracy and bias deterioration after lead time 50 h (not shown). This is likely due to a loss of accuracy in precipitation at later lead times from older forecasts.

We will illustrate some of these ensemble flood forecasting strategies for the Westport flood event (July 17th 2021) and discuss other factors affecting flood forecast prediction

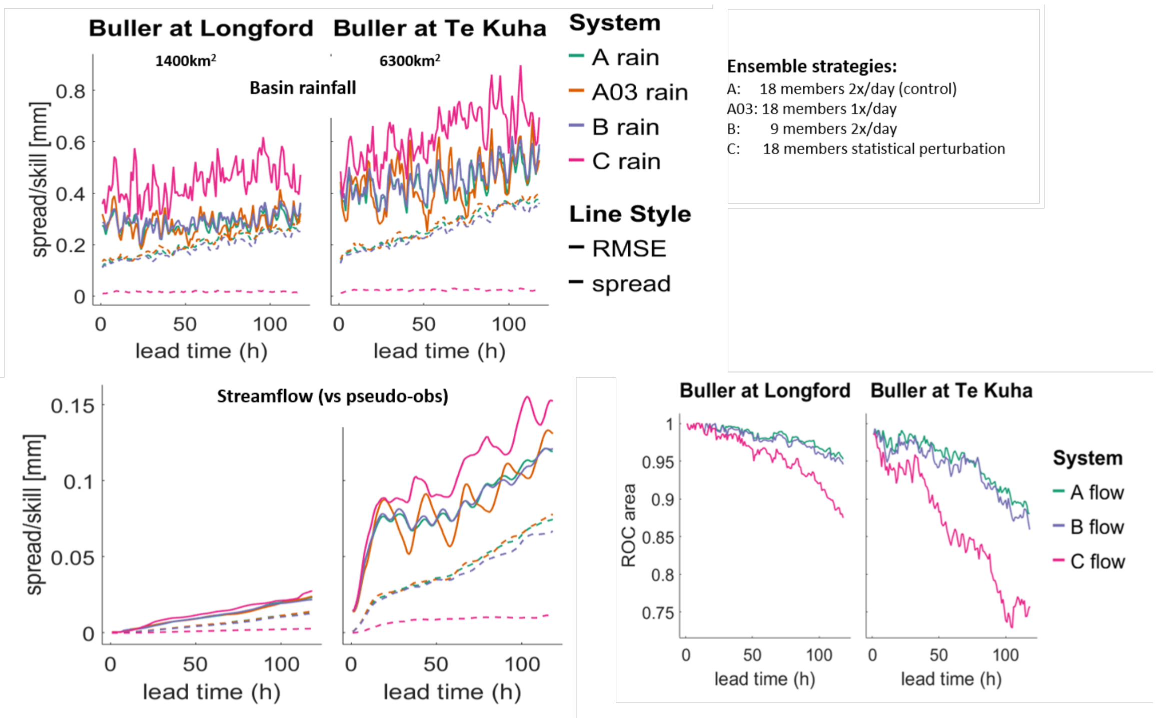

Figure 1: Rainfall and streamflow forecast performance during July-December 2020. Dynamical NWP ensembles (ensemble strategy A, A03, B) provide superior performance to statistically perturbed ensembles (ensemble strategy C) in terms of accuracy, reliability and discrimination over high flow (80%) thresholds (ROC area score). Increasing the NWP ensemble size increases reliability at later lead time but has a small effect on accuracy at early lead times. In the left-hand panels, solid lines show RMSE and dashed lines ensemble spread.

References

Beven, K.J., Lamb, R., Quinn, P., Romanowicz, R., Freer, J., 1995. TOPMODEL. In: Singh, V.P. (Ed.), Computer Models of Watershed Hydrology. Water Resources Publications, Highlands Ranch, Colorado, pp. 627-668.

Cattoën, C., McMillan, H., Moore, S., 2016. Coupling a high-resolution weather model with a hydrological model for flood forecasting in New Zealand. Journal of Hydrology (NZ), 55(1): 1-23.

Clark, M.P. et al., 2008. Hydrological data assimilation with the ensemble Kalman filter: Use of streamflow observations to update states in a distributed hydrological model. Advances in Water Resources, 31(10): 1309-1324.

Goring, D.G., 1994. Kinematic shocks and monoclinal waves in the Waimakariri, a steep, braided, gravel-bed river., Proceedings of the International Symposium on waves: Physical and numerical modelling, University of British Columbia, Vancouver, Canada, pp. 336-345.

McMillan, H.K., Booker, D.J., Cattoën, C., 2016. Validation of a national hydrological model. Journal of Hydrology, 541: 800-815. DOI:http://dx.doi.org/10.1016/j.jhydrol.2016.07.043

Porson, A.N. et al., 2020. Recent upgrades to the Met Office convective-scale ensemble: An hourly time-lagged 5-day ensemble. Quarterly Journal of the Royal Meteorological Society, 146(732): 3245-3265. DOI:https://doi.org/10.1002/qj.3844

Wilks, D.S., 2011. Statistical methods in the atmospheric sciences, 100. Academic press.

ASSESSMENT OF NITROGEN DYNAMICS FOR HEALTHY ECOLOGICAL FUNCTIONING OF ESTUARIES

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Overview

The National Policy Statement for Freshwater Management (NPS-FM) requires Regional Councils to consider the connectivity between freshwater and coastal waters and assess limits in the freshwater domain required to protect the values of estuarine receiving environments. Bay of Plenty Regional Council (BoPRC) has identified Maketū and Waihī estuaries to be sensitive to catchment inflows. The catchments of both Waihī and Maketū estuaries have historically undergone extensive drainage and intensification of land use that result in relatively high nutrient loads. BoPRC wants to determine acceptable levels of catchment derived nutrients into Waihī and Maketū estuaries that would support a healthy environment, particularly in terms of ecological functioning.

DHI developed numerical models of the two estuaries to quantify the conditions that will support healthy estuarine environment. The estuary models included a coupled hydrodynamic model, nutrient transport and fate model, and ecological model of macroalgae and seagrass in the estuaries. Input data derived from the eWater SOURCE modelling and monitoring data were used as catchment inputs for the numerical models.

Three scenarios were modelled. The first scenario (BL) represents a baseline catchment land use and land management practices. The next scenario (S1) represents catchment under natural vegetation, with no contaminant discharges from human activities. The final scenario (S2) represents a potential future land use and land management practice changes. In this paper, results from Waihī Estuary will be presented.

Results

Results (Figure 1) showed that Waihī Estuary, with median nitrogen concentration of 0.98 mg/l in the baseline scenario, is a heavily impacted macroalgal dominated estuarine system based on the classification detailed in MfE 2021.

Results showed that nitrogen recycling from the sediments is a significant contributor to the overall load available for eutrophication. This contribution was predicted to be between 18-35% of the catchment load to Waihī Estuary for the three scenarios. The amount of nitrogen deposition across the estuary (Figure 2) was predicted to be 15-25% of the catchment load in Waihī Estuary for the three scenarios. Modelling showed that that nitrogen deposition is not uniform across the estuary. More than 70 gN/m^2 is predicted to occur predominantly in eastern portion of the Waihī Estuary in BL and S2 runs.

Results predicted biomass of opportunistic macroalgae (Figure 3) ranged from below 100 g/m^2 wet weight to above 300 g/m^2 wet weight in Waihī Estuary. Based on NZ Estuary Trophic Index Screen Tool 2 (Robertson 2016), this classifies Waihī Estuary in Band B of ecological quality.

Regression analysis between catchment nutrient loadings and estuary model predictions showed nitrogen reductions of 71% in Waihī Estuary are required to upgrade the estuary from heavily impacted to slightly impacted trophic state.

The study showed the importance of needing to reduce both catchment loads and internal loads for water quality improvement in Waihī Estuary.

References

Ministry for the Environment. 2021. A guide to setting instream nutrient concentrations under clause 3.13 of the National Policy Statement for Freshwater Management 2020. Wellington: Ministry for the Environment.

Robertson, B.M., Stevens, L., Robertson, B., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Oliver, M. (2016). NZ Estuary Trophic Index Screen Tool 2. Determining Monitoring Indicators and Assessing Estuary Trophic State. Prepared for Environlink Tools Project: Estuarine Trophic Index: 68.

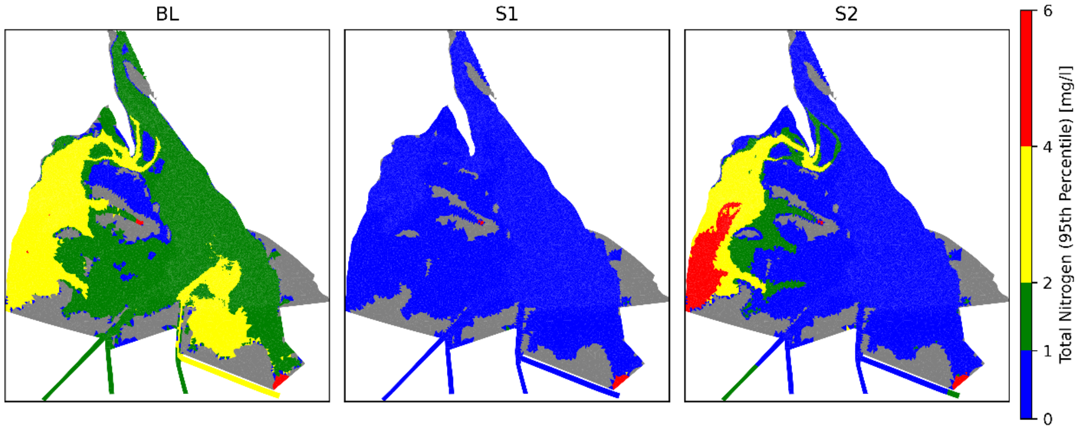

Figure 1 - 95th percentile spatial plots of Total Nitrogen in Waihī Estuary. BL corresponds to Baseline, S1 corresponds to Scenario 1, and S2 corresponds to Scenario 2.

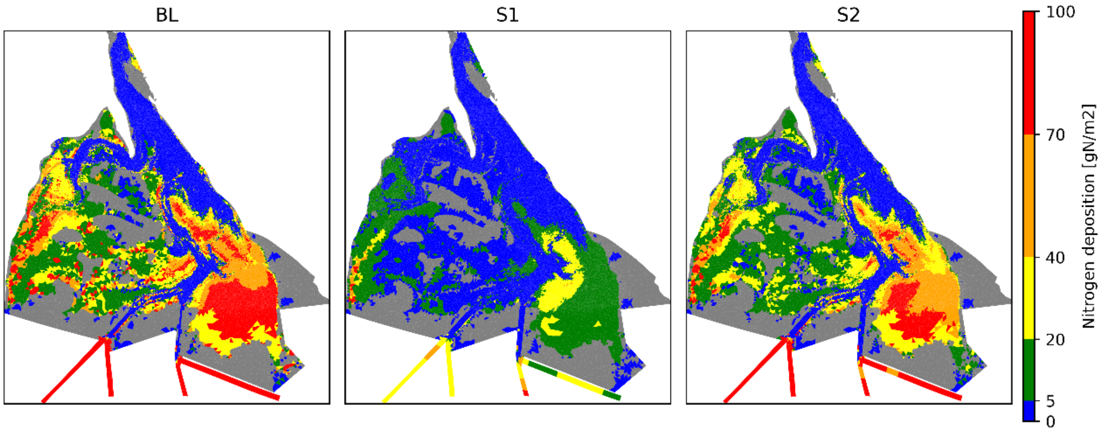

Figure 2 - Spatial distribution of Nitrogen deposition in sediment layer of Waihī Estuary.

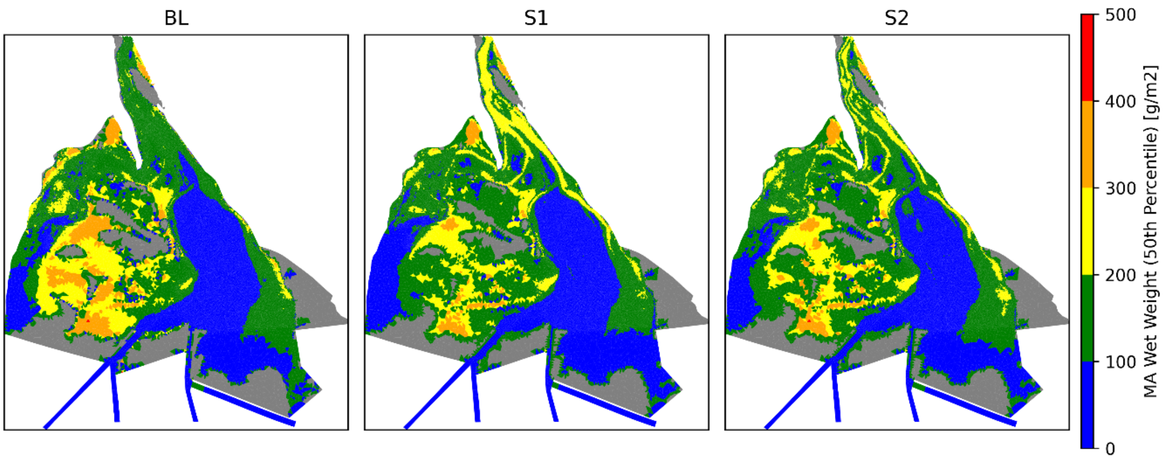

Figure 3 – 50th percentile of Macroalgae wet weight in Waihī Estuary.

DECISION-SUPPORT MODELLING FOR AN UNCERTAIN FUTURE: DEVELOPING FORECASTS OF SEA LEVEL RISE IMPACTS ON GROUNDWATER

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Aims

Sea levels are projected to rise by as much as 1.2 m by 2100 under high emissions scenarios (Kopp et al., 2014). Associated with these sea level projections are increases in the occurrence and severity of coastal inundation and nuisance flooding (Bamber et al., 2019), presenting a wide range of coastal hazards for local communities. This project aims to develop a risk-based, decision-support tool that provides stakeholders (e.g. local and regional councils and the general public) with the tools required to make informed decisions, in response to the risks associated with sea-level rise.

The low-lying coastal urban area of South Dunedin, being reclaimed from coastal marshes and intertidal deposits since European settlement, is particularly susceptible to the impacts of sea-level rise. More than 2,500 homes are only 50 cm above mean sea level and groundwater levels are typically < 1 m below the surface (Cox et al., 2020). As sea levels rise, the groundwater table is also predicted to rise, increasing the probability of inland groundwater inundation (groundwater flooding) in South Dunedin (Rekker, 2012; Cox el al., 2020). It is therefore imperative to develop an improved understanding of the physical controls, and the uncertainty associated with these controls, on the occurrence and severity of the groundwater inundation hazard caused by rising sea levels in South Dunedin.

Method

Model development follows a highly parameterised, "forecast first" workflow (White, 2017). The outcome of this workflow being that a model design is such that it can be used to robustly quantify the uncertainty of decision relevant forecasts and reduce this uncertainty, to the extent that information in available data allows. The specific forecasts required from this project are; (i) the spatial distribution of increases in the groundwater table elevation, and (ii) increases in fluxes entering the drainage system, that may occur in response to updated sea-level rise projections over a 100-year timeframe (2010 – 2110) (Kopp et al., 2014).

Initial work has involved redeploying a historic groundwater flow model of the South Dunedin urban area (Rekker, 2012), within a highly parameterised Uncertainty Quantification (UQ) framework. This approach therefore provides the uncertainty quantification, which forms an essential component of the assessment of risk (i.e. risk = consequence x likelihood). Parameter realisations generated on the basis of adopted prior parameter probability distributions were used in model forecast simulations, providing outputs of groundwater head observations and drain fluxes across the model domain. These outputs were collated to provide a histogram which represents the forecast probability distribution (Figure 1b). This procedure constitutes a prior-based Monte Carlo uncertainty analysis, whereby the prior parameter uncertainty is propagated through the model to provide a description of the uncertainty of the simulated outputs (forecasts).

Preliminary results

This initial Monte Carlo UQ, i.e. 100-year transient simulations for various sea-level rise scenarios (e.g., RCP26, RCP45 and RCP85), provided a prior forecast of groundwater inundation probability. The UQ analysis also revealed current model structure and data deficiencies, for example, predicting high probabilities of groundwater inundation for the "base" scenario (i.e. no sea-level rise over the 100-year simulated timeframe), where there is currently no groundwater inundation (see Figures 1a and 1b). These initial explorations are being used to refine both the model structure and the prior parameter probability distributions, and demonstrate the utility / benefits of the forecast first workflow, which features early in the workflow UQ analysis.

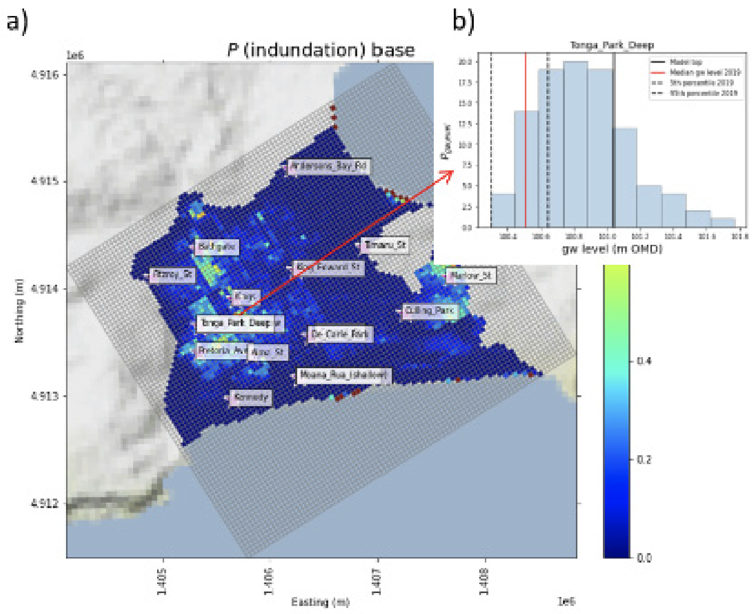

Figure 1. An example of model output, a) being groundwater inundation probability for the “base” scenario and b) being a groundwater level probability distribution for a selected observation location.

The next step of the modelling workflow is history matching (“calibration”), where the objective is to reduce the prior uncertainty of forecast relevant system state observations. The iterative ensemble smoother implemented through PEST++ will be used to implement a highly parameterised history matching and UQ process. The outcome of this step being the derivation of the posterior distributions of forecasts of spatial groundwater inundation and drain influx rates.

References

Bamber, J.L., Oppenheimer, M., Kopp, R.E., Aspinall, W.P., Cooke, R.M., 2019. Ice sheet contributions to future sea-level rise from structured expert judgment. Proc. Natl. Acad. Sci. U.S.A. 116 (23), 11195e11200.

Cox SC, Ettema MHJ, MAger SM, Glassey PJ, Hornblow S, Yeo S. 2020. Dunedin groundwater monitoring and spatial observations. Lower Hutt (NZ): GNS Science. 86 p. (GNS Science report; 2020/1110.

R. E. Kopp, R. M. Horton, C. M. Little, J. X. Mitrovica, M. Oppenheimer, D. J. Rasmussen, B. H. Strauss, C. Tebaldi, Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earths Future 2, 383–406 (2014).

Rekker J. 2012. The South Dunedin coastal aquifer & effect of sea level fluctuations. Dunedin (NZ): Otago Regional Council. 25 p.

White, J. T. (2017). Forecast first: An argument for groundwater modeling in reverse. Ground Water, 55(5), 660–664.
open-source community monitoring of freshwater catchments

OPEN-SOURCE COMMUNITY MONITORING OF FRESHWATER CATCHMENTS

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Aim

In the last 30 years the internet has driven an increasingly fine-grained connectivity of people, places and objects that are beginning to mesh powerful data gathering and processing capabilities. This has allowed the engagement of community groups and volunteers to participate in generating scientific knowledge as cheap, effective digital data capture has dramatically lowered barriers to participation (see D'Hondt et al, 2013).

The process of public engagement in data collection, research and analysis is known as citizen science (Buytaert et al, 2014). It is not a new concept as the engagement of public for empirical observational data is well documented, although collection of hydrological data often requires the use of complex, expensive scientific equipment (outside of collection of manual water quality samples) and has excluded effective citizen science participation (Buytaert et al, 2016). In turn, the need for highly trained specialists in the capture and analysis of hydrological data emphasizes elitism, shaping what data is (and hence isn't) worth capturing (Parkins and Sinclair, 2014). Yet "formal", traditional hydrometric networks typically represent coarse catchment scale spatial dynamics, not necessarily capturing the complex heterogenous nature of freshwater systems and associated contamination (Buytaert et al, 2014).

Citizen science holds great promise for hydrology. This ranges from the use of volunteered geographic information of flood inundation and automatic harvesting of metadata from social media, through to the development of community monitoring networks to gather "informal" sensing data, which this paper will explore. These informal networks utilize cheap open-source technology to generate time-series information to complement traditional formal hydrometric measurements (Storey et al, 2016). Key to ensuring the successfulness of community monitoring is ensuring adequate citizen knowledge, institutional enthusiasm and effective interaction between communities and institutions (Brammer et al, 2016; Capdevila et al, 2020). Integrating formal and informal sensing data can dramatically increase spatial representation and measurement frequency, should effective integration and project co-creation be realized (Jiang et al, 2018; Njue et al, 2019).

This paper will describe a PhD project (year 1) that is investigating the relationship between informal open-source community monitoring networks and formal institutional networks and data. Part of this is the usefulness of informal freshwater data in validating institutional freshwater models. A key theme is the suitability of sensors, both in the comparison of common water resource measurements across the informal/formal spectrum (e.g. water level, flow rates, turbidity), and the utilization of novel technology application (e.g. machine learning algorithmic interpretation of photographic or video records).

Methods

How communities choose to monitor their catchments is, in part, related to how groups access technology. Community group participation is not a fair cross-section of society, rather participation is over-represented by wealthy, well-educated, older persons (Rutten et al, 2017). Accessing and utilising open-source technology can be challenging unless participants are actively working in a related field. To overcome this, the PhD will explore how younger generations (those deemed "digitally native", see Prensky, 2001) can work with community groups through connections with high schools.

An example will be given of a sensor that measures light attenuation in water and was built using 3D printed, Arduino hobbyist electronic and consumer-grade hardware components. Designated a "clarity" meter, it has been designed at a moderate technical level so that reasonably capable high school students studying environmental science, electronics and computing can follow instructions and build their own sensors for a price around $400.

Results will be shared from research (currently underway) to show:

1. How the clarity meter measurements compare to laboratory observations of clarity;
4. Results from an *in-situ* test of the clarity meter against a commonly used turbidity meter; and
5. Information gathered by a high school trialling comparisons of a clarity meter and transparency tubes.

References

Brammer J.R., Brunet N.D., Burton A.C., Cuerrier A., Danielson F., Dewan K., Herrmann T.M., Jackson M.V., Kennett R., Larocque G., Mulrennan M., Pratihast A.K., Saint-Arnaud M., Scott C and Humphries M.M. 2016. The role of digital data entry in participatory environmental monitoring. *Conservation Biology*, 30(6), pp1277-1287.

Buytaert W., Zulkafli Z., Garinger S., Acosta L., Alemie T.C., Bastiaensen J., De Bièvre B., Bhusal J., Clark J., Dewulf A., Foggin M., Hannah D.M., Hergarten C., Isaeva A., Karpuzoglou T., Pandeya B., Paudal D., Sharma K., Steenhuis T., Tilahun S., Van Hecken G. and Zhumanova M. 2014. Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science*, 2(26), pp1-21

Buytaert W., Dewulf A., De Bièvre B., Clark J. and Hannah D.M. 2016. Citizen Science for Water Resources Management: Toward Polycentric Monitoring and Governance. *Water Resources Planning Management*, 142

Capdevila A.S.L., Kokimova A., Ray S.S., Avellán T., Kim J. and Kirschke S. 2020. Success factors for citizen science projects in water quality monitoring. *Science of the Total Environment*, 728

D'Hondt E., Stevens M. and Jacobs A. 2013. Participatory noise mapping works! An evaluation of participatory sensing as an alternative to standard techniques for environmental monitoring. *Pervasive and Mobile Computing*, 9, pp681-694

Jiang, Q., Bregt A.K. and Kooistra L. 2018. Formal and informal environmental sensing data and integration potential: Perceptions of citizens and experts. *Science of the Total Environment*, 619, pp1133-1142

Njue N., Stenfert Kroese J., Graf J., Jacobs S.R., Weeser B., Breuer L. and Rufino M.C. 2019. Citizen science in hydrological monitoring and ecosystem services management: State of the art and future prospects. *Science of the Total Environment*, 693

Ostrom E. 2010. Polycentric systems for coping with collective action and global environmental change. Global Environmental Change, 20, pp550-557

Parkins J.R. and Sinclair A.J. 2014. Patterns of elitism within participatory environmental governance. *Environment and Planning C: Government and Policy*, 32(4), pp746-761

Prensky M. 2001. Digital Natives, Digital Immigrants, *On the Horizon*, 9(5)

Rutten M., Minkman E. And van der Sanden M. 2017. How to get and keep citizens involved in mobile crowd sensing for water management? A review of key success factors and motivational aspects, *WIREs Water*, 4

Storey R.G., Wright-Stow A., Kin E., Davies-Colley R.J. and Stott R. 2016. Volunteer stream monitoring: Do the data quality and monitoring experience support increased community involvement in freshwater decision making? *Ecology and Society*, 21(4):32

A MICROBIAL RISK ASSESSMENT TOOL TO MANAGE THE DISCHARGE OF FAECAL PATHOGENS TO LAND NEAR DRINKING WATER WELLS

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Aims

In 2010 ESR released *Guidelines for separation distances based on virus transport between on-site domestic wastewater systems and wells* (Moore et al. 2010). These guidelines calculate the separation distance between a single drinking water well and a single domestic on-site wastewater management system (OWMS) based on virus transport and fate in the subsurface environment. The 2010 guidelines have some limitations, such as only considering a single OWMS and only providing the 95% confidence limits. The recent delineation of source protection zones for drinking water supply wells has prompted consideration of the risk from a range of activities within these zones.

The Microbial Risk Assessment (MRA) tool being developed (funded by Envirolink Tools) addresses a range of land use activities that might occur within a source water risk management area (also known as a source protection zone) and for the drinking water wells being pumped at a range of rates equivalent to domestic, small town and municipal uses. Users will be able to vary the level of uncertainty from the most probable value (50%) to a 90% confidence level or an even more conservative level such as 99% confidence, so that the entire spectrum from risk averse to risk tolerant solutions can be considered.

Methods

A modular approach is being used that determines the loading of microbes from a particular land use and degree of removal if appropriate (e.g., from an OWMS); transport and removal through the soil and vadose zone; and transport and removal through the groundwater system to the pumping well. Three levels of pumping are considered relating to a domestic well, a small-town supply well, and a municipal supply well. This tool determines the relative microbial risks associated with the following land-use practices:

- Multiple domestic OWMS (previously known as septic tanks)
- Community size OWMS
- Dairy farming
- Sheep and beef farming
- Wildfowl
- Stormwater systems
- Stockyards
- Animal effluent/manure application to land

These land-use activities were identified using a scoping survey that was sent out to 17 councils across New Zealand (Tschritter & Moriarty 2018). The next step focused on the collation and quantification of the source loading inputs for these land use activities from peer-reviewed journal articles, reports, technical notes and book chapters published in the last thirty years (1990-2020). These results were summarised in a technical report (Humphries et al. 2020). Then we fleshed out scenarios that would be simulated to cover the range of land use activities, groundwater flows in the various hydrogeologic setting and the likely rates for microbial loading and removal.

Results

We are simulating microbial transport under near saturated conditions as this is when the majority of transport occurs and at the most rapid rate (Close et al. 2008; 2010). These results are combined with the frequency that those saturated conditions occur for each land use, soil, and climate location combination throughout NZ.

Norovirus was chosen as the most suitable viral pathogen for the MRA tool with regards to the human related land-use scenarios. *Campylobacter* was considered the most appropriate organism to be used for agriculture related land-use scenarios due to its widespread prevalence in animals, and the high rate of infections within the NZ population. *E coli* was included for all land-use scenarios as an indicator of faecal contamination and because of its use in regulatory standards.

The Microbial Risk Assessment Tool is being developed for a range of hydrogeological settings found in NZ. Aquifers can be very heterogeneous, and hydraulic properties can vary over several orders of magnitude, even if measured at wells in close proximity to each other. The accepted approach to overcoming this difficulty is to determine the variability in the aquifer's hydraulic properties and use this as the basis of a statistical model of the aquifer. Geostatistical models are used to describe the spatial variability of a property. Thus, the contaminant transport and pathogen removal are being addressed in a stochastic framework. For each aquifer type multiple realizations of the heterogeneous hydraulic conductivity field are generated, based on field variograms and transiograms from earlier studies, as appropriate for each aquifer type. The steady-state flow solution for each heterogeneous realization is generated using MODFLOW for each pumping rate and depth.

The microbial log-removal is calculated using MT3DMS. Contaminant removal is simulated as a first-order irreversible reaction quantified by a reaction constant. This approach allows multiple sources to be considered in the calculation of risks of microbial contamination, by superimposing solutions. For multiple OWMS, this approach will simply be the superposition of the multiple locations of the multiple OWMS. For a dairy land use grazing a paddock of 7 ha, the approach will be to superimpose the solutions from multiple inputs located throughout the diffused source area.

The outputs from the MT3DMS transport solutions incorporating all realizations will be compiled and form the basis of the probabilistic description of the microbial log-removal that is achieved in the aquifer. The MRA tool will comprise a user interface which will provide a rapid and simple analysis of the microbial risks in any selected context. The interface will enable a user to select options for the site context details from menus.

References

Close, M.; Dann, R.; Ball, A.; Pirie, R.; Savill, M.; Smith, Z. 2008. Microbial groundwater quality and its health implications for a border-strip irrigated dairy farm catchment, South Island, NZ. *J of Water & Health* 6: 83–98.

Close, M.; Noonan, M. Hector, R.; Bright, J. 2010. Microbial transport from Dairying under two Spray Irrigation systems in Canterbury, New Zealand. *J. Env. Qual.* 39: 824-833.

Humphries, B., Weaver, L., Devane, M., and Coxon, S. 2020. Quantification of source loading inputs for a microbial risk assessment tool. ESR Client Report CSC20010 prepared with support from Envirolink Large Advice Grant HZLC158. 65 p.

Moore C., Nokes C., Loe B., Close M., Pang L., Smith V., Osbaldiston S., 2010. Guidelines for separation distances based on virus transport between on-site domestic wastewater systems and wells. ESR Report No. CSC1001. 269 p.

Tschritter, C., Moriarty, E., 2018. Scoping Project for the Development of a Microbial Risk Assessment Tool for Discharges near Drinking-Water Wells. ESR Client report CSC 18007 prepared for Environment Canterbury.

CONFLUENT KNOWLEDGES: NESTED CO-PRODUCTION OF THE NATIONAL POLICY STATEMENT FOR FRESHWATER MANAGEMENT

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Sustainable management of freshwater systems requires an appreciation of the interdependencies between society and freshwater, drawing from a range of knowledge sources. For freshwater management policies to be just, it is important to consider whose knowledges count and how they are counted. This is particularly relevant in Aotearoa New Zealand where Western positivist sensibilities have dominated Māori approaches to freshwater management following European colonisation. Today, this trend is being reversed. One part of this lies in the National Policy Statement for Freshwater Management 2020 (NPS-FM), combining both Te Mana o te Wai and the National Objectives Framework. The NPS-FM thus provides an opportunity to explore how epistemological plurality becomes increasingly established within freshwater management.

To address this issue, this research adopts tools from Science and Technology Studies to examine how different knowledges came to be included within the NPS-FM, and what the knowledge- and policy-making processes demonstrate about the nature of the NPS-FM itself. In the first instance, glimpsed through the lens of co-production, knowledge of freshwater systems is seen as inseparable from the ways policy-makers and stakeholders seek to engage with freshwater, with knowledge and engagement evolving iteratively. Moreover, this co-production is nested within a dendritic network of knowledge transformations, much like the catchments the policy seeks to manage, where different knowledges progressively converged towards the NPS-FM we have today. Furthermore, the knowledges themselves, both cross-cultural and cross-scale, are integrated in a way that seeks to preserve, to some degree, their respective authenticity and distinctiveness while at the same time allowing them to work together towards a common freshwater goal. Taken together, these insights shed light on how diverse freshwater knowledges may be worked together to achieve more equitable and resilient outcomes.

REFLECTIONS AND PROJECTIONS OF HYDROLOGY AND FRESHWATER MANAGEMENT UNDER CLIMATE CHANGE

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Climate change is a defining challenge of our time. Our global history of greenhouse gas emissions has changed the Earth's energy balance, which in turn has changed the global water cycle. Droughts are becoming more extreme, intense rainfall more intense, and the timing of floods is shifting. As our knowledge of these impacts has grown, so too has society's motivation to adapt, and our knowledge of how to adapt. In this presentation I reflect upon how hydrological knowledge and freshwater management with regards to climate change have evolved over the past 10 years in Aotearoa New Zealand, and how they may evolve further over the next 10 years. The most basic change has been the growing sophistication of the modelling, which will continue. Within this modelling there has also been a shift from primarily local case studies to national scale assessments, although regional studies will continue to be important. Also within the modelling has been a growing appreciation of the uncertainties inherent in climate change projections, as well as how decision-making can reach robust plans despite these uncertainties. Such decision-making will also become more sophisticated over the next 10 years, accompanied by targetted monitoring and event attribution programmes. Lastly, reflecting the expanding place of mātauranga Māori in freshwater management and society as a whole, we will see important progress made in decolonising climate change research and adaptation. This large body of work will require increasingly interdisciplinary efforts, straddling science, policy, and society, and the realisation that climate change, like climate variability, is an inescapable component of our work.

A REDUCED-COMPLEXITY FRAMEWORK FOR LANDSCAPE-SCALE SCREENING OF RIVER AVULSION SENSITIVITY IN A LOW-RELIEF, ACTIVE TECTONIC SETTING

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River avulsions are an infrequent, but fundamental process of active alluvial settings. While the media and policy-makers tend to focus on triggering events, over four decades of research emphasize the importance of site preparation. Research emphasis from basin and coastal settings drives perceptions of avulsion causality that may not fully represent avulsions from other geomorphic domains, particularly gravel bed rivers in active tectonic settings. That said, topographic advantage is widely recognized as a necessary condition across all geomorphic settings, though a site's sensitivity to a potential trigger at a given point in time is often more dependent its preparation state than the magnitude of the event itself (Figure 1). Predictive modelling is frequently inhibited by lack of key preparation factor data such as sedimentation rates, capacities and/or erodibility as such investment that may not be feasible, particularly at landscape scales. As filling such data gaps takes time and money, a need exists for a low-cost approach to identify and prioritise sites for disproportionate investment.

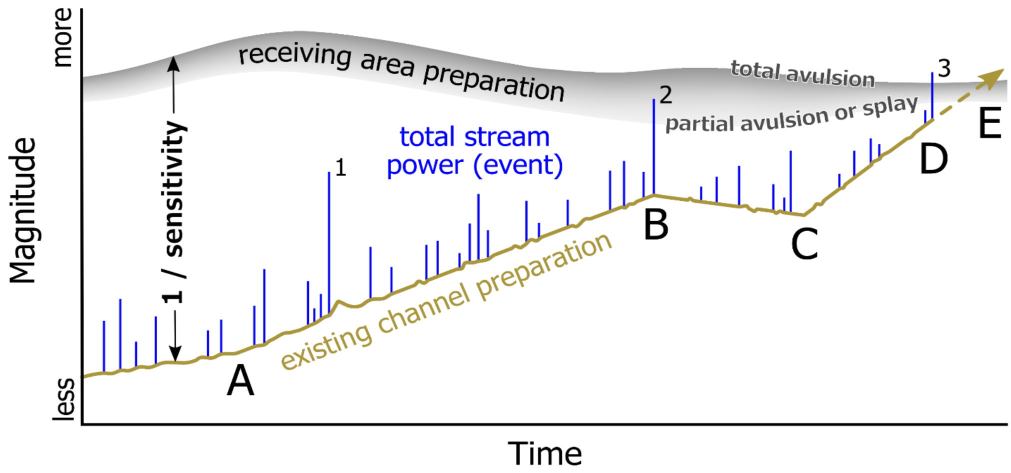

Figure 1. Fluvially-driven avulsion may be triggered by a relatively frequent event depending on the degree of channel preparation relative to a threshold condition (modified from Jones and Schumm, 1999).

Aim

We present a reduced-complexity framework to aid rapid identification and prioritisation of potential avulsion sites at landscape-scale. Examples are provided from the Ruamahanga catchment, located in an active forearc basin on New Zealand's lower North Island.

Method

The general approach uses enhancement of local topographic relief (via DEM-detrending) and to support user-based classification into one of three avulsion sensitivity classes. Because avulsion is specific to a each site along an individual water course, we apply an approach that uses each point along a stream as a datum with a search window that computes proximity-weighted relative elevation. As our interest lies in where the stream could go, methods that detrend based on exisiting drainage structure such as HAND (e.g. Rennó et al., 2008) are not well-suited. Thus, the GIS-based portion of the workflow is modeled after Dilts et al. (2010) which ingests a 2D polyline representing a channel of interest and a DEM (raster). The polyline is converted to a raster, elevations are extracted from the DEM for stream cells, and the stream alignment is detrended using a kernel density method with a user-specified search-radius. Custom colorramps are applied to optimise local relief contrast that facilitates identification of hot-spots. Enhanced visualisation of landforms and fluvial patterns also result, from which fluvial behaviours are interpreted for avulsion sensitivity across a range of potential triggering mechanism (e.g. hillslope, outburst, tectonic, and sedimentary) specific to a site. A simple 3-bin classification ("preparation-insensitive", "preparation-intermediate", or "preparation-sensitive") provides structure to guide follow-on modelling approaches and data needs.

Results

Compared to a conventional DEM (Figure 2, left), the detrended DEM (Figure 2, right) greatly enhances visualisation of local topography. The script (lead author, unpublished) used for this work processed 79.3 kms of river with a 1,000 m search radius at 5 m resolution in only 88.9 seconds on a Windows laptop with a 2.7 GHz i7 processor in an Arcpy and Spatial Analyst (ESRI, 2019) enabled Python 2.7.1 environment. Guidance on sensitivity classification is provided in Conley et al. (in prep) and will be most robust when performed by individuals experienced with geomorphic interpretation and process-based inference from remotely-sensed data.

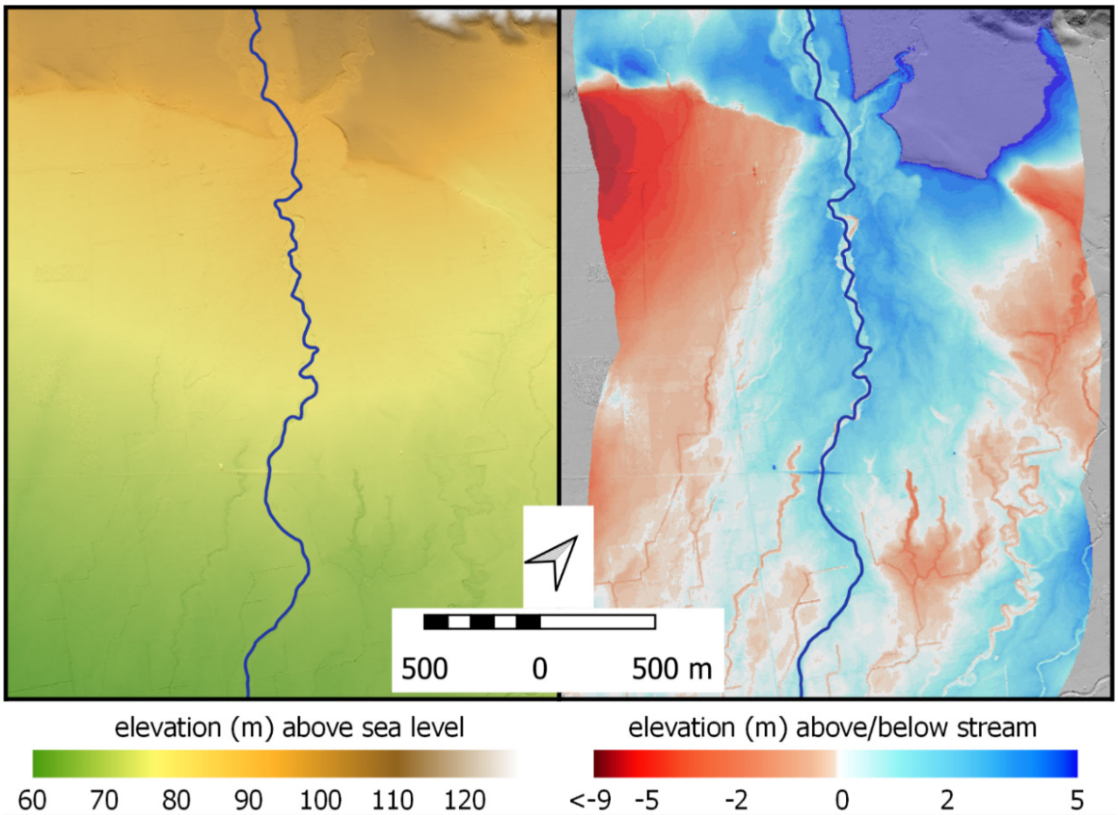

Figure 2. Left: One-meter DEM with vertical datum referenced to sea level and a conventional, linear colorramp that has been compressed to elevations within the frame's extent to enhance contrast. Right: Down-sampled, five-meter rDEM with vertical datum referenced to detrended stream elevation and a non-linear, zero-centered, divergent colorramp applied to enhance visualisation of topographic advantage by trunk (navy blue line). Both panels use the same base hillshade with 70% transparency applied to the elevation models.

Reference List

Conley, W.C., Fuller, I.C., McColl, S.T., Tunnicliffe, J.F. in-prep. Landscape-scale river avulsion sensitivity in a low-relief, active tectonic setting: screening for hazard.

Dilts, T., Yang, J., Weisberg, P. 2010. Mapping Riparian Vegettation with Lidar Data: Predicting plant community distribution using height above river and flood height. *ArcUser*, Winter: 18-21.

Jones, L. S., Schumm, S. A. 1999. Causes of avulsion: an overview, in *Fluvial sedimentology VI*, edited by N.D. Smith and J. Rogers. Wiley Online Library. 472 p.

ESRI. 2019. ArcGIS Desktop: Release 10.7.1 Redlands, CA. Environmental Systems Research Institute.

Rennó, C. D., Nobre, A. D., Cuartas, L. A., Soares, J. V., Hodnett, M. G., Tomasella, J., and Waterloo, M. J. 2008. HAND, a new terrain descriptor using SRTM-DEM: Mapping terra-firme rainforest environments in Amazonia. *Remote Sensing of Environment*, 112(9): 3469-3481.

NEW INFORMATION FROM OLD DATA: ANALYTICS TO PROMOTE CONVERGENCE OF CROSS-SECTION DATA PERCEPTIONS AND FLUVIAL GEOMORPHIC REALITY

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Cross-section (XS) analysis is one of the oldest and most common quantitative approaches to evaluating river channel form and change through time. In New Zealand alone, periodic resurveys of over ten thousand (estimated) benchmarked cross-sections have served as the primary channel monitoring method for decades. Despite increased availability of alternatives, most analyses continue to be spreadsheet-based, often with simple data visualizations (Figure 1) that reflect the limits of 1990s era software. Despite emergence and foreseeable prevalence of remotely-sensed data acquisition methods, the ground-based cross-sectional record will continue to provide an unmatched quantitative view of historic river behaviours and is worthy of updated analytical approaches.

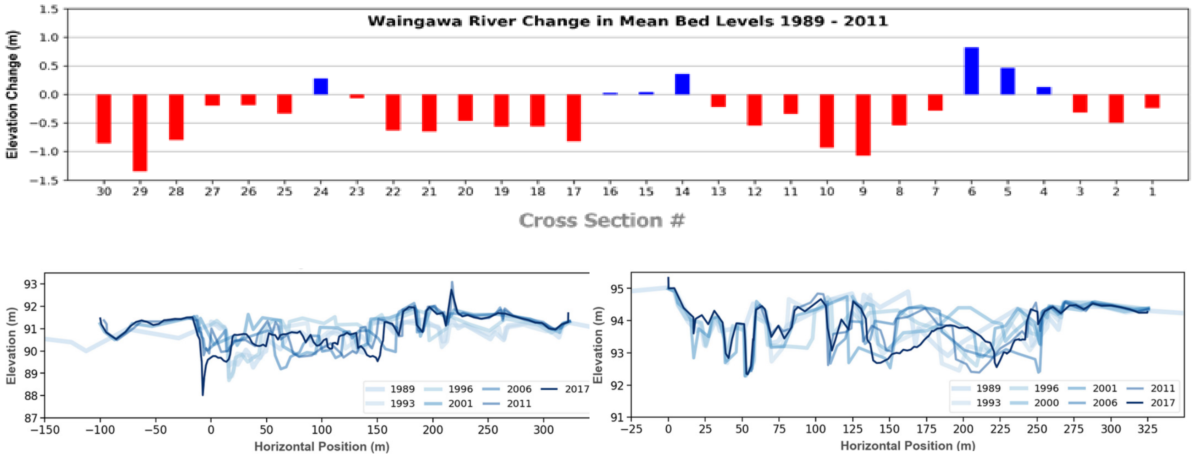

Figure 1. Common visualisations routinely used for cross-section data. Top: Bar plot representing along-profile change for a reach, such as mean bed elevation between two (often first and last) surveys. Bottom: XS-specific (a.k.a. 'spaghetti') plots show individual surveys by XS, ideally differentiated by line attributes.

Table 1. Percent of cross-section instances (n=180) exhibiting contrasting mean bed elevation shifts.

	Degrading	Neutral (+/- 0.1 m)	Aggrading (>0.5m)
Envelope	73%	10%	17% (3%)
Incremental	47%	13%	40% (17%)

Analysis and presentation of XS data are critical because of how they shape management perceptions and drive operations. Further, complications may arise when the same data support seemingly conflicting stories. For example, the net change in mean bed elevation along a profile (Figure 1, top) supports a "River X is incising" narrative that does not explicitly square geomorphically with a parallel narrative, "River X moves around alot", supported by XS-specific plots (Figure 1, bottom) and routine field observations. While the gap is partly explained by lack of spatial continuity and resurvey intervals temporally misfit to channel dynamics, modern analytics enable richer stories to be extracted from the same original source data and resolve such inconsistencies.

For example, analyses focused on net change between first and last surveys (e.g., Figure 1, top; Table 1 "Envelope") may inhibit awareness of actual dynamism revealed by incremental changes over the period-of-record (Figure 2B; Table 1 "Incremental"). Plots such as Figure 2B better communicate 'noise' and facilitate inferences of relative magnitude (e.g., the largest degradation instances are greater magnitude than the largest aggradation instances). Numerical analysis and summary (Table 1, 'Incremental") of the results from Figure 2B reveals 40% (n=72) and 17% (n=31) of all instances involved at least 0.1 and 0.5 m of mean bed rise, respectively. These results better align with inferences of unstable behaviours from field observations and cross-sections.

Geometric analysis of cross-sectional differences circumvents limitations of legacy metrics conceived to simplify computations, such as mean bed level (MBL). Total and net change can be more robustly computed and tracked longitudinally in space and time (Figure 2, all) and even partitioned into channel and non-channel components (not pictured). Doing so preserves insights on epoch-specific dynamics where net change may be small despite significant channel adjustments. For example, Figure 2A shows negligible net changes relative to baseline and prior survey (-1 and -5 m^2, respectively) despite morphological changes involved hundreds of square-meters. While net flux (Figure 2C) may be of interest in terms of budgeting for gravel extraction, it may be less informative than cumulative metrics (Figure 2D) for detecting patterns over longer timescales.

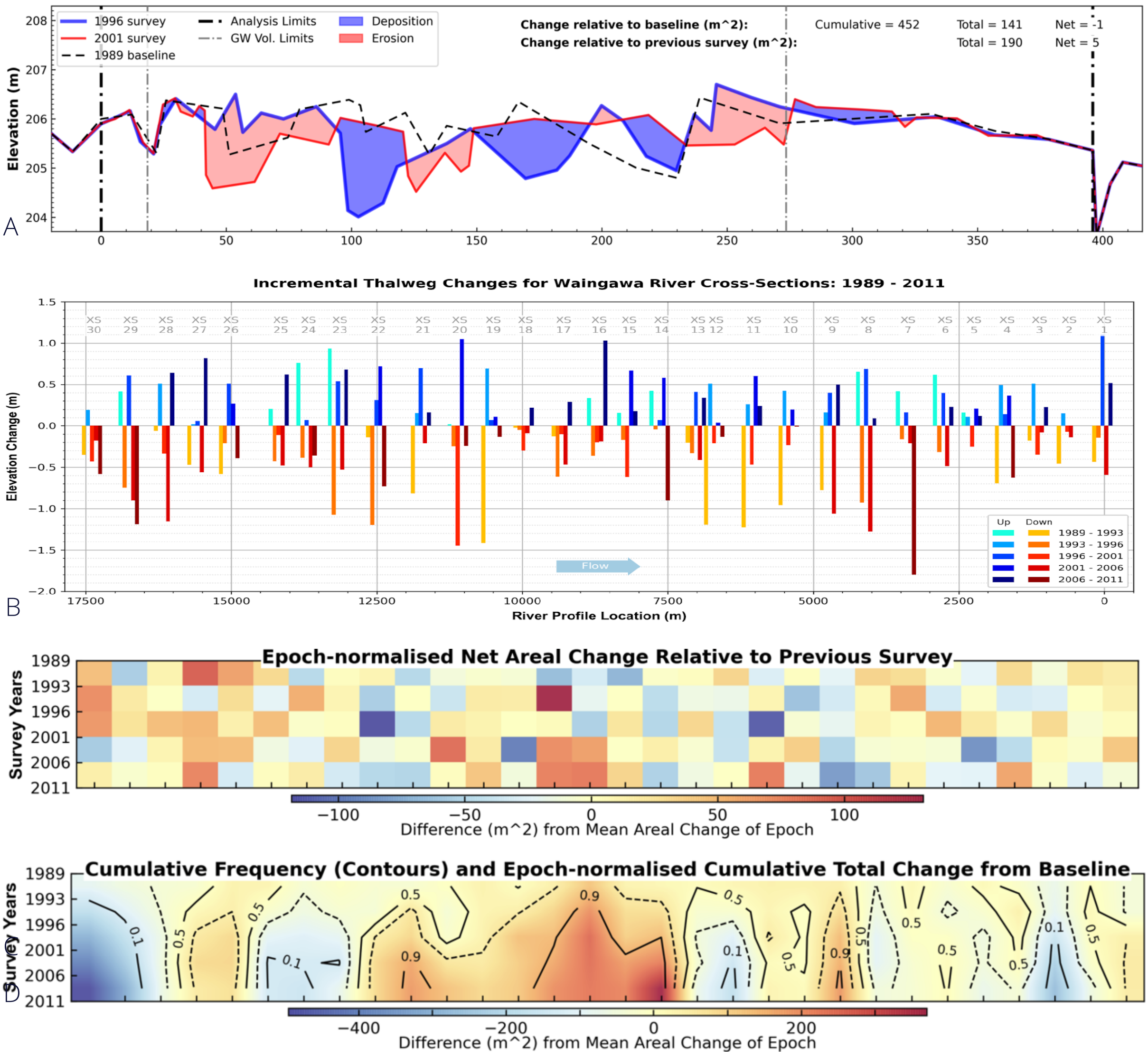

Figure 2. Cross-sectional analyses from modern analytical environments. A: XS differencing based on complex geometry and tracking total change across and net change between surveys. B: Nested barplots of each XS-epoch instance enhance visualisation of along-profile change, noise and frequency of aggradation and degradation. C: Heatmap of net XS change by epoch for all XS over the period of record. D: Total XS change accumulated across epochs for all XS with interpolation aids identification and discretisation of gradients.

Finally, the computational simplicity afforded by MBL as a derived metric is juxtaposed with its tenuous representation of real-world conditions and imprecision of bed limit delineation. Using identical station-elevation (a.k.a. RL-chainage) data, we have identified numerous instances where re-interpretation of bed limits by field managers alters MBL by +0.6 m to -0.9 m. Given such sensitivity to subjective interpretation, there is merit in reconsidering the role of MBL as a management metric.

Applying modern analytical techniques to historic data can produce richer stories across spatiotemporal scales, resolve data conflicts, and provide highly valuable context. Identification and constraint of uncertainties enables more robust analyses that, combined with added contexts, better inform geomorphic interpretation and provide a stronger foundation for evidence-driven management.

EMPIRICAL GEOMETRIC MODELS OF GROUNDWATER INUNDATION AS A CONSEQUENCE OF SEA LEVEL RISE

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Aims

Groundwater is expected to become a major problem in low-lying coastal areas as climate changes and sea levels rise (Bell et al. 2017). By decreasing the unsaturated ground available to store water, rising groundwater will increase the frequency of surface ponding, river flooding and coastal-storm inundation. More directly, it causes instability in building foundations and roads, can infiltrate into and reduce capacity of stormwater and wastewater systems, leads to dampness and mould issues in housing, increases liquefaction potential and can emerge above ground to cause flooding, pollution, salinity stress or other environmental issues. Subsurface stormwater and wastewater networks are vulnerable and potentially prone to system collapse, especially where they are old. Infiltration reduces the network capacity and can result in overflows, with associated public health and environmental costs.

Understanding the intensity and spatial reach of hazards, and how various hazards interplay, is becoming an expectation for planning and mitigation. But shallow unconfined groundwater is for the most-part still poorly quantified/understood, with significant temporal (frequency) and (perhaps more importantly) spatial uncertainty. A commonly adopted 'quick' estimate of the hazard faced by communities is to assume that groundwater levels will equilibrate locally with sea level. Such 'bathtub' models can be generated quickly from digital terrain models, using GIS techniques to provide first-order approximations of land elevation relative to sea level. But while useful for non-specific, generalised desktop assessments of regional asset exposure, the approach reflects little of the principles of groundwater systems and the dynamics of subsurface flow.

Groundwater surfaces are gently sloped, rather than flat, with humps, ridges and hollows caused by the natural flow system and interplay with urban development, drainage, stormwater systems and other engineering features. Unconfined groundwater and the natural position of the water is locally dependent on subsurface storativity (void space); permeability; potentiometric gradients from surrounding topography; capillary action; the presence of large water bodies, such as lakes or the sea; and recharge/loss from rainwater and surface waterways. Humps reflect local inability to flow quickly from rainfall or hillslope recharge or upwards flow, whereas hollows develop through more porous layers or flow to natural or human-made drainage networks. Fully numerical hydrologic groundwater models are commonly able to capture and quantify such features. However, it is rare for these numerical models to have high spatial resolution (e.g. at property scale <100 x 100 m), their development and calibration is time-intensive, and it seems unlikely they can be developed for all our coastal regions in the near-future.

Occupying middle ground, in a compromise between the overly simplistic 'bathtub' approach and more-difficult and computationally expensive full hydrologic models of groundwater, are empirical geometric models which have potential to improve both spatial and temporal understanding of shallow coastal groundwater and hazards over wide areas. There are large variations in facies and related permeability between relatively porous coastal sand dunes, silt-dominated estuarine and marine sediments and gravel- and sand-rich alluvial sediments. In order to capture important hydrogeologic heterogeneity, a modelling process is presented here for places where shallow groundwater monitoring and observations are available. Empirical observations can be used to highlight how local variations in the water table shape and slope are caused by subsurface geology, interact locally with the ground elevation or infrastructure networks, and forecast how this may look under the influence of rising sea level.

Methods

The City of Dunedin (New Zealand) has a large number of assets and critical infrastructure that are situated at, or close to, sea level. Presently protected by a slightly elevated margin of reclaimed land and fragile sand-dunes, the flat-lying coastal land, particularly in South Dunedin, is crucial to present functional operation of the city. A groundwater monitoring network improvement in 2019 provided a significant level of new information on Dunedin's groundwater. Water level, temperature and conductivity observations at 23 sites are recorded at 15 min intervals, then collated into a time-series database hosted by Otago Regional Council (ORC). A recent report describes the first year of observations with a focus towards the spatial analysis of these groundwater data (Cox et al. 2020). A variety of statistics have been generated for each monitoring site, including median, maximum, minimum, 95th and 5th percentiles, mean, standard deviation and range of groundwater levels from 6/03/2019-12/2/2020. Groundwater levels during 2019-2020 were dominated by rainfall-related peaks and recessions, were slightly lower during late summer-early autumn, and contain subtle tidal-related cycles (Cox et al. 2020). Other collated site data include: tidal amplitude, efficiency and phase lag; distance from harbour or sea; sample pH, electrical conductivity and modelled seawater percentage; and a rainfall response index reflecting rainfall recharge efficiency.

Water table elevation (GWL) was interpolated in grids with 20 x 20m cells from piezometer observations, constrained at the harbour and coast using a series of boundary 'control points'. Depth to water (DTW) grids, derived from GWL relative to a LiDAR survey of topography, define the position of the water table relative to ground and highlight associated vulnerability does not necessarily reflect topographic elevation. The lowest lying suburbs do not necessarily coincide with shallowest groundwater. Instead, the water table has elevation and gradient that is variable at kilometre-scales, with important differences from suburb to suburb. The DTW grids provide an indication as to potential groundwater inundation and remaining storage space available for rainfall infiltration. Simple geometric models to depict how sea level rise will affect the water table (SLR) were developed using the present-day statistical surfaces. Scenarios for a range of sea level rise increments (30, 50 and 80 cm) used an offset from the median GWL and a tidal component based on present day observations of tidal amplitude with distance from the coast.

Results

At their simplest, the empirical geometric models assume the absolute position of Dunedin groundwater will also rise with sea level and that the overall shape of the water table in the future will be, on average, the same as at present. By simplifying variables and controlling processes into a single parameter, the geometric models contain implicit assumptions and require many caveats. In the present geometric models calculated for Dunedin, land elevation is assumed to be constant and no distinction has been made between relative and absolute sea-level rise. Spatial precision is controlled by the piezometer distribution in the monitoring network and the local heterogeneity, and sampling rate and longevity enable temporal precision. Perhaps importantly, the models are empirical-based approximations of the present statistical condition, but do not account for groundwater flow and possible changes in water-budget mass balance. Rainfall duration, intensity and event frequency, or air pressure and storm surge, also have at least some potential to cause short-term changes to the water table position and its shape. The geometric models assume (i) these parameters and the magnitude of astronomical tides and harbour amplification effects will not change in the immediate future, (ii) that developments of any springs and runoff will not have profound geometric affects on the water table, and (iii) interaction with stormwater and/or wastewater networks or imperviousness of urban ground surfaces will not change significantly over time. But by taking the mapped position of groundwater into account, the geometric models are quite distinct from 'bathtub models' that assume a horizontal groundwater surface that is everywhere equilibrated with mean sea level. The times at which 30, 50 and 80cm increments of sea level rise will be met are still uncertain, being highly dependent on both absolute versus local sea-level models and human mitigation behaviour (e.g. Bell et al. 2017), but they suggest inundation hazard where the water table is presently shallow and surface-ponding flooding is currently experienced, rather than those areas which are merely low-lying. The empirical models offer a compromise between computationally expensive numerical solutions and the spatial precision required for probabilistic hazard assessment.

References

Bell R., Lawrence J., Allan S., Blackett P., Stephens S. 2017. Coastal hazards and climate change: guidance for local government. Wellington (NZ): Ministry for the Environment. 279 p.

Cox S.C., Ettema M., Mager S.M., Glassey P.J., Hornblow S., Yeo S. 2020. Dunedin groundwater monitoring and spatial observations. Lower Hutt (NZ): GNS Science. GNS Science Report 2020/11. doi:10.21420/AVAJ-EE81.

4D SEDIMENTARY FACIES AND HYDROLOGICAL PROPERTIES MODELS FOR QUATERNARY COASTAL AQUIFER SYSTEMS

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Aims

As part of the "National Aquifer Mapping and Characterisation" project, the relationship between global sea-level, local subsidence, and coastal-aquifer properties is being investigated with the aim of developing 4D sedimentary-facies and hydrological-properties models for Quaternary coastal aquifer systems.

Method

A pilot study was conducted on a groundwater borehole in Wellington Harbour, E3/E3A drilled off the Miramar Peninsula (NZTM 1754154.8 E, 54287722.7 N) in 27 m of water (Stantec New Zealand, 2018). In a novel approach for hydrogeology in New Zealand, the study utilised micropaleontological methods, rather than palynological methods, to characterise the paleoenvironmental setting of sedimentary layers in the borehole. The paleoenvironmental information was then utilised to develop an age model for the borehole and sedimentary facies by fitting a regression line (which represents a proxy for the paleo-shoreline) to the international sea-level curve of Grant et al. (2014).

Preliminary results

The dating of the Wellington Harbour borehole indicates the cored sedimentary record extends back 200,000 years and the negative slope on the regression-line indicates a nett overall subsidence rate of 0.04 m/kyr (Figure 1). The nett subsidence represents the sum-total of near and far-field earthquake and plate boundary deformation at the borehole site.

The grainsizes of sedimentary layers in the borehole that serve as a first-order proxy for hydrological properties and aquifer quality, appear on visual inspection to be linked inversely to sea-level. With for example:

- gravels that serve as aquifers were deposited during periods of cold glacial climate and low sea-level;
- fine-grained muds and silts that serve as aquicludes were deposited during periods of very warm interglacial climate and high sea-level associated with marine inundation; and
- a diverse range of coastal plain deposits (peats, silts, sands, and muddy grits and gravels) were deposited during periods of moderately warm interglacial climate and relatively high sea-level approaching but not exceeding the regression-line (Figure 1).

The pilot study also shows a close and unexpected relationship between the nett rate of gravel accumulation during periods of cold glacial climate and the nett overall rate of subsidence at the borehole site. This relationship is being investigated to verify if the nett rate of gravel accumulation can be used as a proxy for nett long-term subsidence in other boreholes.

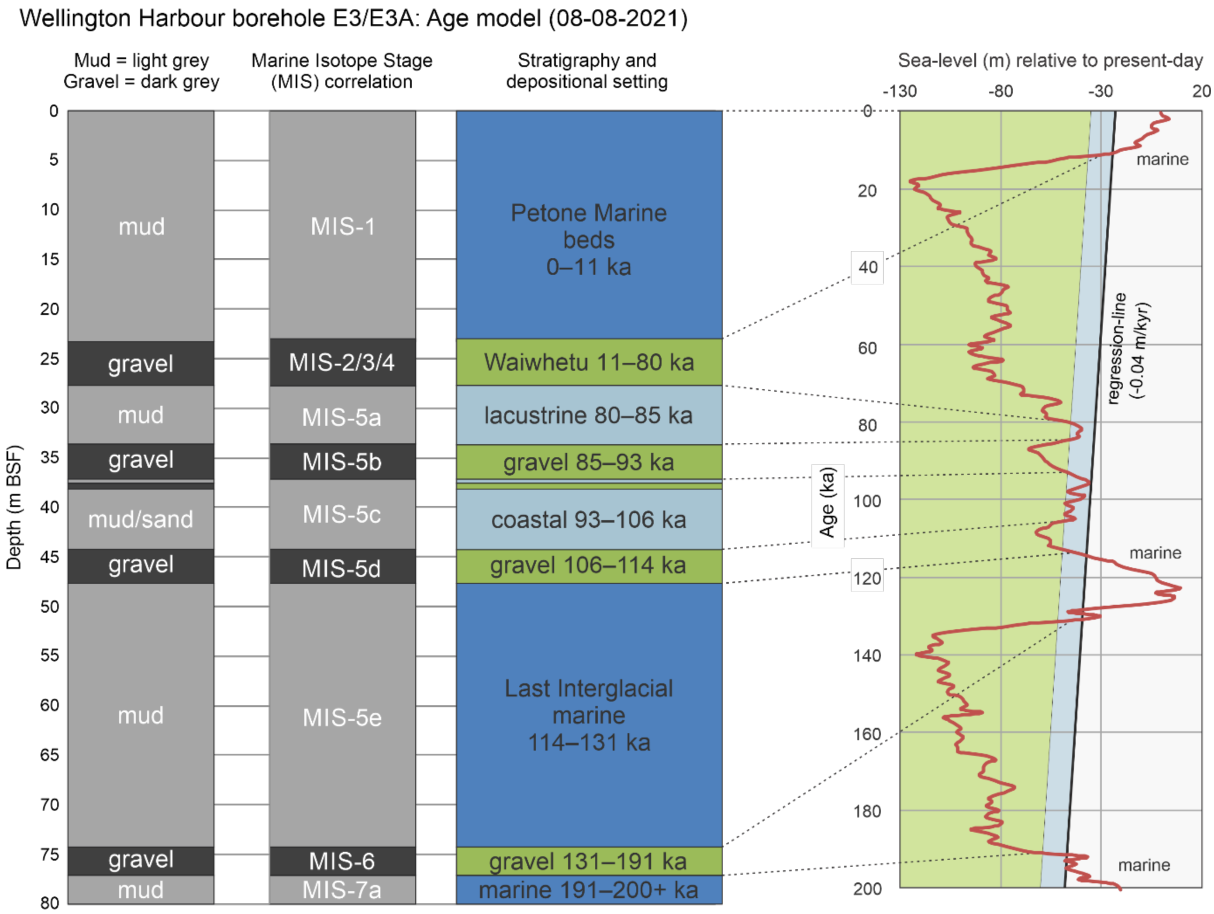

Figure 1. Wellington Harbour borehole E3/E3A. Fluvial gravel (green), coastal plain and lacustrine (light blue), marine (blue). The negative slope on the regression-line fitted to the sea-level curve indicates a nett overall subsidence rate of 0.04 m/kyr.

References

Grant, K.M., Rohling, E.J., Bronk Ramsey, C., Cheng, H., Edwards, R.L., Florindo, F., Heslop, D., Marra, F., Roberts, A.P., Tamisiea, M.E., Williams F., 2014. Sea-level variability over five glacial cycles. *Nature Communications*, 9 p. DOI: 10.1038/ncomms6076

Stantec New Zealand, 2018. Wellington Harbour Exploration Bores. Factual Geotechnical Report – Final, prepared for Wellington Water, 15 March 2018.

GUIDELINES AND A SUPPORTING TOOLBOX FOR PARAMETERISING KEY SOIL HYDRAULIC PROPERTIES IN HYDROLOGICAL STUDIES AND BROADER INTEGRATED MODELLING

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Soil plays an important role in the Earth's water, geomorphic and chemical cycles. Soil's ability to store and filter water benefits the health of a wide variety of ecosystems and the services they provide, such as regulation of floods, supply of clean drinking water and supply of water to crop roots etc. Hence, information on soil hydraulic properties (e.g., soil moisture pressure relationships and hydraulic conductivity) is valuable for a wide range of disciplines including hydrology, ecology, environmental management, and agriculture. However, this information is often not readily available as direct measurements are often costly and time-consuming. Furthermore, as more complex representations of soils are being built into environmental models, users and developers often require sound hydraulic property information while having limited access to specialist knowledge. Indirect methods have been developed to obtain soil hydraulic properties from easily measurable or readily available soil properties via pedo-transfer functions (PTFs). Although an increasing number of papers have focused on PTF development in the last decades, few articles provide guidance for obtaining soil hydraulic properties over a wide range of geoclimatic and regional data availability contexts. This talk describes newly developed guidelines and an associated spatially referenced toolbox, LUCI_PTFs, to speed the process of acquiring sensible soil hydraulic properties for different geoclimatic and data rich/sparse regions. The guide compiles available information about soil hydraulic properties as well as a large number (~150) of PTFs for different geoclimatic regions, not collated in any other guidance to date. LUCI_PTFs is an open-source ArcGIS toolbox which allows users to quickly get values, graphs, and spatial distributions of soil hydraulic properties across a range of different geoclimatic and data availability contexts.
The soil hydraulic properties obtained using the guide and the toolbox can be used as inputs for various models among other purposes. To demonstrate the use of the guidelines and the toolbox in different geoclimatic and data availability contexts, the talk presents two case studies: the Vietnamese Mekong Delta and New Zealand Hurunui catchment. The Vietnamese Mekong Delta shows the use of these guidelines in a tropical, flat location with limited information on soil physical, chemical, and hydraulic properties. The Hurunui catchment represents a case study for a semi-arid and hilly area in an area with detailed soil information.

FORECASTING END-OF-SEASON IRRIGATION WATER USE WITH A NEURAL NETWORK MODEL

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Aim

To ensure that water use is reasonable and efficient, Regional Councils are increasingly imposing seasonal volume limits on resource consents for irrigation water use. Even if water is used efficiently, there is a risk to water users, particularly in high-demand irrigation seasons, that they will reach their seasonal volume limit while demand still exists for irrigation. If this happens, in order to remain compliant with their resource consent conditions they would need to stop irrigating, with consequent reductions in yield or crop quality.

The aim of this work was to develop a tool to predict end-of-season water use. If a prediction showed that water use would exceed their seasonal volume limit, an irrigator could modify their irrigation management strategy to ensure that they were able to continue to the end of the irrigation season without exceeding their volume limit.

Methods

A forecast tool was developed, based on a neural network methods, to predict water use up to four months ahead using the water use to-date and the number of weeks since the beginning of the irrigation as inputs.

The model was implemented in Python, and used a long short-term memory (LSTM) method. This method allows multiple forecast steps to be made at once and requires very little data processing to work well with time-series data, unlike other neural networks that can require a substantial amount of pre-processing.

Outputs from an IrriCalc irrigation demand simulation model for irrigated pasture in central Canterbury were used as the training dataset for the LSTM model. The training data was formatted as cumulative seasonal water use, and then “inverted” to give the remaining water use, i.e. decreasing to reach a minimum value at the end of the irrigation season, and the re-set the following season. This format is consistent with predicting the remaining available seasonal volume.

Various combinations of parameters, including input sequence length, forecast output period and number of neurons and layers in the LSTM model were trialled to determine a practical balance between model error and forecast timeframe. Root mean squared errors were evaluated at each step of the forecast output.

The trained LSTM model was tested with measured water use data from a farm with broadly similar location, soils and irrigation system to the IrriCalc training data. The real-world data was formatted to be consistent with the training data, with measured water use subtracted from the consented volume.

Results

Figure 1 shows an example of forecast outputs for measured input data, using the LSTM model that was trained on IrriCalc data.

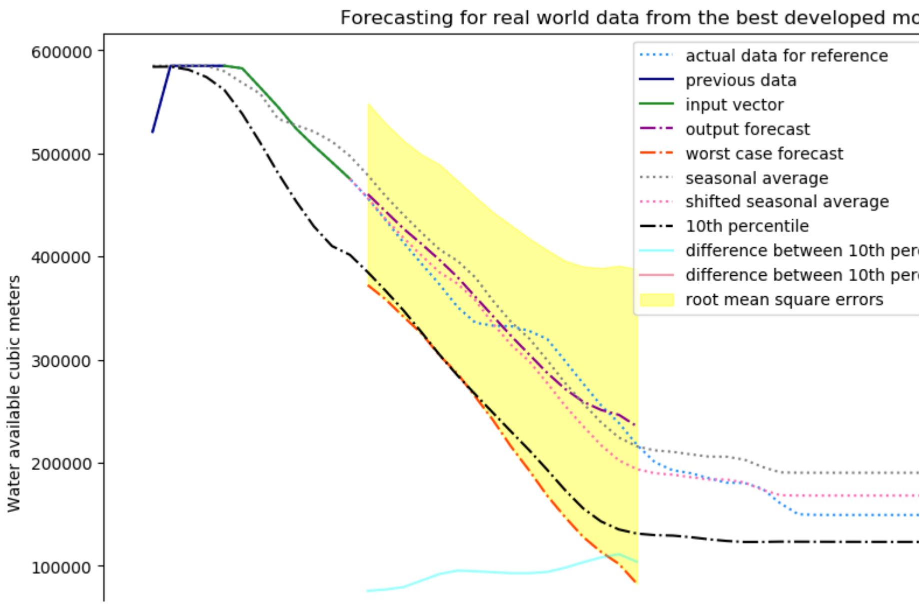

Figure 1: Example of forecast based on measured data, with model trained on model outputs.

The model errors with the measured data were comparable to those in forecast based on IrriCalc outputs, indicating that training of the model can be generalised to some extent.

Results were better in high-demand years; the model tended to struggle in lower-demand years. Considering that the model's intended purpose was to mitigate risk or non-compliance or lost production in high-demand years, the modelling approach shows promise as an operational tool.

Further refinement of the neural network method could likely be achieved by introducing further training data, such as recent rainfall.

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RAPID WATER ALLOCATION OPTION ASSESSMENT USING LIMSIM

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Aims

As part of a Ministry of Primary Industries (MPI) commissioned national-scale assessment of water availability and security, we used LimSim to assess water supply security and future water resource development potential for the whole of New Zealand, based on current allocation rules and modelled hydrology.

There was an inevitable focus on irrigation supply and demand, as this is the largest consumptive use of water, in terms of both rate and volume. A key focus of the project was to identify areas where opportunities exist to improve the availability and security of water for the food and fibre sector and rural communities, to increase resilience and ability to adapt in the face of climate change and regulatory pressure.

The assessment was also to identify areas with the greatest potential for further transformation of the food and fibre sector by increasing the diversity and increasing the value of sustainable land uses enabled by irrigation and, in most cases, water storage.

Methods

The LimSim model was originally developed as part of the MBIE-funded Wheel of Water Research Programme (Contract ALNC1102). It is a national-scale framework for predicting the consequence of water resource limits on a range of biophysical and resource use limits, including water availability and supply reliability (Snelder *et al*, 2013). LimSim uses relatively simple empirical models based on national datasets, which makes it suitable and practical for national-scale assessments. It can also be applied at a more local scale for "optioneering" or rapid creation, assessment, and filtering of options.

LimSim was modified to work with allocation rules specified in a nationally consistent format that we developed. For each allocation block that could be identified from Council plans and Water Conservation Orders, we calculated the security of supply (i.e. the percentage of the maximum allocation that is available on average). Most areas that have potential further demand for water for irrigation, as based on the availability of topographically suitable land, already have allocation rules defined. In some areas where significant development has already occurred there is little or no allocation headroom remaining, which is a constraint on any further development. Current agricultural production in such areas is also likely to be more vulnerable to future regulatory changes and climate change impacts that reduce river flows and available water. For areas where no operative rules could be identified, we calculated security of supply based on default rules from the Proposed NES on ecological flows and water levels (MfE, 2008).

A key component of LimSim is a method for predicting river flow characteristics, particularly the natural (i.e. unaffected by river takes) Flow Duration Curve for each stream reach represented in the REC (Booker and Snelder, 2012). This, along with the compilation of allocation rules, formed the basis of our evaluation of the availability of water and the effects of taking water under specified water allocation rules.

A future mix of land-uses was assigned to all potentially irrigable areas, and for each land-use the ability of the farm enterprise to pay for a reliable water supply was calculated using a farm financial model.

For catchments with potential irrigable land, the water availability and security of supply were used to calculate the hydrological limitation on further development, and the volume of storage potentially required to provide a reliable water supply. Comparing ability to pay with estimates of the cost of water storage and distribution infrastructure provided a filtering of Districts where further development is likely to be both hydrologically and financially feasible. Catchments were categorised according to their likely development potential.

LimSim was also used to assess the flow regime and habitat impacts of abstracting all available water as based on a catchment's allocation rules.

Results

By using LimSim we were able to rapidly test the hydrological and financial feasibility of further water resource development in a large number of catchments throughout New Zealand. An example of upper North Island catchments, categorised according to the ratio of *capitalised value of ability to pay for water infrastructure to the capital cost of water infrastructure*, is shown in Figure 1.

A key driver of development potential was the suitability of areas for high-value horticultural crops, as the financial returns from these crops significantly increase the ability to pay for water infrastructure.

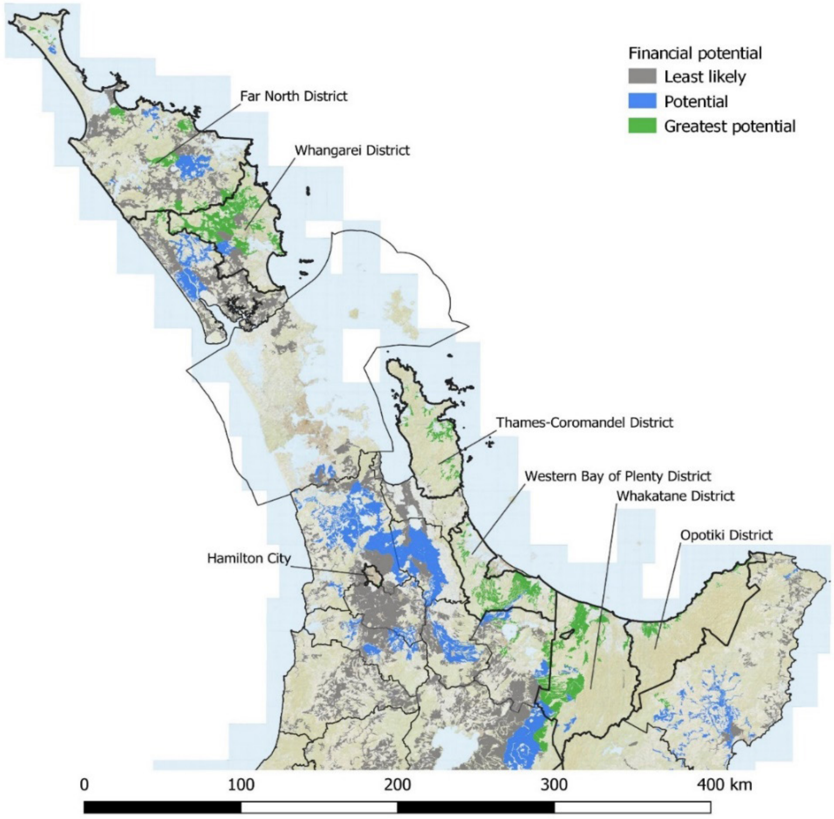

Figure 1: Example of development potential, based on the ratio of ability to pay for water to cost of water infrastructure.

LimSim has been developed into a very cost-effective tool for rapidly exploring the effects of different allocation rules on:

- The amount of water designated to remain in a natural surface waterway (i.e. explicitly allocated to the river or stream) and its reliability.
- The security of water supplied to meet human health needs
- The security of water supplied to meet all other water uses, particularly commercial water uses.

This capability made feasible a rapid national-scale assessment of water availability and security for rapidly exploring the effects of different allocation rules on the hierarchies aligned to Te Mana o te Wai and the potential for irrigated high-value land-uses.

References

Booker, D. J. and Snelder, T. H., 2012. Comparing methods for estimating flow duration curves at ungauged sites, Journal of Hydrology 434: 78-94.

Ministry for the Environment (2008) Proposed National Environmental Standard on Ecological flows and Water levels: Discussion Document.

Snelder, T., Fraser, F., Bright, J. 2013. The 'Water Wheel' – a tool for exploring the balance between economic and Environmental Outcomes. In: Accurate and efficient use of nutrients on farms. (Eds L.D. Currie and C L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 26. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 13 pages.

METHODS FOR LIMITING WATER TAKES TO RECOGNISE TE MANA O TE WAI

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Aims

One of the core principles of Te Mana o te Wai is that the health and wellbeing of the water must be prioritised first. Current water allocation methods do not explicitly recognise this: the highest-reliability water allocated for abstraction is typically given a label such as "A block" or "Band 1". Water that is not allocated for abstraction is only implicitly allocated to the environment.

As one of the inputs to a national-scale assessment of water availability and security, we have compiled allocation rules for the whole of New Zealand in a consistent format that allocates the whole flow regime.

Methods

As each Regional Council / Unitary Authority specifies water allocation rules in a slightly different way, "translation" of rules into a consistent format was required. The key steps of this process, which was applied wherever we could identify operative allocation rules from Council Plans and Water Conservation Orders were:

- Identify the catchment / freshwater management unit (FMU) that the rule relates to, and name it uniquely.
- Identify the RECv1 catchment outlet reach number.
- Identify the RECv1 reach number for the monitoring site (which may be the same as the catchment outlet reach).
- For each allocation block / band that is specified, specify:
    - The cease-take flow,
    - The block's allocation limit, and
    - The proportion of the flow in each block that is allocated to abstractive uses.

In addition to the rules specified in Plans, this framework also allows the explicit inclusion of flows that are allocated to the river environment: both flows below the "minimum flow", and gaps between allocation blocks. For example, water between zero flow and what is normally referred to as the "minimum flow" (for abstraction) is allocated to the river environment. This is the most reliable water in the flow regime, and is labelled as "R1". The proportion of the R1 block allocated to abstraction is zero.

Gaps between abstractive allocation blocks (e.g. where there is water allocated to environmental flows between a primary allocation block and a high-flow harvesting block) are also treated in this way, so that all water between zero flow and the upper limit of the highest allocation block is explicitly accounted for in our allocation framework.

Flows above the upper limit of the highest allocation block are typically allocated to the river environment. The final allocation block does not have a specified upper flow limit as the flow duration curve is unbounded. However, it does have a cease-take flowrate and a proportion allocated for taking. Generally the proportion allocated for abstraction in this block is zero. In some cases water is able to be taken from this block to refill storage ("water harvesting"). To implement water harvesting rules in modelling or analysis it is sometimes necessary to put an arbitrary cap on the upper allocation block.

Flow-sharing rules are implemented by specifying (for each allocation block) the percentage of the allocation limit that is allocated to abstractive uses. For example, if 10 m3/s is allocated for abstraction with 50/50 flow sharing (i.e. 1 m3/s left in the river for each 1 m3/s abstracted) then the block's allocation limit is specified as 20 m3/s and the proportion allocated to abstractive use is set to 0.5.

Results

An example of the nationally-consistent framework is shown in Figure 1 for the Opihi River in South Canterbury. In this case there are two abstractive allocation blocks, with a gap between them: specifying the allocation regime for this catchment requires four allocation bands in total.

Table 1: Example of the nationally-consistent framework for specifying allocation rules: Opihi River, South Canterbury

Region	FMU	FMU Outlet ReachID	Monitoring Site	Monitoring Site ReachID	Allocation Band	Cease-take flow (m^3/s)	Allocation limit (m^3/s)	Allocation Share	Data Source
Canterbury	Opihi	13064640	Opihi at No1 SHB	13064793	R1	0	2.5	0	Opihi River Regional Plan Schedule A
Canterbury	Opihi	13064640	Opihi at No1 SHB	13064793	R2	2.5	5.6	1	Opihi River Regional Plan Schedule A
Canterbury	Opihi	13064640	Opihi at No1 SHB	13064793	R3	8.1	6.9	0	Opihi River Regional Plan Schedule A
Canterbury	Opihi	13064640	Opihi at No1 SHB	13064793	R4	15	1.18	1	Opihi River Regional Plan Schedule A

In total, approximately 1500 allocation blocks were defined using the nationally consistent framework. In most cases this was straightforward. Approximation was occasionally required, for example where an allocation rule refers to flows at multiple monitoring sites. For the national-scale implementation, in cases where the cease-take flows vary by month we selected the monthly value that represented the greatest constraint on mid-summer water availability. The framework would allow specification of monthly rules in a more detailed local-scale application.

Assigning REC reach numbers to the allocation rules enables implementation of the rules in models such as LimSim, and allows them to be displayed spatially.

Structuring allocation regimes in a way that allocates the whole flow regime and explicitly allocates the highest-reliability water to the river represents a shift in thinking from the current methods for specifying allocation rules. We believe that explicitly allocating the whole flow regime is an important step towards recognising Te Mana o te Wai.

REVISITING ESTIMATED BASELINE GROUNDWATER QUALITY IN NEW ZEALAND

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Aims

Baseline water quality, also referred to as background or reference condition, describes the chemical characteristics that can be expected in the absence of human influence (Morgenstern & Daughney, 2012). There is always variation in nature, so baselines are usually defined as a range between upper and lower thresholds based on selected percentiles in the distributions of each monitored parameter under natural conditions.

Baselines for water quality have been defined and used in many countries to aid sustainable management (e.g., Shand et al. 2007; Müller et al. 2008). In New Zealand, water quality baselines have been defined but their use is currently limited to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018). These guidelines include Default Guideline Values (DGVs) that correspond to the 20th and 80th percentiles in the distributions of commonly monitored water quality parameters in New Zealand rivers in the absence of human influence (McDowell et al., 2013), taking account of differences across categories of the River Environment Classification. Note that the DGVs are not water quality standards that have to be met. Rather, DGVs can be used as 'trigger values' which, if exceeded, can prompt further analysis and monitoring to determine if an aquatic ecosystem has sufficient protection.

Previous studies have reported baselines for New Zealand groundwater quality. Daughney & Reeves (2005) applied a multivariate statistical method to data from the National Groundwater Monitoring Programme (NGMP). For example, the 75th and 95th percentiles in nitrate-nitrogen concentrations for oxidised, unimpacted groundwater were determined to be 1.6 and 3.5 mg/L, respectively. Morgenstern & Daughney (2012) used the NGMP dataset in combination with water dating results and concluded that the threshold concentrations that distinguish natural baseline quality water from low-intensity land-use water, and low-intensity from high intensity land-use water, are 0.25 and 2.5 mg/L nitrate-nitrogen, respectively. Note that the former study did not take account of the age of the water, and the latter study did not report percentile-based thresholds.

The aim of this study is to revisit the previously published thresholds for groundwater quality in New Zealand and develop a single interpretation from both the multivariate statistical and water age perspectives, and achieve consistency with the definitions of DGVs for New Zealand rivers.

Methods

Groundwater quality data from the NGMP as presented by Daughney & Reeves (2005) and Morgenstern & Daughney (2012) are used as the basis for this study. The water dating method previously used by Morgenstern & Daughney (2012) is refined to take account of the full age distribution of the water samples, as opposed to the mean age alone. We review the appropriateness of the selected water ages for inference of land use impacts, given updates in data on e.g. livestock numbers in New Zealand. The multivariate statistical method previously applied by Daughney & Reeves (2005) is re-assessed by taking account of fractions of water within specific age ranges, thus providing a set of percentile-based thresholds lacking in Morgenstern & Daughney (2012). The reported baselines are adjusted to correspond to the 20th and 80th percentiles in the distributions of water quality parameters in order to achieve comparability with the established DGVs for rivers.

Results

Reinterpreted ranges of nitrate-nitrogen at NGMP sites are presented in Figure 1, based on the 20th, 50th and 80th percentiles within the three main groundwater quality categories defined by Daughney & Reeves (2005) and the age distributions reported by Morgenstern & Daughney (2012).

The upper threshold (80th percentile) for baseline nitrate-nitrogen in oxic, unimpacted groundwater in New Zealand is calculated to be 2.7 mg/L across all samples. Importantly, this upper threshold shows little variation whether it is based only on samples for which 100% of the groundwater is inferred to be less than 50 years old (2.8 mg/L) or less than 20 years old (3.2 mg/L). This suggests that the multivariate statistical method for separating impacted from unimpacted groundwater is reasonably robust regardless of the age fractions represented within the water samples. The slight decrease in the 80th percentile of nitrate-nitrogen concentration for the population of samples containing the oldest groundwater may indicate some degree of denitrification, which can occur even under ostensibly oxic conditions (Martindale et al., 2019).

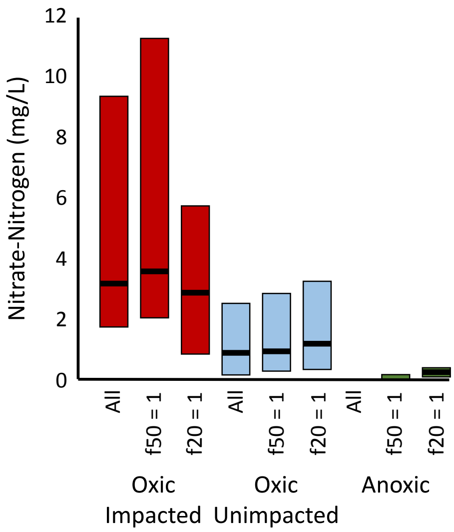

Figure 1. Nitrate-nitrogen concentrations in groundwater at NGMP sites. Boxes run from 20th to 80th percentiles with median indicated by central horizontal bar. Colour coding is based on multivariate statistical classification from Daughney & Reeves (2005) for oxic groundwaters impacted by human activities, oxic groundwaters unimpacted by human activities, and anoxic groundwaters. Three bars for each groundwater quality category are based on age distributions from Morgenstern & Daughney (2012) for all samples, only samples for which 100% of the groundwater is inferred to be less than 50 years old, and only samples for which 100% of the groundwater is inferred to be less than 20 years old.

Figure 1 clearly shows that nitrate-nitrogen concentrations are higher in oxic impacted groundwaters compared to oxic unimpacted groundwaters across all ranges of water age, whereas concentrations in anoxic groundwaters are much lower. These results have been previously reported (Daughney & Reeves, 2005; Morgenstern & Daughney, 2012), but emphasise the importance of developing a means to identify and remove any impacted groundwaters from the population of samples that is used to define baseline, in order to avoid biasing effects. Likewise, oxic and anoxic groundwaters, while both occurring naturally, are distinct populations that each require their own thresholds for the definition of baseline.

References

ANZG. (2018). Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Governments and Australian state and territory governments. Canberra ACT, Australia. Retrieved from www.waterquality.gov.au/anz-guidelines

Daughney, C. J. & Reeves, R. R. (2005). Definition of hydrochemical facies in the New Zealand National Groundwater Monitoring Programme. *J. Hydrol. NZ*, 44, 105-130.

Martindale, H., van der Raaij, R., Daughney, C.J., Morgenstern U., Singh, R., Jha, N. & Hadfield, J. (2019). Assessment of excess N2 for quantifying actual denitrification in New Zealand groundwater systems. *J. Hydrol. NZ*, 58: 1-17.

McDowell, R. W., Snelder, T. H., Cox, N., Booker, D. J. & Wilcock, R. J. (2013). Establishment of reference or baseline conditions of chemical indicators in New Zealand streams and rivers relative to present conditions. *Marine Freshwater Res.*, 64, 387-700.

Moreau, M. & Daughney, C. J. (2021). Defining natural baselines for rates of change in New Zealand's groundwater quality: Dealing with incomplete or disparate datasets, accounting for impacted sites, and merging into state of the-environment reporting. Sci. Tot. Env., 755, 143292.

Morgenstern, U. & Daughney, C. J. (2012). Groundwater age for identification of baseline groundwater quality and impacts of land-use intensification – The National Groundwater Monitoring Programme of New Zealand. *J. Hydrol.*, 456-457, 79-93.

Müller, D., Blum, A., Hookey, J., Kunkel, R., Scheidleder, A., Tomlin, C. & Wendland. F. (2006). Final proposal of a methodology to set up groundwater threshold values in Europe. Specific targeted EU-research project BRIDGE (contract No SSPI-2004-006538)-report D18.

Shand, P., Edmunds, W. M., Lawrence, A. R., Smedley, P., & Burke, S. (2007). The natural (baseline) quality of groundwater in England and Wales. Environment Agency Report RR/07/006.

STORMFLOW WATER QUALITY AND SUSPENDED SEDIMENT IN THE MANAWATŪ RIVER CATCHMENT – TOWARDS INTEGRATED MODELLING

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Aims

The work outlined here forms part of the STEC (Smarter Targetting of Erosion Control) research programme, led by Manaaki Whenua – Landcare Research (MWLR). STEC is developing a comprehensive model framework linking river suspended sediment and related water quality to catchment erosion. The aim of the river stormflow sampling is to provide suitable data for integrated erosion source-sediment modeling.

Many sediment studies have been conducted round the world focussed on sediment *quantity* (mass fluxes integrated to estimate annual loads), and Hicks et al. (2011) have summarised river sediment mass loads for NZ. However, sediment *quality* is as important as sediment quantity for predicting environmental behaviour and effects of suspended particulate matter (SPM). Accordingly, in STEC the analyses of stormflow samples have been considerably broadened compared to 'traditional' river sediment studies – and include organic and nutrient content, optical properties and particle size.

Methods

We are sampling suspended sediment and related water quality at three sites in the Manawatū Catchment that form part of Horizons Regional Council's hydrometric and SoE monitoring networks. The main-stem river is sampled at the Teachers College Station in Palmerston North, and two major tributaries are also sampled: the ('muddy') Tiraumea on the east side of the main divide, and the ('sandy') Pohangina on the west side. Water samples collected over storm events are kindly sent by Horizons staff to NIWA-Hamilton for analysis by the NIWA water quality laboratory.

Table 1. STEC laboratory analyses on stormflows at three Horizon's monitoring network sites.

Analysis	Method	Rationale
Beam-c	Light beam attenuation coefficient measured by beam transmissometer (250 mm path, 530 nm LED)	Quantifies light (beam) attenuation; can be rigorously converted to visual clarity
SSC/VSSC*	Wet-sieving to separate sand at 63 mm, Mud fraction captured on a GF/C filter analysed for TSS/VSS*	SSC quantifies sediment mass concentration. Volatile content (VSSC) quantifes organic SPM
POC/PON	Particulate organic carbon – and nitrogen. Measured on the residue captured on a GF/C filter (acidified); Elementar C-N analyser	Quantifies organic carbon and nitrogen content of SPM
Particle size	EyeTech laser streaming (time-of-transit) analyser (before and after ultra-sonic dispersion)	Quantifies in situ and primary particle size distribution (PSD) – permits modelling of different sediment size 'bins'.

(*) Suspended sediment concentration and its volatile fraction (fired at 400 oC).

Table 1 lists the analyes conducted routinely on river stormflow samples and also on soil (erosion source) samples collected by MWLR from the range of eroding terrains in the catchment that deliver sediment to the river network (analysis of this erosion source data is described in Vale et al. 2020).

A novel analysis applied to both soil and river sediment samples is light beam attenuation (beam-c) – an absolute (SI) measure (Table 1). Beam-c correlates strongly and almost linearly with nephelometric turbidity (Davies-Colley & Hughes this conference) and will provide (local) calibration of continuous field turbidity records at each site. Light beam attenuation can be accurately converted to visual clarity (Zanevald & Pegau 2003), so permitting assessment versus the NPS-FM (2020) "bottom lines" for aquatic life and the MfE (1994) guideline (1.6 m) for swimming.

Results

Eleven storm events have been analysed to date over more than two years. Unfortunately, conditions have been uncommonly dry and few large events have been successfully intercepted from any of the sites. Accordingly, sampling is continuing with the aim of intercepting larger storm events, preferably close to annual flood size, that will be more useful for integrated modelling (an update will be provided at the conference).

Figure 1 shows example data for auto-samples collected over a storm hydrograph (on 15 October, 2019) at the main Manawatū at Palmerston North site. The good correlation of beam-c and turbidity for this and other events means that continuous field turbidity will provide a high-frequency proxy for beam attenuation.

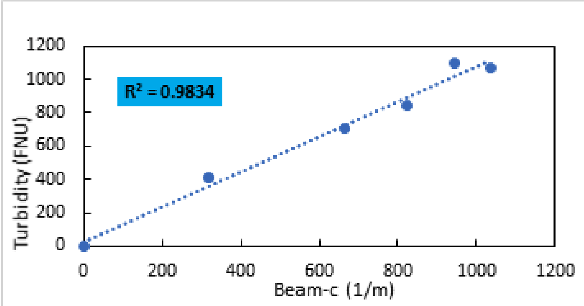

Figure 1. Turbidity vs beam-c measurements on autosamples collected from Manawatū at Teachers College (Palmerston North) over a storm flow event on15 October 2019.

Applications to modelling

An integrated model framework TEST (Temporal erosion and sediment transport) (Dymond 2019) has been developed to describe catchment erosion processes and transport of resulting fine sediment within the river network (Smith 2019; Vale 2020). The model will be driven by meteorological data, integrated spatially, notably the NZ-WAM (Water Assessment Model) described by Zammit et al. (2020) for predicting river flows. We expect to use stormflow auto-sample analyses, such as those in Figure 1, for future modelling with TEST.

References

Dymond JHAS, H.; Zoemer, J.; Basher, L; Phillips, C.; Haddadchi, A.; MacDonald, I.; Zammit, C.; Davies-Colley, R.; and Swales, A. 2019. Catchment-scale soil erosion and sediment transport model for predicting water quality in rivers. New Zealand Hydrological Society annual conference. Energy Events Centre, Rotorua, New Zealand,

Hicks DM, Shankar U, McKerchar AI, Basher LR, Lynn I, Page MJ, Jessen M 2011. Suspended sediment yields from New Zealand rivers. Journal of Hydrology (NZ) 50: 81-142.

MfE 1994. Water quality guidelines No. 2: Guidelines for the management of water colour and clarity. Wellington, Ministry for the Environment.

NPS-FM 2020. National policy statement for freshwater management. Government NZ. Wellington, NZ Ministry for the Environment. 70.

Smith HP, C.; Basher, L.; Betts, H.; Davies-Colley, R.; Dymond, J.; Fuller, I., Haddadchi, A.; Herzig, A; Hicks, M., Hughes, A.; McColl, S. Neverman, A.; Spiekermann, R.; Swales, A. and Vale, S. 2019. Quantifying links between catchment erosion processes and sediment-related water quality in rivers. New Zealand Hydrological Society annual conference. Energy Events Centre, Rotorua, New Zealand,

Vale SS, H.G., Dymond, J.D., Davies-Colley, R.J. and Phillips, C.J. 2020. PREDICTING EROSION SOURCE ATTRIBUTES FOR USE IN MODELLING SEDIMENT-RELATED WATER QUALITY. Weathering the Storm conference NZHS/Rivers/NZFSS. Invercargill,

Zammit CW, R.; Liburne, L; Griffiths, J. 2020. UPDATE ON THE NEW ZEALAND WATER MODEL - HYDROLOGY PROJECT. Weathering the Storm conference NZHS/Rivers/NZFSS, . Invercargill,

Zanevald JRV, Pegau WS 2003. Robust underwater visibility parameter. Optics express 11: 2997-3009.

AGE-TRACER AND STABLE ISOTOPE INTERPRETATION ON THE HINDS-RANGITATA PLAINS, CANTERBURY

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Over the past two decades, the Hinds-Rangitata Plains, located within the Ashburton District, has undergone major changes in land-use and irrigation methods. An upward trend in nitrate-N concentration in groundwater has been reported over a similar period. More recently, the Canterbury Land and Water Regional Plan (LWRP) set water quality targets for the Hinds Plains, including an average nitrate-N concentration in groundwater. To meet these targets, the LWRP established catchment wide reductions of nitrogen leaching from farm activities – that is, a 36% reduction by 2035 – as a regional water management objective.

The LWRP water quality targets are measured against data collected in the Canterbury Regional Council (ECan) monitoring program. However, the Hinds Plains groundwater system, residence time and sources of nitrogen are still not well understood, nor the understanding of when the on-farm nitrogen reductions set in the LWRP might be reflected in the observations. Therefore, the purpose of this research is to provide a preliminary understanding of groundwater recharge pathways, residence time, sources of nitrogen and evidence of denitrification processes.

Groundwater samples were collected from nine bores located along a transect generally aligned with the direction of groundwater flow. The groundwater samples were analysed for a range of water quality parameters including stable isotopes. Groundwater mean residence times (MRTs) were calculated using the exponential-piston flow model (EPM), calibrated against measured concentrations of tritium, chlorofluorocarbons (CFCs) and sulphur hexafluoride (SF_6). To determine the source of nitrogen, samples were assigned an indicator classification based on the relationship between $\delta^{15}N$, $\delta^{18}O$ and nitrate concentration.

The stable isotope ratios of the groundwater samples are consistent with the local meteoric line observed for the Canterbury area. No samples had $\delta^{18}O$ more negative than $-9^0/_{00}$, indicating the predominance of land-surface recharge at all of the sampled wells. Groundwater MRTs ranged from 4 to 154 years, with an apparent relationship between well depth and groundwater age. Deeper wells in the upper part of the plain have considerably younger water than the deeper wells further down the plains, implying shorter flow paths to depth in the upper plains area. The indicator classification taken from the $\delta^{15}N$, $\delta^{18}O$ and nitrate concentration relationship suggests that at least some of the nitrate is passing through to the groundwater system with little retention in the soil. There was no evidence of the occurrence of nitrogen attenuation processes such as denitrification. The analysis of this work is on-going and will be presented complete.

SPATIO-TEMPORAL VARIABILITY OF WATER LOSSES FROM A BRAIDED RIVER TO ITS BRAID PLAIN AQUIFER

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Aims

Canterbury braided rivers exchange water with their associated braid plain aquifer (see Scott Wilson presentation *"Conceptualising surface water-groundwater interaction in braided rivers"*). These water exchanges occur in heterogeneous gravels and are controlled by the hydraulic heads in the river and the groundwater. This study aims at quantifying water losses, and their spatio-temporal variability, from the Selwyn river (Canterbury) to its braid plain aquifer over a study site of around 0.25 km^2.

Method

A network of 24 piezometers have been installed in 2020 to measure water pressure and temperature in the shallow (~2-6 m deep) braid plain aquifer. The diurnal and seasonal temperature fluctuations observed in the river propagate to the groundwater and could be measured in some of our piezometers. The changes in phase and amplitude of thermal waves can be used to derive the river – groundwater velocities. In this study, we used an analytical solution to the 1D heat transport equation given periodic variations in boundary temperature. The appropriate values of the parameters governing heat transport remain largely unknown. Therefore, we rely on inverse modelling to infer the material thermal properties (heat capacity, conductivity and dispersivity), the effective flow path length as well as our variable of interest, the river – groundwater velocity. The interactions between the river and the braid plain aquifer are stage dependent and, as a result, flow pathways might be (de)activated depending on river flow/stage. Therefore, the river – groundwater velocity was considered as a time variant parameter with a resolution of 5 days. The Bayesian probabilistic calibration was undertaken using the $DREAM_{ZS}$ algorithm, which allows us to quantify parameter uncertainty.

Results

The calibrated river – groundwater velocities are up to 100 m/d. Their spatial variability was found to be particularly high, with evidence of preferential flow pathways. Their temporal variability highly depends on piezometer location, with some showing fairly constant velocity while others are well correlated with the river stage/flow. One piezometer even show a switch between low and high river – groundwater velocities after high river flow events, suggesting a flow pathway activation. These insights are limited by the number and location of piezometers in relation to the high spatial heterogeneity of the system. Moreover, this study highlights the difficulty of infering compensatory model parameters. The thermal properties, flow path length and water velocity compensate and cannot all be resolved by our measurement data. Therefore, our river – groundwater velocity estimates integrate the uncertainties assumed in the prior distributions of other poorly resolved parameters.

PROGRESS IN ISOTOPE HYDROLOGY AT NIWA

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Aims

Hydrogen and oxygen stable isotope ratios (δ^2H and $\delta^{18}O$) can be used to quantify hydrological processes across different spatial and temporal scales, where distinct spatial and temporal patterns of δ^2H and $\delta^{18}O$ are present within the hydrologic cycle. In New Zealand, characterization of these spatial and temporal patterns is still in a nascent stage. Our aims are to develop and then improve national-scale models of isotope values in precipitation and river water (i.e. isoscapes) to aid quantification of hydrologic processes, including catchment transit times and fluxes between components of the hydrologic cycle. These developments will aid national scale hydrological modelling through the New Zealand Water Model (NZWaM).

Method

To develop river water isoscapes, we combined a 'water balance' mapping method, which represents hydrologic processes of surface flow and mixing, with a regression-based correction technique using catchment environmental predictors. We applied this method across the stream network of New Zealand, comprising over 600,000 reaches and over 400,000 kilometres of rivers. The complete method uses national rainfall precipitation isoscapes, a digital elevation layer, a national river water isotope monitoring dataset (3 years of monthly sampling at 58 sites) and reach scale river environmental databases across the New Zealand river network. Advances in existing precipitation isoscapes will include model improvement to represent orographic effects, and calculations of sinusoidal seasonality of precipitation isotopes across New Zealand. These improvements will be informed by existing datasets, and new high-elevation precipitation isotope data. New data includes transects across the Southern Alps, and alpine precipitation samples collected via the AotearoaSnow citizen science initiative. Because river isoscapes utilize precipitation isoscapes as inputs, river water isoscape will also be updated following these advances.

Results

New river isoscapes produced for δ2H and δ18O showed close fits to validation data and are freely available through NIWA's NZ River Maps portal. The river isoscape can also be improved through the improvement of the precipitation isoscape, particularly with regard to orographic effects from the Southern Alps; this provided the motivation for the new datasets described above. The improvement of river and precipitation isoscapes will have potential applications in ecology, hydrology and provenance studies for which understanding of spatial variation between precipitation and surface water isotope values are required. These datasets will serve to guide the development and implementation of an integrated isotope-flow model for New Zealand.

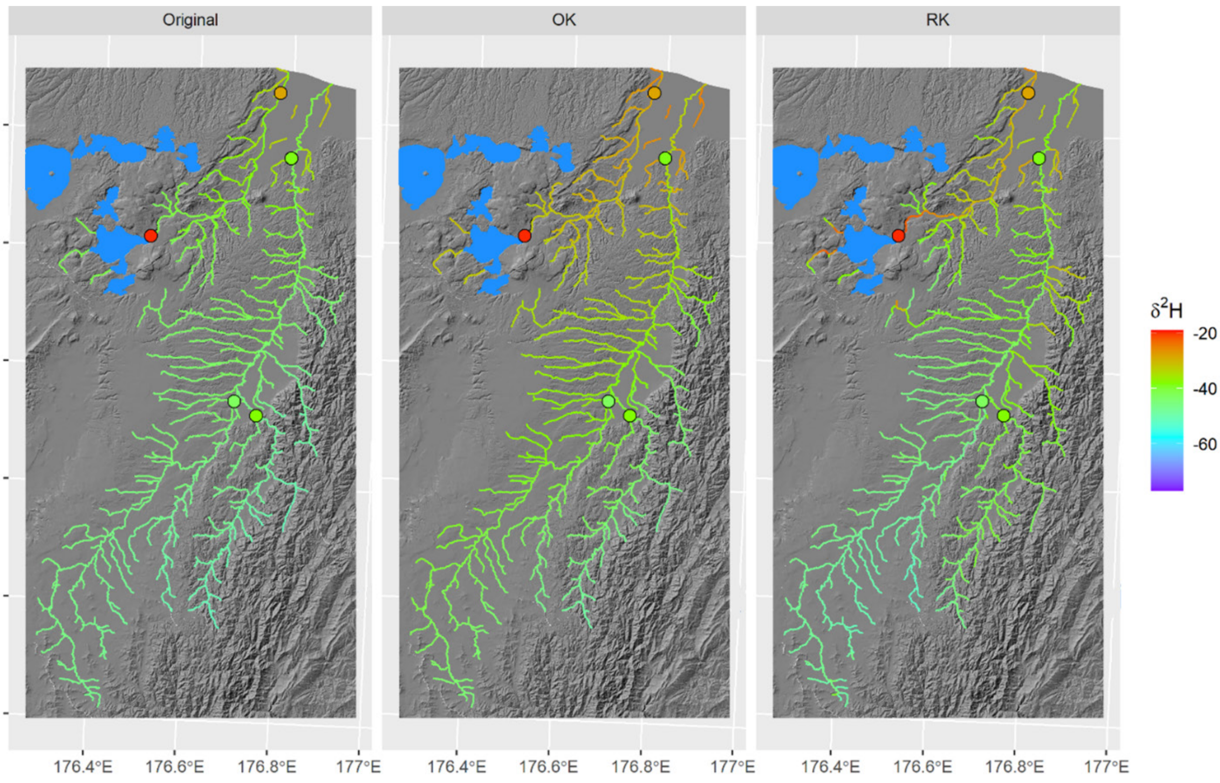

Figure 1. Comparison of modelled δ^2H values of river water across two neighbouring North Island basins (Tarawera basin and Rangitaiki basin). Higher δ^2H values from ^2H-enriched precipitation lower in these catchments are represented by the water balance model ('Original' panel A). Residual correction using ordinary kriging (OK) extends the enrichment effect of Lake Tarawera (top left of each panel) across the entire region. Using regression kriging (RK), the lake enrichment is mostly confined to downstream reaches. Points denote the locations and observed δ^2H values at monitoring sites.

MODELLING FLOW PATHWAYS IN THE PIAKO RIVER HEADWATER CATCHMENT USING SWAT AND MODFLOW

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Aims

We aim to realistically describe the water and contaminant flows through the Piako River headwater catchment (≈110 km2) by using a combination of SWAT and MODFLOW modelling. This work forms part of the MBIE-funded Critical Pathways Programme (CPP), which has the goal of unravelling the sub-catchment scale (10s of km2) nitrogen delivery to waterways. Earlier research using the BACH modelling approach for hydrograph separation and nutrient load partitioning (Woodward and Stenger 2018, 2020) was able to describe flows at the catchment outlet adequately, but a different approach is needed to describe the flows within the catchment in a physically distributed way.

To enable our research to investigate the processes occurring inside the catchment and how individual sub-catchments impact measurements at the catchment outlet we have investigated several commonly-used hydrological modelling tools. Because the BACH modelling previously identified groundwater contributions as significant (55% shallow groundwater and 17% deep groundwater), we have investigated open source tools that enable explicate modelling of the groundwater systems. Specifically, we have looked at GSFLOW and SWAT-MODFLOW. GSFLOW uses a combination of PRMS and MODFLOW, while SWAT-MODLFOW uses SWAT and MODFLOW. A review of the current state of software development and appropriateness for our catchments led us to adopt a SWAT and MODFLOW based approach.

This study covers work on the upper Piako headwaters catchment. The Piako headwaters catchment drains an area of approximately 110 km2 and has two main tributaries, the Piakonui and Piakoiti respectively originating on Maungakawa (~495 m elevation) and Te Tapui (~492 m elevation). Both streams join near Kereone to form the Piako River that exits the catchment outlet at Piako at Kiwitahi (~28 m elevation).

Method

To understand the key processes occurring in the Piako headwaters, significant field investigations have been undertaken. These include the flying of SkyTEM (airborne electromagnetic surveys), the acquisition of LiDAR and multiple gauging and sampling rounds and installation of four weather stations. Further, two permanent continuous flow recorders have been installed on the Piakoiti and Piakoiui above their confluence. Additionally, six stage pressure recorders have been installed in the catchment and associated gauging was conducted to enable the development of a continuous flow record at each location.

These data have been integrated into our SWAT and MODFLOW models, both at the conceptualisation, structural development, and calibration stages. SWAT is a small watershed to catchment-scale model that uses a series of interconnected sub-basins or watersheds to route surface and subsurface water flow. SWAT is used to simulate flow and water quality processes from source to sink and is suitable for systems of low topographic change and moderate groundwater contributions. In catchments where there is significant flow of groundwater between sub-basins, a more detailed simulation of groundwater processes is required. MODFLOW is the de facto industry standard groundwater flow modelling software, which when coupled to bolt-on models such as MT3DMS and RT3D enables the simulation of water quality transport within the groundwater system. While the MODFLOW package SFR2 can simulate surface flow, the flashy response of the Piako headwater catchment requires a more detailed representation of runoff and interflow than can be accommodated by MODFLOW packages alone. To get around the limitations of both software, SWAT and MODFLOW can be coupled together to present an integrated modelling approach. The approach we have adopted is to couple independently developed SWAT and MODFLOW models of the catchment.

The SWAT model was developed using ArcGIS as the model development platform, with the model run using an R script to explore parameter sensitivity. Sensitive parameters were then calibrated to flow and nitrate at the catchment outlet, Piako at Kiwitahi, using the Python implementation of DREAM (Shockley et al. 2017). DREAM is an adaptive Markov Chain Monte Carlo algorithm. It can be used for model calibration and uncertainty analysis. Essentially it is a fully Bayesian approach to global parameter optimisation that fully assesses posterior parameter uncertainty and consequently predictive uncertainty.

A simple one-layer MODFLOW model at a uniform 100 m grid spacing was developed using FLOPY. This was coupled to SWAT using SWAT-MODFLOW 1.3 and an initial simulation is undertaken to extract groundwater recharge. Average daily groundwater recharge was applied to the standalone MODFLOW model to enable initial steady-state calibration to available observation data. The model was then recoupled and transient calibration was undertaken with parameters sampled from within the posterior distribution of parameters identified during initial calibration of each model.

Results

Dream optimisation of the SWAT model has produced a model with multiple posterior distributions of parameters that can equally well represent flow and nitrate at Piako at Kiwitahi. An overall analysis of model results and conceptual understanding for the Piako headwaters suggests there may be limited value in using SWAT-MODFLOW in place of SWAT by itself. For the Piako headwaters, SWAT seems able to represent the physical processes occurring in sufficient detail that the increased computational difficulty of calibration of SWAT-MODFLOW may not represent a sufficient gain in performance to warrant its adoption.

While the SWAT model performs well, model performance is below that of the previously developed BACH model in terms of Nash Sutcliff equivalence. Also, flow apportionment contributions are different, suggesting slightly higher quick flow contributions. The differences are a combination of the reservoir assumptions inherent to SWAT, which are not directly comparable to the BACH model and difficulties in our ability to adequately representing orographically affected precipitation, in turn affecting model calibration. Additionally, analysis of the Piako flow record at Kiwitahi against gaugings suggests there is significant uncertainty in the measured flow. The uncertainty in recorded continuous flow and climate forcing makes direct comparisons between the BACH model and a physical processbased model like SWAT difficult. To improve model performance further work on climate inputs is being conducted. Despite lower calibration performance than the BACH model, the SWAT model is useful, as being spatially distributed it enables processes inside the catchment to be investigated.

Further, being physically based, scenario modelling and analysis is possible.

Whether SWAT-MODFLOW leads to increased model performance is uncertain at this time due to increased model run-times (approximately 1200%) and the difficulties this represents for optimisation. Testing of the SWAT-MODFLOW model is ongoing and the latest results will be presented at the conference.

References

Shockley EM, Vrugt JA, Lopez CF (2017) PyDREAM: high-dimensional parameter inference for biological models in python, *Bioinformatics*, Volume 34, Issue 4, 15 February 2018, Pages 695–697, https://doi.org/10.1093/bioinformatics/btx626

Woodward SJR, Stenger R (2018) Bayesian chemistry-assisted hydrograph separation (BACH) and nutrient load partitioning from monthly stream phosphorus and nitrogen concentrations. *Stoch Env Res Risk Assess* 32:3475–3501. https://doi.org/10.1007/s00477-018-1612-3

Woodward, SJR., Stenger, R (2020) Extension of Bayesian chemistry-assisted hydrograph separation to reveal water quality trends (BACH2). *Stoch Environ Res Risk Assess* 34, 2053–2069. https://doi.org/10.1007/s00477-020-01860-7

ENSEMBLE FLOOD FORECASTING FOR IMPACT BASED EARLY WARNING AND COMMUNITY RESILIENCE

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Aim

Devastating recent flood events and subsequent research highlighted the need to communicate warning messages in terms of likely impact, enhance awareness of risk and uncertainty, and increase preparedness prior to an emergency. Early warning systems are a major component in disaster risk reduction through the emphasis on disaster preparedness. An end-to-end early warning system is comprised of ten essential elements that work together to create a single, cohesive and robust warning system. Like the links on a chain, the overall system is only as strong as its weakest link. The failure of any one of these individual contributory systems will lead to the failure of the entire early warning system. An impact based flood early warning system enables timely response to the flood event, as well as risk-informed development planning. Ensembles flood forecastings system enables forecaster to produce reliable forecasts with lead time and possible impact scenarios.

Methods

The ECMWF 1-15 days ensemble forecasts were tested in various catchments for their performance in flood forecasting systems. The impact-based flood forecasting system is designed based on an end to end early warning system design (Figure 1).

Results

The results indicate that the ECMWF ensemble system provided significantly reliable and accurate forecasts for future rainfall in the study areas. The effectiveness of early warning systems is largely reflective of preparedness and only becomes successful if available and useable by all populations at risk from hazards. Although many countries continue to invest and improve their flood early warning systems, there is still a need for further action to address preparedness capacities, reinforcing risk communication and community capacity building on flood hazards forecasting and early warning system.

Reference

Anderson-Berry, L., Achilles, T., Panchuk, S., Mackie, B., Canterford, S., Leck, A., & Bird, D. K. (2018). Sending a message: How significant events have influenced the warnings landscape in Australia. *International Journal of Disaster Risk Reduction*, ***30***, 5-17. doi:doi:https://doi.org/10.1016/j.ijdrr.2018.03.005

Fakhruddin, B. S. (2018). Senior Disaster Management Conference. APEC Committee. 25-26 September 2018. Kokopu, Papua New Guinea.

Fakhruddin, S. H., Swail, V., & Lee, B. (2014). *Coastal Inundation Forecasting Demonstration Project (CIFDP) - System Design for Bangladesh.*

Golnaraghi (Ed.), M. (2012). *Institutional Partnerships in Multi-Hazard Early Warning Systems: A Compilation of Seven National Good Practices and Guiding Principles.* Geneva: Springer.

IFRC. (2009). *World Disasters Report: Focus on early warning, early actions.* Satigny/Vernier, Switzerland.

Figure 1: An end to end impact based EWS (Source: Fakhruddin, 2019)

FIFTY YEARS OF GROUNDWATER NITRATE MONITORING – DOES IT VALIDATE KNOWLEDGE OF WAIMEA PLAINS GROUNDWATER FLOW?

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Aims

A review of over 50 years of water quality, isotope and geohydrology information was completed for Tasman District Council (Fenemor, 2020) to inform policy development required under Government's NPSFM 2020 to better manage excessive nitrate-nitrogen concentrations in some Waimea Plains aquifers and spring-fed streams.

This presentation summarises that review but goes further by asking whether the evolving predictions for nitrate transport and attenuation based on nitrate concentrations measured since 1969 are consistent with our understanding of the geohydrology of the Waimea Plains.

This question is important for establishing effective land management policy to reduce nitrate contamination of water bodies, and for longer term integrated modelling of groundwater flow, combined with nitrate leaching as a management tool, especially following the scheduled 2022-23 commissioning of the Waimea Community Dam to augment river flows and groundwater throughflows.

Method

The review is structured using a 'cause and effect' conceptual model (Figure 1) because the policy responses need to focus on interventions at both the source (land management and discharges) and in the various receiving waters (groundwater, streams and the estuary).

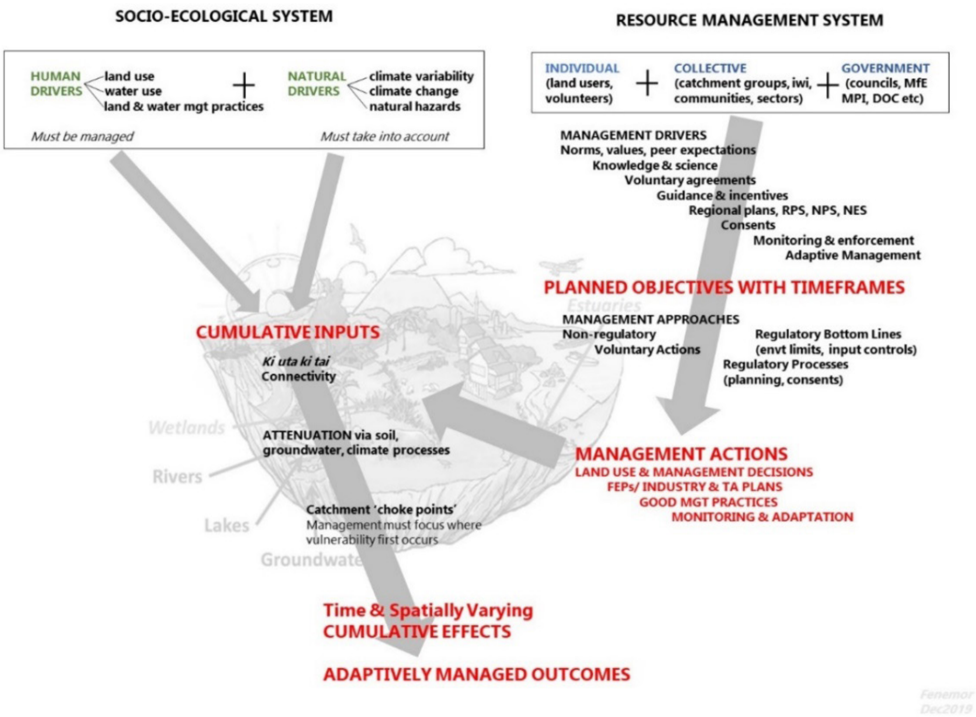

Figure 1: Conceptual catchment management system (from Freshwater Independent Advisory Panel 2020)

Results

Primary sources of nitrate contamination in the Waimea catchment are horticultural and livestock land uses. Monitoring and SPASMO modelling show that the land uses with highest N losses are dairy (24-69 kgN/ha/yr), outdoor vegetables (16-51), hops (8-32), grapes (4-18), and then apples (3-18). The most sensitive plains soils for nitrate leaching are the stony soils; soil water-holding capacity is a much greater determinant of nitrogen losses than presence or absence of irrigation.
Water quality surveys since 1975 confirm the movement of a plume in groundwater of elevated nitrate from the confined aquifer recharge areas near the closed piggery in the south-east (Figure 2) progressing northwards. Overall concentrations are slowly declining, however high concentrations were found since 2016 around Blackbyre and Bartlett's roads where the Upper Confined Aquifer (UCA) and Appleby Gravels Unconfined Aquifer (AGUA) merge (Figure 2 time series).

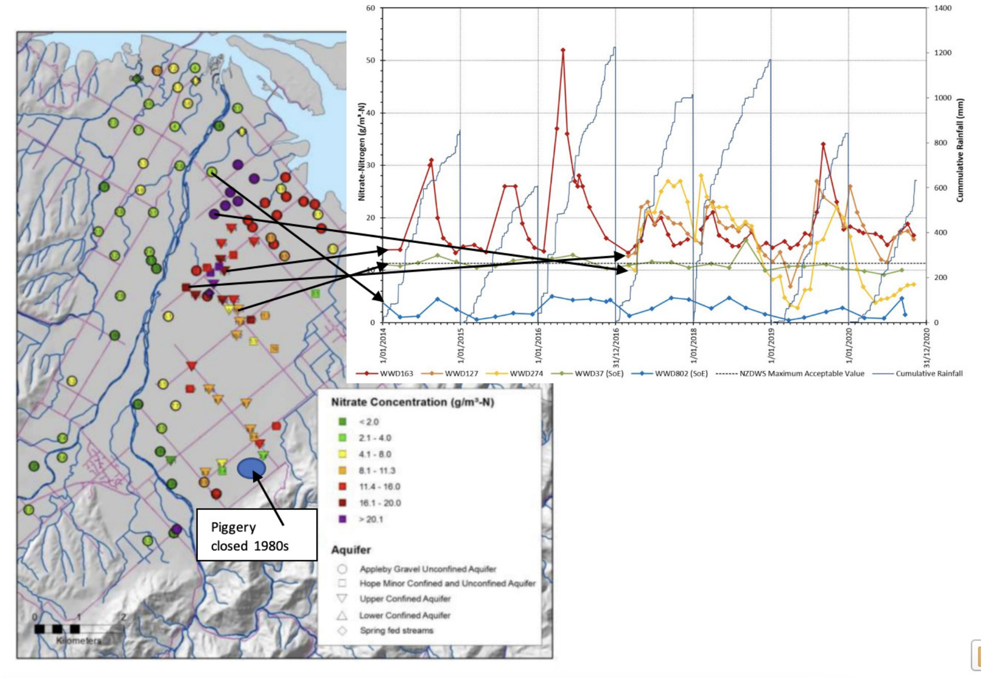

Figure 2: 2016 nitrate results by water body (LHS) and quarterly and monthly nitrate concentrations vs cumulative rainfall near Bartlett Road (RHS) from Stevens (2017) and Westley (pers comm)

Monthly groundwater nitrate data (also Figure 2) suggest that the connectivity between the shallow AGUA and underlying UCA is more widespread than earlier thought, and this is indicated by the 3D geological modelling of White and Reeves (1999). The data suggest that the historic contamination from the piggery closed in the 1980s has likely passed and that the nitrate signature in these wells is caused by local and upstream intensive land uses, particularly market gardening (vege growing).

Three spring-fed streams are receiving waters for high N groundwaters. All have median concentrations exceeding the nitrate toxicity limit of 2.4 mg/l of the NPSFM 2020. Without improved nutrient management, increased area in market gardening would increase N concentrations further.

The review concludes that there is already sufficient science information to adequately inform development of a policy response for managing nitrates on the Waimea Plains. The leakiness of the UCA and LCA are being accounted for in the 3rd generation Waimea groundwater model (Weir 2021).

References

Fenemor, A.D. 2020. Waimea plains nitrate issues – science summary 2020. Consultancy report for Tasman District Council, 41p. Waimea Catchments | Tasman District Council

Freshwater Independent Advisory Panel 2020. Report CR423 to Minister for the Environment Hon David Parker, 27 February 2020. 100p. Essential Freshwater Report (environment.govt.nz)

Stevens, G. 2017. Waimea groundwater nitrate synoptic survey. Tasman District Council Environment & Planning committee report 17-06-05. June. 24p.

Weir J, 2021 (draft). Waimea Plains Groundwater Model: Model Documentation. Tasman District Council. Aqualinc Research Limited.

White, P.A. and Reeves, R.R. 1999. Waimea Plains aquifer structure as determined by three-dimensional computer modelling. Journal of Hydrology (NZ) 38 (1) 49-75.

OPTIMISING WATER USE THROUGH UNDERSTANDING HYDROLOGY

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Aim

Obtaining new consents to abstract surface water is becoming more challenging, with the shift in focus from allocating the available resource to ensuring environmental sustainability. There is a growing trend to review abstraction and infrastructure to improve efficiency and use of the available water to meet future needs. Options range from incorporating new technologies to control abstraction, to investigating the storage of water 'harvested' during high flows. Optimisation, however, requires going 'back to basics' regarding hydrology.

This paper presents a case study of a water abstraction from Waiteti Stream in the Waikato. At present, only 44% of the consented take was used, but it was unclear whether this is sufficient to meet future demand.

Method

The availability of water from the Waiteti Stream and the 'deficit' of water that was not being abstracted but permitted were quantified. This involved analysis of the flow at three sites on the Waiteti Stream; one upstream of the take, one at the take, and one further downstream. The upstream flow gauge provided 'baseline' or natural flow conditions, the second gauge the actual abstraction, and the third gauge the downstream effects. Flow at the three sites were used to assess the frequency and magnitude at which abstraction must cease and therefore whether this contributed to not being able to abstract the maximum consented volume.

Once a 'baseline' understanding of the hydrology was determined, a water balance was used to determine current and future water demand. Consideration could then be given to optimising water abstraction to meet demand. This included a high level storage analysis.

The key issues investigated were:

- Is there a lack of water?
- Can water be harvested during higher flows and stored for use later?
- Is there a need for an additional water supply?

Results

During low flow conditions, Waiteti Stream flows just above the minimum cut-off (7-day rolling mean flow of 0.57m3/s) as measured at the upstream gauge. Consequently, abstraction of up to 200L/s can occur. However, at the point of take, there were periods when flows would drop below this, because of the abstraction, thus resulting in periods when no water take could occur (Figure 1).

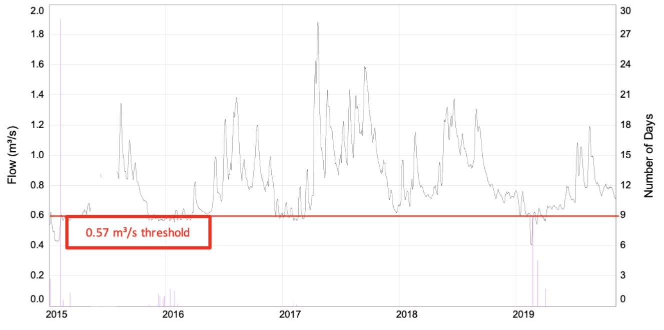

Figure 1:Total number of consecutive days that the 7-day rolling mean flow at Waiteti Stream at take site below 0.57m³/s.

Consequently, there is sufficient water in the Waiteti Stream to meet current irrigation demand. However, this depends on the pumping regime. Taking any water above 0.57m³/s (based on the 7-day rolling mean) at a maximum rate of 200L/s, irrespective of soil moisture levels, would provide the greatest volume of water, but would require on site storage.

Different water balance scenarios, when combined with the flow record, showed that there was generally sufficient water in the stream. The timing and nature of abstraction affects the volume of water abstracted. Figure 2 shows large quantities of water available during winter; however, this is not when irrigation is required and so none was actually 'harvested'. Abstracting water during higher flow conditions would allow the volume of water needed to irrigate the current demand area more easily, even during extreme dry conditions; however, storage would be required to balance supply and demand.

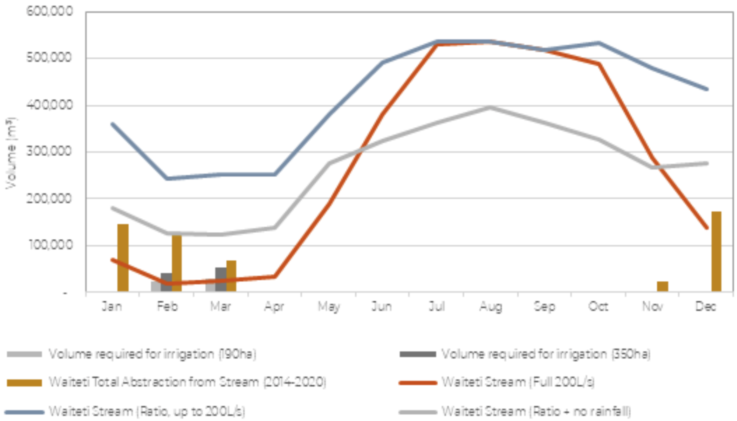

Figure 2:Mean year water balance modelling of annual water volume available in the Waiteti Stream (using three abstraction approaches) versus volume required for irrigation (1964-2020) compared to average monthly abstraction from 2014-2020.

WATER EXCHANGE IN BRAIDED RIVERS – A HYDROGEOLOGICAL HYPOTHESES TEST WITH HYDROGEOSPHERE

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[2] Lincoln Agritech Ltd, Hamilton

Aims

The braided river systems of many of New Zealand's biggest rivers have important functions in the hydrological cycle of the country. While it is known that they influence groundwater recharge, for example in the Wairau Plains (Wöhling et al. 2018), the exact nature of the exchange of water between river and groundwater in braided systems is still unknown. Thus, the vulnerability of these systems to climate change, overexploitation or other significant alterations is similarly obscure. While different hypotheses about the hydrogeological conditions in braided systems, and the accompanying systems of exchange, exist (see Brunner et al. 2009, for example), testing such hypotheses in practise is almost impossible. Therefore, we propose vigorous examination of the plausibility of these hypotheses utilizing a highly complex, coupled surface water – groundwater model.

Method

We set up a complex, three-dimensional surface water – groundwater model of a study area in the Wairau River and Wairau Plain aquifer on the South Island of New Zealand in HydroGeoSphere. Nesting of the model within a regional groundwater model, as well as implementation of a vast amount of detailed measurements of groundwater and surface water properties serves as a rigorous basis for the implementation of several possible hypotheses of hydrogeological conditions in and below braided rivers in different model variants. Simulations under different forcings are then undertaken with these variants to estimate the influence of the tested hypotheses on several quantitative and qualitative targets to assess their plausibility.

Results

The nested approach proved essential to estimate the boundary fluxes of the small-scale coupled river – groundwater model correctly. This led to general flow directions and a groundwater surface that is in agreement with local measurements of the system. A promising hypothesis, the "braidplain aquifer" seems a plausible explanation of the Wairau Plain system. A braidplain aquifer is a near-surface reservoir directly underneath the river channel, typically constructed of recent fluvial sediments, in braided rivers that are perched above the regional water table. The braidplain aquifer is recharged by the river and facilitates both hyporheic exchange as well as groundwater recharge.

The implementation of the braidplain aquifer concept in the model generated plausible results of the river flow and subsurface patterns that are apparent in the system from various monitoring campaigns. Further steps are the implementation of groundwater data to quantitatively evaluate the hypotheses, as well as the simulation of transient river flows to observe its influence on the water distribution and exchange processes at various scales.

References

Brunner, P., Simmons, C. T., Cook, P. G. (2009). Spatial and temporal aspects of the transition from connection to disconnection between rivers, lakes and groundwater. *Journal of Hydrology*, 376, 159-169.

Wöhling T., Gosses, M. Wilson, S., Davidson, P. (2018). Quantifying river-groundwater interactions of New Zealand's gravel-bed rivers: The Wairau Plain. *Groundwater*, 56(4), 647-666.

THE LEGACY OF PFAS CONTAMINATION AT PALMERSTON NORTH AIRPORT AND THE MECHANISMS BY WHICH THIS CONTAMINATION MIGRATES OFF-SITE.

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[1] Pattle Delamore Partners Limited
[2] Palmerston North Airport Limited

Background

Poly- and per-fluorinated alkyl substances (PFAS) have been used in firefighting foams since the 1950s. The PFAS form a surfactant layer which allows the foam to spread rapidly over burning volatile fuels, reducing the availability of oxygen and suppressing flames. The import, use and manufacture of PFOS and PFOA is currently prohibited in New Zealand. They are considered to be persistent organic pollutants with potential effects on human health and the environment.

Palmerston North Airport, like many other New Zealand airports, historically used PFAS containing foams for training and fire suppression between the 1960s and the 2000s. Regular training exercises were undertaken at a fire training area located to the north of the runway and foam was flushed from tanks and hoses near the former fire station located to the south of the runway. Fire training ceased in 1989 with peak foam usage occuring in the 1970s and 1980s.

The use of PFAS foams discontinued at Palmerston North Airport in 2017. A series of targeted investigations were commissioned by the airport company in 2018. Variable levels of PFAS were identified within the soils, stream sediments, surface water and groundwater in the vicinity of both the fire training area and fire station. PFAS bioaccumulates, therefore eels were considered to potentially be of risk to human health if consumed, due to their longevity. The results of biota sampling indicate that PFAS is present within eels collected from the surface waterways near the airport.

Results

The key risks to human health are the consumption of groundwater, surface water or eels containing elevated concentrations of PFAS. The concentrations within the soils at the site were below the guidelines for the current landuse and the risks are being actively managed via a management plan.

The aquifer system below the site comprises interbedded fine sands and silt horizons, with some gravel deposits present at depth. The aquifer is highly anisotropic and laterally variable making it difficult to trace confining layers over distance. The water table is relatively shallow (<5 m depth) but deeper bores (~100m depth) are flowing artesian due to a regional upwards vertical head gradient.

PFAS contamination is present within the shallow groundwater at the airport and is likely to have migrated off site, to the northwest and west, where there are a number of private bore supplies. These are screened in the deeper artesian parts of the aquifer system so the upwards head gradients suggest the risks of PFAS contamination are low. However, samples were collected to confirm this and measurable concentrations of PFAS were not detected (ppt LOD) in any of these bores.

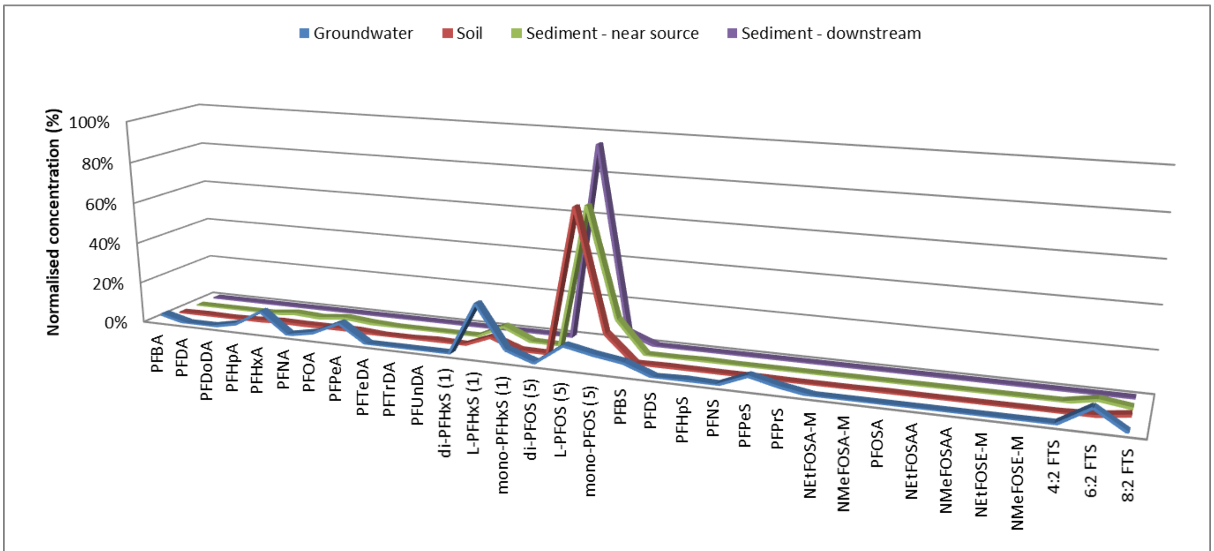
The shallow groundwater discharges into the local streams which flow south towards the Manawatu River. The parts of the plumes with the highest concentrations are likely to have already migrated off site, as active use of PFAS containing foams at the airport has ceased, but may intersect the local streams. Surface water monitoring indicates that PFAS is generally present in measurable concentrations in the small streams bordering the airport and when water levels are low is also detected in the larger Mangaone Stream. These streams also receive run-off from roads, residential and large industrial areas.

During the period when PFAS containing foams were being actively used at the site, it is likely that run-off from the fire training area and fire station was the dominant cause of elevated PFAS concentrations within the streams. However, this is not necessarily still the case. Run-off from areas where the shallow soils are contaminated with PFAS is one mechanism, but discharge of PFAS contaminated shallow groundwater into the stream and leaching from PFAS contaminated sediments are also potential sources.

Attempts have been made to determine which is the main contribution to focus the monitoring efforts and attempt to minimise the ongoing effects. These have focussed on the following areas:

- Surface water sampling under various flow and rainfall conditions to assess variability.
- Looking at the different proportions of each of the PFAS compounds in the different source media and comparing these to the surface water results.

The results suggest the dominant PFAS compounds within the soils are PFOS, mainly L-PFOS and to a lesser extent mono-PFOS, with minor amounts of other PFAS compounds. The results for the sediments are similar near the source, but further downstream L-PFOS becomes the sole PFAS compound detected. The groundwater samples had more variable signatures, but were distinctly different from the soil and sediment results. PFHxS compounds tend to dominate, with lower concentrations of PFOS and more of the other minor PFAS compounds also being detected.



Average signature profiles for different source media

The results for the surface water samples vary between the different streams and with different conditions. Using the average profiles for the soils and groundwater, it has been possible to estimate the run-off vs groundwater discharge ratio. The results suggest that run-off contributes between 0% and 40% of the measured PFAS concentrations within the streams, depending on flow and location.

This estimate assumes that the run-off leaches the contaminants evenly. It is acknowledged that this is highly dependent on the nature of the soils and the available PFAS compounds and can can vary temporally and spatially, depending on site specific conditions (Li *et al*, 2018). However, the low levels of PFHxS within the soils mean that for a first approximation it is reasonable to assume that the run-off is likely to more closely reflect the soil signature profile even with partitioning effects.

Attempts have been made to correlate the results with the average 3 day stream flow within the Mangaone Stream. The results indicate that the run-off contribution may be more dominant in the drain which flows south from the fire station, whereas PFAS from groundwater discharge may be more significant in the other streams. Further sampling is currently underway to provide more information to help quantify the different fluxes into the streams and provide information for the future management of the legacy PFAS contamination at the site.

Conclusions and Future Management

A variety of techniques have been used in an attempt to quantify the flux of PFAS contamination leaving Palmerston North Airport in the surface water. This information will be used to develop on going monitoring and mitigation measures to ensure that the effects of this legacy contamination on human health and the local ecosystems are minimised as much as possible.

References

Li, Y., Oliver, D.P., Kookana, R.S. 2018. A critical analysis of published data to discern the role of soil and sediment properties in determining sorption of PFASs. Science of the Total Environment, 628-629: 110-120.

2021 UPDATE ON THE NEW ZEALAND WATER MODEL (NZWAM)

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[2] GNS Science
[3] Manaaki Whenua Landcare Research

Aims

NZWaM-Hydrology (NZWaM) is a multi-year science project that aims to improve the understanding of hydrological process using field observation associated to an ensemble of hydrological models, to facilitate the development and implementation of land and water policies in New Zealand.

The objective of the project is to improve hydrological understanding of New Zealand landscapes by combining targeted field experiment (co-developed with research partners) and hydrological information data mining, to support development of novel hydrological models that can be incorporated into operational tools to assist water resource managers to implement national land and water policies.

Methods

The project is designed around a national-scale suite of hydrological models that integrate surface water and groundwater processes. This suite provides accurate hourly flow predictions for all reach-scale segments of the latest digital river network (> 3 million sections of the river network), corresponding catchment reach-scale hydrological fluxes, and groundwater level on a 250 meter national grid.

The project is a collaboration between three CRIs (NIWA, GNS Science, and Manaaki Whenua Landcare Research), three regional councils (Environment Southland, Horizons Regional Council, and Gisborne District council) and three central government departments (Ministry for Environment, Ministry for Primary Industry, and Stats New Zealand). This forms NZWaM's Stakeholder Reference Group (SRG).

The NZWaM framework provides hydrological data for land and water management in New Zealand. This data is used for regional and catchment planning (implications of land use and climate change impacts); water take and use consenting; and setting resource-use limits (contaminant load estimation) as required by the National Policy Statement for Freshwater Management.

Results

The highlights of outputs produced by the project during 2020-2021 are given below:

- Hydro-geofabric (national-scale spatio-temporal database of hydro-geological data)
- Identification of potential groundwater catchments using models with a-priori parameterization (with GNS)
- Provided public access to surface-water hydro-geofabric data
- Development of a hydro-geofabric guidance manual for end-users

Isotope hydrology

- Completion of the national steady state young water fraction map
- On-going stable isotope sampling (rainfall and surface water) and analysis within the three partner regions
- Dissemination of updated isotope data via the Isotope Hydrology webpage

HydroDesk-NZ (online tool to run models using NZWaM)

- Development of user and guidance manual
- Refinement of output visualization
- Development of a plan for coupling of surface and groundwater models

Surface water module

- Loosely coupled surface water/groundwater uncertainty analysis (with GNS)
- Catchment scale surface water take module tested across New Zealand

Groundwater module

- Outline a-priori parameterization of TopNet-GW at national scale
- Test catchment scale irrigation using groundwater abstractions and return flows module
- Compare uncalibrated and calibrated TopNet-GW and GNS EWT models for case study catchments
- Development of an initial national scale MODFLOW 6 groundwater model (aligned with Te Whakaheke o Te Wai)

Water consent planning tool

Development and beta-testing of modules within Hydro-desk-NZ online tool

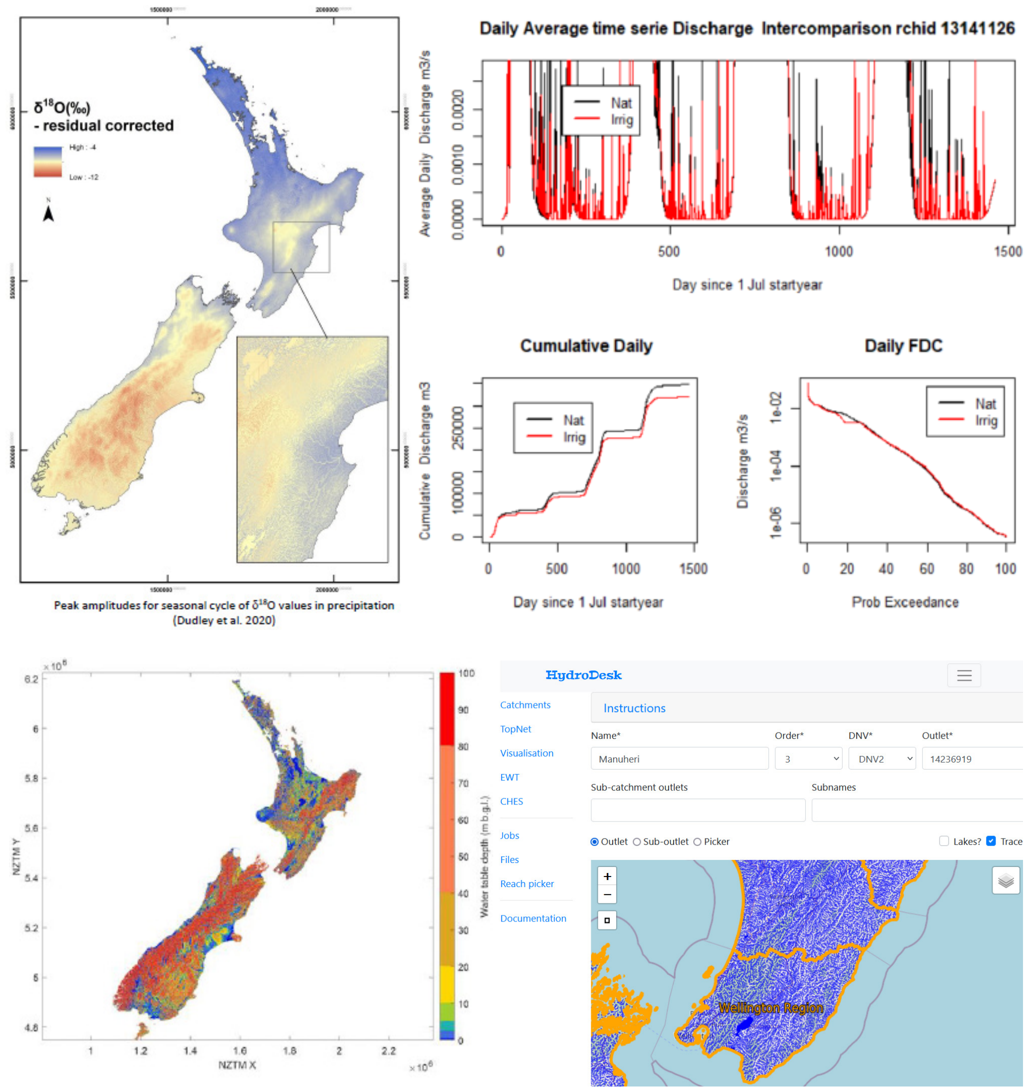

Figure 1 Outputs from NZWaM (clockwise from top right): Peak amplitudes for seasonal cycle of δ18O values in precipitation (Dudley et al. 2020); timeseries output summary from TopNet surface water model; Equilibrium Water Table estimation of water table depth; and screen-shot of HydroDesk-NZ.

A UNIT HYDROGRAPH APPROACH TO EARLY FLOOD WARNING IN SAMOA

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Introduction

Lying mid way between the Equator and the Tropic of Capricorn the Samoan archipelago is exposed to tropical cyclones each year between November to mid-May (predominantly from late December to mid-May). The capital of Samoa, Apia, on the north side of Upolu Island, and experiences an average of 2,800 mm of rainfall per year (with a maximum of 450 mm in January and a minimum of 80 mm (3.2 in) in July and August). The Vaisigano River runs from the highlands of the island's interior to the harbor in Apia (Figure 1). In recent years Samoa has been hit by a number of large tropical depressions which have resulted in extensive flooding and subsequent mitigation and remediation work. An early warning system is being developed for the Vaisigano catchment to protect the urban population of Apia during large flood events.

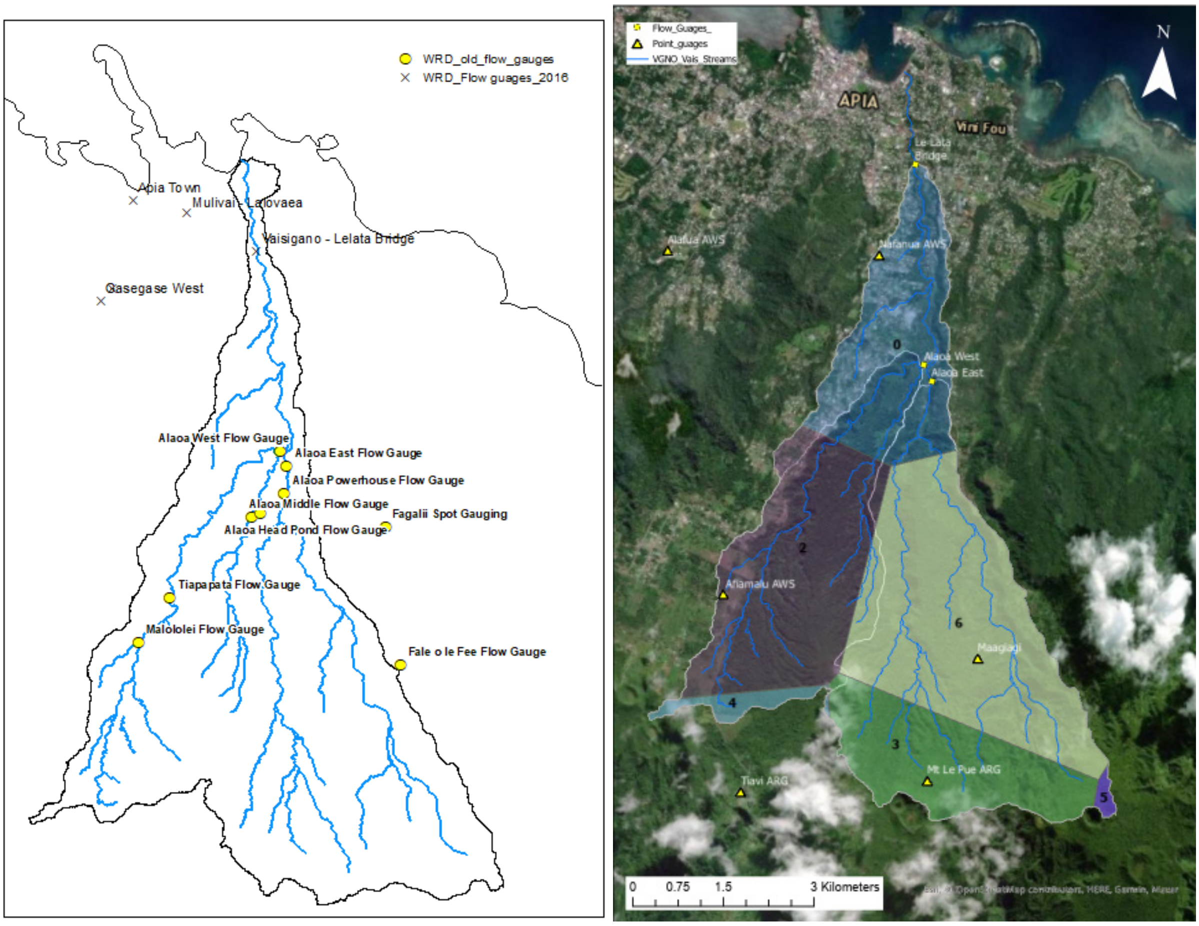

Figure 1 Vaisigano catchment on the north coast of Upolu Island, Samoa.

Aims

Previous flood models of Apia focused on mathematical simulation and mapping of historic floods. Such models are complex and are difficult to run consistently on a real-time basis. As a result, there is no real-time flood modelling system in place, and flood early warnings are based predominantly on regional rainfall forecasts.

The aim of this work was to develop a parsimonious rainfall-runoff model that would allow robust estimation of the timing and magnitude of peak flows in the Vaisigano catchment based on forecast rainfall. This was particularly challenging due to the fast hydrological response of the catchment and relatively

Methods

A unit-hydrograph approach was developed from historic rainfall and runoff data held for the Vaisigano catchment. Data from two tropical cyclone seasons (from 2018 to 2020) were used to first build a unit hydrograph (Figue 2). The perfrmance of the model was validated and subsequently improved using data from flooding that occurred in the 2021 cyclone season.

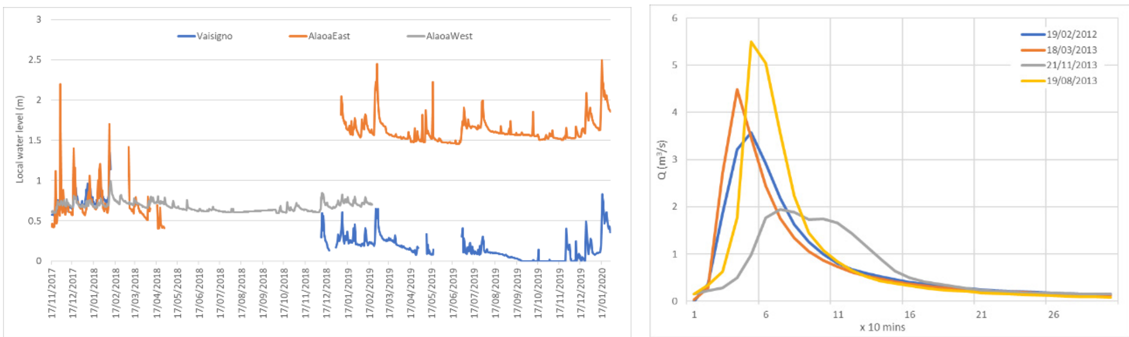

Figure 2 Vaisigano river water level data for three stations on the Vaisigano, and 10-minute unit hydrographs derived for Alaoa East gauging station.

Results

The model was highy depenent on rainfall and stream flow data used to derive the unit hydrographs for specific locations. However the model performance could be improved by varying the rainfall loss factor relative to antecedant moisture or time of year.

The model was subsequently used in comination with observed rainfall and streamflow data to provide better flood warning in the Vaisigano catchment but will be revised at regular intervals as new rainfall and streamflow data becoem available.

MEASURING THE CONTRIBUTION OF BANK EROSION TO A SUSPENDED SEDIMENT BUDGET

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Aims

Catchment-scale sediment budgets are useful tools to capture the relationships between sediment sources, transport pathways, sediment storage and catchment sediment yields (Wilkinson et al. 2009). Sediment budgets, however, need to be used carefully since they include high uncertainties (Parsons 2012), notably associated with determining the net sediment supply from river bank erosion and bank deposition. Moreover, while budgets may consider the sediment contributions from visibly eroding banks, diffuse drapes of sediment on banks and point bars are often ignored, giving an apparent overestimation of net riparian sediment contributions. The aim of this study is to combine repeat LiDAR-based surveys of channel banks with high frequency flow and suspended sediment concentration data to fully quantify the suspended sediment budget of a river reach, thereby resolving the true influence of eroding banks on catchment sediment delivery.

Method

Two monitoring sites (Wallacetown and Taramoa) were established in the lower reach of the Ōreti River, located in Southland, New Zealand, bounding a 5.8 km-long single-thread meandering channel that is shaped by severe bank erosion. Continuous records of flow and cross-section-averaged suspended sediment concentration (SSC) at each site determined the gain or loss in suspended sediment load within the intervening reach over the epochs between bank surveys.

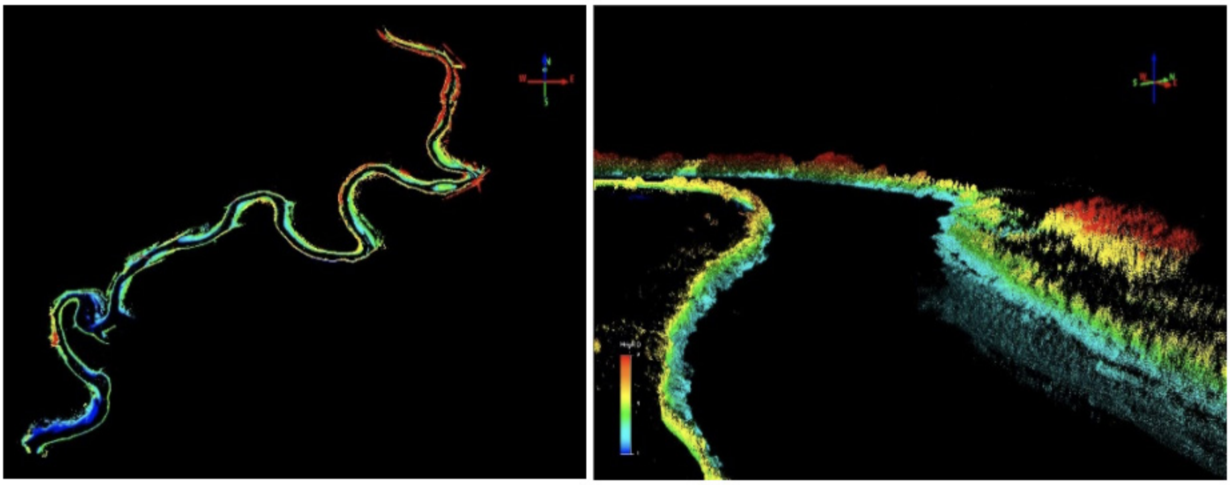

Figure 1. Pointcloud map from the baseline survey of the bank erosion study reach in the Oreti River (left), with a detailed map for a meandering bend (right). The point elevations are colore coded with red the highest and dark blue the lowest elevations.

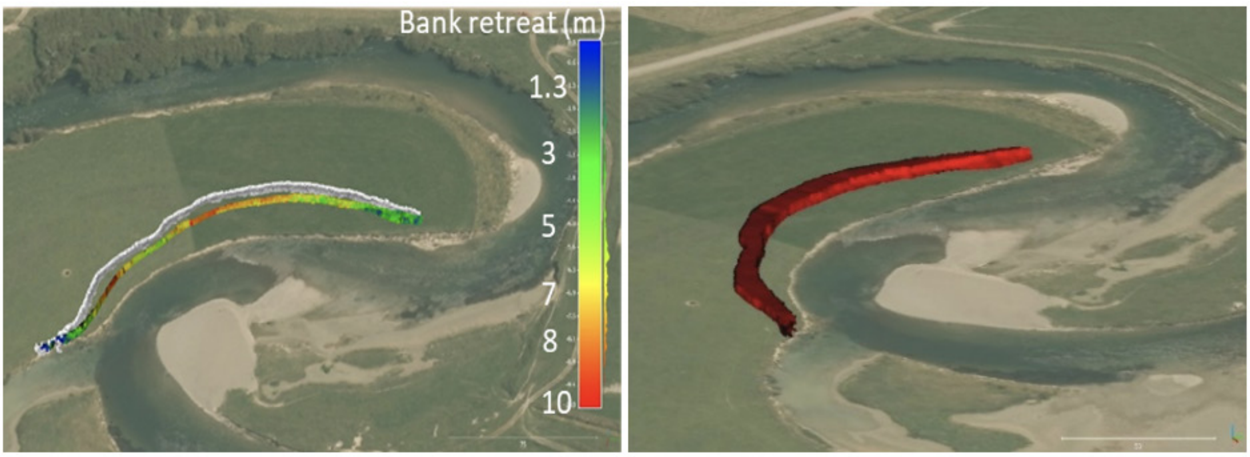

Figure 2. Bank retreat (left) and bank erosion volume (right) between second and third surveys for a meandering sub-reach. Base image was taken in 2014. Band positions in 2017 and 2020 added to the base map.

The banks along the study reach were surveyed using a jetboat-mounted mobile LiDAR scanner, with point-cloud differencing used to calculate volumetric changes of the river banks between repeat surveys. While the LiDAR did not penetrate water, scanning from a vessel within the channel at baseflow allowed capture of most of the bank profile, and inherently contains information of the bank height. A Trimble R10 Real-time kinematic (RTK) GPS was deployed in the study reach to record positional corrections required for post-processing. Three bank scans were conducted along the study reach. The first two were completed within eight weeks between 17 June 2017 and 11 August 2017, while a third scan was conducted 2.5 years later on 14 February 2020. Two small flood events , with peak flows of 132 m3 s-1 and 231 m3 s-1, occured between the first two surveys, whereas 57 flood events of various sizes were recorded within the 2.5 years between the second and third surveys. The third survey was conducted immediately after one of the largest recorded flood events in the Ōreti River, with a peak flow of 1070 m3 s-1. Proper alignment of the LiDAR pointclouds (Fig 1) was checked by comparing the scans against RTK GPS points. The volumetric change between surveys, caused by bank erosion, was calculated using the multiscale model-to-model cloud comparison M3C2 (Lague et al. 2013) plugin in the CloudCompare (2020) software (Fig 2).

To calculate the fine (suspended) sediment content of the eroded bank material, the stratigraphy of the eroding banks was surveyed and sampled for size grade analysis at 13 locations on both the left and right banks within the study reach. The bulk density of the fine sediment component was estimated at 1.9 t m-3 in order to convert the volumetric erosion to a mass supply of fine sediment.

Results

Analysis of the first and second LiDAR survey data showed that the bank retreat averaged 0.5 m along the study reach (combining retreat from both right and left banks), with a maximum retreat of 5 m in one meander bend (Fig 3, left). The bank retreat between the second and third surveys (Fig 3, right) ranged between 0 m to 29.9 m, with an average retreat of 5.3 m (combining values from both left and right bank sides, Fig 3).

Comparing the suspended sediment loads at two enclosing monitoring sites showed that an extra 1704 t of suspended sediment was transported out of the reach between the first and second surveys, while preliminary analysis of bank volume changes using LiDAR data showed approximately 2700 t of fine sediment were eroded from the river banks. The difference suggests about 1000 t of fine sediment must have been deposited within the reach as diffuse sediment drapes including near-bank depositions. During the 2.5-year period between second and third LiDAR surveys, 75991 t of suspended sediment were gained by comparing the load from the two monitoring sites, with bank volume analysis for this period is currently being processed to allow quantifying riparian deposition.

While analysis of the results remain preliminary, awaiting an assessment of final volumes and associated errors in the budget components, it nonetheless shows the value of closing the sediment budget on an actively eroding reach by combining bank surveying and sediment load monitoring. In particular it shows that the net riparian sediment contribution from an apparently severely eroding reach can be muted by diffuse desposition that is hard to measure and quickly hidden by vegetation growth. The study thus provide a unique contribution to suspended sediment dynamics science and has implications for managing river catchment sediment delivery, for example as now required in New Zealand, under the National Policy Statement for Freshwater Management (NPS-FM 2020).

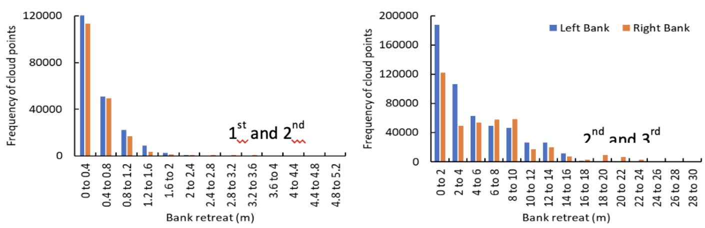

Figure 3. Frequency of bank retreatment between baseline and first, and second and third surveys.

Reference

CloudCompare (2020) (version 2.11.3) [GPL software]. (2020). Retrieved from http://www.cloudcompare.org.

Lague D, Brodu N, Leroux J (2013) Accurate 3D comparison of complex topography with terrestrial laser scanner: Application to the Rangitikei canyon (N-Z). ISPRS Journal of Photogrammetry and Remote Sensing 82:10-26. https://doi.org/https://doi.org/10.1016/j.isprsjprs.2013.04.009

NPS-FM (2020) National Policy Statement for Freshwater Management 2020, New Zealand Government August 2020.

Parsons AJ (2012) How useful are catchment sediment budgets? Progress in Physical Geography: Earth and Environment 36:60-71. https://doi.org/10.1177/0309133311424591

Wilkinson SN, Prosser IP, Rustomji P, Read AM (2009) Modelling and testing spatially distributed sediment budgets to relate erosion processes to sediment yields. Environ Model Softw 24:489-501. https://doi.org/https://doi.org/10.1016/j.envsoft.2008.09.006

REDOX CONSIDERATION IN WAIKATO GROUNDWATER MONITORING

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Redox conditions are fundamentally important in influencing groundwater chemistry and notably the most ubiquitous and topical issue of nitrate contamination. Natural denitrification processes result in nitrate essentially not occurring in anaerobic environments (Korom, 1992). Redox conditions are therefore an important consideration in state of environment (SOE) design, monitoring and reporting. Changes in redox condition may not, however, be evident without specific investigation but may nevertheless influence groundwater monitoring variably throughout the country.

Recent work in the Waikato, including the re-drilling of 18 shallow SOE wells by coring, further demonstrated the importance of understanding the hydrogeological and notably redox conditions. Despite these wells being shallow (<10 m), four encountered previously unknown redoxclines.

Considerable work has been undertaken throughout the Waikato, and notably the Lake Taupo catchment, to investigate the redox distribution and factors influencing it. This has included the use of the Childs' test (Childs, 1981) on cored formation; tracer testing (including push-pull, and in-situ mesocosms) and investigation of vertical redox gradients (Stenger et al., 2018) to understand the processes involved. This work suggests controls may include the occurrence of paleosols and peat layers, but these may not be directly evident at the site.

The redox status of groundwater can be inferred from selected determinands such as dissolved oxygen, nitrate, ammonia and dissolved iron and manganese. The general approach of McMahon and Chappelle (2008) has been used in the Waikato to group monitoring wells into four redox related categories being aerobic, anaerobic, mixed and indeterminate. There are two networks monitored by Waikato Regional Council being an SOE network of 110 wells monitored annually (with a subset of 30 monitored quarterly) and a network of 80 community supplies (rural schools) monitored every two years.

Anaerobic groundwater is more commonly found in the Community network (~24 %) than the SOE network (~4.5 %). As a corollary, SOE network wells are more frequently aerobic (~57 %) compared to the Community network (35 %). Nitrate concentrations are also generally lower in the Community wells than in the SOE network with medians of 0.91 mg l^{-1} and 3.6 mg l^{-1} respectively. Higher nitrate concentrations are more prevalent in shallower wells where aerobic conditions are more likely. It is noted that median depths of the regional and community supply networks are 16 m and 36 m respectively. Such differences highlight the need for explicit consideration of important factors such as redox condition in monitoring network design. Other influences on nitrate occurrence include land-use loading and lag times.

Spatial predictive mapping of redox conditions was undertaken for the Waikato region based on a similar approach with respect to categories and related to formation characteristics using linear discriminant analysis (Close, 2015). Reducing conditions are predicted to dominate in the low lying poorly drained areas of the lower Waikato basins and Waipa catchment. Aerobic conditions, by contrast, are indicated to be more common in elevated terrain, particularly of the Upper Waikato. Reducing conditions are more likely to occur with depth in the Hamilton Basin and with distance northward along the Hauraki Plains.

National scale mapping of predicted redox categories using statistical learning methods has been carried out by Wilson et al., (2020). This work shows that anaerobic conditions are common in the coastal and lowland plains of New Zealand where artificial drainage is common. Also, the spatial extent of reduced groundwater increases with depth.

More specific investigation of redox distribution throughout the country may substantiate more widespread occurrence of anaerobic conditions where they are not readily predicted by hydrogeologic factors. This could improve the understanding of land-use loading effects.

References

Childs, C.W., 1981. *Field Tests for Ferrous Iron and Ferric-organic Complexes (on Exchange Sites or in Water-soluble Forms) in Soils.* Aust. J Soil Res (19) 175-180.

Close M, 2015. Prediction of Subsurface Redox Status for Waikato Healthy Rivers - Plan for Change: Wai ora He Rautaki Whakapaipai. Environmental Science Research client report CSC 15010 for Waikato Regional Council. 21pp.

Korom, S. F. 1992: Natural denitrification in the saturated zone: *A review, Water Resources*. Res., 28, 1657–1668

Stenger, R., Clague, J.C., Morgenstern, U., Clough, T.J., 2018: Vertical stratification of redox conditions, denitrification and recharge in shallow groundwater on a volcanic hillslope containing relict organic matter. Science of the Total Environment, Vol. 639, 1205-1219.

Wilson, S.R., Close, M.E., Abraham, P., Sarris, T.S., Banasiak, L., Hadfield, J.C., 2020: Achieving unbiased predictions of national-scale groundwater redox conditions via data oversampling and statistical learning *Journal of the Total Environment vol. 705* (2020)135877.

GEOSTATISTICAL INFORMED MICROBIAL PROTECTION ZONES (GIMPZ) FOR CANTERBURY GROUNDWATER

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Aims

The importance of microbial risk management at source for drinking water supply protection is becoming more widely recognised through national regulations such as the Water Services Bill 2020 and through implementation of regional plan rules. Determination of the areas of land and the land use activities that pose a potential water supply well microbial contamination risk is challenging, however. The purpose of this pilot project was to explore the suitability of the provisional protection zones defined in the Canterbury Land and Water Regional Plan (LWRP) and the practicality of using geostatistical modelling methods to improve knowledge and management of microbial contamination risks to community drinking water supplies. We identified two main questions for our research accordingly:

1. Are land use activities outside of a provisional protection zones likely to cause microbial contamination of the well?
2. Can geostatistical modelling be used to significantly reduce likelihood of Type I and II statistical errors?

Our pilot study area comprises three Waimakariri District Council community water supply wells of varying depths.

Method

The main components of our methodology can be summarised as follows:

1. Define a model domain for each of the three wells and extract groundwater level and hydraulic conductivity data from the previously developed Waimakariri Zone numerical groundwater model (Etheridge and Hanson, 2019) for each domain.
2. Process well log data for the study area using a categorisation scheme which simplifies the lithology into description-based inferences of low, medium and high hydraulic conductivity classes.
3. Evaluate the spatial continuity of each hydrogeological category through variography.
4. Generate multiple 3-D geostatistical realisations of the hydrogeological categories within each model domain via two interpolation methods: Sequential Indicator Simulations and Multiple Point Statistics.
5. Evaluate the results of the geostatistical and select preferred method (MPS)
6. Construct a Modflow model for each domain and import the geostatistical realisation data, head data and boundary condition data (head boundaries, drains, pumping wells and recharge).
7. Assign hydraulic conductivity values such that aggregate model domain transmissivity aligns with the Waimakariri Zone numerical model transmissivity with variability between the hydrogeological category lateral and vertical conductivity values assigned via a set of ratios (e.g. Category 1 lateral conductivity = 10 x Category 2 value). Compare the aggregate vertical hydraulic implemented via this method to leaky aquifer pumping tests analysis-based vales.
8. Run Modpath simulations to simulate groundwater transport pathways.
9. Use E. coli sampling results for wells screened close to the water table across the whole region as a proxy for microbial concentrations at the water table.
10. Develop tool to calculate microbial removal via empirically-based first order pathogen removal and inactivation rates along the Modpath-derived flow paths.
11. Assign empirically-based pathogen removal rates to each modelled particle flow path
12. Utilise pore water velocity data derived from previous field studies to model transport velocities in combination with empirical microbial inactivation rates.
13. Develop a conservative tracer source zone (i.e., no microbial removal and no microbial inactivation).
14. Develop a source zone assuming that all flow occurs though open framework gravels.

15. Develop a source zone assuming that a specified percentage of the travel in each geological unit occurs through the matrix; and therefore, has a higher removal and lower particle velocities.

16. Compare the results from steps 13, 14 and 15 to the LWRP provisional source protection zones

Results

Regarding Question 1 (see aims), even the protection zones modelled with the greatest microbial removal showed some areas outside of the provisional protection zones potentially contributing microbial contaminants to the well. There was relatively low model agreement around these areas, however. We therefore concluded that although some of the land outside of a provisional protection zone could potentially contribute microbial contaminants to a well, the likelihood of this is currently unclear. In addition, more wells would need to be studied before any wide-ranging conclusions about the provisional protection zones are reached. We therefore consider that it would be prudent to further investigate the suitability of the provisional source protection zones.

Although Question 2 (see aims) is more difficult to address, but we believe that a geostatistics-based approach provides several advantages over the provisional source protection zones method:

- It provides a site-specific source protection zone that includes all known geological information about the area and is less likely to have an unexpected Type II error than the current provisional source protection zones.
- The user can tailor the protection zone to align with risk management objectives via parameterisation and the interpretation. This allows a protection zone to be developed in conjunction with other features such as the size and demographics of the population served, and the type and quality of water treatment. As an example, a bore that serves very few people and has a high degree of treatment may benefit from a reduced protection zone (less conservative parameterisation) than a bore that serves a larger population and is untreated.
- The user can also tailor the protection zone based on the number of models which agree on an area occurring in a protection zone (again in combination with other factors).
- The user can create a number of risk-based zones for each well, where higher risk zones have more stringent land use management, while lower risk zones have less stringent regulations. This would allow a source protection regime to be developed based on cost/benefit analysis of microbial management at source versus management at the point of supply (i.e. treatment).
- The methodology can be scaled efficiently. Although some analysis is necessary for each site, many elements of the analysis can be partially automated, and others can apply to multiple sites.

Our methodology also has a number of disadvantages and limitations. Some key limitations include use of E. coli as a proxy for viral loading rates, our simplistic treatment of pore water velocities and exclusion of age tracer data from the analysis. We believe it is possible to address many of these limitations and that, overall, the method has the potential to support significant improvements in source water risk management within the Canterbury region and more broadly.

References

Etheridge, Z. and Hanson, M. 2019. Waimakariri Land and Water Solutions Programme; Numerical Groundwater Model Conceptualisation, Design, Development and Deployment. *Environment Canterbury Report No R19/XX*

IN SEARCH OF A SOLUTION – LOOKING FOR WATER WHEN THE OBVIOUS ISN'T POSSIBLE

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[1] Aqualinc Research Limited

As with many district councils in New Zealand, Queenstown Lakes have the issue of an ever expanding population and increasing demand for drinking water. Finding reliable drinking water supplies in and around the Central Otago lakes (Queenstown and Wanaka) would be assumed to be easy, as you would with endless supply water through relatively high rainfall and the regions lakes and rivers. However, during periods of heavy rainfall, the sediment load in the lakes and rivers increases to the point that high levels of treatment are required.

One option for obtaining drinking water is the use of bores drilled adjacent to lakes and rivers in order to extract surface water which has undergone bed or bank filtration and therefore the issue of sediment load in the lakes and rivers is reduced or even eliminated.

Aqualinc have been working with Queenstown Lakes District Council in an attempt to identify suitable locations for bores, in order to supply water to various townships in the region including Wanaka, Queenstown, Albert Town and Luggate. The process has met with varying levels of success, with some sites surprisingly failing, including sites immediately adjacent to Lake Wanaka.

However, in Luggate the process has been successful. Exploration drilling and installation of monitoring piezometers identified water-bearing river bed gravels adjacent to the Clutha River on a low river terrace. Testing of water quality from samples obtained from the piezometers suggested that the water was of suitable quality for human consumption and the characteristics of the sediments suggested that suitable yields were possible from the gravels. The decision was made to complete drilling of 3 production bores in order to further assess the suitability of the sediments, and this drilling took place in the autumn of 2021.

Aquifer testing and water quality sampling of the new Luggate production bores suggest that the source of water is the Clutha River, the combined yields of the bores are able to provide over and above the current and future requirements for the township and the water is of drinking water quality.

This paper will describe some of the highs and lows of investigations for water sources, and some of the unexpected results obtained.

Figure 1: Preparing casing and screens prior to installation

EFFECTS OF SALTWATER INTRUSION ON MICROBIAL COMMUNITIES

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[1] GNS Science

Aims

Groundwater in many areas is under threat from saltwater intrusion caused by sea level rise or increasing abstraction (Moore and Joye, 2021). Guidelines exist for safe limits of chloride in water used for drinking, irrigation or watering livestock (Ministry of Health, 2018, Marlborough District Council, 2011, Government of Western Australia, 2021). However, safe limits for the health of an entire ecosystem have not been determined (Tornabene et al., 2020, Venâncio et al., 2019).

This study aimed to investigate the potential effects of saltwater intrusion on groundwater microbial communities carrying out essential ecosystem services such as cycling nitrogen, carbon and iron.

Methods

Groundwater samples were filtered through a 0.1 µm filter which was then placed in a growth medium designed to support denitrification. The headspaces were adjusted to match those of the sample *in situ* and cultures were incubated at 16 °C with shaking at 150 r.p.m. Stable mixed communities were then used to inoculate triplicate tubes of the same medium with either no, low, medium or high levels of chloride. The effects of chloride were monitored over time via:

- Measurement of optical density of cultures at 600 nm (OD_{600});
- DNA sequencing of the 16S rRNA gene (marker gene);
- Quantification (qPCR) of the ***nosZ*** gene (specific for the final stage of denitrification).

Results

Each groundwater sample responded to increasing chloride concentrations slightly differently, depending on the microbial community present within the sample. Some microbial communities showed declines in growth only in response to high concentrations, while other samples had significant increases in growth as chloride concentrations increased (Figure 1).

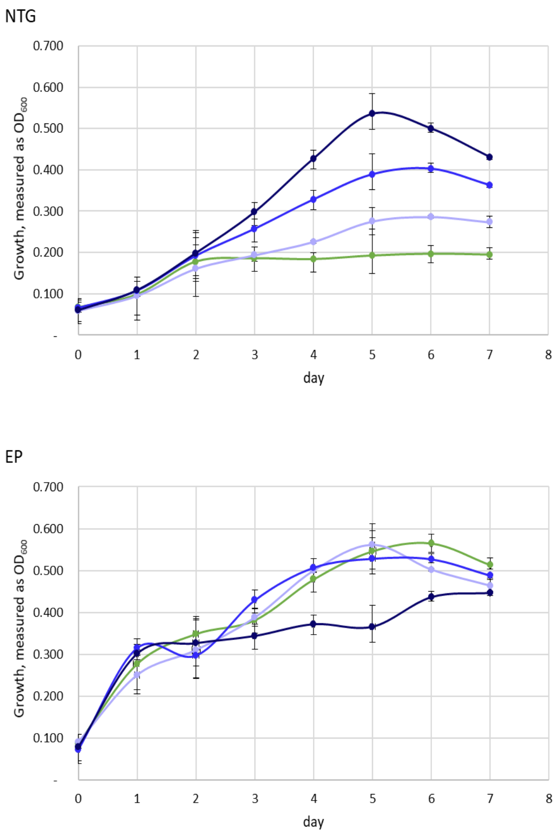

Figure 1: Growth of microbial cultures from two groundwater samples with varying chloride concentrations. Green line, control (0 mg/l-1 Cl-); light blue line, low (250 mg/l-1 Cl-); mid blue line, medium (700 mg/l-1 Cl-); dark blue line, high (2000 mg/l-1 Cl-).

DNA sequencing of marker genes allowed identification of the microbial community members and inferences of their ecological roles within groundwater. This showed that microbes involved in denitrification (reducing nitrate to dinitrogen gas) such as *Albidiferax* and *Rhodanobacter* were often adversely affected by the increase in chloride (Figure 2). However, generalist bacteria such as *Brevundimonas*, which use sugars and peptides for energy, often increased in abundance under high chloride conditions.

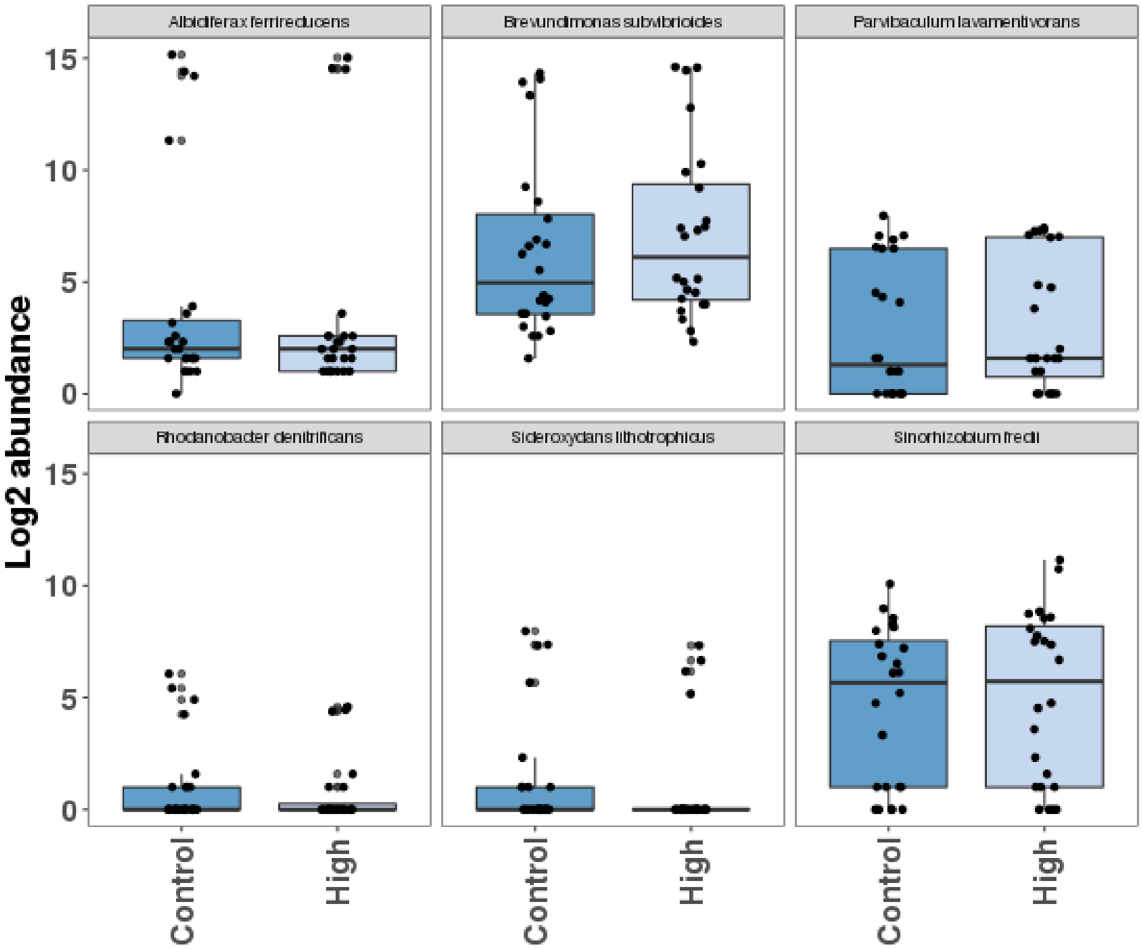

Figure 2: Boxplots of selected species which showed substantial differences between control and high chloride conditions. Abundance is total number of reads from all samples.

Quantification of the *nosZ* gene over time also showed the detrimental effects of high chloride concentrations on the denitrification process.

Analysing microbial community composition is important when predicting the effects of saltwater intrusion on ecosystem functions, and determining which groundwater systems need to be protected from sea level rise or increased abstraction.

References

Government of Western Australia. 2021. Water Quality for Livestock [Online]. Department of Primary Industries and Regional Development. Available: https://www.agric.wa.gov.au/livestock-biosecurity/water-quality-livestock [Accessed 16/10/2020].

Marlborough District Council 2011. Wairau/Awatere Resource Management Plan. Blenheim, New Zealand.

Ministry of Health 2018. Drinking-Water Standards for New Zealand 2005 (Revised 2018). Wellington, New Zealand.: Ministry of Health.

Moore, W. S. & Joye, S. B. 2021. Saltwater Intrusion and Submarine Groundwater Discharge: Acceleration of Biogeochemical Reactions in Changing Coastal Aquifers. Frontiers in Earth Science, 9.

Tornabene, B. J., Breuner, C. W. & Hossack, B. R. 2020. Relative Toxicity And Sublethal Effects Of Nacl And Energy-Related Saline Wastewaters On Prairie Amphibians. Aquatic Toxicology, 228.

Venâncio, C., Castro, B. B., Ribeiro, R., Antunes, S. C., Abrantes, N., Soares, A. M. V. M. & Lopes, I. 2019. Sensitivity Of Freshwater Species Under Single And Multigenerational Exposure To Seawater Intrusion. Philosophical Transactions Of The Royal Society B: Biological Sciences, 374.

CENTRAL HAWKE'S BAY MAR PILOT PROJECT – GEO-SPATIAL TECHNICAL ASSESSMENT FOR SITE SUITABILITY.

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Aims

The Hawkes Bay Regional Council (HBRC) commissioned Wallbridge Gilbert Aztec (WGA) to conduct a stepwise feasibility assessment of the use of Managed Aquifer Recharge (MAR) as a tool to support water resources management in the Central Hawke's Bay (CHB) area. An initial step to assess the relative suitability of areas for MAR consisted of a geo-spatial technical assessment to identify areas with the most suitable conditions for a MAR trial.

For the purposes of the initial assessment, two general MAR techniques have been considered:

- Infiltration – which uses surface structures (basins, pits, wetlands) to recharge water into an underlying shallow unconfined aquifer.
- Injection – which uses a purpose-built bore to recharge water into deeper strata within the aquifer system, which can be semi-confined to confined, and potentially recover some of that water at a later date.

The objective of the geo-spatial assessment was to identify between eight and ten areas to be prioritised for further detailed assessment. This prioritisation did not imply that other areas were unsuitable for MAR but rather that the objectives of the MAR trial could be most effectively achieved in these areas.

Method

To assess the physical settings WGA has:

- Acquired topographic, hydrological, hydrogeological, ecological and water abstraction information, collated this information in a project GIS database.
- Integrated selected datasets from the GIS database to assess the relative suitability of areas within the CHB for MAR operations.

The prioritisation of a MAR trial site had to address recharge objectives for both the shallow and deeper groundwater systems. Consequently, the initial geo-spatial assessment followed parallel paths for these two aquifer systems (Figure 1), leading to preferred areas based on hydrogeological factors. Once these hydrogeological preferred areas had been identified, the potential for the delivery of source water at an appropriate volume and quality was spatially assessed. Incorporation of these factors into the site prioritisation process led to an overall assessment of areas suitable for the establishment of a trial integrated recharge system. These preferred areas were then reviewed against community, cultural and environmental limitations (step 4 of Figure 1).

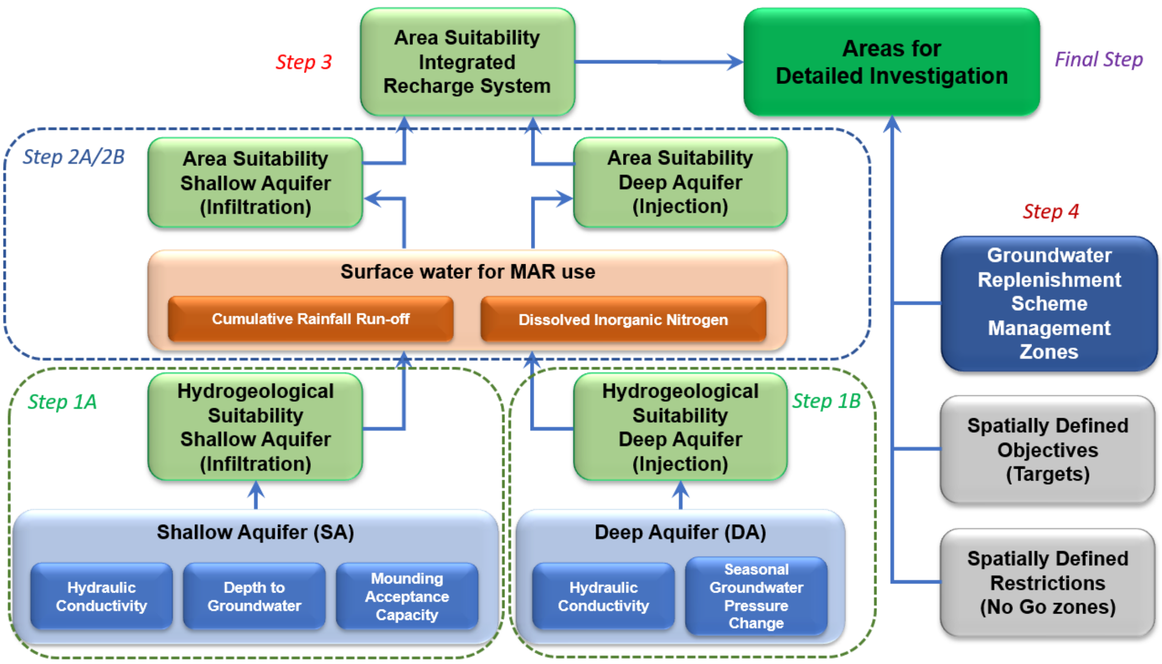

Figure 1: Site suitability assessment flow chart.

Results

A total of nine preferred sites have been mapped as on overlay layer on the GIS database. The sites have been divided into Priority 1 (five sites) and Priority 2 (4 sites) areas. Although this has been done with a view to initially prioritising areas most suitable for the development of MAR trials, the outcomes are equally useful for planning the design of a Groundwater Replenishment Scheme (GRS) for the CHB.

References

WGA. 2021. Central Hawke's Bay MAR Pilot Project – Stage 1 Site Selection Summary. Technical Assessment. WGA200502-HG-RP-0004.

https://wgaz.maps.arcgis.com/apps/webappviewer/index.html?id=94b9ff77f23645b49265d14c99dbecbd

EFFECTS OF FLOOD HARVESTING ON FINE SEDIMENT DEPOSITION IN BRAIDED RIVERS

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Aims

The alp-fed braided rivers of Canterbury are under threat from land-use intensification and a growing demand for irrigation water. With river baseflow and groundwater resources fully allocated (and controlled by minimum flow rules) in most catchments, the only remaining available water is that which gushes to the sea during floods and freshes – thus floodwater "harvesting" into large off-river storage ponds, for regulated release into irrigation networks, is an expanding activity.

Anecdotal evidence suggests that flood harvesting can cause deposition of fine sediment downstream of water diversions in large braided rivers. This is consistent with field data and laboratory experiments for small streams (Parker et al. 2003), but little evidence exists for large braided rivers.

We use the Rangitata River as a case study to investigate fine sediment deposition in braided rivers.

Method

We collected suspended sediment and bed substrate data in the braided, gravel-bed, Rangitata River, to investigate the effects of flood harvesting on fine sediment deposition.

Suspended sediment gaugings were conducted at Environment Canterbury's Rangitata at Klondyke flow recorder. We measured cross-section average sediment concentration and grain size distribution at a range of flows.

Surveys of surface grain size distribution were made in two reaches of the Rangitata in April/May 2001 (Hudson, 2001) as part of a habitat suitability modelling study (Duncan & Hicks, 2001). In this study we use data from the downstream reach and compare it with new data collected in the same reach. We carried out repeat surveys in 2019 and 2020, using a sampling methodology based on the original surveys.

Results

We present a conceptual model for how flood harvesting reduces the transport capacity of the larger grain size fractions of suspended load (i.e. sands). Applying this model to the Rangitata River suspended sediment concentration data allowed us to quantify potential deposition of sand. We found that, for the case of the Rangitata, reducing transport capacity due to water harvesting has the potential to cause approximately 1/3rd of the suspended sand load to be deposited. We also found that the change in transport capacity is likely to be much more significant than sand trap flushing as a cause of fine sediment deposition.

Data from the braided Ealing reach of the Rangitata shows increased presence of fine sediment drapes over the cobbly substrate in recent surveys compared to 2001. The median grain size of the substrate has also reduced. Most fines present on the bed surface were fine sands rather than silts, supporting the conceptual model that reduction in transport capacity causes deposition.

Variations in fine sediment cover between the 2019 and 2020 surveys suggest that flood sequencing may exert a strong influence on the presence of fines on the bed surface. We hypothesise that large floods may reset the riverbed to a state less influenced by flood harvesting, but this remains uncertain.

References

Duncan, M., Hicks, D. M. 2001. 2D habitat modelling for the Rangitata River. NIWA Client Report:CHC01/72.

Hudson, H. R. (2001). Rangitata River Substrate for 2-D Habitat Simulation. EMA Report to RDR Management Ltd.

Parker, G., Toro-Escobar, C. M., Ramey, M., & Beck, S. 2003. Effect of floodwater extraction on mountain stream morphology. Journal of Hydraulic Engineering, 129(11), 885–895. https://doi.org/10.1061/(ASCE)0733-9429(2003)129:11(885)

ON-SITE WASTEWATER MANAGEMENT SYSTEMS: IMPLICATIONS FOR GROUNDWATER QUALITY

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[2] Environment Canterbury
[3] Waimakariri District Council
[4] Northcott Research Consultants Ltd

Municipal wastewater treatment plants service nearly 75% of New Zealand's current population with the remaining population (>1 million) relying on on-site wastewater management systems (OWMS) (GHD, 2021). This number increases throughout the year when those who typically dwell in reticulated wastewater urban areas visit peri-urban, rural or sensitive environments (e.g. holiday hotspots and national parks) where on-site wastewater systems are the only available treatment system. In New Zealand on-site wastewater systems range from servicing a single dwelling (e.g. rural home or holiday house) to a rural school or marae with systems that can service several hundred people and experience the stress of high, variable and seasonal loads. Inadequate treatment, inappropriate land application systems, aging, poorly serviced and unmaintained systems, can result in a risk to environmental and public health. On-site wastewater systems are often located within our shallow groundwater systems in which nearby shallow wells are utilised for drinking water.

Aims

The aim of this study is to instrument a domestic on-site wastewater system in Canterbury to explore:

- the chemical and microbiological risks to the post land application system (LAS) discharge receiving environment, in particular groundwater quality.
- the arbitrary 50-meter setback distance 'rule' that councils often apply to on-site wastewater systems and down gradient drinking water wells.

Methods

We are employing hydrogeophysical methods to map discharges from the on-site wastewater land application system through the subsurface, and determining residence times in the unsaturated zone, where most pathogen removal is assumed to occur (Figure 1). These methods include:

- in-situ effluent samplers within the effluent LAS
- x5 down gradient multi-level groundwater monitoring wells
- tracer experiments using bacteria and bacteriophage (as a surrogate of viruses) alongside a conservative chemical tracer
- time-domain Electrical Resistivity Tomography (ERT) methods to track the development of an effluent plume from the effluent LAS within the vadose and saturated zone.

Results

The alluvial outwash gravels at the study site, which are typical of the low-lying surficial geology of much of the South Island, rank lowly in their efficacy for pathogen removal. Preliminary results suggest that the alluvial substrate at the site contains rapid infiltration and tends to be poor at attenuating nitrate pollution. Conservative preliminary estimates of the groundwater flow velocity at the site range from between 8 – 12 meters per day. Collection and analysis of the field data is ongoing. Further results will be presented at the conference.

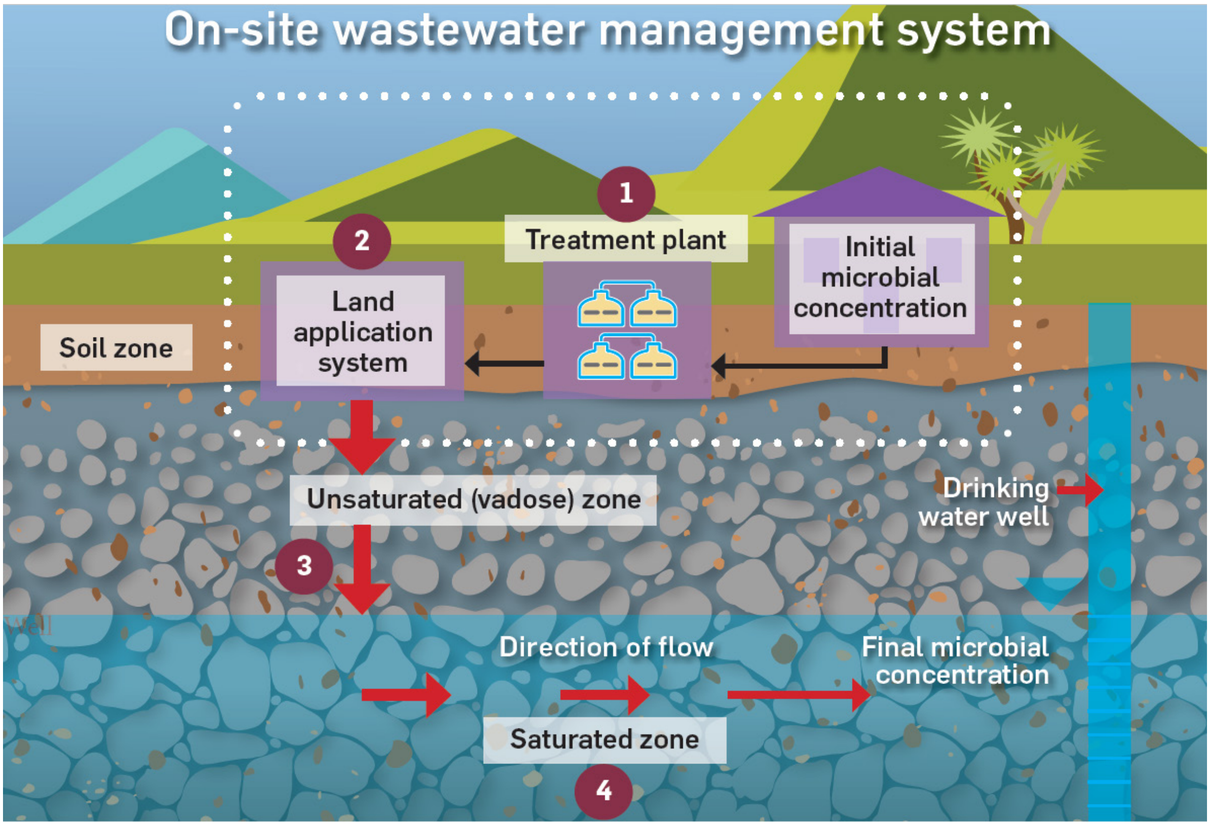

Figure 1: Opportunities for microbial removal within an on-site wastewater management system and the receiving environment: 1) the OWMS treatment plant, 2) land application system, 3) vadose zone and 4) saturated zone.

References

GHD. 2021. Department of Internal Affairs – Three Waters Review - Cost Estimates for upgrading Wastewater Treatment Plants to meet Objectives of the NPS Freshwater, Final Report. August 2021. Boffa Miskell, GHD.

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AN INNOVATIVE, CLOUD-BASED, HYDRONET FLOOD WATER CONTROL ROOM FOR MELBOURNE WATER

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[1] Water Technology
[2] Melbourne Water, Gate

Aims

Melbourne Water (MW) have extensive monitoring equipment and data management systems to assist them to play a leading role in supporting them and their partners to prepare for, respond to, and recover from potential flooding events and other urban drainage related management responsibilities across the region. However, that data is located at various disparate internal and external data sources only accessible to technical experts, leading to workarounds and delays in providing the personalised information required by staff, management and partner organisations (Metro Councils and VicSES) for effective and coordinated decision making around events. MW thus sought to improve this information provision by implementing the HydroNET Water Control Room (WCR), enabling easy access and use of the disparate data to generate personalised dashboards, forecasts, alerts, notifications and reports on-the-fly without burdening the data source and system administrators and without the need to implement a new data warehouse.

Method

The implementation of the HydroNET WCR was conducted using an Agile approach over four phases. The project commenced with an initial functional design phase to formulate the various HydroNET dashboards required. Secure, real-time connections to the required disparate hydrological and meteorological databases where then configured in a second phase.

Digital Delta Approach:

The HydroNET WCR methodology is known as the Digital Delta approach, where all services are delivered directly from the disparate data centres, over the internet, removing the need to duplicate data and circumventing any versioning issues while ensuring that the user is seeing the latest master data available. A further benefit is provided by the HydroNET WCR architecture, which uses a HydroNET server hosted in the cloud to do the intensive data processing required to support the various tools, and the HydroNET Portal to provide the individual users with the tools they need to visualise the information in the customised way they require.

Data Connections:

The HN WCR was initially connected to the MW Flood Information Decision Support System (FIDSS) providing MW users access to MW's rain gauge, river level gauge, tidal gauge, water quality gauge and drainage basin gauge network data. The Bureau of Meteorology (BoM) weather data FTP connection was also configured to provide BoM weather data, including their new Rainfields 3 high resolution, bias adjusted radar rainfall data and radar based high resolution, short term rainfall forecasts up to two hours ahead (known colloquially as NowCast). HydroNET also set up a further process to adjust the BoM radar rainfall data against the MW rain gauges to provide MW with a radar rainfall product with improved calibration against rain gauges.

In the 3rd phase, the HydroNET WCR tools were made available as an added value service to translate the archived and operational weather and water data into valuable tools, applications, personalised dashboards and reports. These were then used to set up initial benchmarking dashboards in support of an extensive Site Acceptance Testing (SAT) process that followed over a period of 12 weeks. This was guided by a SAT document and included an extensive issue identification and resolution logging process.

Once the SAT and benchmarking was approved, the final 4th phase - currently in progress - commenced. This is an initial 1-year trial subscription to the HydroNET software as a service (SaaS) system with included helpdesk, support and maintenance. The system will continue to be tested and

improved during this trial. All four phases and the associated data connections and HydroNET tools are summarised in figure.

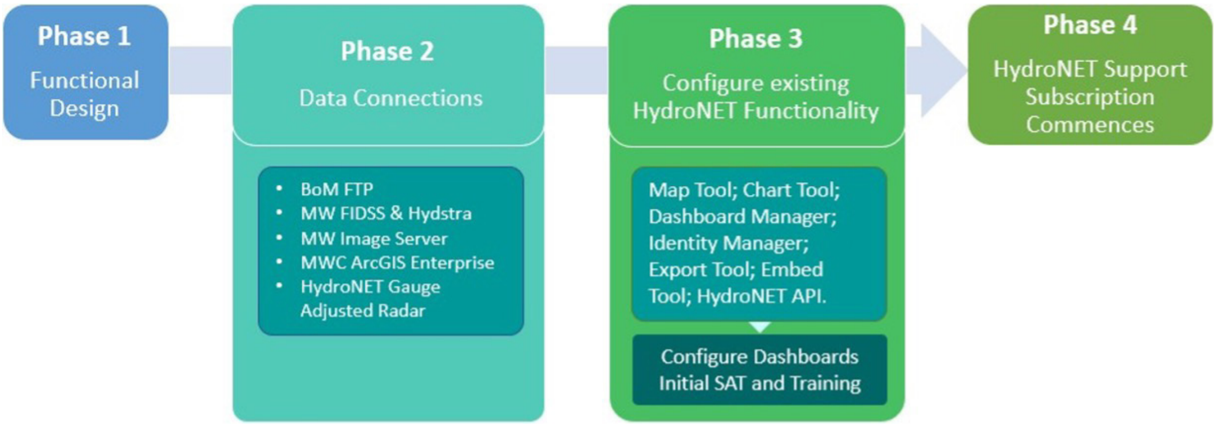

Figure 1. Trial HydroNET WCR phased implementation process.

Results

HydroNET now provides MW with simple, robust tools for accessing and sharing the live information required for various needs before, during and after events, based on the same underlying data. This greatly improves joint decision making. Staff now have numerous dashboards that can be configured in various ways by themselves without the need to request database administrators or programmers to do it for them. An example is shown in figure 2 below.

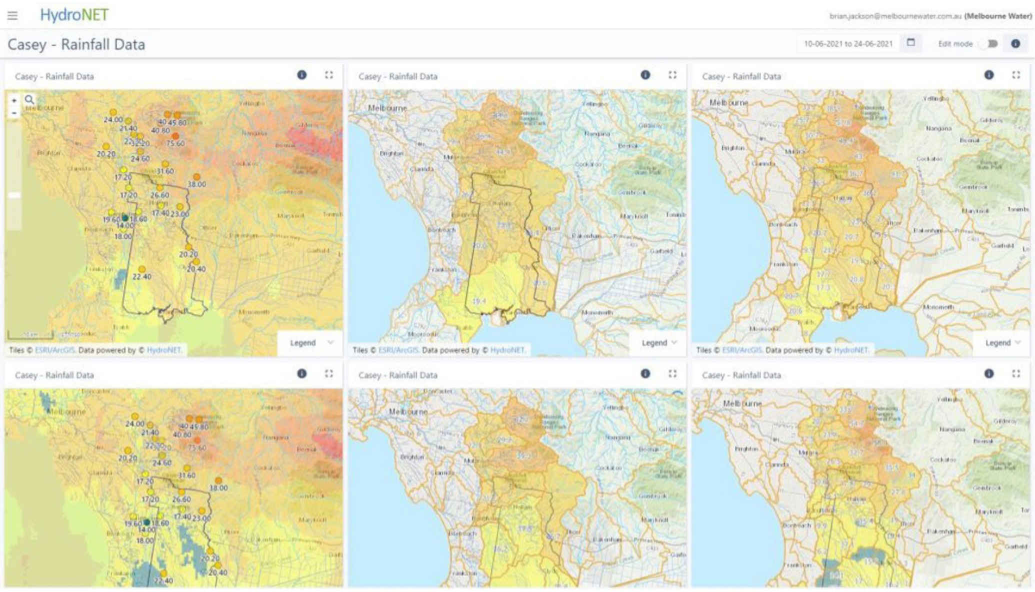

Figure 2. Rain Gauge and Radar rainfall data from the BoM, MW FIDSS and HydroNET data sources all visualised in HydroNET in various ways, including catchment aggregated rainfall calculated on-the-fly.

Highlights Include:

- Improved information sharing for diverse decision-making needs.
- Improved forecasted and observed rainfall and alerting with rain gauge adjusted radar data.
- Water level monitoring of over 200 gauges.

Further work currently in progress includes:

- Connections to more cloud data sources for Urban Drainage Visualisation (urban drainage monitoring) needs, including the MW Hydstra database.
- Implementation of an alerting trial to provide flood alerts to Emergency Management Victoria.
- Dashboards for several Metro Councils to improve MW's data sharing responsibilities.

GROUNDWATER VULNERABILITY AND STORMWATER DRAINAGE IN WAIPA DISTRICT

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Aims

The Waipa District Council is looking to renew their district-scale stormwater discharge consent. Beca is assisting the council with evaluating the potential vulnerability of groundwater for present and future stormwater system management of four main Waipa towns: Ōhaupō, Pirongia, Te Awamutu and Kihikihi, and Cambridge and Leamington.

Method

The GIS-based DRASTIC method offers a standardized framework giving structure to the limited geological and hydrogeological information available across the district. Whilst the method was created for evaluating contaminant vulnerability, it essentially assesses the connection between groundwater and activities undertaken at the surface, and hence can be used to help categorize catchments in terms of overall risk of impact from surface development, stormwater management etc.

The DRASTIC acronym stands for seven parameters with the most influence on the aquifer vulnerability (EPA, 1985; Shira S.M. et al., 2012):

- **D**epth to groundwater – identifying how deep the water table is
- **R**echarge rate – quantifying the infiltrating water, which ultimately feeds the underlying aquifer
- **A**quifer media – geology of the aquifer
- **S**oil media – material description of the upper meter of the ground surface
- **T**opography – slope analysis for runoff
- **I**mpact to the vadose zone –material description of the unsaturated zone between the soil and the aquifer
- **C**onductivity – hydraulic conductivity of the aquifer

Those seven hydrological and geological factors are given a weight () from 1 to 5 reflecting their potential impact to aquifer vulnerability, with 1 for factors with minor impacts and 5 for the most influencing ones (Table 1). Each factor is divided into classes, which are in turn similarly given a rating (ranging from 1 to 10 with 1 for less vulnerable and 10 for most sensitive classes.

The GIS platform provides an interactive and flexible workspace for data visualization, interpretation, and processing, with the option of overlapping other factors such as potentially hazardous activities, stormwater drainage systems, and water supply wells.

Results

This hydrogeological assessment resulted in a risk-based map produced for each town to identify locations where stormwater catchments are more likely to impact shallow groundwater. We then used the maps to qualitatively assess potential impacts to groundwater such as changes in baseflow to streams, aquifer recharge, and mounding.

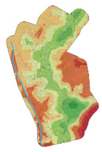
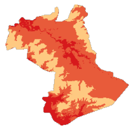
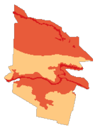
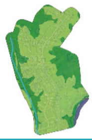
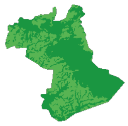
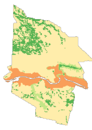
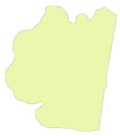
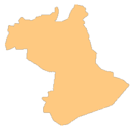
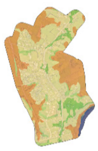
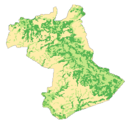
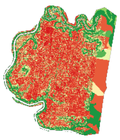
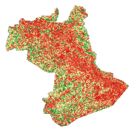
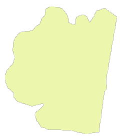
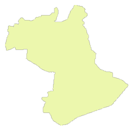
The vulnerability assessment highlights a range of assessed catchment vulnerabilities, with higher risks generally associated with permeable material outcropping and shallow groundwater. These areas are likely to have greater constraints in terms of stormwater management and have been targeted for further investigations and monitoring.

References

EPA, 1985: DRASTIC: A standardized system for evaluating ground water pollution potential using hydrogeological settings – US Environmental Protection Agency EPA/600/2-87/018

Shira, S.M. et al., 2012: GIS-based DRASTIC method for groundwater vulnerability assessment: a review. *Journal of Risk Research*, 15(8): 991-1011.

Table 1: DRASTIC parameters, associated ratings, and output maps for each location.

Parameters		Rating	Weight	Ōhaupō	Pirongia	Te Awamutu	Cambridge
D	**Depth to water (m)**						
	0 - 1.5	10	5				
	1.5 - 4.6	9					
	4.6 - 9.1	7					
	9.1 - 15.2	5					
	15.2 - 22.9	3					
	22.9 - 30.5	2					
	> 30.5	1					
R	**Net recharge (mm/h)**						
	> 254	9	4				
	178 - 254	8					
	102 - 178	6					
	51 - 102	3					
	< 51	1					
A	**Aquifer media**						
	karst limestone	10	3				
	gravel / conglomerate	8					
	clay, gravel / silt, sand, fine gravel	7					
	sandstone / limestone with shale	6					
	sand / sandstone with clay	5					
	silt, clay, gravel / clay, sand	4					
	weathered metamorphic igneous	4					
	silty clay	3					
	marl / massive shale / silt and clay	2					
	clay	1					
S	**Soil media**						
	gravel or thin soil	10	2				
	sand	9					
	peat	8					
	loamy sand	7					
	sandy loam / sandy clay (coarse)	6					
	loam	5					
	silty clayey loam / silty loam	4					
	clayey loam	3					
	silty clay (fine)	2					
	clay	1					
T	**Topography (slope %)**						
	0 - 2	10	1				
	2 - 6	9					
	6 - 12	5					
	12 - 18	3					
	>18	1					
I	**Impact to vadose**						
	karst limestone	10	5				
	basalt	9					
	gravel / sand	8					
	silty sand	7					
	sandstone / clayey sand	6					
	silty clay with sand	5					
	sandy clay	4					
	silty clay, silt / shale	3					
	marl, clay / silt and clay	2					
	clay	1					
C	**Hydraulic conductivity (m/d)**						
	>81.49	10	3				
	81.49 – 40.75	8					
	40.75 - 28.52	6					
	28.52 - 12.22	4					
	12.22 - 4.07	2					
	4.07 - 0.04	1					

THE ACCURACY OF GEOPHYSICAL METHODS IN PREDICTING GROUNDWATER PRODUCTION BORE YIELDS

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With an increasing demand on groundwater resources throughout New Zealand along with the availability of geophysical surveys, the use of geophysical methods for determining target drilling locations for groundwater production bores is becoming more and more common. The objective of this study is to assess the value of geophysical methods for aquifer exploration from an industry perspective. Two different geophysical surveys that have been conducted in the Bay of Plenty, New Zealand in 2021 are investigated, and comparisons are made between bore yield predictions and the actual yields that were obtained onsite once the bores had been drilled.

The seismoelectrical method has been used in which the subsurface is analysed by its generation of electromagnetic waves upon being subject to seismic waves. Statistical comparison is limited to the final predictions of the seismoelectrical surveys and does not cover data collection and processing. The seismoelectrical surveys were conducted in fractured rock aquifers with investigation depths of up to 360m.

The findings of this study indicate a strong correlation between predicted and observed bore yields with a Pearson correlation coefficient of 0.87. The study is limited to six production bore sites and a higher number of comparisons would therefore be required to verify this relationship.

ARE SENTINEL WELLS A VIABLE OPTION FOR MONITORING GROUNDWATER DRINKING WATER SUPPLIES?

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Aims

Public water supply wells are regularly monitored for various water quality indicators in order to detect pathogen, nutrient and chemical contamination that can occur from agricultural and urban activities. However, the Havelock North outbreak and the more recent Waiwhetu aquifer contamination incident demonstrated that testing the supply well alone does not provide sufficient warning for mitigation actions to be successful. Restricting the land use surrounding the supply well is a common protective measure, however complete restriction is impractical and often impossible (particularly in urban areas), and the full extent of the well capture zone is nearly always uncertain.

The use of a monitoring network surrounding a supply well allows for early detection and remediation. The network success rate depends on several factors such as the sampling frequency and the number and location of the sentinel wells. Further uncertainty arises when the contaminant source location is unknown, and the transport velocities vary greatly due to aquifer heterogeneity.

The aim of this study was to assess the applicability of a monitoring network of sentinel wells for early detection of elevated contamination levels in public water supply wells. In particular this study investigated how contaminant detection probability was affected by aquifer spatial heterogeneity and dispersion characteristics by considering a hypothetical monitoring network of varied size and sampling frequency, designed to provide sufficient warning for mitigation measures to be implemented to ensure the safety of the water supply.

Method

The model conceptualization and deterministic parameters were chosen to loosely conform to the Waiwhetu Aquifer flow conditions in New Zealand's North Island, in the vicinity of the Waterloo borefield. The model domain is 3km long by 2km wide with a grid discretisation of 5m x 5m, constant head boundaries and uniform recharge. The aquifer heterogeneity is addressed through the hydraulic conductivity, which is assumed a lognormally distributed, stationary, second order and anisotropic process (Paleologos and Sarris, 2011). A single pumping supply well was considered with a non-uniform flow field converging towards the well, and a permanent, conservative contaminant leakage from a source randomly placed in each realisation.

The flow and transport in the heterogeneous aquifer were studied in a stochastic framework using a Monte Carlo approach. 2D random hydraulic conductivity fields were generated using the Sequential Gaussian Simulation method (Deutsch and Journel, 1997). The numerical steady state flow solution was obtained using MODFLOW-NWT (Niswonger et al. 2011), the transport problem was solved using MT3D-USGS (Bedekar et al. 2016), and the estimated stochastic contaminant arrival times were obtained using MODPATH version 5 (Pollock, 1994). Once all the realizations had been undertaken, the point detection probability statistics were calculated at each grid cell. Optimal network arrangements were obtained by maximizing a novel weighted risk function that considered true and false positive detection probabilities, sampling frequency, and the uncertainty in contaminant travel time towards the well.

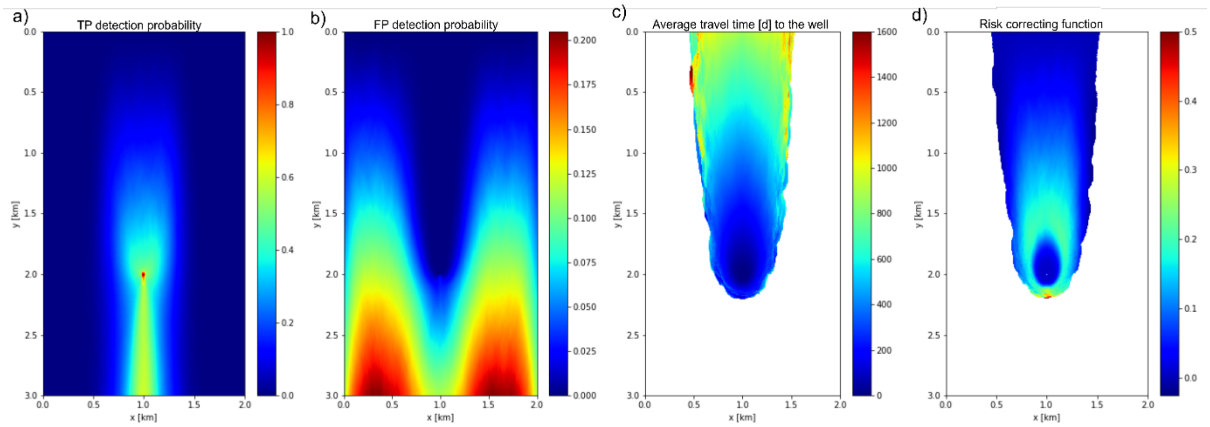

Figure 1: a) True positive (TP) detection probability, b) false positive (FP) detection probability, c) average travel time to the pumping well in days, and d) the weighted risk function for a set of realisations with low dispersivity. White area: particles never reach the well in any realisation.

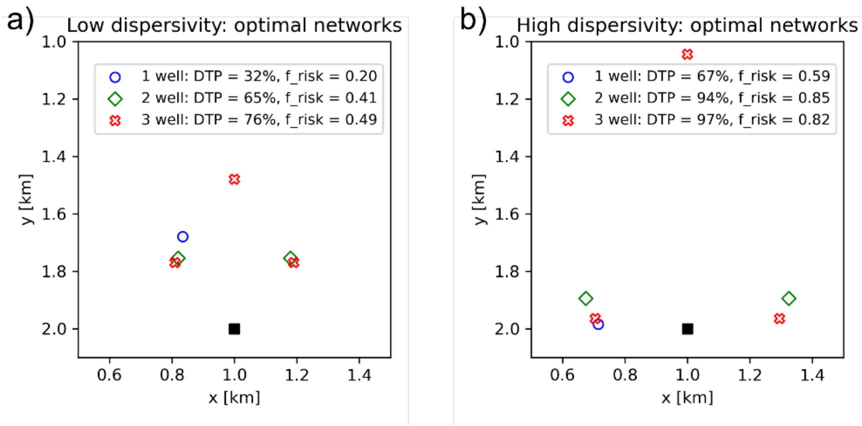

Figure 2: Monitoring network arrangements for 1 to 4 wells, optimised by maximising the weighted risk function (f_risk). a) low dispersivity, b) high dispersivity. The contaminant detection probability (DTP) increases with number of wells and dispersivity. Black square: pumping well.

Results

The contaminant detection probability of an optimised monitoring network increased with the number of sentinel wells, dispersivity, and sampling frequency, and decreased with the correlation length for the hydraulic conductivity field. Anisotropy made no significant difference.

A single sentinel well was found to be optimally placed to one side of the pumping well, 2 sentinel wells were upgradient and either side of the pumping well, and 3 wells were optimally placed with 2 either side and 1 directly upgradient. As dispersivity increased, the optimal network layout spread outwards with the sentinel wells further downgradient and almost in line with the pumping well. With low dispersivity, increasing the number of sentinel wells made a large difference to the detection probability. As the contaminant plume doesn't spread far in the transverse direction, more sentinels are needed to detect all possible cases. Whereas with high dispersivity there was minimal improvement when adding more than 2 sentinel wells on either side of the pumping well. Just 2 wells were generally enough to detect over 90% of randomly sourced contaminants. The contaminant plume spreads far in the transverse direction, so even if a source is directly above the well it is likely to travel to the side and be successfully detected.

References

Paleologos, E.K., and Sarris, T.S. 2011. Stochastic analysis of flux and head moments in a heterogeneous aquifer system. *Stochastic Environmental Research and Risk Assessment* 25 (6):747-759.

Deutsch, C.V., and Journel, A.G. 1997. *GSLIB:Geostatistical Software Library and User's Guide*. 2nd ed. New York: Oxford University Press.

Niswonger, R.G., Panday, S., and Ibaraki, M. 2011. A Newton formulation for MODFLOW-2005. *U.S. Geological Survey Techniques and Methods* 6–A37:44.

Bedekar, V., Morway, E.D., Langevin, C.D., Tonkin, M.J. 2016. MT3D-USGS version 1: A U.S. Geological Survey release of MT3DMS updated with new and expanded transport capabilities for use with MODFLOW. In *Techniques and Methods*. Reston, VA.

Pollock, D.W. 1994. User's Guide for MODPATH/MODPATH-PLOT, Version 3: A Particle Tracking Post-processing Package for MODFLOW, the US: Geological Survey Finite-difference Groundwater Flow Model.

RAIN DATA CHECKING

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[1] Rainfall.NZ
[2] NIWA

Aims

A system was required to efficiently check the quality of hourly rainfall data from over a thousand sites throughout New Zealand

Method

A series of eleven Python functions were prepared (https://github.com/RainfallNZ/RainCheckPy), each applying a specific test to hourly rainfall data and generating a timeseries of each test's index. Data quality rules were established for each climate region of New Zealand which specified the test index thresholds that might be used to determine if an observation was acceptable, suspect, or to be rejected. The tests and rules were applied to hourly rainfall data available from the NIWA Climate Database and the NIWA Water Resources Archive, including copies of data from all of the Regional Councils.

The tests included:

Outliers	Homogeneity	Non-numerics or negatives
Duplicate times	Dry spells	Repeated values
High compared to neighbor	Low compared to neighbor	Dry compared to neighbor
Observed during sub-zero temperature	Related streamflow events	

Results

186 million observations from 1118 sites were checked.

The primary issues were duplicated values, dry spells, rain during freezing conditions, and outliers. While outliers and dry spells did not show any clear spatial form, repeated values appear to be associated with specific data source agency regions, and is suspected to be an artefact of check-gauge correction methodologies. Manual inspection of many outliers and long dryspells highlighted the difficulty in being clear-cut about whether an observation is in error or not. Inclusion of the 'related streamflow event" check helped with this distinction and mirrors a commonly taken manual approach.

The quality-checked data is being used to assist with the validation of hourly-resolution climate modelling. Utilising a common quality checking methodology for all the rainfall data improves confidence in the data and, in turn, the validated climate model output.

EFFECTS OF DOWNSCALING AND MODEL RESOLUTION ON SIMULATIONS OF GROUNDWATER AGE

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Aims

Effective management of water resources requires the ability to simulate a range of complex processes at various spatial and temporal scales. Representing hydrologic processes at the appropriate spatial and temporal scales to support management decisions poses a significant challenge for modellers. The models need to capture the decision critical behaviour of the system while avoiding excessive computational burden. For example, coarser national scale models used to inform national policy are necessarily less complex than finer local scale models used to inform source protection zones. However, the boundaries of the coarse scale models often align with hydrologic boundaries (e.g. watershed divides or oceans) while the boundaries of the finer scale models often rely on assumptions about inputs from the surrounding area. As such, the potential benefits of simulating the more complex processes required to make local scale decisions may be compromised by increased uncertainty associated with these local model boundary assumptions.

The aim of this work is to develop a method of downscaling information from a coarse national scale model to inform finer local scale models in a rapid, consistent way. In particular, in this project we explore model downscaling in the context of simulating groundwater age. We evaluate the trade-offs between using finer scale models (more complex) and coarser scale models (less complex) in terms of uncertainty quantification, process simulation, and computational demand. Emphasis is placed on how downscaled boundary conditions, and model discretisation affect prior and posterior estimates of groundwater age which can be derived from particle tracking simulations, or more directly from simulations of water age using advection dispersion equations.

Methods

A national scale MODFLOW 6 model of New Zealand was co-developed with the New Zealand Water Model project (NZWaM). This model incorporates nationally consistent datasets and provides seamless coverage over the nation. This consistency provides an optimal starting point for the rapid generation of regional and local scale models that can be modified to address specific questions in areas of interest across the country.

Regional and local submodels are then developed which inherit structure, boundary conditions, and prior hydraulic parameter values from the national scale model but use a refined spatial and temporal discretisation. These submodels can then be deployed to provide estimates of a prior predictive probability distribution. In addition, the enhanced parameterisation of the submodels can then be used to more fully assimilate information from data and reduce the uncertainty of predictions. In this project the key predictions being investigated are the spatial distributions of groundwater and surface water ages.

Metrics are used to demonstrate the performance of the submodels. The data-processing capacity of different model scales in terms of the quantified uncertainty of key predictions is one such metric. This metric includes a consideration of the trade-offs between greater model boundary certainty at the watershed scale and aquifer plain scales. The utility of a framework for rapid builds of prediction focussed models forms another metric, when comparisons are made with models produced outside of this national-submodel framework.

Results

Testing to date has focusses on the Heretaunga plains and Wairau valley groundwater systems (Figure 1). We present a demonstration of the methodology described above, that focusses on the groundwater system in the Wairau valley. A regional scale model of both watersheds was constructed from the national scale model. Local scale models of the Heretaunga plains and Wairau plains were then constructed from the watershed models. These models were generated using a python-based scripts to ensure a consistent, reproducible approach. These scripts rely heavily on open-source packages available on GitHub (FloPy, pyEMU, modflow-setup) as well as custom packages develop at GNS. Initial heads, boundary conditions, and hydrogeologic properties are inherited from the national scale model. In the case of the watershed models, the edge of the model coincides with the topographic watershed boundary. In the case of the local scale models of the plains, the edge of the model coincides with a somewhat arbitrary boundary delineating the flat, low-lying valley floor from the surrounding hills. Preliminary comparisons of the national and regional and subregional model simulations of predicted groundwater age in the Wairau are presented.

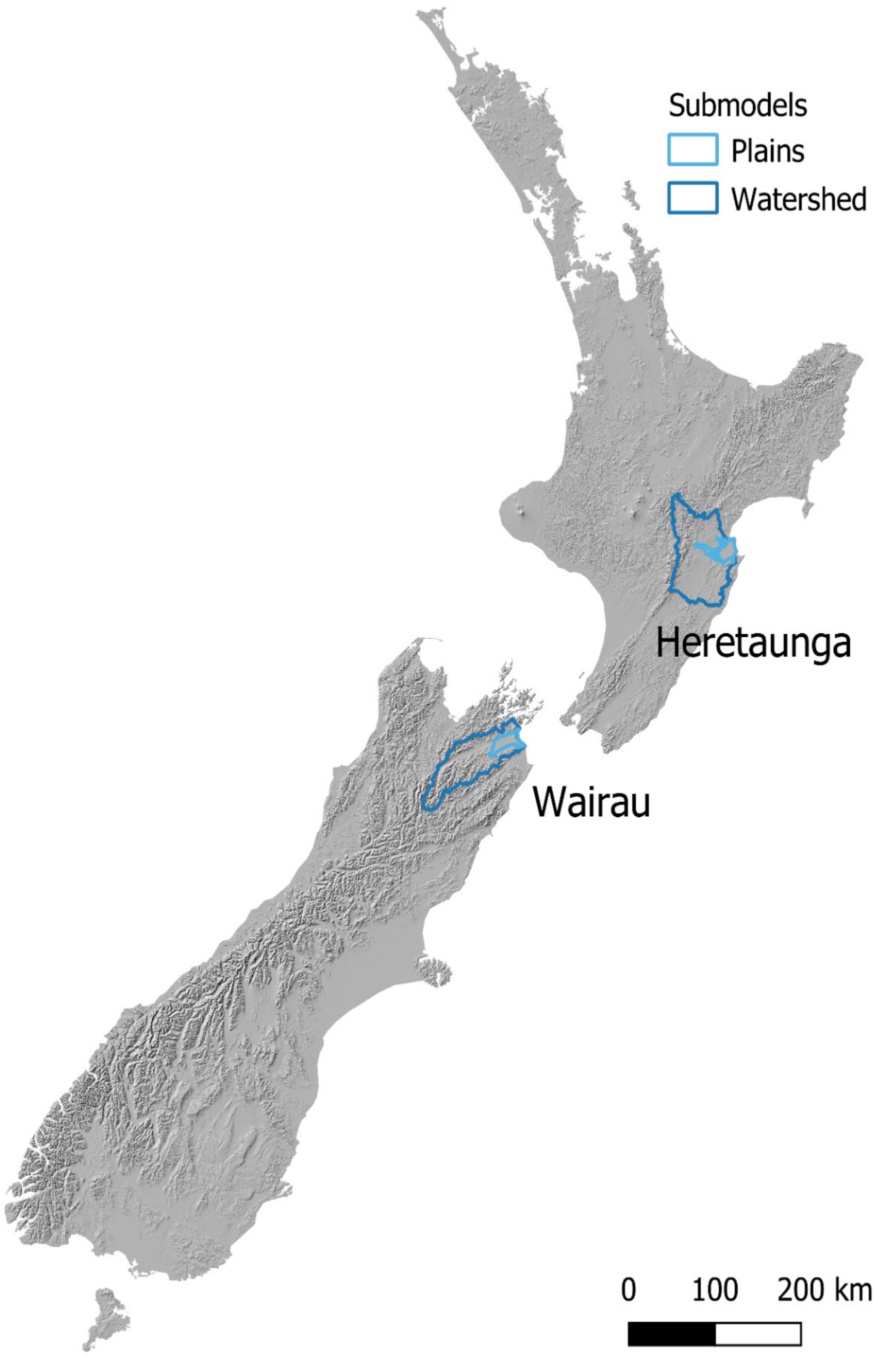

Figure 1: Map of study areas. The dark blue line indicates the model boundary based on surface topography. The light blue line indicates the model boundary based on the relatively flat, low-lying plains. The national scale model covers all of New Zealand.

DELINEATING GROUNDWATER CONTRIBUTING AREAS TO SURFACE WATER CATCHMENTS

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[2] GNS Science-Wairakei
[3] GNS Science-Avalon

Aims

Water stored in groundwater aquifers is the world's largest accessible source of water representing about 30% of world's fresh water while only 1% is found in river and lakes. In New Zealand, groundwater accounts for approximately 80% (1.7×1012m3) of total freshwater making it a vital source of water for agriculture, drinking water supply and recreation (Toebes, 1972). As the concerns over water resources grow, the importance of considering ground water and surface water as a single resource has become increasingly evident. It is important to accurately estimate the groundwater flux, its flow direction, and the role of groundwater interactions with streams. Effective water management requires a better understanding of surface water and groundwater in the context of changes in land use, water use, and climate.

The New Zealand Water Model (NZWaM) provide a flexible modelling platform capable of simulating various complex interactions that are dependent on climate, geology, and land use. The ability to simulate the interactions between surface water and groundwater is essential for effective water management in many parts of the country. These interactions must be considered to achieve the correct water balance and a more realistic estimation of streamflow, as well as inform the influence of surface water on groundwater resource. These options can be represented at various levels of complexity ranging from simple bucket models to transfer functions to highly parameterized 3D groundwater models. Each level of complexity incurs a concomitant computational burden that may not inform the relevant objective. As such, a flexible modelling platform requires option for simulating these interactions, along with an assessment of the trade-offs between accuracy and accessibility.

In this work, we present a method to estimate groundwater flux to a particular surface water catchment using two different models: the Equilibrium Water Table model (Westerhoff et al., 2018), and a newly constructed national scale MODFLOW 6 model (developed as part of Te Whakaheke o Te Wai). This paper builds on the novel method presented last year (Shankar et.al., 2020), in which the extent of groundwater contribution was based on models using a-priori hydrogeologic parameters using a "groundwater DEM" (gw-DEM). We aim to identify groundwater catchments and groundwater flow direction across New Zealand to better inform the NZWaM model. Also, this dataset will be used to improve the conceptualization processes in NIWA's TopNet-GW in order to enhance the accuracy of the current discharge predictions, at both catchment and regional scales. A detailed comparison of groundwater catchment extent and groundwater fluxes are presented.

Method

Results of groundwater head from the national EWT and MODFLOW models were used as "gw-DEMs" to evaluate groundwater flow. ESRI's ArcHydro tools were used to fill pits (i.e. remove sinks) in the gw-DEMs. Flow direction and flow accumulation rasters were computed using the flow direction and flow accumulation tool in ArcGIS Pro. Flow direction vectors for all sub-catchment across New Zealand are used to investigate the interactions between groundwater and surface water in each sub-catchment. The flow results for each model cell was normalized by the total flow for the entire groundwater catchment for each model to estimate the relative potential for groundwater discharge to the surface. The sum of this value in each sub-catchment gives the relative potential for groundwater contributing to streamflow. The relative contribution of groundwater to each sub-catchment in three areas of interest is compared between the models.

Results

The groundwater flow direction for the whole country was estimated and the results indicate groundwater catchments generally align with surface water catchments in most parts of New Zealand, with some important exceptions. Groundwater catchment delineation and estimates of groundwater-surface water exchanges for three areas are evaluated in more detail. The groundwater and surface water catchments for the Taruhera are shown in Figure 1 below. Going forward, we will select several aquifer systems across the country with groundwater level data to validate the groundwater model results. Additionally, the new dataset provided by GW-prep Tool will be fed into TopNet-GW model to model the groundwater recharge across New Zealand aquifers.

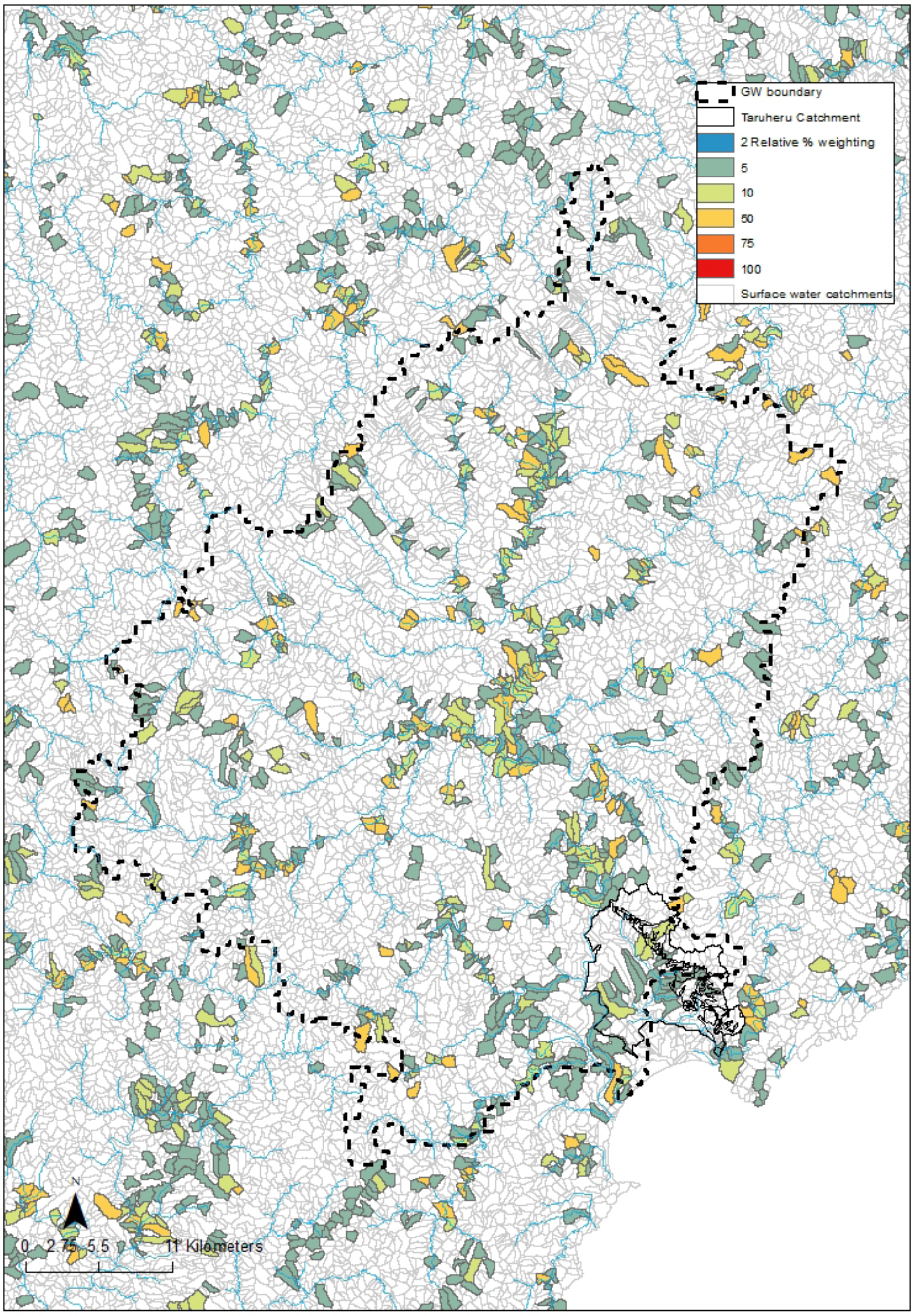

Figure 1: Map of the Taruhera catchment showing potential groundwater contributing areas (extending into the Waipaoa River catchment) overlaid on a surface showing the relative contribution of groundwater to each subcatchment. Note the sub-catchments near confluences have a greater potential groundwater contribution and the polygons close to the Waipaoa-Taruhera surface water catchment suggest high groundwater flow.

References

Shankar, U.; Taves, M.W.; Zammit, C. 2020 Delineating groundwater contributing areas to surface water catchments. IN: Weathering the storm: NZHS, NZ Rivers Group & NZFSS Joint Conference: Conference handbook : poster abstracts. [Wellington, N.Z.]: New Zealand Hydrological Society

Westerhoff, R., White, P., and Miguez-Macho, G. Application of an improved global-scale groundwater model for water table estimation across New Zealand, Hydrol. Earth Syst. Sci., 22, 6449–6472, https://doi.org/10.5194/hess-22-6449-2018, 2018.

Toebes, C. 1972. The water balance of New Zealand. Journal of Hydrology (New Zealand), 11(12): 127-139.

DEVELOPMENT OF A NATIONAL SCALE GROUNDWATER MODEL USING MODFLOW 6 TO FACILITATE SIMULATION OF GROUNDWATER-SURFACE WATER INTERACTIONS WITHIN NZWAM

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Aims

The New Zealand Water Model (NZWaM) is a modular modelling system developed to represent complex, relevant hydrologic processes from national/regional to local catchment scale. The modular design gives NZWaM the flexibility to represent various processes using different sub-models and with different levels of complexity. Groundwater-surface water interactions is one such important process that has been represented by the Equilibrium Water Table model (EWT; Westerhoff et al., 2018), a computationally efficient model for estimating groundwater head based on topography, recharge, and transmissivity. While the results of the EWT can be used to inform estimates of groundwater-surface water exchange, there is no direct representation of surface water processes in the EWT model. We aim to expand the options available in NZWaM by adding a national scale MODFLOW 6 groundwater model with the ability to couple groundwater-surface water between the two models. The co-development of a national scale MODFLOW 6 model to simulate groundwater age as part of the "Te Whakaheke o te Wai" project will allows users of NZWaM to simulate processes at various levels of complexity depending on their needs.

MODFLOW is the most widely used groundwater modelling software in the world. MODFLOW 6 is the latest core version of MODFLOW to be released by the United States Geological Survey. MODFLOW 6 is designed to facilitate the exchange of information between models, making it the obvious choice to fulfil the goal of creating a fully coupled groundwater-surface water model. Current python packages (e.g. FloPy, modflow-setup, pyEMU) available on GitHub provide a relatively easy way to systematically change the level of complexity and discretization of a MODFLOW 6 model, offering the opportunity to rapidly generate MODFLOW models at the appropriate level of complexity.

Methods

A python-based scripting method is used to create a national scale MODFLOW 6 model based on NZWaM's Hydro-Geofabric database. This method relies heavily on open-source python packages (e.g. FloPy, pyEMU) and custom packages developed within GNS. The response in model behaviour (run times, convergence, mass balance errors) and results (groundwater head, groundwater-surface water exchange) to boundary conditions, data pre-processing algorithms, and discretization are explored.

The Streamflow-Routing Package in MODFLOW 6 (SFR6) is used to simulate groundwater interactions with a stream network. The Surface Water Network (SWN) package developed by GNS is used to convert streams in the Digital River Network (DN) database into SFR model inputs. The Drain Package (DRN) in MODFLOW 6 allows water to discharge from the top surface of the model when the groundwater head exceed the surface elevation. This process is similar to the "saturation excess runoff" (aka Dunnian flow) simulated by TopNet, the surface water component of NZWaM. This water (typically a few percent of the total) can be routed into the SFR package using the MODFLOW 6 interface.

Results

Simulating higher levels of complexity (e.g. groundwater-surface water interactions) and model resolution (e.g. 240 meter vs 960 meter horizontal grid spacing) can result in simulations taking orders of magnitude longer to run but may not facilitate a better understanding of the hydrologic system. The impacts of input data pre-processing (e.g. smoothing, parameter bounds) are evaluated in terms of both model performance and results. Our results show the trade-offs between model complexity and resolution in terms of simulation results and model performance. Surface water discharge from the DRN package, streamflow, and groundwater recharge and discharge is compared to results from the TopNet model in the context of meeting the future goal of coupling the TopNet and MODFLOW 6 models.

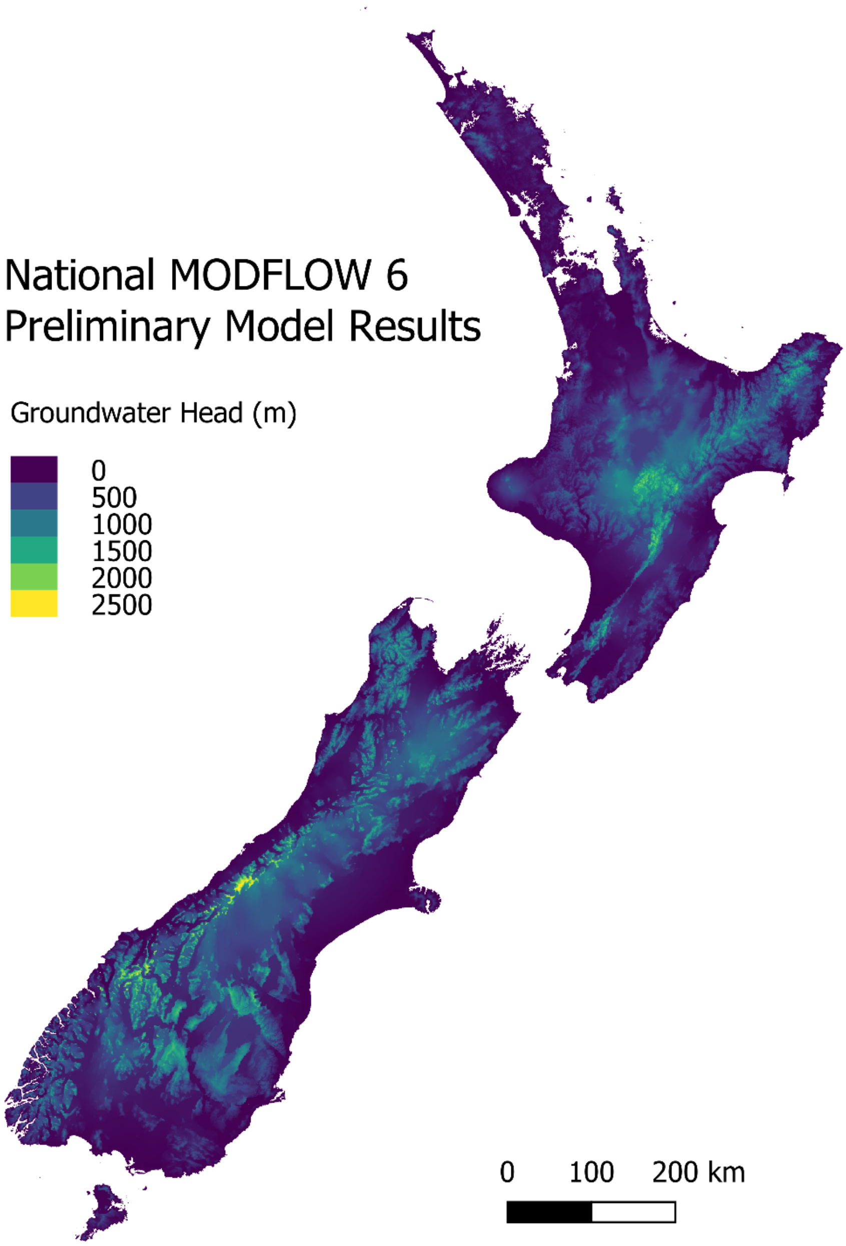

Figure 1: Preliminary results of groundwater head from national scale MODFLOW 6 model.

References

Westerhoff, R., White, P., and Miguez-Macho, G. Application of an improved global-scale groundwater model for water table estimation across New Zealand, *Hydrol. Earth Syst.* Sci., 22, 6449–6472, https://doi.org/10.5194/hess-22-6449-2018, 2018.

OPEN ACCESS HYDROLOGICAL DATA REPOSITORY

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[3] Environment Southland

Aims

Scientists spend a large part of their time accessing and processing data for use in their scientific analysis. As a consequence, much duplication occurs in the scientific community and data might not even be available for the scientists. There are a lot of open access data available in New Zealand and around the world, but they are all stored and distributed in many different ways under many different licenses. If hydrological data were stored and distributed in an easy and open way, then scientific work can be performed more efficiently and be more reproducible then the current status quo.

The aim of the repository and the associated website (https://envlib.org) is to enable the development and distribution of knowledge in the environmental sciences. The repository and the companion application programming interface (API) called Tethys provides open access to monitoring data and modelled/simulation data from across New Zealand and beyond.

Methods

Access to the data and a description of the project can be found at https://envlib.org. Direct programmatic access to the data is provided by a Python API and a web API. Direct programmatic access allows scientists to embed the data access directly into their processing and analysis scripts making their work easily transferable and reproducible by other scientists. The Python API uses packages familiar to environmental scientists to handle the geospatial data including Pandas and Xarray. The APIs to access data are responsive enough to be used for one-off downloads for analysis or real-time reporting applications accessed by many users.

The metadata about the datasets allows the user to know exactly what kind of data is available and how it can be used. This not only includes the type of parameter (e.g. temperature, streamflow, precipitation), but also how the result was recorded, the owner of the data, the measurement frequency, the data license and attribution, etc. As it is designed for geospatial data, the results can have up to four dimensions (x, y, z, and time) with the x and y dimensions stored as sparse (points, lines, or polygons) or gridded data.

Results

A wide variety of hydrologic data is currently available in the repository. This includes monitoring data from many regional councils, NIWA, and FENZ. There are also modelled/simulation data from the University of Canterbury, Environment Southland, MetService, European Centre for Medium Range Forecasts (ECMWF), and others. Some datasets cover the entire country while others are regional.

The repository and associated API are already being used in real-time reporting applications for local government agencies and private companies. One example of a reporting application utilising the repository is the open source surface water allocation accounting web tool for Environment Southland (Figure 1). Monitoring data is regularly processed into the repository, which is then automatically picked up for additional processing and analysis before being dumped back into the repository. This additional processing and analysis includes streamflow statistics, stream naturalisation, stream depletion, and catchment allocation accounting.

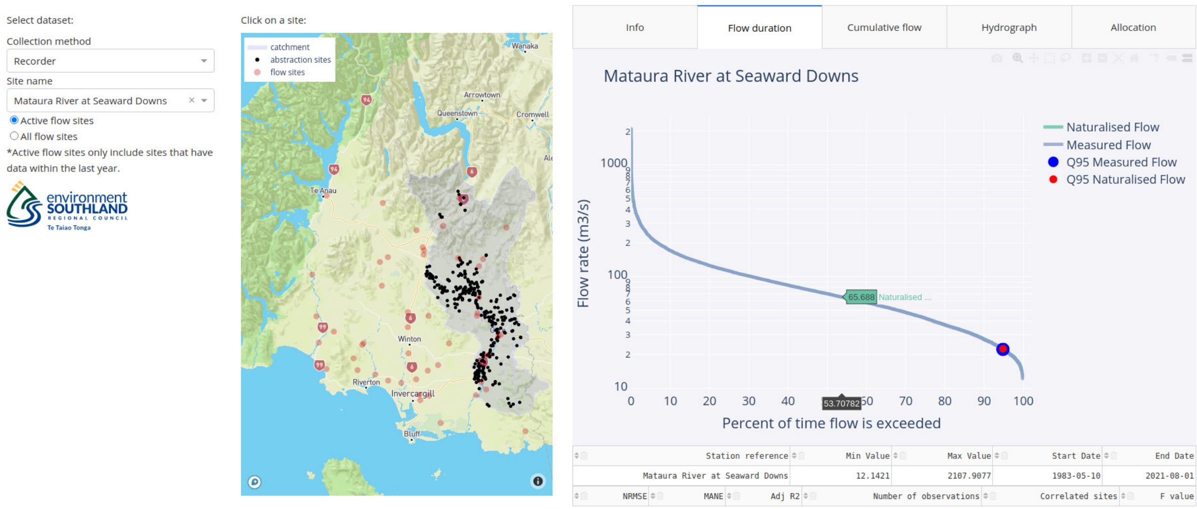

Figure 1. Screenshot of the surface water allocation accounting web tool for Environment Southland that utilises Tethys for accessing hydrological data.

QUALITY OF CHRISTCHURCH'S RETICULATED DRINKING WATER SUPPLY

Knopick, M.,[1] Mager, S. [1]
[1]University of Otago

Aims

This research tests whether asbestos or trace metals (with a focus on Lead) are present in the drinking water of Christchurch City. Christchurch's water supply network is 1814.15 km in length, with 825.95 km of asbestos cement (AC) pipe and 189.210 km cast iron (CI). These materials degrade over time; 28% of the CI pipes were installed prior to 1940 and are assumed to contain Lead (Pb) joints. In New Zealand, AC pipes were used from 1935 and were the material of choice for New Zealand's reticulation and trunk water mains from the 1950s to the mid-1980s. AC piping is estimated to last approximately 50 years, meaning that most of New Zealand's AC pipe network is now degrading. Globally, there's evidence that asbestos fibres are entering drinking water through degraded AC water supply infrastructure. However, New Zealand has no official guidelines or asbestos fibre limits set for drinking water quality. The lack of guidelines regarding asbestos in drinking water may be an oversight of the indirect carcinogenic pathways that might result from drinking water contamination and therefore lends the significance of the project's results. New Zealand drinking water standards set the maximum acceptable value for Lead at 0.01 mg/L. Ideally, this research will assist New Zealand's water utilities in gauging timelines for pipe replacements. A further understanding of water supply piping degradation characteristics will forge pathways for future work to interpret economic and health-related implications from the impact of aging piped networks. This study assesses drinking water quality and the effect of pipe deterioration rates across several parameters.

Method

The project starts with a literature review regarding the associated health and financial consequences of contaminated drinking water. It involves the assessment of the current condition of the water mains pipe networks through geospatial analysis. Several factors need to be considered regarding pipe corrosion conditions, including variables such as water chemistry (hardness/aggressiveness), water pressure, trench characteristics, and other pipe data including diameter, and rupture rates. A deeper understanding of pipe conditions and degradation characteristics will improve the resolution of research findings. A stratified sampling method was employed to use data obtained by geospatial analysis and target water that had been in contact with aged CI or AC mains in Christchurch's reticulated water system.

83 samples were collected at 59 locations from both hydrants (direct to mains) and residential properties. Of these, 46 samples were collected at 35 sites where water has been exposed to AC pipe older than > 50 years and analysed for asbestos fibre concentrations under transmission electron microscopy (TEM) by the US EPA method 100.1 protocol. EPA method 100.1 is currently the most renowned analytical method for determining asbestos fibres in water. If evidence of asbestos is found, asbestos type and fibre size will be correlated with water aggressiveness (LSI) and the geospatial analysis. In New Zealand, household tapware and pipe fittings containing Lead are still being imported and widely used. Therefore, our trace metals investigation extends to consumer end contamination and the possible release of trace metals from residential plumbing or tap fittings. 37 samples were gathered at 24 sites to test water exposed to aging CI pipes (1904-1956), fittings, or residential plumbing. These samples are analysed under inductively coupled plasma mass spectrometry (ICP-MS) to test for the presence of heavy metals (Pb, Cu, Ni, and Cr). Sampling methods are designed to differentiate point source contamination from mid-network, tap fittings, and residential plumbing sources. Therefore, end-use consumer locations were sampled for a 5-minute flush and a first draw sample with hydrant samples representing water in direct contact with mains infrastructure.

Results

Currently awaiting results. All samples have been collected, and sample distributions are as followed:

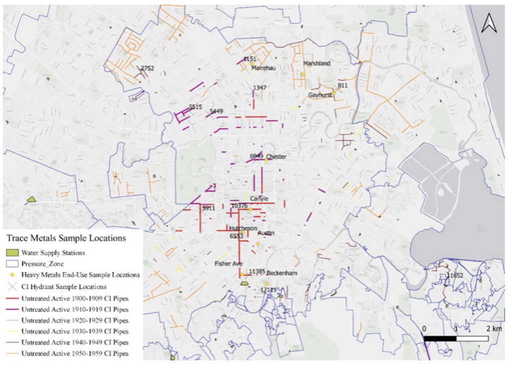

Figure 1.0 Trace metals sample locations in the central supply zone.

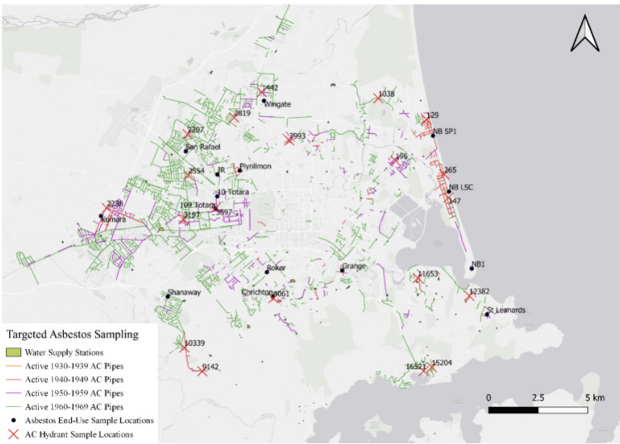

Figure 2.0 The distribution of asbestos in drinking water sample locations for Christchurch City and Lyttelton township.

IN LIGHT OF A HIDDEN FRESHWATER RESOURCE

Kreleger, A.,[1] Morris, R.,[2] Aitchison-Earl, P.[1]
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[2] Greater Wellington Regional Council

Telling the groundwater story

Groundwater Scientists at regional councils, like many other scientists, produce science reports about their investigations and sometimes journal articles. Academically trained, we know how important it is to clearly present our data and interpret the information objectively. We describe our methods, results and conclusions related to the science work and the drafts often go through a peer review process.

These investigations help us improve our understanding of the region's groundwater resources. We use this understanding to support resource planning and decision-making processes. These processes rely on sound science, but science is not the only factor decision makers and planners take into account. And with groundwater being the hidden freshwater source in the water cycle, it is often more challenging to get our message across.

Our peers probably understand the importance of our work, but our audience will likely be disengaged or sceptical if they don't know what's in it for them. This could be problematic if our audience is a decision maker, if we are promoting behavioural changes or if we are trying to obtain research funding. For an audience to understand what's in it for them, we need to find ways to engage them with our groundwater story. They need to hear the why and not just the what. They need to be able to relate to our story. Using jargon and science reports as a limited communication tool might not be the way to get there.

Awareness for better Groundwater Science Communication is growing. At last year's NZHS conference in Invercargill (2020), Philippa Aitchison-Earl presented that the Groundwater Section at Environment Canterbury has established a SciComm Working Group to improve how we communicate as a Section about our work. The Groundwater Forum also recognises that we need to get better in getting Groundwater Science Research on the Resource Management research agenda of the Regional Sector. A small group of enthusiasts are keen to get the ball rolling with a Groundwater Forum Communication Plan.

The successful collaboration between microbiologist Siouxsie Wiles and Spinoff illustrator Toby Morris during the COVID-19 pandemic shows how effective science communication can inspire politicians, engage large crowds and change public behaviour. What can we learn from this collaboration? Research has also shown that the uptake of Covid-19 vaccinations improves when people become aware of the benefits for their community, whereas debunking conspiracy theories and vaccination myths are not effective. How can we incorporate this knowledge in our groundwater story telling?

Together with the conference audience we would like to explore good initiatives and examples that help us bring to light the story about our precious but hidden groundwater resource and the main challenges we face getting our story out there. The visual of Animate Your Science on the next page gives some humorous clues about these challenges!

Amber Kreleger recently attended a workshop with Siouxsie and Toby organised by the Science Media Centre and in the conference presentation she would like to share some of the insights she learned there and since then and how she tries to incorporate these in her Groundwater Science work. Rebecca Morris is the current convenor of the Groundwater Forum and as the driver behind the forum's Communication Plan she will explain the importance of getting this plan over the line.

The journey and challenges from publication to impact (Source: [https://www.animateyour.sci--ence/post/welcome-to-scicommland](https://www.animateyour.science/post/welcome-to-scicommland)

NITRATES: THE CONUNDRUM OF RAPID RESPONSE AND TIME LAG

Legg J.,[1] Rutter, H.K.[2]
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Abstract

Groundwater concentrations of Nitrate-N (NO_3-N) are increasing in many areas of New Zealand. (MfE & Stats NZ, 2020). They often display a seasonal cycle in response to recharge via rainfall (Hanson, 2002), in addition to the longer-term trend. The rapid response to rainfall recharge is at odds with the fact that age dating and other data often suggest that there is a substantial time lag anticipated in terms of seeing the effects of land use on nitrates in groundwater. For example, plotting NO_3-N concentrations against cumulative rainfall for the Selwyn - Waihora catchment shows a clear correlation. *Chart based on ECan and NIWA data*

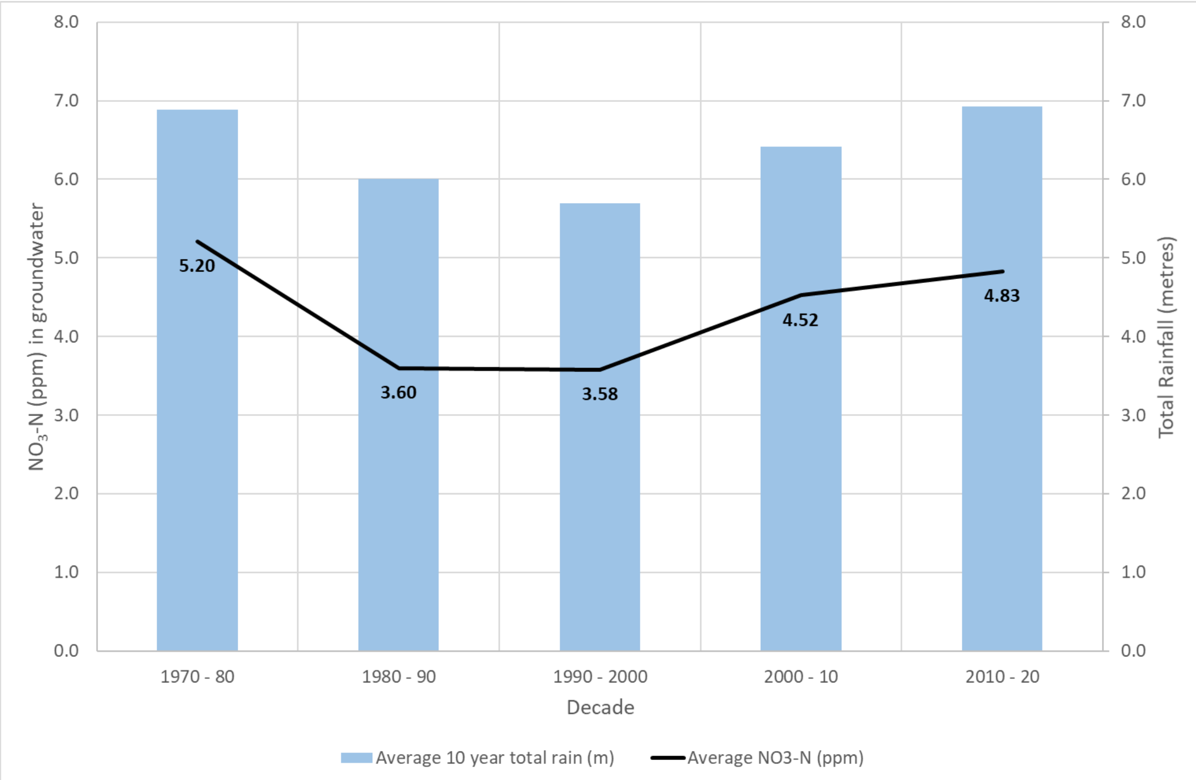

Figure 1 Groundwater NO_3-N concentrations against cumulative rainfall for the Selwyn - Waihora catchment

In late May 2021, Central Canterbury experienced a 1 in 200-year rain-event, with the Ashburton Catchment receiving ≈450 mm over a 4-day period (Carey-Smith, 2021) giving us an opportunity to investigate the short-term nitrate response to a major rainfall event. MHV Water Ltd (MHV) commenced monitoring 56 bores on a weekly basis for a six-week period between 2 June and 9 July. This schedule was then extended to a fortnightly basis, with monitoring still ongoing in August 2021.

It was expected that we would observe a clear increase in NO_3-N concentrations, as would be expected following a major recharge event after a prolonged period of drought. However, after an initial six weeks of monitoring, the results indicated a complex relationship, with NO_3-N concentrations increasing significantly in some areas and decreasing in other. Whilst many bores, at depths of up to 30 m, showed an increase in NO_3-N concentrations, the trend, in terms of direction and magnitude was variable. The lack of a clear pattern with depth/location is likely to be a result of:

- Local point sources vs diffuse sources, including breaching of the Ashburton water treatment plant (Lawrence, 2021);
- Soil properties and sediment properties, including the differing potential for denitrification and preferential flow in the heterogeneous soils and sediments;
- Local hydrogeological heterogeneity and/or anisotropy; and,
- Possible changes in flow regime, as rivers breached banks.

The observed rapid response to rainfall appears at odds with the long-time lags that are anticipated for nitrate-N to move through aquifer system. However, it is analagous to observations in other aquifers (e.g. Foster, 1975) where dual porosity/permability of the aquifer resulted in some solutes being transported through rapid transport pathways, whilst the remainder was transported through the matrix, following a much slower pathway. In Foster's (1975) case, the transport processes were complicated by diffusion between matrix and fractures, depending on the concentration gradient. The geology of the Canterbury Plains aquifer system is similarly complex, with rapid pathways (open framework gravels) within much less permeable matrix-supported sediments (Hanson and Abraham, 2010; Legg, 2021), and solute mass transfer could occur between mobile and immobile facies, resulting in potentially anomalously long mass retention timescales (Wang and Burke, 2017)which is mainly causedby agricultural activities, remains an international problem. It can cause serious long-term environmental and human health issues due to nitrate time-lag in the groundwater system. However, the nitrate subsurface legacy issue has rarely been considered in environmental water management. We have developed a simple catchment-scale approach to investigate the impact of historical nitrate loading from agricultural land on the nitrate-concentration\"trends in sandstones, which represent major aquifers in the Eden Valley, UK The model developed considers the spatio-temporal nitrate loading, low permeability superficial deposits, dual-porosity unsaturated zones, and nitrate dilution in aquifers. Monte Carlo simulations were undertaken to analyse parameter sensitivity and calibrate the model using observed datasets. Time series of annual average nitrate concentrations from 1925 to 2150 were generated for four aquifer zones in the study area. The results show that the nitrate concentrations in 'St Bees Sandstones', 'silicified Penrith Sandstones', and 'non-silicified Penrith Sandstones' keep rising or stay high before declining to stable levels, whilst that in 'inter-bedded Brockram Penrith Sandstones' will level off after a slight decrease. This study can help policymakers better understand local nitrate-legacy issues. It also provides a framework for informing the long-term impact and timescale of different scenarios introduced to deliver water-quality compliance. This model requires relatively modest parameterisation and is readily transferable to other areas. (C. Even without diffusion, the fact that there are different solute pathways, will affect the timing of nitrate transport through the system.

This paper will outline some of the observations from longer term responses, as well as the response to the May rainfall event, as well as consider the broader implications, such as the potential for previously unaccounted diffusion between mobile and immobile porosity, due to changes in the solute concentration gradient (Wang and Burke, 2017) which is mainly causedby agricultural activities, remains an international problem. It can cause serious long-term environmental and human health issues due to nitrate time-lag in the groundwater system. However, the nitrate subsurface legacy issue has rarely been considered in environmental water management. We have developed a simple catchment-scale approach to investigate the impact of historical nitrate loading from agricultural land on the nitrate-concentration\"trends in sandstones, which represent major aquifers in the Eden Valley, UK The model developed considers the spatio-temporal nitrate loading, low permeability superficial deposits, dual-porosity unsaturated zones, and nitrate dilution in aquifers. Monte Carlo simulations were undertaken to analyse parameter sensitivity and calibrate the model using observed datasets. Time series of annual average nitrate concentrations from 1925 to 2150 were generated for four aquifer zones in the study area. The results show that the nitrate concentrations in 'St Bees Sandstones', 'silicified Penrith Sandstones', and 'non-silicified Penrith Sandstones' keep rising or stay high before declining to stable levels, whilst that in 'inter-bedded Brockram Penrith Sandstones' will level off after a slight decrease. This study can help policymakers better understand local nitrate-legacy issues. It also provides a framework for informing the long-term impact and timescale of different scenarios introduced to deliver water-quality compliance. This model requires relatively modest parameterisation and is readily transferable to other areas. (C. We outline what findings might mean and outline the need for more research in this space. If we are failing to account for a store of slow-moving nitrate, then the implications for the future management of our resource and the environment are significant. The issue also raises the question as to what we are sampling when obtaining a groundwater sample for measurement.

Bibliography

Carey-Smith, T., 2021. NIWA calculates 1:200 year flood for parts of Canterbury [WWW Document]. NIWA. URL https://niwa.co.nz/news/niwa-calculates-1200-year-flood-for-parts-of-canterbury (accessed 6.8.21).

Foster, S. S. D. 1975. The Chalk groundwater tritium anomaly — A possible explanation, J. Hydrol., 25, (1), 159–165.

Hanson, C., 2002. Nitrate concentrations in Canterbury groundwater – a review of existing data (No. R02/17). Environment Canterbury (ECan), Christchurch, New Zealand.

Hanson, C., Abraham, P., 2010. Nitrate contamination and groundwater chemistry – Ashburton-Hinds Plain (No. R10/143). Environment Canterbury (ECan), Christchurch, New Zealand.

Lawrence, K., 2021. Sewage mixing with floodwater after Ashburton water treatment plant floods. The Press.

Legg, J., 2021. Ground & Surface Water Sampling 2020 Annual Report. MHV Water Ltd, Ashburton.

MfE & Stats NZ, 2020. New Zealand's Environmental Reporting series: Our freshwater 2020. the Ministry for the Environment & Stats NZ., Wellington, New Zealand.

Wang, L., Burke, S.P., 2017. A catchment-scale method to simulating the impact of historical nitrate loading from agricultural land on the nitrate-concentration trends in the sandstone aquifers in the Eden Valley, UK. Sci. Total Environ. 579, 133–148. https://doi.org/10.1016/j.scitotenv.2016.10.235

THE MOUSE THAT ROARED –

HOW A FARMER LED CO-OPERATIVE IS SPEARHEADING WATER MONITORING ON THE HEKEAO HINDS PLAINS

Brooks, M.,[1] **Legg, J.,[1]**
[1] MHV Water Ltd

Introduction

MHV Water Ltd (MHV) is a farmer owned water co-operative that provides water from the Rangitata Diversion Race to over 200 farm shareholders via 320km of open race and approximately 100km of piped infrastructure, servicing an area of approximately 58,000 ha of the Hekeao Hinds Plains in Mid Canterbury.

In 2016 MHV started monitoring groundwater in their catchment. The farmers recognised the importance of improving their understanding the groundwater following the development of their Sub Regional Plan Change as part of the Canterbury Land and Water Regional Plan. The Plan Change was notified in 2014 and gazetted in 2018. In 2020 following further discussions with farmers, presentations of what the initial modelling had established and the release of the Central Government's 2019 Action for Healthy Waterways Discussion Paper (MfE, 2019), MHV reviewed its existing internal groundwater monitoring program. This paper will outline how a farmer led co-operative is now spearheading the largest collaborative Integrated Water Management Program in Aotearoa.

Development

MHV commenced routine quarterly groundwater monitoring of NO_3-N in 2016. As the initial focus of the programme evolved over time, so had the survey design - resulting in spatial and temporal gaps in the dataset. The revised program was developed on a 2 km bore spacing (based on a WQN10 drawdown assessment (Kaelin, 2015)) as well as Boolean logic in QGIS to consider riparian zones, known contamination sites, lowland springs and drains as well-known areas of elevated NO_3-N (Aitchison-Earl, 2019)

Implementation

Consultation, communication, and collaboration were key to the viability and success of the program. As part of the design and implementation of the program, MHV collaborated with:

Te Rūnanga o Arowhenua	Hekeao Hinds Water Enhancement Trust (HHWET)
Hinds Drains Working Party (HDWP)	Fish and Game
Environment Canterbury (ECan)	Shareholders and Landowners

to ensure that all community, cultural and shareholder interests were addressed.

Outcomes

By March 2021, the monitoring program had developed to 140 bores, ranging in depth from 5 m to 155 m (representing a survey area of 108,300 ha) (Figure 1). The data provided statistical confidence indicating that the NO_3-N concentrations in both shallow and deep groundwater was declining (Figure 2) and on track to meet the ecological target of NO_3-N = 6.9 PPM under Plan Change 2 of the Canterbury Land and Water Regional Plan (Environment Canterbury, 2017).

Of equal importance, the collaborative nature of the program, as well as its size, enabled MHV to respond quickly to the Ashburton flood event in May 2021. Subsequently, MHV was able to monitor 55 bores on a weekly basis once flooding had subsided for during June and then fortnightly through July and August. Results from this work is still pending.

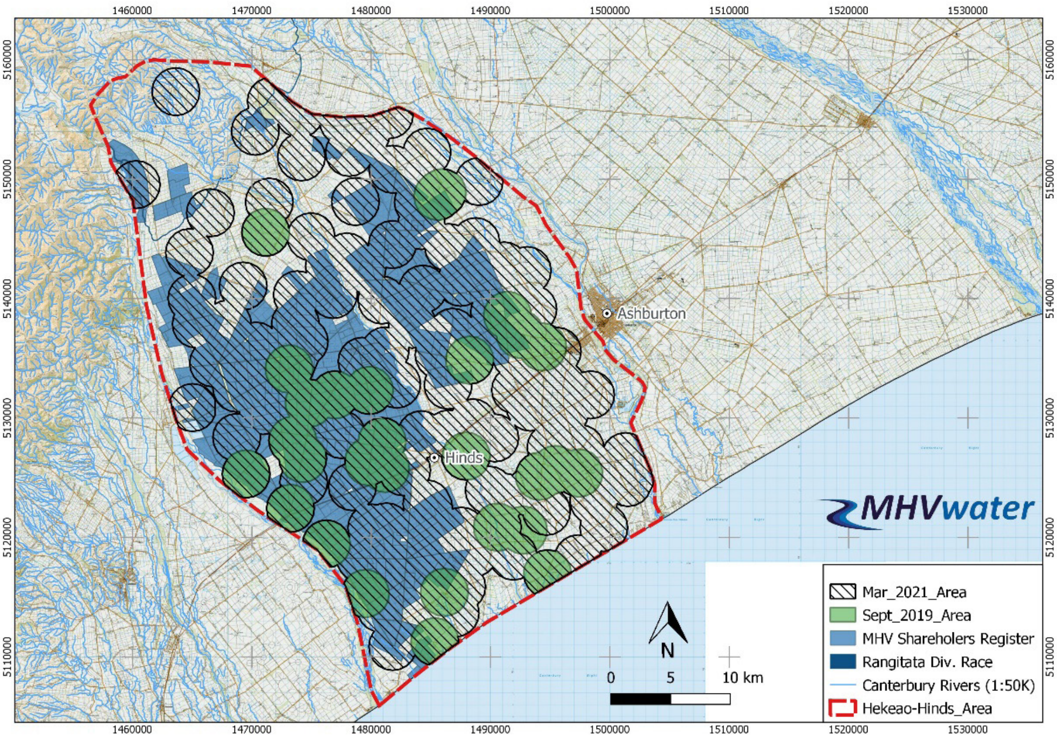

Figure 1 Location of MHV area with 2019 and 2021 groundwater monitoring program area

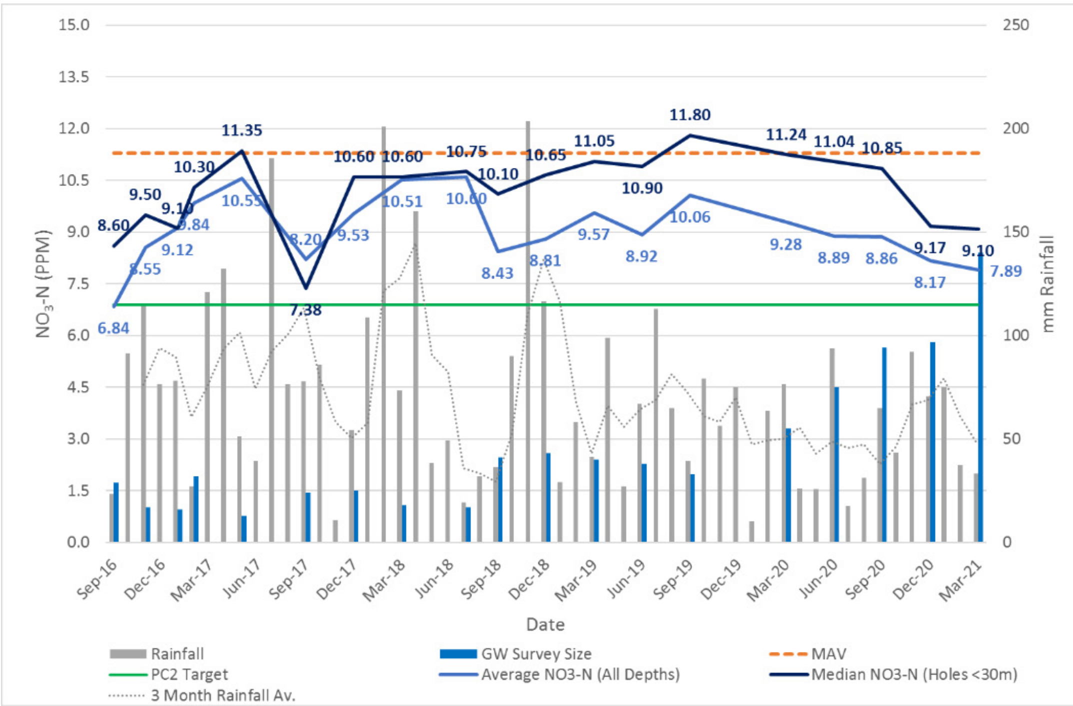

Figure 2 Groundwater NO3-N results for groundwater

Reference List

Aitchison-Earl, P., 2019. Sources of nitrate in groundwater in the Tinwald, Ashburton area (No. R19/85 (PU1C/8628)). Environment Canterbury (ECan), Christchurch, New Zealand.

Environment Canterbury, 2017. Canterbury Land and Water Regional Plan.

Kaelin, N., 2015. Guidelines for analysing and reviewing aquifer tests that support consent applications and/or comply with consent conditions (No. 4921). Environment Canterbury (ECan), Christchurch, New Zealand.

MfE, 2019. Action for Healthy Waterways. Ministry for the Environment, Wellington, New Zealand.

THE GROUNDWATER RESOURCES OF THE DUNSTAN ROHE

Levy, A.,[1] Ettema, M.,[1] Rekker, J.,[1] Yeo, S.,[1]
[1] Otago Regional Council

The Dunstan rohe encompasses the upper catchment of the Clutha Mata-Au river and it holds significant hydrological and economic values for Otago. The rohe includes the upper tributaries of the Clutha Mata-Au and the area downstream of the large lakes of Wakatipu, Wanaka, and Hawea. These catchments contain diverse landscapes such as the rugged Kawarau gorge, the primarily native-covered Shotover catchment, and the extensive agriculture and fruit growing areas around Lake Dunstan.

The rohe's geomorpholoy and hydrogeology has been substantially impacted by extensive glacial and alluvial processes. The rohe includes several basins/Groundwater Management Zones, some of which are divided into smaller aquifers. Most of these are found in alluvial gravels, although there is also a variability in hydrogeological settings, with some aquifers having extensive gravel sequences (e.g. Bendigo) whilst others are narrow alluvial ribbon aquifers (e.g. the Cardrona Alluvial Ribbon Aquifer) [Otago Regional Council (ORC), 2021a]. These aquifers are managed differently, with groundwater takes from alluvial ribbon aquifers included in the surface water allocation. Conversely, the larger aquifers have a separate annual groundwater allocation.

Groundwater use in the Dunstan rohe is high, with 999 completed bores currently registered in ORC's database. Bore depths range between 2.0 and 169.0m. The main groundwater uses are domestic & stock water, irrigation, community supply, and monitoring. There are 238 resource consents to abstract groundwater in the rohe, with a total consented volume of around 89.874 million m^3/year. However, some of the takes are allocated from both groundwater and surface water, hence the volumes are higher. The annual consented volumes range between 4,500 and 8.87million m^3/year.

Groundwater quality is monitored in 16 bores across the rohe. The results suggest that groundwater quality in the rohe is generally good with low E. coli and nitrate concentrations in most bores. However, groundwater quality in some bores reflects the rapid development in some areas of the rohe, which can lead to elevated E. coli, nitrate, and DRP concentrations. Furthermore, arsenic can also be an issue in the rohe, due to the prevalent schist lithology. Although arsenic concentrations in most monitoring bores are below the Drinking Water Standards limits, it is important that bore owners regularly test their water (ORC, 2021b).

The ORC is currently progressing a new Land and Water Regional Plan (LWRP), where groundwater quality and quantity is managed by FMU/rohe. The following challenges for the LWRP are currently being addressed:

1. Improving aquifer conceptual understanding and delineating recharge sources
2. Determining current groundwater use
3. Calculating groundwater recharge volumes and identifying allocation limits
4. Tightening regulatory and non-regulatory measures in order to improve bore security and reduce groundwater contamination risks.

Refereneces

Otago Regional Council. 2021a. Regional Plan: Water. Accessed online. https://www.orc.govt.nz/media/10040/regional-plan_water-for-otago-updated-to-1-june-2021-final-17-june.pdf

Otago Regional Council. 2021b. *State of the Environment Groundwater Quality in Otago.* Prepared by Amir Levy, Marc Ettema, and Xiaofeng Lu. ISBN 978-0-908324-68-2.

QUANTIFYING THE HUMAN IMPACT ON DROUGHT: A CASE STUDY OF THE LINDIS RIVER IN THE CLUTHA CATCHMENT

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[1] University of Otago

Aims

This research aims to investigate the degree to which human water use modifies the magnitude and frequency characteristics of hydrological drought. Drought is a natural hazard but is becoming increasingly aggravated by human actions. Meteorological indices such as the SPI and SPEI are often used to monitor drought as they are readily available and easy to model compared to hydrological data. Therefore meaning they are widely used, but generally these do not directly include the human influence on drought occurrence or magnitude. As such, the focus for this research comes from the difficulty in quantifying the disconnect that exists between drought and human activities. The study location is the Lindis River in the Clutha catchment near Wānaka.

Method

River flow data for the relatively natural upper Lindis (Lindis Peak gauging station) and substantially impacts lower catchment (Ardgour Road) were obtained for the 2006-2019 period), alongside rainfall and air temperature data from the nearest weather station (Wānaka Airport). The meteorological indices explored were the Standardised Precipitation Index (SPI) and Standardised Precipitation-Evaporation Index (SPEI). Potential Evapotranspiration (PET) was calculated using the Hargreaves method. A threshold level method approach was used to identify drought events in the discharge record, with the 95th percentile used to determine the top low river flow events. Comparisons were subsequently made between the characteristics of dry periods identified by the standardised indices and observed river flow records in the upper and lower Lindis River.

Results

The 95th percentile of mean daily river flow at the (upper) Lindis Peak is 1.105 m^{-3} s^{-1}, compared to 0.205 m^{-3} s^{-1} at the (lower) Ardgour Road gauging station. River flow variability at the two study sites correlate strongly in general, but when assessing extreme events there are stark differences in magnitude and length. Ardgour Road experiences fewer but more prolonged drought events compared to Lindis Peak (Table 1). Generally, this was more likely to occur during the summer months (November-April) and matched the long term average trends for monthly river flow.

Table 1) Lindis Peak and Ardgour Rd, with the number of events of low flow, average length of each event and the number of days per event spent below the 95th percentile threshold.

	Lindis Peak	Ardgour Rd
Number of events	29	17
Avg. length of event	10.13	17.25
Avg. number of days per event	9.07	15.11

Drought occurrence represented by <-1 of SPI and SPEI values generally correspond well with low river flow for the Lindis Peak record. However at Ardgour Rd, initial results show that there are substantial differences in the timing and magnitude of low flow events for meteorological indices versus the discharge record. As such, these results suggest that caution is required when using meteorological drought indices as proxies for hydrological drought when there are strong direct anthropogenic impacts on surface water resources such as in the Lindis River.

WATER QUALITY AND SEDIMENT REGIME OF THE PRISTINE HAAST RIVER, NZ

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Aims

To present an overview of the water quality and sediment regime of the near-pristine Haast Awarua River, including dynamics of sediment and contaminants over a large flood event.

Background

There is comparatively little information on the water quality and sediment regime of pristine (or nearly so) rivers from around the world, despite there being good reasons for studying such systems (Larned et al. 2019). Typically, the remoteness and difficulty of access of pristine systems makes their sampling difficult – particularly over episodic storm flows. The Haast Awarua River, south Westland, is one of New Zealand's most pristine rivers, with a catchment almost completely within the Te Wāhipounamu South-West Wilderness world heritage area. The Roaring Billy hydrometric site operated by NIWA has been sampled monthly for 32 years in the National Rivers Water Quality Network (NRWQN, since 1989 ,Davies-Colley et al. 2011) giving a good overall picture of 'baseline' water quality; however, systematic sampling of event flow water quality is not captured as a part the NRWQN sampling strategy. We combined sediment quantity and quality data from a large event (4 February 2020) with data from smaller events (February 2019 and January 2020), and long-term monthly water quality data from the NRWQN to provide a comprehensive picture of the sediment and water quality regime of this near-pristine river and to explore how water quality and particulate load change during stormflows.

Methods

The Haast Awarua River drains 1,020 km2 of conservation land, including the central portion of the Southern Alps. Flow is monitored by level recorder at Roaring Billy (169.298 ºE; 43.943 ºS), 30 km from the Haast township. Water quality (including visual clarity) has been measured monthly at this site (Site GY4 in the NRWQN) since 1989. Since 2014 a turbidity sensor (Forest Technologies, DTS-12) has been operated by NIWA at the Roaring Billy site. Recently we instituted a campaign to install automatic samplers (ISCO 3700C) at the Roaring Billy site ahead of forecast rainstorms and resulting stormflows – to collect samples for sediment-related water quality analyses augmenting monthly sampling. Storm events were intercepted in January 2019, and January and February 2020 (largest).

Auto-samples were analysed at the University of Otago for SSC and turbidity measured via portable handheld units (unit FNU (Hach 2100Q-is) and NTU (Hach 2100P)), and particle size on selected samples by Malvern 3000 laser diffraction analyser, mineralogy by portable XRF, and particle features using scanning electron microscopy. Auto-samples were also analysed in the NIWA-Hamilton laboratory for: light beam attenuation (accurately convertible to visual clarity – Zanevald & Pegau 2003) total nitrogen and total phosphorus ([Standard methods]) and the favoured freshwater faecal indicator *E. coli* by the Colilert® multiwell standard method (IDEXX; APHA9223B). Particle sizing (selected samples) was also done with an EyeTech laser streaming analyser (time-of-transit principle).

Results

Long-term water quality monitoring at Roaring Billy in the NRWQN shows that the quality of this near-pristine river is very high. For example, median total phosphorus is very low at 4 g/m^3 (10th percentile among NRWQN rivers). Nitrate-nitrite-nitrogen is low at 32 g/m^3 (18th percentile) as is total nitrogen at 56 g/m^3. *E. coli* is very low with the lowest median in the NRWQN of (about) 2 CFU/100 mL, apparently reflecting very low catchment densities of feral mammals and birds.

Despite the very high overall quality of the river, the visual clarity is not unusually high (median about 2.25 m) compared to other near-pristine New Zealand rivers (median of medians in NRWQN is 1.3 m). Other near-pristine rivers are generally appreciably clearer (e.g., the Motueka at the Gorge where visual clarity averages about 10 m,Smith et al. 1997)rivers, NZ, optics, clarity, yellow substance, flow</keyword></keywords><dates><year>1997</year></dates><urls></urls></record></Cite></EndNote>. The fine particle content of the river may be attributed to its glaciated headwaters, mostly contributed by the Landsborough tributary.

On the 4th February 2020 event, the SSC concentration reached a peak of 11,900 g/m^3 when visual clarity (as inferred from beam attenuation) would have been only <1 cm. As is frequently observed at Roaring Billy during storm events, peaks in sediment and turbidity occurred after peaks in discharge. This lag of sediment versus flow seems to be typical of forested catchments and contrasts with pasture catchment where sediment tends to ***lead*** flow (Haddadchi & Hicks 2020). The suspended sediment particle size distribution changed only slightly through the storm event, with particles being predominantly fine silt-sized. *E. coli* tended to increase with discharge (r = 0.61), peaking at 813 CFU /100 mL and showing a rather different pattern from SSC and beam-c.

Discussion

By combining targeted sampling of stormflows with long-term water quality monitoring, we have been able to achieve a comprehensive picture of the water quality and sediment regime of the Haast Awarua River. As expected, this near-pristine system has much higher water quality than rivers in pasture or urban land in NZ (e.g., Larned et al. 2016) but suspended sediment is not as low as might otherwise be expected from undisturbed land, apparently owing to glacial flour; this makes the near-pristine Haast River an excellent research site to understand sediment, turbidity, and visual clarity dynamics. *E. coli* and sediment increase strongly with flow, and in much the same way (with similar slope coefficients) as they do in degraded systems. For example, *E. coli* (median ~ 2 CFU/100 mL) is roughly two orders of magnitude lower than in pasture catchments (typical median ~ 300 CFU/100 mL) over the whole flow range – from low baseflow to high flood events. Over a large flood event, water quality of the Haast Awarua River was comparatively poor, with elevated *E. coli,* although still much better than in pasture catchments in flood flow.

References

Davies-Colley RJ, Smith DG, Ward R, Bryers GG, McBride GB, Quinn JM, Scarsbrook MR 2011. Twenty years of New Zealand's National Rivers Water Quality Network: benefits of careful design and consistent operation. Journal of the American Water Resources Association 47: 750-771.

Haddadchi A, Hicks M 2020. Understanding the effect of catchment characteristics on suspended sediment dynamics during flood events. Hydrological Processes 34: 1558-1574.

Larned ST, Moores J, Gadd J, Baillie B, Schallenberg M 2019. Evidence for the effects of land use on freshwater ecosystems in New Zealand. New Zealand Journal of Marine and Freshwater Research 1-41.

Larned ST, Snelder T, Unwin MJ, McBride GB 2016. Water quality in New Zealand rivers: current state and trends. New Zealand Journal of Marine and Freshwater Research 50: 389-417.

Smith DG, Davies-Colley RJ, Knoeff J, Slot GWJ 1997. Optical characteristics of New Zealand rivers in relation to flow. Journal of the American Water Resources Association 33: 301–312.

Zanevald JRV, Pegau WS 2003. Robust underwater visibility parameter. Optics express 11: 2997-3009.

KAITIAKI FLOWS IN THE AWAHOU STREAM CATCHMENT: DEVELOPMENT WITH NGĀTI RANGIWEWEHI AND TRANSLATION TO THE TANIWHA SPRING MUNICIPAL SUPPLY RESOURCE CONSENT

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Introduction

New Zealand environmental legislation and Treaty of Waitangi settlements recognise the value of water to Māori and enable their aspirations for a greater role in water management. However, consequent opportunities for iwi, such as the exercise of kaitiakitanga (guardianship), are hampered by barriers including a lack of established methods to transfer traditional Māori knowledge into policy and less-than-full Māori participation in water management decisions.

Ngāti Rangiwewehi based around Lake Rotorua, in the Bay of Plenty region, are kaitiaki of Awahou Stream and its associated spring complex including the Taniwha Spring (also known as Pekehaua Puna). Stories of the taniwha who made his lair in Taniwha Spring are central to the iwi's traditions and identity (Mohi, 2016).

In 1966, land around Taniwha Spring was acquired by Rotorua County Council (subsequently renamed as Rotorua Lakes Council, RLC), under the Public Works Act 1928, to supply water to Ngongotahā (Waitangi Tribunal, 1991). This action triggered a significant grievance between the iwi and the Crown. The Ngāti Rangiwewehi Claims Settlement Act (2014) aimed to address this grievance. This Act recognised the impact that taking of land under the Public Works Act 1928 had on the iwi and offered an apology.

In 2008, following an Environment Court appeal, RLC was granted a resource consent to take water from the Spring. Since this consent was granted, RLC and Ngāti Rangiwewehi have developed a partnership and in May 2018 RLC and Ngāti Rangiwewehi's Pekehaua Puna Reserve Trust lodged a joint-consent application (with technical support from Pattle Delamore Partners Ltd) for the continued use of the Spring for public supply.

The new Taniwha Spring consent application led the iwi (with support from GNS Science) to develop a 'kaitiaki flow' that addresses the decline in mauri, identified by Ngāti Rangiwewehi since the Taniwha Spring land acquisition, and considers iwi needs such as amenity, environment, food-bearing capacity, spiritual, sustainability and economic needs.

An objective of the joint consent application was the commitment to include new conditions to preserve the kaitiaki flow regime given the significant adverse cultural effects of the water take. Appropriate resource consent conditions ensure that actual or potential adverse environmental effects of an activity (in this case the water take) are appropriately avoided, remedied or mitigated. However, the process to define the kaitiaki flow had not been completed by May 2018.

Method

Three hui were integral to the definition of kaitiaki flow by Ngāti Rangiwewehi and GNS Science. Hui 1 (5 October 2017) marked the start of the project. This hui discussed the importance of Awahou Stream to iwi and whānau, collated iwi feedback on issues associated with the Stream and introduced iwi to the proposed science engagement framework and to the research team (Ngāti Rangiwewehi and GNS Science).

Following field work in the Awahou Spring complex, Hui 2 (9 June 2018) explored iwi preferences for the kaitiaki flow and the regime, that led to the focus group recommending a regime to Hui 3, which identified the preferred regime. The meeting began with discussion of the results from Hui 1 and four themes from iwi and science perspectives: the location of streamflow, streamflow seasonality, streamflow rate and stream water quality. Workshops in Hui 2 sought iwi opinions on each theme using visual media and hydrological data.

Hui 3, which was held on 9 June 2019 at Tarimano Marae, considered the focus-group recommendations and identified a preferred kaitiaki flow and regime. The hui also discussed the potential contents of a Ngāti Rangiwewehi capability plan focussing on future iwi capabilities in water management. The preferred kaitiaki flow and regime were recommended to RLC and Te Pekehaua Puna Reserve Trust for inclusion in the new joint consent. Then, RLC and the Trust, with support from Pattle Delamore Partners Ltd, have worked collaboratively with the Bay of Plenty Regional Council (BOPRC) and GNS Science to develop new consent conditions to take account of the kaitiaki flow.

Results

The preferred kaitiaki flow, agreed at Hui 3, had a moving-minimum mainstem flow that is 90% of the daily-mean naturalised flow and was agreed by RLC and the Trust. The regime included a new, permanent, stage-recording measurement site to be located in the Awahou Stream mainstem at Te Awatere Bridge (downstream of the Taniwha Spring confluence).

The new, proposed consent conditions require installation of this new measurement site. Future actions include BOPRC certification of an initial rating curve for the site and site construction. Consent conditions will require the kaitiaki flow to be preserved at all times, except during water shortage events or temporary emergency situations. The proposed consent conditions have been designed to preserve the kaitiaki flow and ensure that the water supply to Ngongotahā can be maintained.

References

Mohi, G. 2016. Bay of Plenty Regional Council Mātauranga Māori Project: Taniwha Spring, Rotorua case study. Te Maru o Ngāti Rangiwewehi Iwi Authority. Pouwhenua Consultants on behalf of the Ngāti Rangiwewehi Iwi Environmental Unit. 36p.

White PA, Bidois L, Mohi G, Tschritter C, McGrath W. 2020. Derivation of Kaitiaki flow in the Awahou Spring complex. Journal of Hydrology (New Zealand). 59(1), p.63-78.

GROUNDWATER – SURFACE WATER INTERACTION AND NUTRIENT UPTAKE KINETIC INFLUENCES ON DOWNSTREAM WATER COMPOSITION

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Exchanges between stream surface water and groundwater are ubiquitous and have receieved significant and increased attention. However, predicting their dynamics and downstream influences remains challenging. Despite this, we have made significant progress in the last decades towards measuring and understanding catchment-stream linkages and runoff source areas, the magnitudes and variations of groundwater-surface water exchange and its manifestation as hydrologic turnover, and the uptake kinetics of nitrogen, phosphorous, and carbon retention that can additionally modify downstream water composition.

Here, we synthesize stream network scale experimental data and process modeling across multiple catchment environments to highlight some of the key processes important for understanding and managing catchment-stream-groundwater systems. First we highlight dynamic hydrologic connectivity between landscapes and streams that sets streamflow magnitude. Next we document solute tracer based approaches to quantifying stream gains from and losses to groundwater over successive stream reaches. We then present visualizations for how stream-groundwater exchange over successive stream reaches leads to hydrologic turnover and shifting streamwater compositon from upstream to downstream, and finally we present experimental evidence for the influence of in-stream biota and their single and dual nutrient uptake kinetics in influencing downstream water quality. Appreciation of these processes operating in all environments can allow landscape attribution of observed water quality, mitigation of existing degraded water quality, and minimized development and disturbance impacts by supporting enhanced planning.

PROPOSED METHODOLOGY FOR ESTIMATION OF DESIGN FLOWS WITH CLIMATE CHANGE IMPACT: AN APPLICATION TO THE TAIERI RIVER AT OUTRAM

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Aims
To produce flow hydrographs corresponding to specific exceedance probabilities for the Taieri River at Outram which accounts for climate change impact.

Method
Frequency analysis has been carried out on the Taieri River flows at Outram to produce "estimated" flows corresponding to specific exceedance probabilities "design flows" based on historical data. The maximum annual series and the partial duration series have been used in the frequency analysis. Frequency analysis produces only design peak flows, while the whole design flow hydrograph is needed for the proper assessment and management of the Lower Taieri flood protection scheme. Based on an analysis of observed high flow events, the flood event of July 2017 has been selected to produce a relative hydrograph, which is used to produce the whole hydrograph from the peak design flow. A HEC-HMS rainfall-runoff model has been developed for the Lower Taieri catchment downstream of Tiroiti, which has a catchment area of 2292 km2. Flow from the Upper Taieri catchment, which are usually much less than flows of the Lower catchment during large flood events, are input to the HEC-HMS model at Tiroiti. Frequency analysis of Tiroiti peak flows was carried out to produce design flows for the Taieri River at Tiroiti, which will be used as input to the rainfall-runoff model based on the needed design flow at Outram. Design rainfall events, corresponding to historical and needed climate change scenarios have been obtained from NIWA HIRDS software to be applied to the rainfall-runoff model. However, the rainfall-runoff model requires rainfall hyetographs for 10 rainfall sites, and there is no way that all the rainfall sites will have the same return period for the selected design event. A reduction factor is usually applied based on the catchment area, however there is no study to estimate this reduction factor for the Lower Taieri catchment, and it is prudent not to use a reduction factor based on other regions/countries. In this study, the rainfall site which produced a return period for its 48-hr rainfall of the July 2017 which is close to the return period of the peak flow for the July 2017 flow at Outram was selected to represent the Lower Taieri catchment regarding design rainfalls obtained from HIRDS, and rainfalls at other rainfall sites were produced based on their relative hyetographs to this site for the July 2017 event. The rainfall-runoff model was used to produce flow hydrographs corresponding to the design rainfall hyetographs of the historical and the different climate change scenarios. The "relative flow to historical" of these produced design flow hydrographs were applied to the historical design flow hydrographs to produce the "proposed" flow hydrographs corresponding to different climate change scenarios.

Results
The events used for the partial duration series included all peak flows higher than 100 m^3/s, and were carefully investigated to exclude any dependent events. Furthermore, baseflows were separated and an independent frequency analysis was carried for the baseflows and the effective flows. The partial duration series, for either the "independent" effective flows or the base flows of the Taieri River at Outram included 135 events. Results of model testing, as shown in Table 1 in addition to the comparison between the historical and modelled histograms, recommend the choice of the Generalised Pareto "GPareto" distribution. Table 2 shows a summary of the results of the frequency analysis the Taieri River at Outram, showing the design effective flows and their corresponding base flows which will be added to the effective flows to produce the total design flow at Outram. Table 2 also shows the corresponding design flows at Tiroiti which will be used as input to the rainfall-runoff model.

The July 2017 flood event lasted about two days, and thus 48-hr design rainfalls were used to produce the design flows. The return period of the 48-hr rainfall at Nenthorn "21 years" was the closest, among other rainfall sites to the return period of the Taieri peak flow at Outram for the same event "22.9 yrs". Thus, Nenthorn design 48-hr rainfalls for the historical and the different climate change scenarios were obtained from NIWA HIRDS, and were used to produce design rainfall hyetographs at all rainfall sites by using the relative hyetographs to Nenthorn's hyetograph of the July 2017 event. Applying these design rainfall hyetographs corresponding to the historical and different climate change scenarios to the HEC-HMS model, produced flow hydrographs at Outram, which were used to produce ratios of these scenarios' flows to the historical flow. These ratios were applied to the "corresponding" historical design flow hydrograph to produce the design flow with climate change impact for that scenario, as shown in Figure 1 for the case of the 100-yr design flow hydrographs.

Table 1: Goodness of Fit Testing for the Partial Duration Series Frequency Analysis Modelling

Test		Gumbel	GEV	GPareto	Pearson3	Log-Pearson3
Kolmogorov Smirnov Goodness of Fit	Tabulated statistic =	0.117	0.117	0.117	0.117	0.117
	Calculated Value =	0.184	0.094	0.088	0.119	0.064
	Fitted Model is	Rejected	Accepted	Accepted	Rejected	Accepted
Chi 2 Goodness of Fit	Tabulated statistic =	15.52	14.08	14.08	15.52	15.52
	Calculated Value =	172.7	20.2	11.8	7.7	12.4
	Fitted Model is	Rejected	Rejected	Accepted	Accepted	Accepted
Filliben Correlation Coefficient		0.908	0.990	0.993	0.989	0.992

Table 2: Proposed flows for the Taieri River at Outram and their corresponding selected Tiroiti Flows

Return Period (yrs)			Design Flows (m^3/s)			Total Outram Design Flow (m^3/s)
Outram Effective flow	Outram Base flow	Tiroiti Flow	Effective Outram flow	Outram Base flow	Tiroiti Flow	Effective + Base
20	10	15	1531.314	80.74456	443	1612
50	20	35	2247.791	87.44497	522	2335
100	50	75	2952.812	93.7169	522	3047

Figure 1 100-yr Taieri at Outram “proposed” design flows for different Climate Change Scenarios

Note: Sc_4.5_31-50 indicates climate change scenario RCP4.5 for the period 2031-2050

MĀTAURANGA MĀORI AND NUMERICAL GROUNDWATER MODELLING

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Aims

Approaches for combining indigenous sources of knowledge, with other sources of information and scientific methodology, are being developed to improve groundwater management tools. The specific focus of the work described in this paper is in the Bridge Pa area in Hawkes Bay (Figure 1), and involves a local-scale numerical groundwater model and surface and groundwater mātauranga Māori (Maori knowledge). The aim of this combination of groundwater modelling and mātauranga Māori is to give a numerical voice to the concerns of the community, and to explore how community observations of long term changes in the groundwater system can reduce the uncertainty of predictions used to underpin water management decisions.

Methods

The methodology for this work combines five main components; (i) gaining an understanding of the nature of community concerns surrounding groundwater and surface water; (ii) research into the long-term changes in the groundwater and surface water system; (iii) collating all available long-term and recent data to form a conceptualisation of the groundwater-surface water system, and building a numerical model on this basis; (iv) undertaking history matching, predictive simulations, uncertainty quantification analyses, and exploring the extent to which key predictions are reduced by the information in different data; (v) exploring the feasibility of mitigation options in the context of the understanding of the system encapsulated in the model, while acknowledging the remaining uncertainties.

Results

Working with Ngāti Kahungunu over the past two years, including a two-week long hui in Hawke's Bay from March 8th – 19th 2021, has supported learning first-hand of the water resource issues faced by the community at Bridge Pā. A particular concern at Bridge Pā is the progressive reduction in streamflow that has occurred in the Paritua Stream which runs alongside Mangaroa Marae. The timing and frequency of the drying of the stream and unravelling the combination of physical conditions and stressors that lead to these dry stream bed conditions provide the focus of one of the model predictive simulations. Also of concern is the long term lowering of groundwater levels which had led to many of the shallow drinking water wells in the community and at the marae unable to pump from the lowered groundwater levels.

The kōrero (discussions) and mahi (work) around identifying the long-term changes in the groundwater-surface water system has centred around identification and mapping of features and indicators in the wider area Heretaunga Plains area, and around Bridge Pā, that hold significance to local iwi. A database of observations that span both space and time has been developed, including a spring stocktake whereby all known springs have been accurately mapped and identified. This has also involved archival research, working with early maps of the area located at the MTG (Napier Museum), as well as those created for the Māori Land Court hearings in the 1870s. This information is supported by aerial photographs, oral histories, and collectively provides a record of observed behaviour and long-term changes in the groundwater and surface water system.

This long-term information/knowledge encapsulated in mātauranga Māori, has been combined with information provided by Hawkes Bay Regional Council (HBRC) including water flow, water levels and water chemistry data to form a conceptualisation of the groundwater system. This conceptualisation is also supported by recent water age tracer and chemical analyses that confirm that the Paritua Stream is sourced by throughflow from the limestone hills located to the south of Bridge Pā. Geophysical data (Skytem) is being used to better define the basement to the aquifer system.

Shorter term information is being used to explore the more recent declines in groundwater levels in the aquifer around Bridge Pā that have been experienced over the past 20-30 years, which may be associated with the increased abstraction of groundwater. A compounding mechanism may be the large-scale gravel extraction occurring in the area, which might reduce the recharge from the river to the aquifer in that area.

The numerical model has been built to incorporate these and other sources of information about the groundwater and surface water system around Bridge Pa. The model is being used to test hypotheses of the main drivers of the observed groundwater level declines, and changes to the Paritua stream flow at Bridge Pā. We are history matching to four significant points of change in the long-term history of the groundwater-surface water system in the area. These four points of change serve to isolate the major stressors identified over this historical period and comprise the following periods: (i) pre-development (pre 1860), (ii) post drainage (late 1890's), (iii) prior to the large scale abstraction currently occurring (1970), (iv) present day.

Collectively, this work will allow us to better understand the major causes of these issues experienced at Bridge Pā and also to understand what uncertainties remain. This will allow us to formulate an answer to the question of what would it take to restore Paritua Stream at Bridge Pā to what it was? It will also allow us to quantify the uncertainty around the success of restoration measures, as well as determine what further data could help reduce this uncertainty.

Acknowledgments

This work is part of the MBIE-funded 'Te Whakaheke o Te Wai (The Pathways of the Waters)' programme led by GNS.

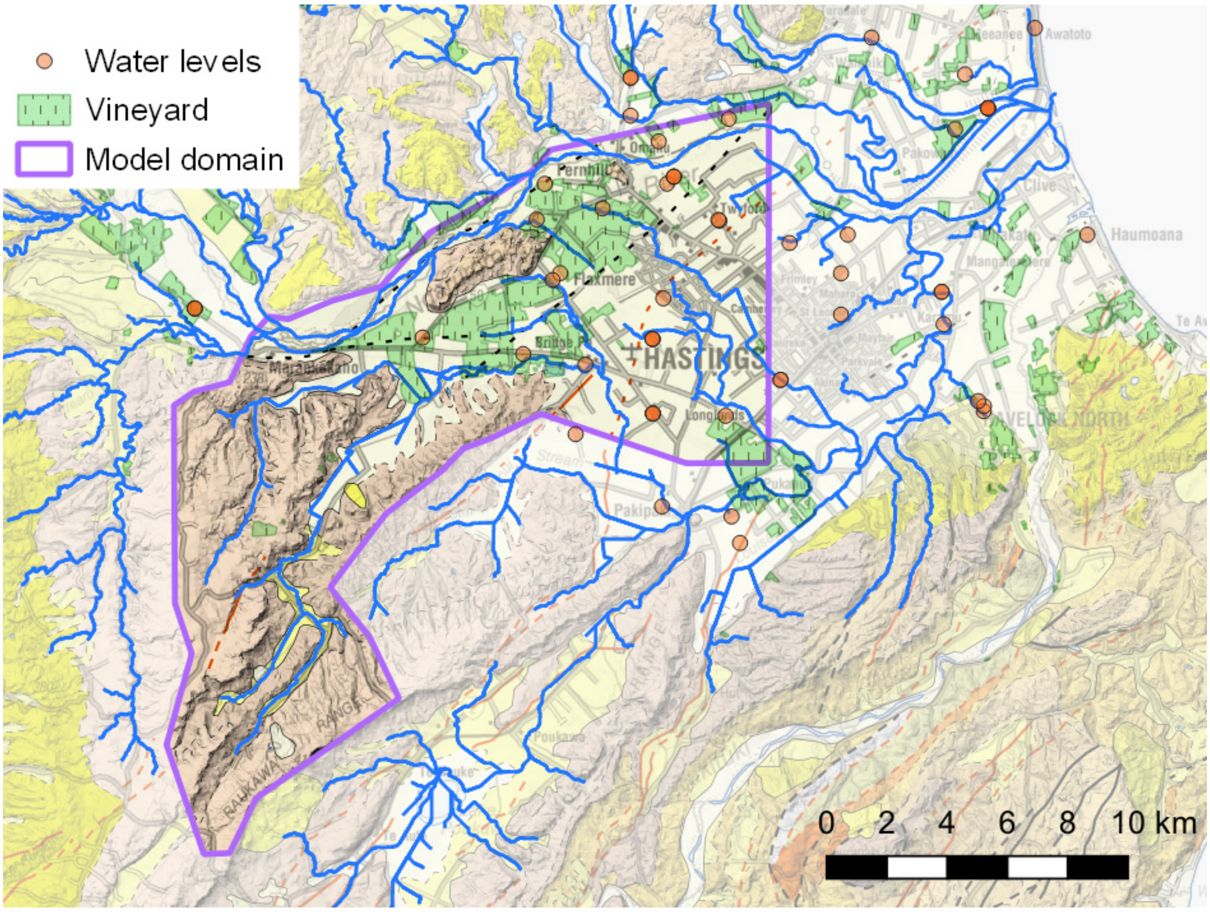

Figure 1. Numerical model domain around Bridge Pa, Hawkes Bay.

UPSCALING OF PARTICLE TRAVEL TIMES IN ALLUVIAL GRAVELS

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Aims

The provision of safe drinking water from alluvial gravel aquifers can be compromised by the presence of connected small-scale open framework gravel (OFG) facies that, because of their exceptional permeability, allow very rapid transmission of contaminants in groundwater. However, upscaling of the connected high-permeability structure of OFG facies to allow the assessments of risks in larger scale field problems remains a computational challenge. Fogg & Zhang (2016) suggest that the challenge of determining the stochastic nature of prediction specific heterogeneity at field scales is likely the biggest stochastic contaminant hydrogeology challenge of all time.

Upscaling refers to the averaging process through which model-cell-scale hydraulic properties are derived from point-scale measurements of hydraulic properties in a way that preserves the validity of the discretised partial differential equations of groundwater flow. Theory shows that this averaging process can only be approximate and is often flow-regime-dependent; see, for example, Zhang et al (2008). This study explores global upscaling to derive field scale descriptions of hydraulic property structure. These field scale hydraulic property structures aim to preserve the effects of connected small-scale open framework gravels on predictions of contaminant transport time.

Methods

We investigate the performance of upscaling options within a Bayesian framework. Firstly, the utility of different methods for deriving upscaled distributions of hydraulic property priors are explored. These upscaled priors are all based on a fine scale categorical geostatistical model of alluvial facies including OFG. This fine scale geostatistical model was derived from detailed lithological logs in the Canterbury plains alluvial aquifer system (Burbery 2017). Secondly, using a global upscaling methodology we derive equivalent field scale parameterisations of the structure of the same alluvial facies, including OFG. The global upscaling method is based on deriving the values of the upscaled hydraulic properties that correspond to observations of cell by cell travel times and head distributions that are generated by a fine scale model. Finally, geostatistical sampling of the upscaled parameter realisations are used to derive both continuous and categorical 'upscaled' descriptions of hydraulic parameter structure.

Results

Distributions of the mean and variance of predictions generated from fine scale and their corresponding upscaled property values are compared over multiple fine-coarse realisation pairs (Fig 1). These comparisons are made for different upscaling measurement constraints, e.g. global upscaling methods conditioned by cell by cell travel times, heads, and the combination of the two, and alternative conditioning measurements such as aquifer drawdown, groundwater tracer data etc. The performance of these different components of the upscaling methodologies are assessed using a range of predictive reliability metrics, including comparisons with large scale tracers present in New Zealand alluvial aquifers.

References

Fogg, G. E., Zhang Y., 2016. Debates—Stochastic subsurface hydrology from theory to practice: A geologic perspective, Water Resour. Res., 52, 9235–9245, doi:10.1002/2016WR019699.

Burbery, L.F., Jones, M.A., Moore, C.R., Abraham, P., Humphries, B., Close, M.E., 2017. Study of Connectivity of Open Framework Gravel Facies in the Canterbury Plains Aquifer using Smoke as a Tracer. Geology and Geomorphology of Alluvial and Fluvial Fans: Terrestrial and Planetary Perspectives. Geological Society, London, Special Publication 440.

Zhang, P., Pickup, G and Christie, M., 2008. A new practical method for upscaling in highly heterogeneous reservoir models. SPE Journal March 2008, 68 – 76.

Acknowledgments

This work is part of the MBIE-funded 'Te Whakaheke o Te Wai (The Pathways of the Waters)' programme led by GNS.

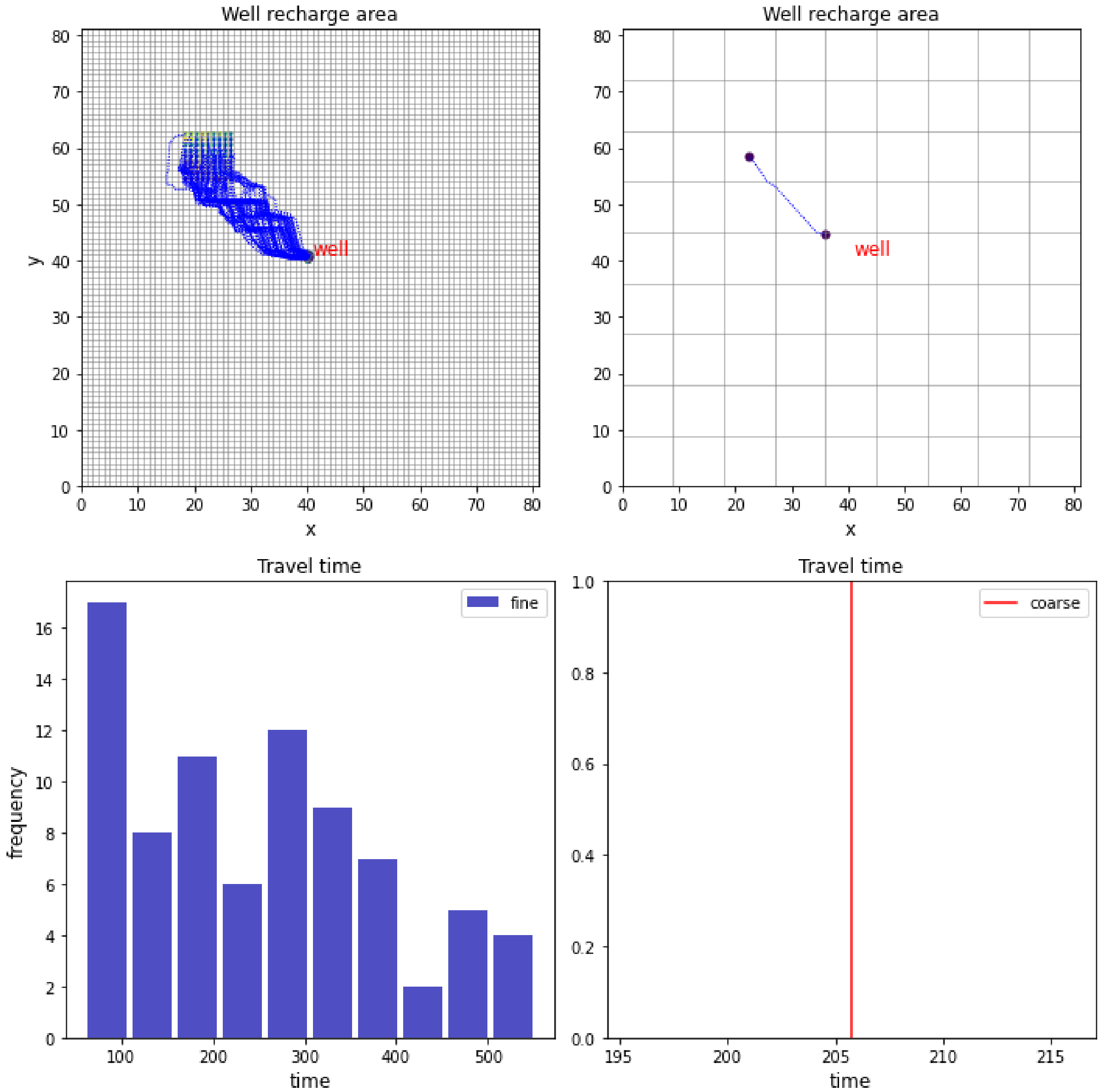

Figure 1. Paired of fine and coarse discretised model simulations of a forward model particle track to a well (top row), and the corresponding travel time distributions for the simulated particle tracks in the fine and coarse discretised models.

BENEFITS AND TRADE-OFFS OF INCREASING RECHARGE MODEL COMPLEXITY WHEN ASSESSING GROUNDWATER ALLOCATION LIMITS

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Aims

The management of groundwater abstraction limits requires an understanding of the sources of recharge fluxes to the aquifer system. Often recharge that results from rainfall percolation through the subsurface is one of the critical recharge fluxes. There are many recharge models available for the calculation of rainfall recharge fluxes. Some of these are more complex, requiring many parameters, that cannot be measured or verified, and are computationally expensive. This makes it difficult to undertake data assimilation (or calibration) and predictive uncertainty processes using these recharge models. Other recharge models are based on more simple and lumped representations of the recharge processes that occur through different soil profiles, with different vegetation. These simpler models often have a greater utility, but may be accompanied by additional 'simplification' induced errors.

Regardless of the method used, the uncertainty of these recharge predictions can be high. However, the question of whether using a more complex recharge model provides benefits, in terms of reducing the uncertainty of the groundwater management question being investigated, is currently not considered. This study aims to demonstrate a workflow that can be used to answer that question, for a particular water management case study in Western Australia.

Methods

We adopt a workflow as described in Doherty and Christensen 2011, where the performance of more complex and simpler models is assessed in terms of the extent to which simpler models may degrade the assessment of the uncertainty of predictions. We use the workflow within the groundwater allocation management context. In this groundwater abstraction limit context, recharge estimates often become part of a groundwater flow model history matching (or calibration) exercise. Therefore, we explore the performance of different recharge models in this context, where both recharge model parameters and groundwater hydraulic parameters are adjusted in order to achieve a good model-to-measurement fit. In this context, the propensity for predictive bias can be evaluated through a paired-model analysis, using the following steps, which involve the definition of a "correct" model and a complementary simple recharge model:

1. Populate a complex recharge model and it's coupled groundwater model with a suite of random parameter fields sampled from the prior parameter probability distribution. Run the coupled recharge-groundwater model under both calibration and predictive conditions using each of these parameter fields.

2. Formulate a calibration dataset derived from each of the complex model parameter sets. History match the simpler recharge and coupled groundwater model parameters to this dataset.

3. Create a scatter plot in which the prediction made by the complex recharge-groundwater models are plotted on the y axis while the predictions made by the complementary simple recharge-groundwater model is plotted on the x axis (Figure 1). Investigate any propensity for predictive bias incurred from adoption of the simpler recharge model.

Results

We apply this methodology to a synthetic representative of Western Australia's groundwater models, particularly those located in the Central West and South-West of Western Australia, where the amount of recharge is a key component of the assessment for water allocation. Using the methodology described above we compare a cell-by-cell Richards' equation-based recharge model, 'WAVES' (Dawes and Short, 1993) that is part of Vertical Flux Manager (VFM; Silberstein et al., 2009) with a series of simpler contender models, including an upscaled version of the VFM-WAVES model, a model that calculates annual gross recharge as a function of annual rainfall by an empirical equation with looked-up coefficients derived by from WAVES (URS, 2008 and 2009), the Farm process of MODFLOW-OWHM (Boyce et al., 2020), and the LUMPREM model (Doherty 2021).

References

Dawes WR and Short DL (1993) The efficient numerical solution of differential equations for coupled water and solute dynamics: the WAVES model. CSIRO Division of Water Resources Technical Memorandum 93/18, Canberra, ACT, http://hdl.handle.net/102.100.100/244379?index=1.

Doherty, J. and Christensen, S., 2011. Use of paired simple and complex models in reducing predictive bias and quantifying uncertainty. Water Resources Research. 47, W12534, doi:10.1029/2011WR010763.

Doherty, J., 2015. Calibration and uncertainty analysis for complex environmental models. Published by Watermark Numerical Computing, Brisbane, Australia. 227pp. ISBN: 978-0-9943786-0-6. Downloadable from www.pesthomepage.org.

Doherty, J. (2021). LUMPREM. A Simple Lumped Parameter Model for Unsaturated Zone Processes. Watermark Numerical Computing. Downloadable from https://pesthomepage.org/documentation.

Boyce SE, Hanson RT, Ferguson I, Schmid W, Henson W, Reimann T, Mehl SM and Earll MM (2020) One-Water Hydrologic Flow Model: A MODFLOW based conjunctive-use simulation software. U.S. Geological Survey Techniques and Methods 6–A60, 435pp, doi: 10.3133/tm6a60.

Silberstein R, Barr A, Hodgson G, Pollock D, Salama R and Hatton T (2009) A vertical flux model for the Perth groundwater region. Hydrogeological Record Series no. HG33, Department of Water, Perth, Western Australia, accessed August 2020, <https://www.water.wa.gov.au/__data/assets/pdf_file/0003/4494/89217.pdf>.

URS (2008) Peel-Harvey Coastal Groundwater Model WA: Conceptual Model. Report prepared for CSIRO, URS Australia P/L, Perth, WA, 102pp.

URS (2009) Peel-Harvey Coastal Groundwater Model WA: Calibration and Validation. Report prepared for CSIRO, URS Australia P/L, Perth, WA

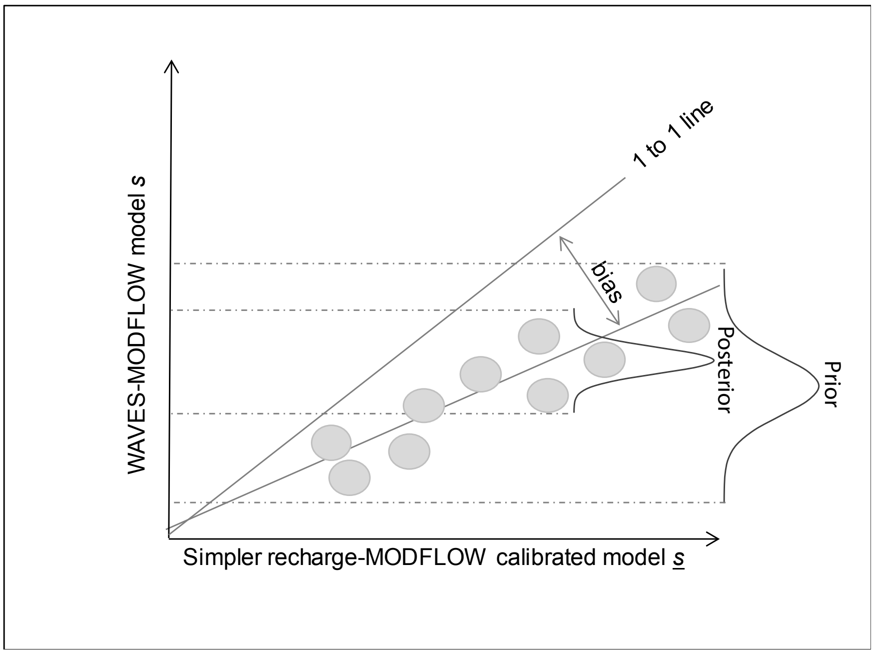

Figure 1. Comparison of predictions made on the basis of a complex recharge model and a simpler recharge model; based on Doherty (2015).

COLLABORATIVE DEVELOPMENT OF A NATIONAL HYDROGEOLOGICAL MAP: STARTING AT THE COAST, USING DEPOSITIONAL FACIES TO ATTRIBUTE PROPERTIES

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Aims

Hydrogeological maps are purpose-built resource management tools that integrate geology, aquifer properties, groundwater quality and quantity information (Gleeson et al. 2014). The "National Aquifer Mapping and Characterisation" project aims to provide a nationally-consistent approach for mapping aquifers. This approach is based on the current level of understanding of aquifers and on eight hydrogeological system types: coastal basin, coastal volcanic, coastal independent, inland basin, inland volcanic, inland river valley, basement infill and basement hard rock (Moreau et al. 2019). This paper presents the first step of mapping hydraulic properties of the coastal systems. These coastal systems (244 in total nationwide) can be divided into three main sub-categories (coastal basin, coastal volcanic, coastal independent (Moreau et al. 2019). Mapping integrates the geological depositional facies and is to be completed in consultation with regional experts to ensure the produced maps will be fit-for-purpose. This project is resourced through the MBIE Science Strategic Investment Funding (2019-2024) and integrates outputs from other aligned projects.

Method

The first step was to consider the geological depositional environments of the coastal systems and to identify similar types. The Hydrological System map (Moreau et al. 2019), the 1:250,000 geological map (QMAP, Heron et al. 2014) and the Hydrogeological-unit map (White et al. 2019) were utilised for this purpose. The next step aimed to (i) select a representative area for each coastal aquifer system type; and (ii) develop a 3D facies map. Mapping involves the use of local (e.g. borehole records), sub-regional (e.g. 3D geological model) or national datasets (e.g. depth to hydrogeological basement map; Westerhoff et al., 2019). The assignment of hydraulic properties to facies will be based on aquifer test results, lithology and or literature values. Representative 3D maps will then be utilised to inform the mapping of other coastal aquifer systems of the same type. The mapping approach will be recorded in a guideline document, will list useful datasets and incorporate new information as it become available (e.g., airborne electromagnetic data).

Results to date*

Twelve coastal aquifer system types were identified (Figure 1) For instance, the Wairau Plain was selected for the "Fluvial Fault Depression" type. The different coastal aquifer systems have also been classified according to these 12 types and representative areas have been selected. 3D facies mapping is now underway for four representative areas: Wairau Plain (Fluvial Fault Depression), Heretaunga Plains (Fluvial-Open Plain), Aupouri Peninsula (Coastal Dunes), Wellington Harbour (Fluvial-Open Plain).

References

Gleeson T., Moosdorf N., Hartmann J., van Beek L. P. H. 2014. A glimpse beneath earth's surface: GLobal Hydrogeology MaPs (GLHYMAPS) of permeability and porosity. Geophysical Research Letters, 41(11):3891-3898

Heron D. W., (Ed). 2014. Geological Map of New Zealand 1:250 00, 1DVD containing digital vector data + all 21 QMAP texts as PDFs, GNS Science, Lower Hutt.

Moreau M., White P.A., Mourot F., Rawlinson Z., Tschritter C., Cameron S.G., Westerhoff R. 2019. Classification of New Zealand hydrogeological systems. Lower Hutt (NZ): GNS Science. 28 p. (GNS Science report; 2018/35). doi:10.21420/42QW-MC74.

Westerhoff RS, Tschritter C, Rawlinson ZJ. 2019. New Zealand groundwater atlas: depth to hydrogeological basement. Lower Hutt (NZ): GNS Science. 19 p. Consultancy Report 2019/140.

White, P.A.; Moreau, M.; Mourot, F.; Rawlinson, Z.J. 2019 New Zealand Groundwater Atlas : hydrogeological-unit map of New Zealand. GNS Science. 89 p. (GNS Science report; 2019/144).

* early August 2021

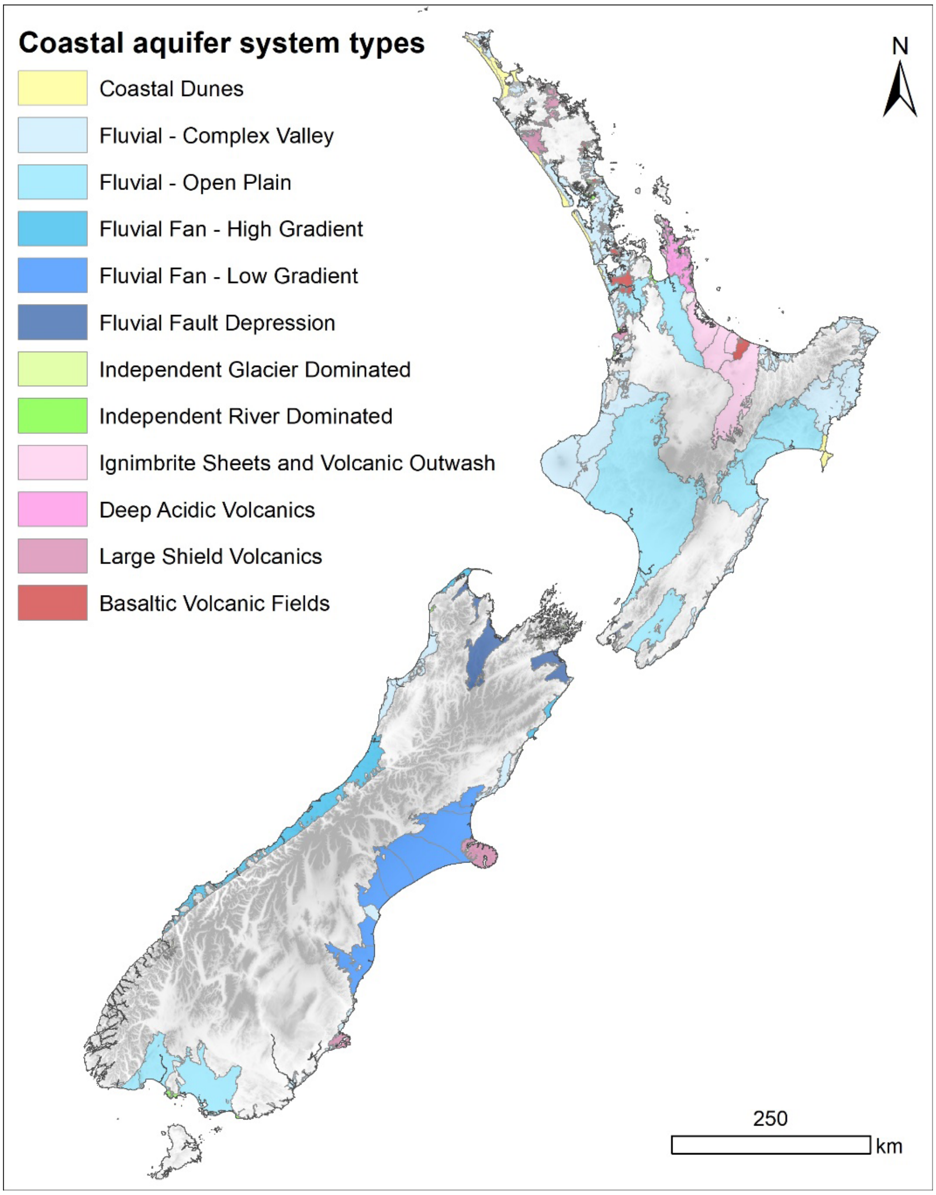

Figure 1:Spatial distribution of coastal aquifer system types.

GROUNDWATER DYNAMICS AND HYDROCHEMICAL EVOLUTION AS INFERRED FROM THE WEST COAST REGIONAL AGE AND CHEMISTRY TRACER DATA

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Aims

Following the NPS-FM 2020, which underpins the importance of meeting target attribute states set in the National Objectives Framework (Ministry for the Environment 2020), one of West Coast Regional Council (WCRC)'s tasks is to improve water quality and ecological health where required. This study aims to holistically describe the flow sources, pathways and lags of water moving through catchments and aquifers of the West Coast region. This information is required to ground truth improved groundwater models and management tools in order to prevent land use degradation of rivers and aquifers that impact on cultural values, drinking water supplies, agriculture and tourism. This study is co-funded through the MBIE Envirolink fund (C05X2005) and the MBIE Endeavour programme 'Te Whakaheke o Te Wai'.

Method

Groundwater chemistry and age tracer data were assembled from a range of sources: national datasets (groundwater monitoring programme, national tracer survey); regional datasets (State Of the Environment monitoring and site investigations); historical data from the Water Dating laboratory, and samples collected in March 2020 as part of this study. The aggregated dataset consisted of groundwater chemistry collected at 97 bores, two springs and one river spanning from 1998 to March 2020.

The spatial distribution of environmental tracers (age, isotopes, temperature, gas and chemistry) was combined to graphical analysis (e.g. Piper diagram) and hierarchical cluster analysis to obtain a better understanding of the groundwater flow and hydrochemical processes in the aquifers of the West Coast region.

Results to date

West of the Alpine fault, which is the focus of this study, short (less than 8 years) residence times are typical. Three geographically distinct hydrochemical signatures are consistent with topography and geological distinct areas (Figure 1): pristine, alpine foothills (Cluster A); impacted coastal or fluvial (cluster B1 and B2) and dilute valley with signs of human-impact (cluster C1, C2 and C3).

In the Grey Valley, which coincides with the largest use and demand, the variability in groundwater age tracers and chemistry is likely to reflect heterogeneous connections between successive gravels which make the valley floor with in places strong interaction with surface waters (Mourot and White 2020). Where age dating was repeated, the available data was not sensitive enough to identify impact on groundwater circulation from the increased groundwater demand between 2012 and 2017 (West Coast Regional Council 2014). It is expected from the age dating results that any chance in resource management may be rapidly picked up in future monitoring data.

References

Ministry for the Environment. 2020. National Policy Statement for Freshwater Management 2020. Wellington (NZ): New Zealand Government. 70 p.

Mourot F, White PA. 2020. Groundwater quantity allocation limitsfor the West Coast Region: case study in the Upper Grey River Freshwater Management Unit.Lower Hutt (NZ): GNS Science. 32p. Consultancy Report 2020/125.

West Coast Regional Council. 2014. Regional Land and Water Plan. Greymouth (NZ): West Coast Regional Council. 282 p.

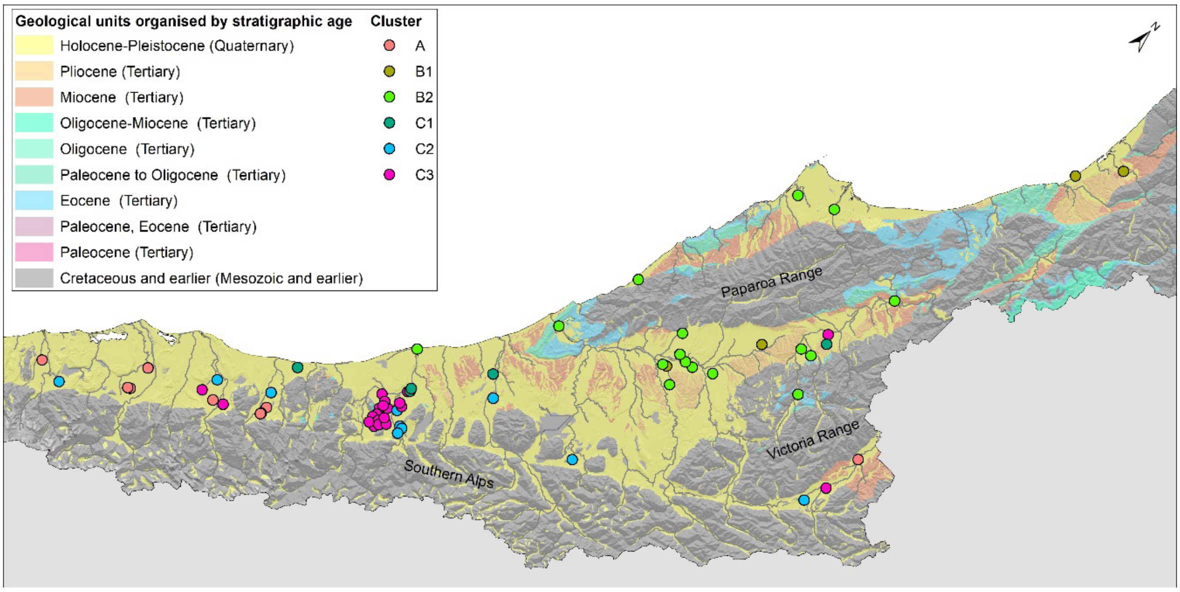

Figure 1:Geographic distribution of sites assigned to clusters using Hierarchical Cluster Analysis.

THERE IS MORE THAN MEETS THE EYE TO LONG-TERM ENVIRONMENTAL MONITORING PROGRAMMES

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Aims

Effective monitoring programmes address clear questions, use consistent and accepted methods to produce high-quality data and are connected to research programmes to ensure both continual use of the data and rapid integration of emerging issues (Lovett et al. 2007). Data generated by such programmes provide unique insights and can be used for multiple purposes beyond environmental reporting.

Recent reports (Ministry for the Environment 2019; Parliamentary Commissioner for the Environment 2019) have outlined some issues in our environmental monitoring data particularly around moving across monitoring scales (e.g., consistency in indicators, legacy networks, lack of overarching strategy). In addition, this essential part of environmental science is often regarded as outdated, operational and expensive.

This study will expose, through specific worked examples, the strong connection between long-term environmental monitoring, legislative requirements, operative plans and emerging research, that is essential to maintain when considering optimisation. It will also celebrate decades of coordinated work across teams that have significantly contributed to our understanding of Aotearoa, demonstrating that long-term monitoring can be adaptive, leading-edge and cost-effective.

Method

Three monitoring programmes were selected to represent a range of environmental domains and monitoring scales. For each programme, a specific aspect unique to long-term environmental monitoring but transferable between domain is demsontrated:1) the value of the duration of the record to uncovered natural processes (Rotorua Geothermal System, RGS monitoring); 2) the ability to test-drive methods through a range of environmental setting and gained insight on temporal variability (National Groundwater Monitoring Programme, NGMP) and 3) the impact of policy implementation and technological innovation on urban air quality observed through the Auckland Council air particulate matter speciation programme (Air Particulate Matter).

Results

The RGS monitoring was established in 1982 in response to the waning of Rotorua's surface geothermal features and supported the Government enforced bore closure programme in 1987. Later monitoring data was subsequently reported and reviewed at regular short-term intervals and as a synthesis less frequently. The 2021 review commissioned by BOPRC brought together over 30 years of monitoring along with aspects of past and on-going research to inform a review of the Regional Plan (Scott et al. 2021). Unprecedented observations were enabled by the length and consistency of the monitoring record which triggered rethinking of the geothermal field dynamics and highlighted opportunities to optimise the monitoring network.

Age dating at NGMP sites started in 2005 and attained national coverage in 2009. Since then, repeated measurements are rotated between sites at a lower frequency than chemistry sampling to remain cost-effective. Together with State of the Environment regional data, the long-term chemistry and age records enabled the elucidation of the effect of extreme drought on the groundwater quality directly linked to changes in the well's contributing recharge area (Moreau et al. 2016). This led to the development of a new age tracer model (Binary Mixing Model) which now commonly used.

Air particulate matter sampling and compositional analysis was initiated across five urban monitoring sites in Auckland from 2004 to identify and apportion the sources contributing to urban air pollution (Davy et al. 2020). The observed spatial variability in source contributions has been used to assess the human health impacts of motor vehicle emissions (from traffic density and proximity to major roadways) that was extrapolated to the rest of New Zealand, while the temporal trends have shown that motor vehicle engine technology improvements lead the way to reduced tailpipe emissions. However, despite the introduction of a National Environmental Standard for wood burners and associated media campaigns, air pollution resulting from domestic fire use appears to be slowly increasing in Auckland. Meanwhile, the trends observed for the natural background of oceanic generated aerosol suggests that Southern Hemisphere circulation patterns are changing over Auckland, likely to be linked to climate variability.

References

Davy PK, Trompetter WJ. 2020. Composition, sources and long-term trends for Auckland air particulate matter: summary report. GNS Science Consultancy Report 2019/151. 32 p. + appendices.

Lovett G. M., Burns D. A., Driscoll C. T., Jenkins J. C., Mitchell M. J., Rustad L., Shanley J. B., Likens G. E., Haeuber R. 2007. Who needs environmental monitoring? Front. Ecol. Environ. 5(5):253-260

Ministry for the Environment and Stats NZ. 2019. New Zealand's Environmental Reporting Series: Environment Aotearoa 2019. 125p.

Moreau, M.; Morgenstern, U.; Davidson, P. 2016 Changes in groundwater age and source during drought conditions and connections between surface water and groundwater in the Lower Wairau Valley, New Zealand. abstract 2214 IN: Groundwater and society : 60 years of IAH : 43rd IAH Congress, September 25-29th 2016, Montpellier, France. International Association of Hydrogeologists

Parliamentary Commisioner for the Environment. 2019 Focusing Aoteara New Zealand's environmental reporting system. 100p.

Scott, B.J.; Kissling, W.M.; Moreau, M.; Sajkowski, L.; Burnell, J.G.; Brakenrig, T.; Reeves, R.R. 2021 Assessing the Rotorua Geothermal System : a review of data sets. GNS Science consultancy report 2020/84. 101 p.

GROUNDWATER RECHARGE SOURCE IN THE HERETAUNGA PLAINS SOUTH OF ROYS HILL

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Aims

To enable improved groundwater resource management tools, the Endeavour funded 'Te Whakaheke o Te Wai' research program aims to explore the origin and duration of groundwater flow pathways. For the Heretaunga Plains groundwater system south of Roys Hill, declining water levels and flow depletion of the Paritua Stream called into question the existence of Ngaruroro River recharge into the aquifer through the passage south of Roys Hill. Our initial data suggested absence of river recharged groundwater in this area (Morgenstern et al., 2017).

Methods

We used the isotope, dissolved gas, and hydrochemistry signature of the groundwater to identify its recharge source in this area. Coastal rain and rivers from inland catchments have contrasting stable isotope and chemistry signatures, groundwater from local rain versus river recharge have contrasting excess air concentrations, land use activities cause elevated nitrate concentrations in locally rain recharged groundwater compared to river water from pristine catchments, and contrasting geology between catchments causes contrasting hydrochemistry in their water discharges.

A radon survey of the Ngaruroro River, together with flow measurements, was used to identify losing and gaining stretches of the river. The contrast between high radon concentrations in groundwater and low concentrations in surface water allows the identification of fresh groundwater discharges into the river, as indicated by elevated radon concentrations in the river water.

Results

During summer 2021 we collected groundwater samples from 12 shallow wells in the area south of Roys Hill to robustly identify the recharge source of the groundwater. All independent indicators were found to have signatures inconsistent with those of river water. Elevated chloride concentrations in the groundwater indicate near-coastal local rain as recharge source; elevated magnesium and calcium concentrations are inconsistent with low concentrations of river water from the greywacke dominated catchment; high excess air indicates recharge from local rain; the stable isotope signature of the groundwater is inconsistent with the high-altitude river catchment water signature; and elevated nitrate concentrations in the groundwater contrast to low river water nitrate concentrations. A summary of recharge source indications is shown in Figure 1. Mean residence times of the groundwaters are between 6 and 19 years.

High river water radon concentrations upstream of Roys Hill indicate that the Ngaruroro River is gaining flow in this area. This is consistent with flow gauging performed on the same day which shows increasing surface flow up to Roys Hill. These measurements indicate the river does not lose water into the groundwater system in this area.

Collectively, all these results, from independent techniques, consistently indicate the Ngaruroro River does not contribute measurably to groundwater recharge in the area south of Roys Hill.

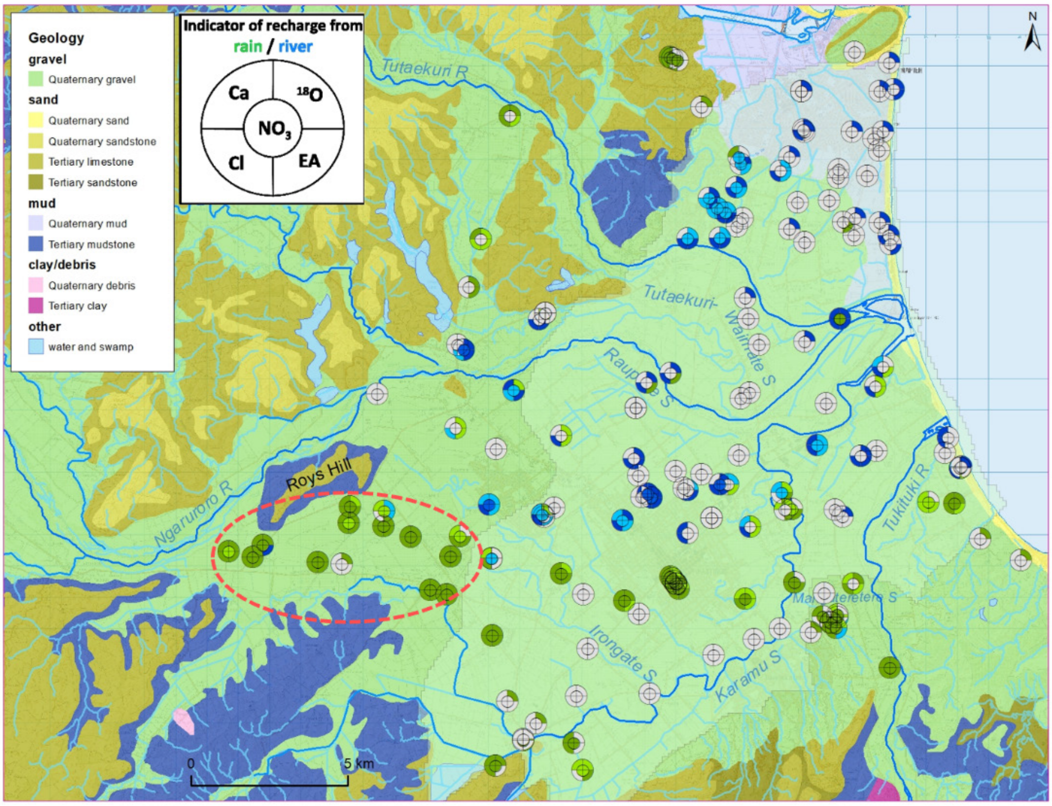

Figure 1: Groundwater recharge source Indicators. Circle segments in green represent local rain recharge, and in blue represent river/stream recharge source. Darker colours indicate stronger evidence. Red ellipse indicates study area south of Roys Hill.

References

Morgenstern U, Begg JG, van der Raaij RW, Moreau M, Martindale H, Daughney C, Franzblau R, Stewart M, Toews M, Trompetter V, Kaiser J, Brown L, Gordon D. 2017. Heretaunga Plains Aquifers: Groundwater Dynamics, Source and Hydrochemical Processes as Inferred from Age and Chemistry Tracer Data. Lower Hutt (NZ): GNS Science. 50 p. (GNS Science report 2017/33). doi:10.21420/G2Q92G.

Acknowledgments

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PROVIDING A RESILIENT GROUNDWATER SUPPLY FOR OUR CAPITAL CITY

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Aims

The groundwater resource of the Lower Hutt Valley, sourced from the artesian Waiwhetu Aquifer, provides up to about 40% of the annual water supply for the greater Wellington metropolitan area. This can increase to 70% on a daily basis during summer when rivers are low.

The Lower Hutt Valley, a sedimentary basin formed by tectonic subsidence and infilled by Te Awa Kairangi/Hutt River valley fluvial system, has been one of the most intensively investigated aquifer systems in New Zealand over the last half century because of its water supply importance of the city. The infill sequence contains three distinct gravel aquifers - the Taita (unconfined), Waiwhetu (the public water supply source) and the Moera aquifers. The basin begins at Taita gorge and extends under the Wellington harbour as far as the harbour entrance. The conceptual understanding of the basin continues to evolve, particularly with respect to the nature of the aquitard above the Waiwhetu Aquifer and offshore hydrogeology.

Greater Wellington Regional Council (GWRC) and Wellington Water Limited work together through a newly-established collaborative 'Hutt Aquifer Management Team' to co-ordinate management of the resource. Principal management criteria relate to water supply security, saline intrusion risk, long-term climate change impacts, risks to changes in aquifer recharge and flow dynamics due to modifications to the Hutt riverbed morphology, seismic risk to supply infrastructure, and potential risks of activities in the wellfield capture zone. The ongoing Wellington Water 'Gear Island and Waterloo Wells Replacement Project' is focussed on optimising use of the resource and enhancing infrastructural and supply resilience. This is a multi-million dollar project in response to the 2017 aquifer contamination investigation that identified significant vulnerabilities not reflected in the Hutt Aquifer Model v3 (HAM3) conceptual model. To date the project included a range of geological and hydrogeological investigations to fill information gaps – such as the construction of six fully cored geological exploration and multi-level monitoring bores (including 4 new sites upstream of the wellfield), investigating the supplementary supply potential of the deeper Moera aquifer, construction of new multi-level saline intrusion bores on the Petone foreshore, down-hole and surface geophysics, water age dating and isotope analysis. Wellington Water/GWRC completed a drilling project in Wellington Harbour in 2018 to improve understanding of the offshore extension of the groundwater system and enhance understanding of saline intrusion risk.

These investigations are currently feeding into the development of a Leapfrog 3D geological model that will support the construction of a new Hutt Aquifer numerical groundwater flow model - HAM5. Unlike the previous HAM3 and HAM4 models (Gyopari 2014, 2018) which were flow models only (the latter being a dual density flow model focussing on the sub-harbour aquifer), the HAM5 model will have a broader flow and solute transport scope. It will inform the wellfield replacement project and be used to optimise abstraction, design a sentinel water quality monitoring system and assist management of water quality and water safety risks. HAM5 will fully incorporate predictive uncertainty and adopt a different a more advanced modelling framework, but will build on prior knowledge and model learnings.

Methods

The proposed HAM5 modelling framework comprises the development of three components:

- A Database model,
- Predictive scenario analysis, and
- Operational tools.

The Database model will be a deterministic, 'history-matched' (or 'calibrated') numerical groundwater flow model that will act as a starting point for subsequent predictive simulations. It will incorporate information from previous revisions of the Hutt Aquifer Model, as well as additional information collected since. The basis of the Database model will be a three-dimensional hydrostratigraphic model of the Lower Hutt aquifer (Begg, 2021). The numerical model flow is proposed to be developed in MODFLOW 6 with history-matching/parameter estimation conducted using PEST (Doherty, 2010).

Predictive scenario analysis will be used to support decisions about important issues required from resource operators and managers, such as optimisation of production well placement with respect to aquifer yield, saline intrusion, drawdown and contamination constraints. The simulated scenarios are intended to "expose the uncertainties of decision-critical predictions" (GMDSI, 2021) and reduce those uncertainties where possible. To do this, A multi-model prediction-specific rapid model-build framework is proposed to be developed, using tools such as ***FloPy*** (Bakker et al., 2016) and ***PEST++*** (White et al., 2020a). The predictive scenarios will comprise a suite of 'child' models that are based on the Database model but with refinements particular to the predictions of interest. Predictive simulations may also be used for data assimilation and validation of the Database model.

Operational tools provide model results in a context useful for both resource operators and resource managers. Wellington Water currently uses tools developed from previous iterations of the Hutt Aquifer Model as part of their daily operations. These tools are founded on relationships between river flows, aquifer recharge, groundwater abstraction rates and drawdowns observed in numerical model outputs and are used to assist in the optimisation of water yield from the Hutt Aquifer. The evolution of these operational tools will incorporate predictive simulation outputs (e.g., stochastic impulse-response emulators, White et al, 2020b) developed as part of HAM5 to assist with real-time management of this precious resource.

Greater Wellington's Senior Groundwater Scientist, Rebecca Morris, will discuss the complexities involved with managing the Hutt Valley groundwater resource and collaborative approach taken to understand the highly dynamic aquifer system. Dr Jeremy Bennett will explain the proposed modelling framework for HAM5, including methods for numerical modelling of groundwater flow and transport under uncertainty. He will also describe how the outputs of HAM5 are intended to be used by resource operators and managers.

References

Bakker, M., Post, V., Langevin, C.D., Hughes, J.D., White, J.T., Starn, J.J., Fienen, M.N., 2016. Scripting MODFLOW Model Development Using Python and FloPy. *Groundwater* 54, 733–739. https://doi.org/10.1111/gwat.12413

Begg, J.B. 2021. *New 3-D geological model (Leapfrog) the for the lower Hutt-Port Nicholson groundwater basin.* In preparation for Wellington Water Ltd and Greater Wellington Regional Council.

Doherty, J., 2010. *PEST, Model-Independent Parameter Estimation,* 5th ed. Watermark Numerical Computing, Brisbane, Australia.

Groundwater Modelling Decision Support Initiative, 2021. *A Manifesto for Decision-Support Groundwater Modelling* [WWW Document]. URL https://gmdsi.org/about/manifesto/

Gyopari, M. 2014. *Lower Hutt Aquifer Model (HAM3): Sustainable Management of the Waiwhetu Aquifer.* Report for Bulk Water Division, Greater Wellington Regional Council.

Gyopari, M. 2018. *Wellington Harbour Exploration Bores Project. Hydrogeological Analysis of SP1a Exploration Phase: Abstraction Feasibility Assessment & Recommendations (HAM4 model).* Prepared for Wellington Water Limited.

White, J.T., Hunt, R.J., Fienen, M.N., Doherty, J.E., 2020a. Approaches to highly parameterized inversion: PEST++ Version 5, a software suite for parameter estimation, uncertainty analysis, management optimization and sensitivity analysis (*Report No. 7-C26), Techniques and Methods*. Reston, VA. https://doi.org/10.3133/tm7C26

White, J.T., Knowling, M.J., Fienen, M.N., Feinstein, D.T., McDonald, G.W., Moore, C.R., 2020. A non-intrusive approach for efficient stochastic emulation and optimization of model-based nitrate-loading management decision support. *Environmental Modelling & Software* 126, 104657. https://doi.org/10.1016/j.envsoft.2020.104657

POTENTIAL IMPACTS OF CLIMATE CHANGE ON GROUNDWATER: CASE STUDIES IN OTAGO AND HAWKE'S BAY

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Aim

Increased emissions of greenhouse gases in the atmosphere have led to a changing climate on Earth. In New Zealand (NZ), changes vary according to the location and are predicted to continue over the next decades (Ministry of the Environment, 2018). Changes in climate (e.g., rainfall frequency, intensity, temperature) impact on freshwater bodies' hydrology. Over the last decades, research has focused on surface water, and less on the impacts of climate change on groundwater, mainly due to the complexity of processes involved (Moseki 2018). Yet, groundwater has the potential to "buffer" the impacts linked to increased climate variability and provide resilience to climate change in the communities (Clifton et. al., 2010). This study provides key information on potential impacts of climate change on groundwater to inform decision making and support adaptation and resilience to climate change using NZ case studies.

Method

The first stage was to select potential case study areas. The main criteria were (i) availability of a recent NIWA climate change projections; (ii) contrasted results covering both the North and South Islands; and (ii) good knowledge of the hydrogeological settings of the region.

The second stage involved collation of climate projection data[1] and methodology development to assess the potential impacts of rainfall and temperature changes on regional aquifers and groundwater receiving environments[2]. Mean annual and seasonal data were input into GNS' National Groundwater Recharge Model (Westerhoff et. al, 2018b) and National Equilibrium Water Table Model (Westerhoff et. al., 2018a) to infer potential changes in groundwater recharge and water table elevation. Changes in groundwater discharge to surface water were also investigated. Within each region, individual catchments were studied to explore potential impacts on local aquifers and groundwater specific receiving environments.

Results

The Otago and Hawke's Bay regions were selected as case studies; climate change projections are described by Macara et al. (2019) and Fedaeff (2017). Change in groundwater recharge (Figure 1), water table elevation and discharge to surface water were assessed for RCP4.5 and RCP8.5 scenarios, for mid and end-century.

In Otago, changes are contrasted region-wide (Figure 1), with for instance increased recharge and higher water table for the western ranges and coastal margins and reduced recharge and lower water tables in Central Otago. Local case study of catchments (Cardrona and Shag rivers catchments), indicate mixed results (e.g., both increases and decreases in groundwater recharge), depending on the location within the catchment.

In the Hawke's Bay, groundwater recharge and water table elevation are projected to mostly decrease, with more pronounced changes in the western ranges and less changes in the coastal and large valley systems.

For both regions, changes are more significant for the RCP8.5 end of century scenarios. The reduction in groundwater recharge is larger in Hawke's Bay than for Otago, with the difference up to approximately 1 mm/day. Similarly, decreases in water table elevation are more widespread and greater in Hawke's Bay, compared to Otago.

[1] Climate change projections for rainfall and temperature from the 1986-2005 period to mid-century (2031-2050 period) and end-century (2081-2100 period) for two representative concentration pathways (RCP): RCP4.5 (stabilised emissions) and RCP8.5 (high emissions) scenarios were kindly provided by NIWA.

[2] this assessment does not consider anthropogenic effects (e.g., irrigation, abstraction).

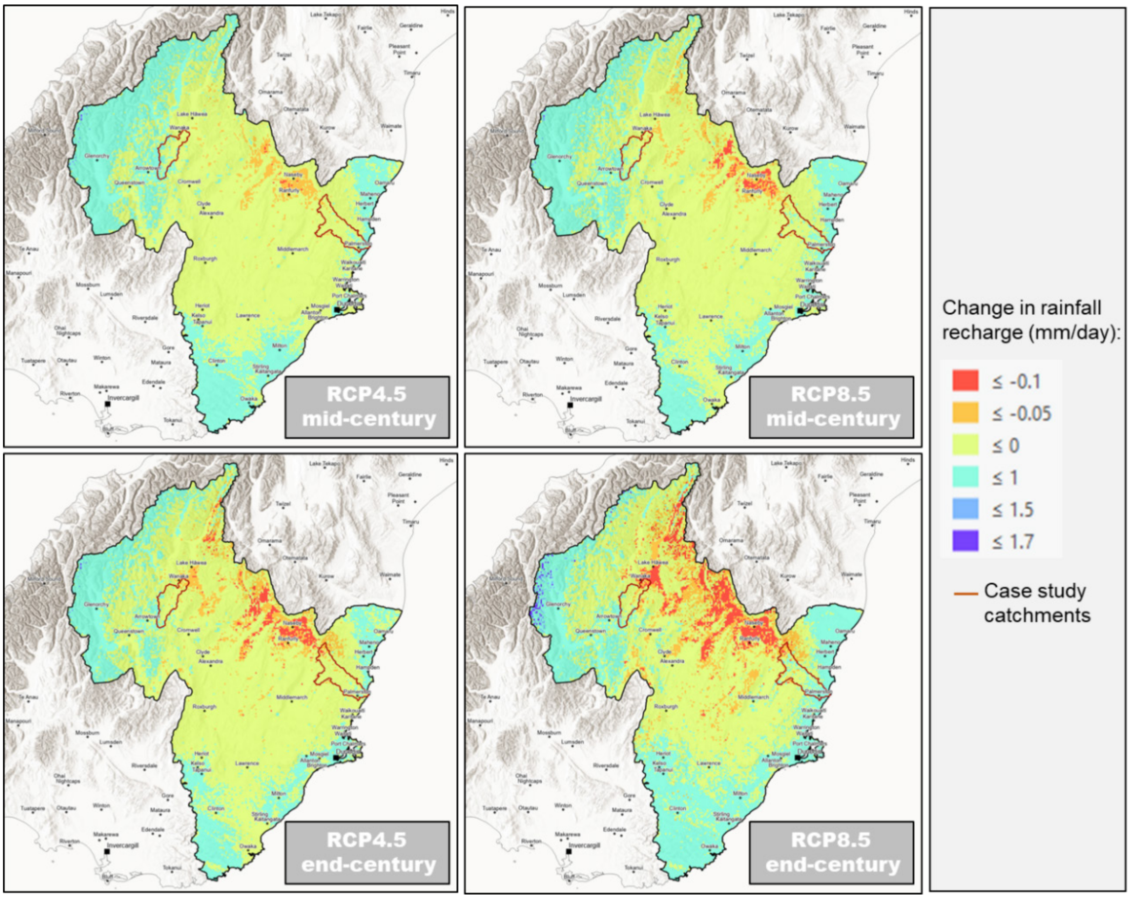

Figure 1: Changes in groundwater recharge for the Otago Region from 1986-2005 to mid century (2031-2050) and end-century (2081-2100) for RCP4.5 and RCP8.5, stabilised emissions and high emissions scenarios, respectively. Estimates based on NIWA's projected seasonal mean rainfall and temperature changes*.
Negative values indicate decreased rainfall recharge and positive values increased rainfall recharge.

References

Clifton C, Evans R, Hayes S, Hirji R, Puz G, Pizarro C. 2010. Water and climate change: impacts on groundwater resources and adaptation options. Water Work notes 25. 76 p.

Fedaeff N. 2017. Hawke's Bay Climate Change Projections. Auckland. 28 p.

Macara G, Woolley JM, Zammit C, Pearce P, Stuart S, Wadhwa S, Sood A, Collins D. 2019. Climate Change Projections for the Otago Region. Auckland: NIWA. 136 p.

Ministry for the Environment 2018. Climate Change Projections for New Zealand: Atmosphere Projections Based on Simulations from the IPCC Fifth Assessment, 2nd Edition. Wellington: Ministry for the Environment.

Moseki MC. 2018. Climate change impacts on groundwater: literature review. Environmental Risk Assessment and Remediation. 02. doi:10.4066/2529-8046.100033.

Westerhoff R, White P, Miguez-Macho G. 2018a. Application of an improved global-scale groundwater model for water table estimation across New Zealand. Hydrology and Earth System Sciences. 22(12):6449–6472. doi:10.5194/hess-22-6449-2018.

Westerhoff R, White P, Rawlinson Z. 2018b. Incorporation of Satellite Data and Uncertainty in a Nationwide Groundwater Recharge Model in New Zealand. Remote Sensing. 10(1):58.

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COMBINING REMOTE SENSING AND IN-SITU MONITORING DATA TO INFORM WATER ALLOCATION IN AFFORESTED CATCHMENTS

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Aim

Understanding the potential effects of afforestation on water quantity has become crucial in the context of climate change and increasing water scarcity issues. The processes involved are complex and involve the water, energy and water cycles (Ellison et al., 2017). In New Zealand (NZ), afforestation is highly promoted (e.g., One Billion Trees Programme) to help the nation to meet its carbon emission targets (He Pou a Rangi the Climate Change Commission, 2021). This study follows on the literature review on the potential effects of afforestation on the water yields (stream flows and groundwater recharge) and regional-scale hypothetical models of Mourot et al. (2020). It aims to complement this work by ground-truthing theorical scenarios and combining local in-situ monitoring and remote sensing data. The overall purpose is to improve the understanding of the impact of afforestation on catchments' water quantity to inform allocation limits.

Method

The Mangahahuru Stream (Northland) and Oraka Stream (Waikato) catchments were monitored for the following parameters: rainfall, stream flow and afforestation for over 30 years. There were no sites available providing groundwater level data.

In both catchments, three types of analyses were then undertaken:

i The NZ Land Cover Database (LCDB; LCDB.v5, 2019) and the Global Forest Change dataset (Hansen et al., 2013) were used to investigate land use changes;

ii Stream flows were decomposed into baseflow and quickflow, using digital filtering (Eckhardt, 2005). Rainfall, total stream flows and baseflow were then analysed for trend;

iii Remote-sensed data (both from UAV imagery captured as part of this study and from satellite imagery) was used to assess groundwater recharge. The NZ Groundwater Recharge Model (Westerhoff et al. 2018) was utilised with an approach using vegetation indices and evapotranspiration estimates, similar to Mourot et al. (2019).

Findings were combined with the literature review of Mourot et al. (2020) to make recommendations to the regional councils in term of water allocation limits and environmental monitoring.

Results

The case study catchments exhibit contrasting characteristics, e.g. size, climate, geology, slope, percentages of forest cover. The Mangahahuru Stream catchment (at County Weir) has an area of 2,122 ha and had an exotic forest cover up to c. 80 % in 2008. The Oraka catchment (at Pinedale) is larger (13,268 ha) and has more diverse land uses, with a maximum exotic forest cover of c. 46 % in 2012. In both catchments afforestation mainly occurred between 2001 and 2008 (LCDB.v5, 2019). Stream flow timeseries indicate clear correlations to rainfall for the Mangahahuru Stream (Figure 1), but not for the Oraka catchment. In the later, the baseflow component is larger and longer timelags are inferred.

Based on satellite data, Mourot et al. (2020) observed larger evapotranspiration (ET) rates over forests compared to grassed areas. As part of this study, we have noted more significant differences between forests and harvested areas: estimated differences in ET over different LCDB time windows (1996, 2001, 2008, 2012, 2018) were up to c. 14% and 11 % of the 1980-2019 mean flow for Mangahahuru and Oraka catchments, respectively.

Both the processes linked to climate and forests are interlinked and untangling these effects on catchments' water balance still requires further investigations to be fully understood. In this presentation we will yet mention our "best recommendations" regarding water allocation in afforested catchments, based on our work.

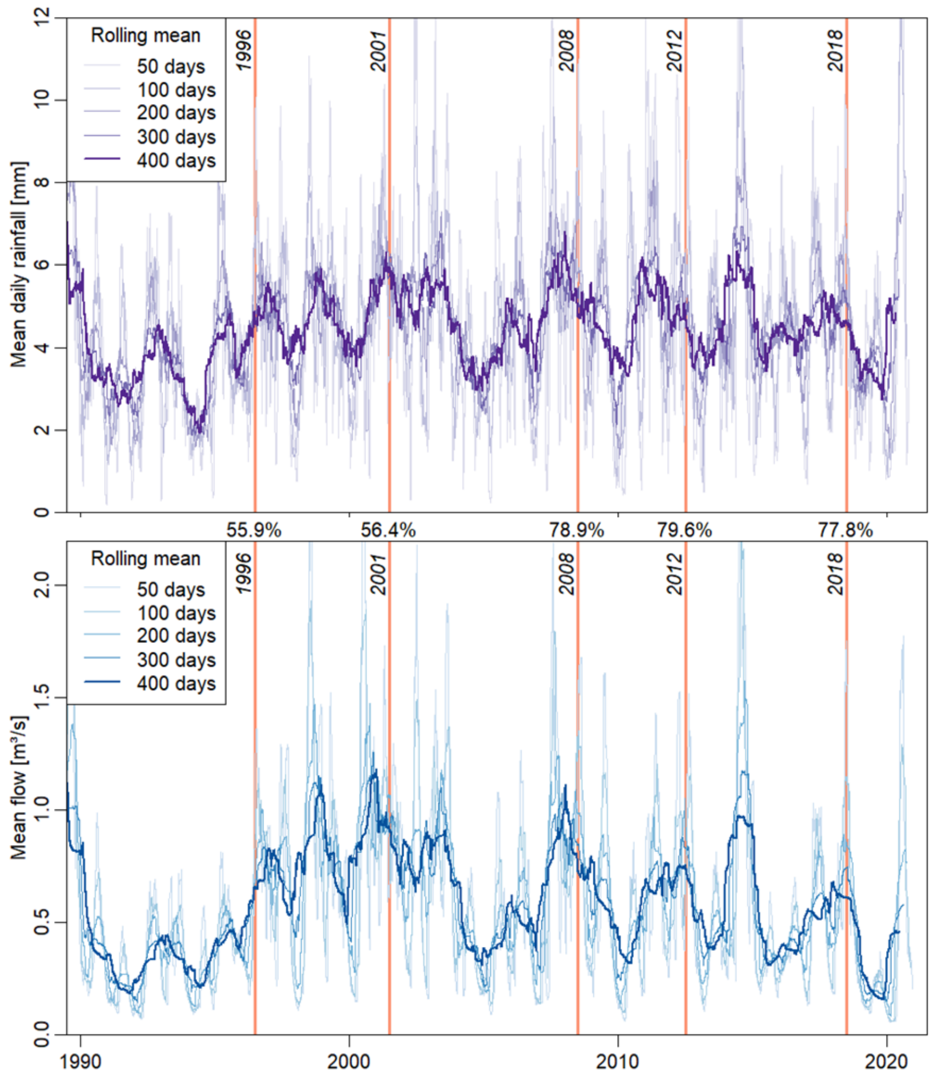

Figure 1 - Rolling mean values for rainfall (top) and stream flow (bottom) for the Mangahahuru Catchment (Northland) between 1990-2020. The values labelled on the stream flow chart represent the percentage of exotic forest cover in proportion to the catchment total area, according to the LCDB dataset.

References

Eckhardt K. 2005. How to construct recursive digital filters for baseflow separation. Hydrological Processes. 19(2):507-515. doi:https://doi.org/10.1002/hyp.5675.

Ellison D, Morris CE, Locatelli B, Sheil D, Cohen J, Murdiyarso D, Gutierrez V, Noordwijk Mv, Creed IF, Pokorny J, et al. 2017. Trees, forests and water: Cool insights for a hot world. Global Environmental Change. 43:51-61. doi:https://doi.org/10.1016/j.gloenvcha.2017.01.002.

Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, Tyukavina A, Thau D, Stehman SV, Goetz SJ, Loveland TR, et al. 2013. High-resolution global maps of 21st-Century forest cover change. Science. 342(6160):850-853. doi:10.1126/science.1244693.

He Pou a Rangi the Climate Change Commission. 2021. Ināia tonu nei: a low emissions future for Aotearoa. Wellington: He Pou a Rangi Climate Change Commission. 418 p.

LCDB v5.0 - Land Cover Database version 5.0, Mainland New Zealand. 2019-. Revision 19. Lincoln (NZ): Landcare Research. [updated 2020 Jan 29; accessed 19/05/2020].

Mourot F, Westerhoff R, Macdonald N, Cameron S. 2019. Better spatial characterisation of evapotranspiration and rainfall recharge estimates to groundwater using remote sensing multispectral techniques at lysimeter sites. Lower Hutt (NZ). 82 p.

Mourot F, Westerhoff RS, Cameron SG. 2020. Effects of afforestation on groundwater recharge: Perspectives for New Zealand in relation to the One Billion Trees Programme. Wairakei, NZ: Science G. 97 p.

Westerhoff R, White P, Miguez-Macho G. 2018. Application of an improved global-scale groundwater model for water table estimation across New Zealand. Hydrology and Earth System Sciences. 22(12):6449-6472. doi:10.5194/hess-22-6449-2018.

CHANGES IN SUSPENDED SEDIMENT LOADS UNDER FUTURE CLIMATE SCENARIOS FOR NEW ZEALAND

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Aims

Accelerated soil erosion is a significant environmental and economic issue both nationally and internationally, leading to increased fine sediment loads in receiving environments and significant costs due to production losses and storm damage to land and infrastructure (Basher et al 2020, Dominati et al 2014; Wood & Armitage, 1997). Fine sediment is a major contaminant in New Zealand waters, with high sediment loads adversely affecting the structure and function of aquatic ecosystems (Buendia et al 2013).

Climate change is expected to have a direct impact on soil erosion through changes in the frequency and magnitude of rainfall events, leading to altered fine sediment loads entering rivers and receiving environments. The 2020 amendment to the National Policy Statement – Freshwater Management (NPS-FM 2020) saw the introduction of suspended fine sediment as an attribute regional councils will now be required to manage. Planning catchment management strategies to achieve objectives related to fine sediment will therefore require councils to consider the likely impact of climate change on erosion processes. To date, there has been no published quantitative assessment of national-scale changes in fine sediment loads anticipated under climate change in New Zealand.

We present a modelling framework to quantify the potential impact of climate change on catchment suspended sediment loads at national scale.

Method

To model suspended sediment loads under climate change it is important to recognise the contribution of different erosion processes to sediment loads and how these erosion processes are differentially affected by climate change. Mass movement, surficial erosion, and riverbank erosion are the dominant erosion processes contributing to fine sediment loads in New Zealand rivers, and their contributions vary spatially (Trustrum et al 1999; Basher 2013; Spiekermann et al. 2017). Mass-movement erosion processes such as shallow landsliding are dominant in soft rock pastoral hill country in New Zealand (Eyles, 1983), while surficial erosion processes dominate hillslope-derived loads in lowland terrain (Basher et al 2020).

We created three erosion process domain classes (Table 1) based on the Erosion Terrains layer (Dymond et al 2010) to define the spatial variation in dominant erosion sources across the country. The New Zealand empirical erosion model (NZeem, Dymond et al 2010) is used to obtain baseline (1971-2005) mean annual catchment total sediment loads for all process domains. In soft rock hill country and lowland terrains, the RUSLE model, adapted by Donovan & Monaghan (2021) to account for livestock grazing impacts in New Zealand, is used to estimate baseline sediment loads from surficial erosion. The surficial erosion loads are differenced from the NZeem total loads to estimate bank erosion loads in the lowland domain (where mass movement is expected to be negligible) and mass movement loads in soft rock hill country (where mass movement erosion tends to dominate longer-term loads, e.g., Trustrum et al, 1999). Loads from hard rock and mountain steepland are represented by NZeem.

The effects of future climate change on soil erosion and suspended sediment loads are modelled

following the approach of Basher et al. (2020) and Manderson et al (2015). Changes in mean annual rainfall erosivity drive changes in surficial erosion, and changes in storm magnitude and frequency drive changes in mass movement erosion. We improve on previous work by including changes in riverbank erosion, driven by changes in mean annual flood magnitude (Smith et al 2019).

Changes in sediment load are estimated for mid-century and end-of-century for four forcing scenarios (RCPs) from the IPCC AR5 (IPCC 2013) using dynamically downscaled regional climate models (RCM) derived from six CIMP5 global climate models (GCMs) by Ministry for the Environment (2018).

Table 1: Erosion process domains used to represent the spatial extent of erosion processes and determine the models used to produce baseline and future loads.

Erosion Process Domain	Erosion Processes	Load Derivation	Climatic Driver
Mountains and Hill Country – Hard Rock	Hillslope	NZeem	Δ Mean Annual Rainfall
Hill Country – Soft Rock	Mass Movement	NZeem - RUSLE	Δ Storminess
	Surficial	RUSLE	Δ Mean Annual Rainfall
Lowland	Bank Erosion	NZeem - RUSLE	Δ Mean Annual Flood
	Surficial	RUSLE	Δ Mean Annual Rainfall

Results

Gridded estimates of the proportional change in surficial erosion, riverbank erosion, and mass-movement erosion have been produced at national scale, showing distinct regional responses in soil erosion to climate change. Suspended sediment loads are modelled along the REC2 digital river network and projected to mid-century and end-of-century under future climate scenarios. Results are summarised and presented at catchment to national scale.

References

Basher, L.R., 2013. Erosion processes and their control in New Zealand. In *Ecosystem services in New Zealand – conditions and trends*, edited by Dymond, J.R. Lincoln, New Zealand: Manaaki Whenua Press: 363-374.

Basher, L., Spiekermann, R., Dymond, J., Herzig, A., Hayman, E., and Ausseil, A-G. 2020. Modelling the effect of land management interventions and climate change on sediment loads in the Manawatū–Whanganui region. *New Zealand Journal of Marine and Freshwater Research*, 54: 490–511.

Buendia, C., Gibbins, C.N., Vericat, D., Batalla, R.J. and Douglas, A., 2013. Detecting the structural and functional impacts of fine sediment on stream invertebrates. *Ecological indicators*, 25: 184-196.

Dominati EJ, Mackay A, Lynch B, Heath N, Millner I 2014. An ecosystem services approach to the quantification of shallow mass movement erosion and the value of soil conservation practices. *Ecosystem Services* 9: 204–215.

Donovan, M. and Monaghan, R., 2021. Impacts of grazing on ground cover, soil physical properties and soil loss via surface erosion: A novel geospatial modelling approach. *Journal of Environmental Management*, 287: 112206.

Dymond, J.R., Betts, H.D., Schierlitz, C.S. 2010. An erosion model for evaluating regional land-use scenarios. *Environmental Modelling and Software*, 25: 289–298

Eyles, G.O., 1983. The distribution and severity of present soil erosion in New Zealand. *N.*

Z. Geogr., 39: 12–28

East, A.E. and Sankey, J.B., 2020. Geomorphic and sedimentary effects of modern climate change: current and anticipated future conditions in the western United States. *Reviews of Geophysics*, 58(4), 2019RG000692.

IPCC. 2013. Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY: Cambridge University Press.

Manderson, A., Dymond, J., Ausseil, A-G. 2015. Climate change impacts on water quality outcomes from the Sustainable Land Use Initiative (SLUI). *Horizons Report No. 2015/EXT/1451*. Palmerston North: Horizons Regional Council.

Ministry for the Environment 2018. Climate change projections for New Zealand: atmosphere projections based on simulations from the IPCC fifth assessment. 2nd ed. Wellington:Ministry for the Environment.

Smith HG, Spiekermann R, Dymond J, Basher L (2019) Predicting spatial patterns in riverbank erosion for catchment sediment budgets. *New Zealand Journal of Marine and Freshwater Research* 53: 338-362.

Spiekermann, R., Dymond, J., Betts, H., Marden, M. 2017. SedNetNZ modelling of sediment sources and loads in the Northern Hawke's Bay Region. *Manaaki Whenua – Landcare Research Contract Report LC2815* prepared for Hawke's Bay Regional Council.

Trustrum, N.A., Gomez, B., Page, M.J., Reid, L.M., Hicks, D.M. 1999. Sediment production, storage and output: the relative role of large magnitude events in steepland catchments. *Zeitschrift für Geomorphologie N.F. Supplement* 115: 71–86.

Wood, P. J., and Armitage P.D. 1997. Biological Effects of Fine Sediment in the Lotic Environment. *Environmental Management,* 21(2): 203–217.

IDENTIFICATION OF METHANE-DRIVEN DENITRIFYING MICROBIAL COMMUNITIES FROM AN ALLUVIAL GRAVEL AQUIFER USING RNA-SIP AND HIGH-THROUGHPUT SEQUENCING

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Aim

To identify the microbial communities capable of methane driven denitrification in aerobic groundwater. In addition, to determine whether denitrification was enhanced in microaerobic conditions.

Methods

To investigate the potential for methane driven denitrification, we collected biomass from an alluvial gravel aquifer in Canterbury and used this biomass to inoculate two packed bed column reactors loaded with glass beads and operated under aerobic (98% air, 2% CH_4) and microaerobic (2% O_2, 2% CH_4, 96% N_2) conditions. Each reactor was continuously recirculated with nitrate mineral salt containing 10 mM nitrate to provide a nitrate source. Secondary carbon compounds (metabolites) produced during the methane oxidation and used to drive nitrate removal (via denitrification) in the reactors were identified using HPLC. Anoxic batch experiments were performed with the carbon compounds.

For the labelling experiments, anoxic batch experiments were set up by inoculating with biofilm samples from both packed-bed reactors, supplemented with the exogenous compounds labelled with (heavy) ^{13}C to confirm the secondary carbon compounds involved in the nitrate removal process. At set time intervals, samples were taken and centrifuged to separate the heavy/labelled RNA. The RNA was extracted, fractionated and sent for sequencing to identify the communities present. Nitrate removal rate was measured using Doane assay while nitrite production was measured using Griess assay.

Results

Acetate, methanol, formaldehyde, and acetaldehyde were identified as compounds produced during methane oxidation and used as substrates by denitrifying microorganisms in both the aerobic and microaerobic reactors. *Methyloversatilis* and *Hyphomicrobium* were the dominant microorganisms utilizing methanol in both reactors. *Pseudomonas* and *Limnohabitants* were the dominant acetate-denitrifiers in both reactors while *Azospira* and *Limnohabitants* were the dominant acetate-denitrifiers in the microaerobic reactor and aerobic reactors respectively (Fig. 1). Fig.2 shows the result of anoxic batch experiments performed to determine nitrate removal rates by biofilms from the aerobic and microaerobic reactors. The nitrate removal rate in the microaerobic reactor samples varied among the carbon substrates. Nitrate removal rate did not differ significantly in microaerobic reactor samples from the aerobic reactor samples. However, nitrate removal rate with acetaldehyde and acetate were significantly higher than formaldehyde and methanol in both reactor samples but did not differ significantly from each. Nitrite accumulation matched nitrate consumption.

Conclusion

The results show that multiple metabolites can be used by denitrifying organisms, but the rate of nitrate removal varies depending on the metabolite. Acetaldehyde was identified for the first time as a major carbon compound driving nitrate removal in a methane-driven denitrification study.

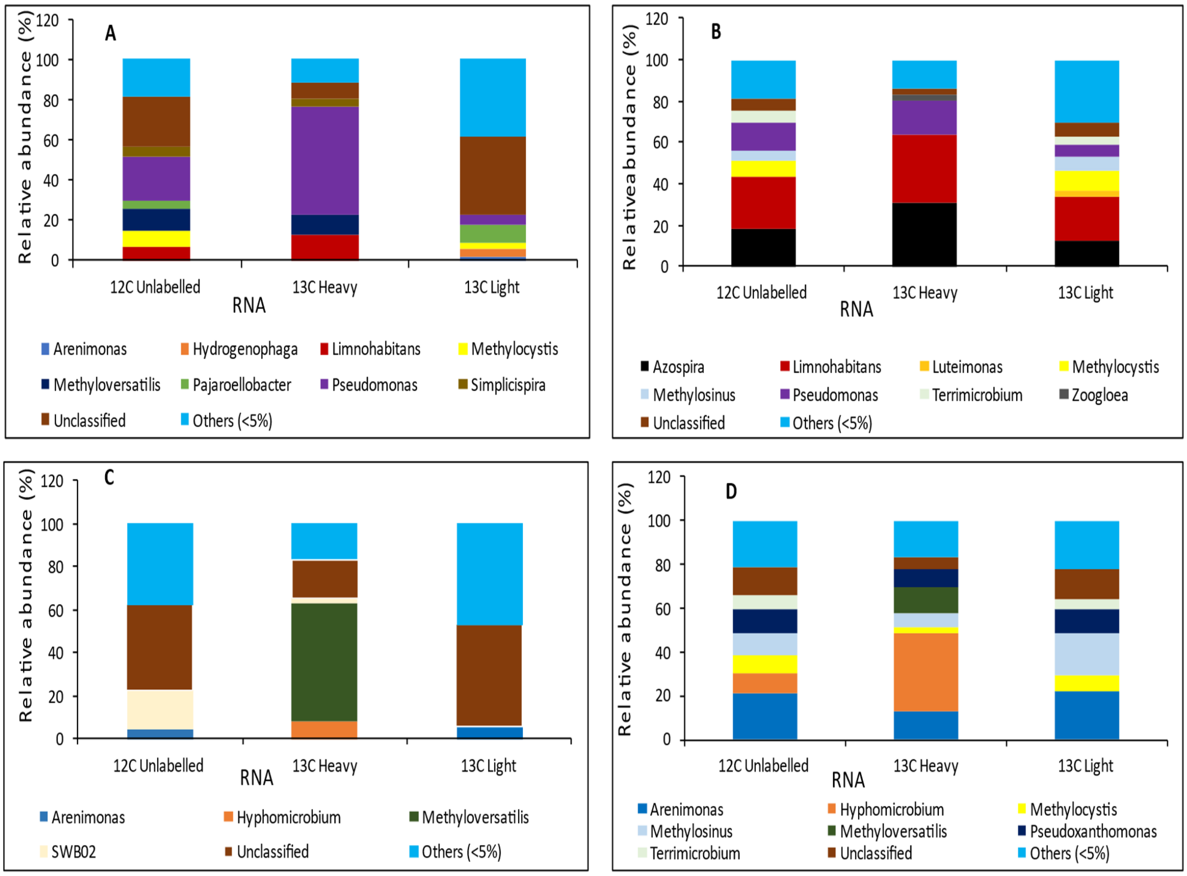

Figure 1: Relative abundance (RA) of acetate and methanol RNA-SIP labelled microorganisms. A is the RA of acetate labelled microorganisms from the aerobic reactor at 24 h. B is the RA of acetate labelled microorganisms from the microaerobic reactor at 24 h. C is the RA of methanol labelled microorganisms from the aerobic reactor at 96 h. D is the RA of methanol labelled microorganisms from the microaerobic reactor at 96 h.

Figure 2: Nitrate removal rates using carbon substrates identified in the two reactors. Error bars represent standard deviation of triplicate treatments. The blue bars represent the maximum nitrate removal by microaerobic reactor samples while the orange bars represent the maximum nitrate removal rates by the aerobic reactor samples

SWAT-MODFLOW MODEL OF WAIOTAPU CATCHMENT USING SKYTEM GEOPHYSICAL CONDUCTIVITY AND HALF HOURLY IMERG PRECIPITATION DATA

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Aims

Constructing a catchment-scale surface and groundwater model is a major challenge because the properties of the surface and subsurface vary significantly and the fitting of the model requires a large amount of data, which is often not available. To meet the data requirement, we used both high spatial resolution data from a SkyTEM geophysical conductivity survey and long-term high temporal resolution data of IMERG precipitation (Huffman, G. et al. 2014) and flow data. We chose a fully coupled SWAT-MODFLOW model (Bailey, R.T. et al. 2016) because the model can simulate integrated solute transport of surface water and groundwater and a short-term interaction of surface water and groundwater and perform a long-term (20 years) simulation in several hours. We also plan to add chemical data to the model fitting later and evaluate the paths of nitrate and phosphate transport and the flow of surface water and shallow groundwater in the Waiotapu catchment.

Method

To construct a SWAT-MODFLOW model of the Waiotapu catchment, we used the data of SkyTEM geophysical electrical conductivity survey performed in April 2019 and IMERG precipitation data from June 2000 to June 2021. A time-shift was applied to the IMERG data since the timing of calibrated half-hourly IMERG precipitation was not accurate. The required shift was determined from precipitation data at five weather stations installed for the project in the Waiotapu catchment.

The SkyTEM data provides a 20 m spatial resolution along the flight path, a 200 m resolution across the flight path, and a 3 to 45 m vertical resolution. It shows a relatively sharp increase in electrical conductivity at the water table. Using this property, we estimated the elevation of the water table in the Waiotapu MODFLOW model. We also clustered the SkyTEM data into hydrogeophysical units to represent subsurface structure in the model.

Results

Between 2001 and 2020, the average annual rainfall of the calibrated IMERG data was 1575 mm and the annual rainfall ranged from 1200 to 1900 mm in Waiotapu (Figure 1a). The average annual rainfall is similar to the long-term average annual rainfall (1600 mm). Although the timing of the major rainfall of IMERG showed about a 3-hour shift from the measured data and their peak magnitude differ significantly (Figure 1b), recent data (year 2020 and 2021) of IMERG reasonably reproduced major rainfall events detected with our weather stations (Figure 1b) and the accumulated rainfall roughly reproduced that of weather stations within the measurement error. Thus, we used IMERG data with the time shift for our model calibration. Compared with the rainfall, the flow yield varied more significantly and is roughly proportional to annual rainfall (Figure 1a).

We adopted a two-step approach for our modelling: (1) We constructed a separate SWAT and MODFLOW model and calibrated each model separately and (2) coupled the two models and calibrated them as a fully coupled model. For the first step, we constructed a MODFLOW model using 11 hydrogeophysical units derived from the clustered SkyTEM data, and the recharge rates from a separate SWAT model, and the fitted model using PEST (Doherty, J., 2015) roughly reproduced the estimated water table derived from SkyTEM data. Considering the vertical resolution of SkyTEM (3m), this is an encouraging result. However, since the clustered hydrogeophysical units assume a unique hydraulic conductivity for each unit, the model was not sufficiently flexible and resulted in dry cells (very low hydraulic head) on the east where the elevation is high (Figure 2).

For the second step, we constructed a fully coupled SWAT-MODFLOW model. However, we discovered the basic unit of calculation in SWAT (a subbasin) is not compatible with the grids of MODFLOW. For example, the elevation of a subbasin in SWAT is far off from the elevation of each grid in MODFLOW. As a result, SWAT-MODFLOW could not properly simulate the surface water and groundwater interaction. We believe a grid-based SWATPlus-MODFLOW model (Bailey, R. T. et al. 2020) would be an appropriate option for this type of modelling. We will present the fully coupled grid-based SWAT-MODFLOW model at the conference.

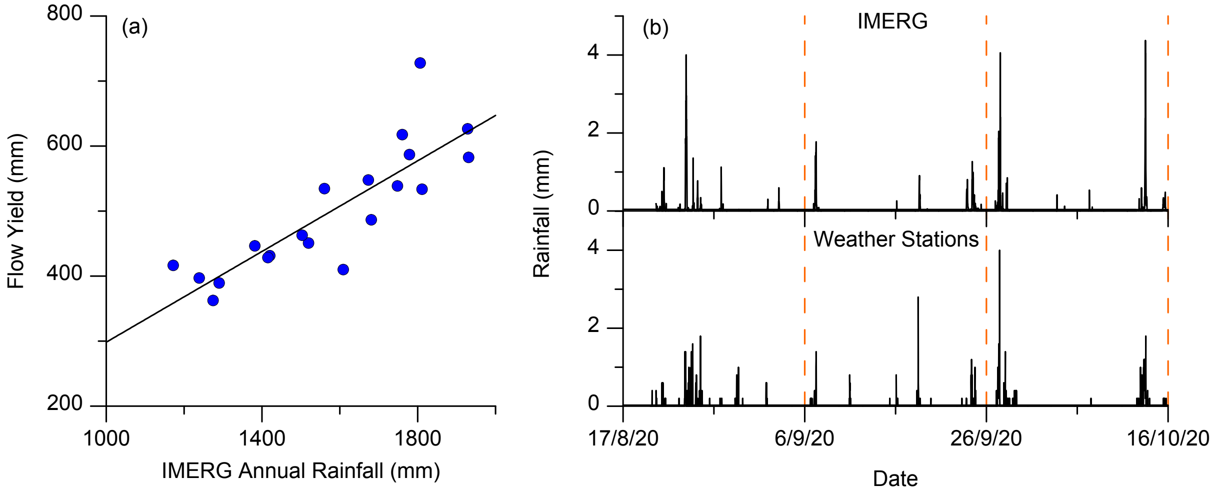

Figure 1: (a) Yearly rainfall of IMERG and flow yield in Waiotapu catchment. (b) The comparison of recent rainfall data from IMERG and our weather stations in Waiotapu.

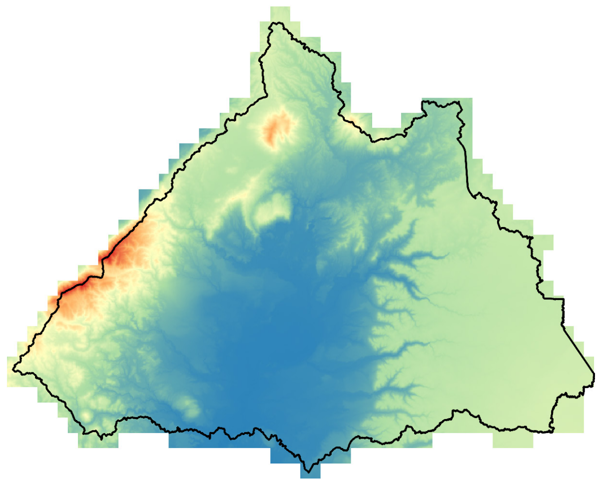

Figure 2: The elevation map of Waiotapu. The elevation changes from light blue (about 300m) to brown (950m).

References

Bailey, R.T. et al. 2016. Assessing regional scale spatio-temporal patterns of groundwater–surface water interactions using a coupled SWAT–MODFLOW model. Hydrol. Process. 30 (23), 4420–4433.

Bailey, R. T. et al. 2020. Enhancing SWAT+ simulation of groundwater flow and groundwater-surface water interactions using MODFLOW routines. Environmental Modelling and Software, 126, 104660.

Doherty, J., 2015. Calibration and Uncertainty Analysis for Complex Environmental Models. Watermark Numerical Computing, Brisbane, Australia. ISBN: 978-0-9943786-0-6.

Huffman, G. et al. 2014: Integrated Multi-satellite Retrievals for GPM (IMERG), version 4.4. NASA's Precipitation Processing Center, accessed 31 March, 2015, ftp://arthurhou.pps.eosdis.nasa.gov/gpmdata/.

A NOVEL FRAMEWORK FOR THE INTERACTIVE MAPPING OF ATTRIBUTE DATA FOR NATIVE MIGRATORY FISH

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The fish of New Zealand's freshwater environment are unique and valued contributors to the biodiversity of our aquatic ecosystems. However, intensifying urban development and wider land-use intensification are imposing increasing pressures upon New Zealand's freshwater fauna. Declining water quality, habitat degradation, water diversion, and loss of longitudinal river connectivity pose significant challenges to the welfare of indigenous freshwater fish; in particular, to those species whose lifecycles depend on seasonal migrations between freshwater and marine biomes.

The new freshwater reforms under the 2020 National Policy Statement for Freshwater Management have now taken effect, and require regional council engagement with local communities and tangata whenua (aligning with Te Mana o te Wai). With respect to New Zealand's native freshwater fish, it is therefore critical that a consolidated and accessible body of knowledge exists to support collaborative decision-making for the design and remediation of instream structures. Specifically, tools should be available to aid in the identification of freshwater species inhabiting specific stream reaches alongside their unique characteristic abilities and environmental requirements. This will assist the targeting of designs to meet the needs of those species most vulnerable to specific instream works and barriers.

A framework for an integrated GIS mapping platform has been developed to synthesise current knowledge of New Zealand's native migratory fish, and present this information interactively and geospatially. Based on the review of most recent scientific literature, the framework applies a database of native migratory fish characteristics to national freshwater fish survey observations, and hydrological and topographic data. Primary attributes for each of New Zealand's native migratory species include: migration mode and peak upstream migration times, movement style and swimming speeds, predominant habitat types, and visual identification features. This framework was applied to Christchurch's Avon River to demonstrate the framework's key features and future potential. The framework is intended to help bridge the gap between ecology, hydrology, and engineering: unifying current knowledge of native migratory freshwater fish, to support research-based planning and design.

MANGANESE IN CANTERBURY GROUNDWATER

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Introduction

Manganese occurs naturally in rocks, minerals, and groundwater. In some areas of Canterbury, dissolved manganese in groundwater has been observed at concentrations exceeding the aesthetic guideline values (GV) (for staining- 0.04 mg/L, and taste- 0.01 mg/L) and the health-based Maximum Acceptable Value (MAV) (0.4 mg/L) for drinking water in the Drinking-water standards for New Zealand (Ministry of Health, 2017). Elevated concentrations of manganese are problematic because groundwater is the primary drinking water source in Canterbury, and some private well owners may not be aware of this issue.

Aims

Despite long-held knowledge that manganese can be present in concentrations above MAV, this study represents the first region-wide review of manganese in Canterbury groundwater. This work aimed to corroborate our existing data and increase our understanding of spatial occurrences and reasons for elevated manganese concentrations by identifying the main sources (i.e., geological, or anthropogenic) and potential drivers (e.g., the presence of organic carbon, and reducing groundwater redox state) for elevated manganese concentrations.

Method

Manganese is tested annually in Environment Canterbury's State of the Environment monitoring programme and in many one-off groundwater investigations. Thus far, 2,855 wells have been sampled for manganese in the Canterbury region. We mapped maximum recorded concentrations in each well to determine areas where manganese concentrations have exceeded the Maximum Acceptable Value. To interpret our data and determine reasons for the distribution of manganese concentrations, we reviewed relevant national and international scientific literature, and internal reports from previous investigations in Canterbury.

Results

Thus far, 185 wells (6.5% of total wells sampled) have exceeded the manganese MAV for drinking-water at least once. Most manganese in New Zealand groundwater is likely to be of natural origin (Daughney, 2003), and, in Canterbury, the spatial scale of manganese presence in groundwater suggests that there are diffuse, natural sources of manganese, which are released via desorption from manganese-bearing aquifer minerals (oxides and hydroxides) when groundwater is in a reducing redox state.

Although there is a diffuse source of manganese to groundwater, presence and concentrations vary across the region. For example, the proportion of wells exceeding GV and MAV are relatively higher in Kaikōura, Hurunui-Waiau, South Coastal Canterbury and Waimakariri zones. Conversely, manganese concentrations are generally lower in the Central Canterbury Plains. The lowest concentrations are typically found in the Upper Waitaki zone, where 70% of samples tested were below laboratory detection limits.

At local scales, there are several types of point-sources where highly elevated manganese concentrations occur due to human activities. For example, nearly all manganese values exceeding the MAV of 0.4 mg/L in the Christchurch zone are from wells near to historical or currently operating landfill. The association between elevated groundwater manganese concentrations and landfills may be because manganese is present in landfill material (e.g. manganese is used extensively in the steel industry and is present in batteries and glass). However, elevated manganese near landfills could also be due to the leaching of dissolved organic carbon, causing underlying groundwater to enter a reducing redox state, leading to reductive dissolution (and desorption of manganese) of naturally occurring manganese-bearing aquifer minerals.

Our findings have been included in a technical report to be used by scientists, but this project also aims to raise awareness of potential (either geological or anthropogenic) contamination to owners of private wells.

References

Daughney, C.J. 2003. Iron and manganese in New Zealand's groundwater. Journal of Hydrology (New Zealand), 11-26.

Ministry of Health. 2017. Guidelines for Drinking-water Quality Management for New Zealand (3rd edn). Wellington: Ministry of Health.

ATMOSPHERIC CONTROLS OF EXTREME SNOWMELT EVENTS IN THE SOUTHERN ALPS

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Aims

Large/extreme snowmelt events play an important role in controlling hydrological processes of alpine catchments. A number of processes control the atmospheric conditions of seasonal snowpacks at different scales ranging from micro scales to large scales. Variability in timing and magnitude of such events is, however, largely influenced by synoptic-scale atmospheric patterns. The Southern Alps of New Zealand host the largest snow and ice fields in the Southern Hemisphere outside the Antarctic and South America (Fitzharris *et al.*, 1999). Even though the contribution of snowmelt to river flows in the Southern Alps is lower compared to other typical northern hemisphere alpine catchments, meltwater from seasonal snowpacks can contribute up to 40-50% of the discharge in upper alpine catchments which in turn feed major rivers in the Southern Alps (Sirguey, 2009). Mid-latitude seasonal snowpacks, such as those in the Southern Alps, are highly sensitive to climate variations. Rising global temperatures in a warming climate can bring about significant changes in magnitude, extent and duration of seasonal snow cover resulting in a shift in hydrological regimes. The efforts to explore the atmospheric forcing controlling spring- and winter-melt at higher altitudes of the Southern Alps have been hindered in the past mainly due to the lack of observational measurements of snow throughout the year. However, the establishment of Snow and Ice Monitoring Network (SIN) by the National Institute of Water and Atmospheric Research (NIWA) has provided a unique opportunity to investigate the snow hydrology processes in a typical maritime condition.

A better understanding of the synopticscale weather patterns can provide an insight into the distinct characteristics of atmospheric forcing impacting snow snowmelt processes, especially in remote mountain regions. Therefore, the main objectives of this study are to: (1) determine the frequency and intensity of large snowmelt events during winter and spring (2) investigate the relationship between atmospheric circulation patterns and large snowmelt events.

Data and Method

This study utilised the daily snow depth observations from Mueller Hut automatic weather station (1818 masl), near the Main Divide of the Southern Alps over a course of 8 years (2010-2018).

A decrease in daily snow depth was used as a proxy for snowmelt. Snowmelt events were divided into two categories: winter-melt during the accumulation months (1st June to 30th September) and spring-melt during the melting months (1st October to 31st December). A large snowmelt event was defined based on the value of 90th percentile of daily snowmelt; consequently, days with snowmelt greater than or equal to this value were defined as large snowmelt episodes.

The meteorological variables during melt is provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) re-analysis dataset. ECMWF's ERA-Interim data (i.e. sea level pressure (SLP) and temperature at 500, 700 and 850 hPa (T500, T700 and T850)) were retrieved at 6-hourly temporal resolution and 0.5° × 0.5° spatial resolution for a synoptic window of 10°S-60°S and 130°E-160°W.

To characterize the influence of atmospheric controls on snowmelt episodes, a composite anomaly approach was carried out. Composite anomaly approach is a simple synoptic-climatological technique that paints a physically reasonable picture of atmospheric variations. Based on this approach, the differences between average values of atmospheric variables for a particular phenomenon (e.g. snowmelt episodes) and climatic normal are computed. A long-term average of meteorological variables (1979-2018) during the accumulation months (June to September) and melting months (October to November) were used as the climatic normal.

Results

Prior to this research being undertaken there was limited knowledge about the synoptic drivers of large snowmelt events in the Southern Alps. Observations at Mueller Hut station show that snowmelt during winter months varies from less than 1 mm/day to 299 mm/day averaging 12 mm/day. During spring months decrease in snow depth changes from less than 1 mm/day to 330 mm/day with an average of 46 mm/day. The 90th annual percentile threshold for daily melt is approximately 75 mm/day leading to 221 events between 2010 and 2018 at Mueller Hut (Figure 1a).

Analysis reveals that around 20% of the large snow melt events are occurring in winter. Frequency analysis indicates that spring melst are the more frequent in November and December, while winter melt seems to be more uniformly distributed (Figure 1b).

Using a composite anomaly approach (e.g. Figure 2), this study has identified the atmospheric circulation patterns during large snowmelt events in the Southern Alps. Findings show that while days with above normal pressures associated with anticyclonic systems account for the majority of snowmelt events, the highest winter-melt and spring-melt rates (up to 330 mm/day) occurred mainly during troughing regimes with below normal pressure. Anomaly analysis of temperature of the atmospheric column shows rising mid- and low-tropospheric temperatures (at 500, 700 and 850 hPa) during both high-pressure and troughing systems associated with large snowmelt in the Southern Alps demonstrating that anomalously high temperatures are key drivers of these rapid melt episodes. Further research that takes the dominant synoptic weather patterns identified in this study, and explores the associated snowsurface energy exchange will improve knowledge of the connection between large scale weather systems and seasonal snow cover. Providing a baseline for a better understanding of the current knowledge of atmospheric forcing influencing such events, these findings have important implications for investigating the possible future changes in frequencies of synoptic weather patterns in a warming climate.

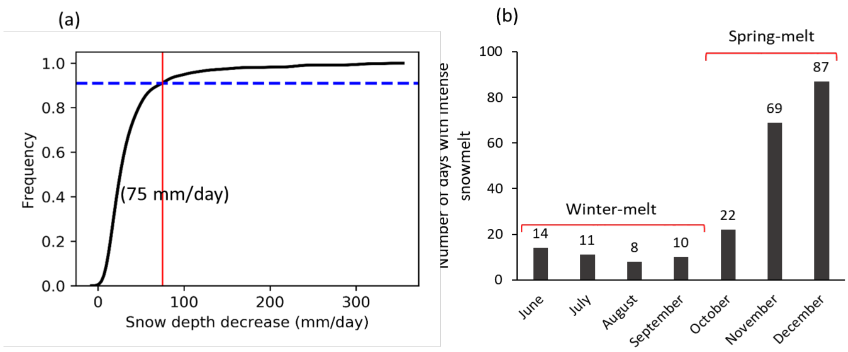

Figure 1: (a) Frequency of melt events at Mueller Hut. The red line marke the 90th percentile (75 mm/day), and (b) number of days with large snowmelt during accumulation season (June to September) and melt season (October to December) from 2010/11 to 2017/18.

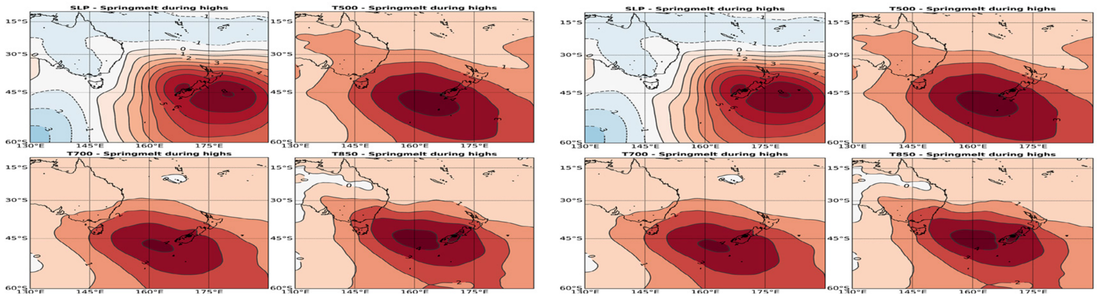

Figure 2: Examples of atmospheric variables anomalies during melt season (1st October to 31st December) during highs.

References

Fitzharris, B., Lawson, W. and Owens, I. 1999. Research on glaciers and snow in New Zealand, Progress in Physical Geography: Earth and Environment, 23(4), pp. 469–500. doi: 10.1177/030913339902300402.

SIRGUEY, P., MATHIEU, R. & ARNAUD, Y. 2009. Subpixel monitoring of the seasonal snow cover with MODIS at 250 m spatial resolution in the Southern Alps of New Zealand: Methodology and accuracy assessment. Remote Sensing of Environment, 113, 160-181.

GENERATION OF HYDROLOGICAL STATISTICS FOR LIMIT SETTING IN OTAGO

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Aim

The National Policy Statement for Freshwater Management 2020 (NPS-FM 2020) requires regional councils to set freshwater objectives and limits for resource use in their regional plans. The NPS-FM defines a limit as `the maximum amount of resource use available, which allows a freshwater objective to be met.' In terms of water quantity, for instance, the limit is the total amount of water that can be taken out of a freshwater body without compromising the desired outcomes (freshwater objective).

In accordance with the NPS-FM, the Otago Regional Council (ORC) is preparing to draft and notify a new regional plan (the Land and Water Regional Plan or LWRP) by December 2023. The LWRP will give effect to the requirements of the NPS-FM (and other relevant national and regional legislations) through establishing values and objectives for the management of region's freshwater resources. A key component of this plan will be setting water quantity and quality limits to assist with meeting these objectives. ORC has identified a number of freshwater management units (FMUs) and smaller management zones (Rohe). Limits will be set up at varying spatial scales for each Rohe and FMU. ORC has grouped the FMUs into four categories based on issues and values, which fall on a continuum of information needs; Category 1 being the catchments with generally low hydrological modification, high water quality and high natural values, and Category 4 at the other end with complex hydrology and diverse pressures on competing values.

To assist the limit setting process ORC requires hydrology data and information for the FMUs. It is expected these data and information not only will provide knowledge on the current states of key waterbodies within each FMUs to enable a realistic setting of limits, but will also assist with determining default minimum flows and primary allocation limits within the region. To meet information demands, ORC intends to complete the generation of required hydrology information through a staged process. ORC and NIWA embarked on a project to complete the Stage 1 of the process that includes development of hydrological flow time series across the Otago region and associated hydrological statistics. The project aimed at using multiple methods to arrive at hydrological statistics to provide an independent verification of the each one of them in the absence of long time series of observed data and to cover reliable predictions through entire spectrum of the flow. This presentation will outline the methodology and results from Stage 1 process.

Method

ORC flow database consists of mean daily flow time series for 250 gauging stations. However, only 89 sites had at least five acceptable years of data, where we define an acceptable year as having at least 11 months of data. The flow time series were further filtered to exclude sites that were affected by large engineering projects such as dams, diversions or substantial abstractions (greater than 30% of the estimated median flow), and this further reduced the number of gauging station to 59 sites. The flow data recorded from these 59 sites were used to bias correct (see below) our models and then improve the predictions of model results.

NIWA's uncalibrated rainfall-runoff model TopNet (Clark et al. 2008) was used to develop hourly flow time series for all streams of Strahler order 3 or above in the region. The resulting time series were then aggregated to daily flow. The uncertainty associated with the uncalibrated rainfall-runoff model can be significant in some catchments and therefore requires bias correction. In order to improve the time series outputs from the hydrological model, we bias corrected them using the Flow Duration Curves (FDCs) of the observed flow time series of the 59 sites and method presented in Farmer et al. (2018). For ungauged sites, we used a generalisation method based on Booker and Woods (2014). This method uses catchment characteristics to predict the FDC at ungauged sites by using a "Random Forest" regression method trained on FDCs at gauged sites. This correction is applied to all streams of Strahler order 3 or above for bias corrected time series of flow.

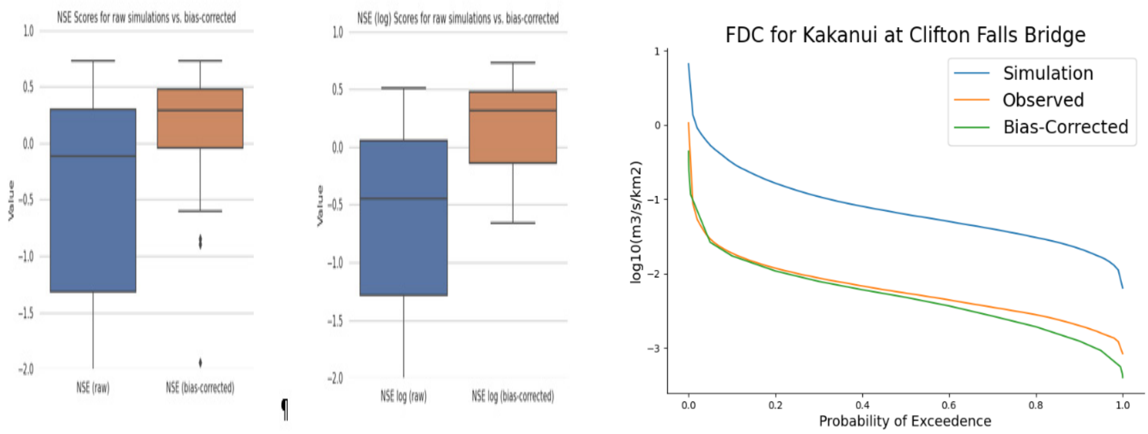
Hydrological statistics were developed using both observed and modelled naturalised flow time series from 1972 to 2020. The statistics developed are mean flow, median flow, 7-day mean annual low flow (MALF), one-in-five year 7-day low flow (Q5), average number of high flow events per year that exceeded three times the median flow (FRE3), and proportion of flow in February (Feb; driest month). Many hydrological statistics are scale-dependent; larger catchments have larger values of mean, median and MALF than smaller catchments. We therefore standardised mean, median and MALF by dividing by catchment area. We compared three methods for calculating hydrological statistics at ungauged locations. These methods ranged from purely empirical to those applying more physically-based approaches. These methods are:

- Method 1: Random forest regression using available catchment variables and flow data;
- Method 2: Bias corrected TopNet; and
- Method 3: NZ River Maps - regression from available catchment variables using all national 482 flow sites, but only 32 from Otago.

Results

The relationship between observed mean discharge and catchment area for 32 gauging stations in Otago and the national model (482 sites) shows a reasonable agreement but have slightly less flow per unit catchment area for some gauges especially in larger catchments indicating the mountain rain-shadowing and consequent dryness of much of Central Otago.

The bias correction of the uncalibrated simulations of flow time series (raw) based on FDC improved the outputs significantly when compared against the observation as shown in Figure 1.



(a) (b)

Figure 1: Improvement after bias correction with respect to raw simulations. (a): Nash-Sutcliffe efficiency (NSE) log performance, (b) example of flow duration curve for a typical flow site.

When calculating hydrological statistics at ungauged locations, no one method proved to be the best for all statistics. For example, Method 2 produced the best correspondence between observed and modelled values of mean and median flows whereas Method 1 produced best correspondence between observed and modelled values for MALF, Q5, FRE3 and Feb. The study therefore recommended taking into account the best methods identified for different statistics for limit setting. The uncertainties in hydrological estimates for gauged sites were also quantified and presented in terms of performance metrics: mean error, root mean square error, normalised root mean square error, percent bias, ratio of standard deviations and NSE. These uncertainties can be considered when applying the estimates to make informed decisions.

References

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* DOI: 10.1016/j.jhydrol.2013.11.007

Clark, M.P., Rupp, D.E., Woods, R.A., Zheng, X., Ibbitt, R.P., Slater, A.G., Schmidt, J., Uddstrom, M.J. 2008. Hydrological data assimilation with the ensemble Kalman filter: Use of streamflow observations to update states in a distributed hydrological model. *Advances in Water Resources*, 31(10): 1309-1324. 10.1016/j.advwatres.2008.06.005t

Farmer, W. H. Over, T. M. Kiang, J. E. 2018. Bias correction of simulated historical daily streamflow at ungauged locations by using independently estimated flow duration curves. *Hydrol. Earth Syst. Sci.* 22(11): 5741-5758.

HAWKE'S BAY 3D AQUIFER MAPPING PROJECT USING AIRBORNE TIME-DOMAIN ELECTROMAGNETICS (SKYTEM): 2021 UPDATE

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[1] GNS Science
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[4] Project Haus

The Hawke's Bay 3D Aquifer Mapping Project is a three-year project (Sept 2019 – Dec 2022) that is jointly funded by the Provincial Growth Fund, Hawke's Bay Regional Council (HBRC) and GNS Science (GNS).

In early 2020, SkyTEM data for the project was collected by SkyTEM Australia using a specially equipped helicopter flying over Hawke's Bay along flight lines about 200 m apart. Close to 8000 km of data was collected over the Heretaunga Plains, the Ruataniwha Plains, and the Otane and Poukawa Basins.

An overview and update at the NZHS annual conference in 2020 described the survey design and objectives, the successful communication approach taken, flight details, preliminary datasets, and the advanced data processing and inversion being undertaken, as well as some preliminary results from the Otane and Poukawa Basins.

This 2021 update will describe the resistivity models developed for all three survey areas; hydrogeological interpretations of the Otane and Poukawa Basins; preliminary hydrogeological interpretation information from the Heretaunga Plains; and details from supporting drilling that was undertaken within the Heretaunga and Ruataniwha Plains.

A DECADAL COMPARISON OF TIPPING BUCKET RAIN GAUGE, RADAR AND SATELLITE DERIVED RAINFALL ESTIMATES IN THE AUCKLAND REGION

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Aims

Accurate Rainfall information is important for 3-waters stakeholders for a diverse range of applications including flood and bathing water quality forecasting, catchment development planning and analysis of post-event performance of stormwater assets. River, flood and rural catchment management also benefits from improved rainfall information.

In the New Zealand context, rainfall observations are almost exclusively derived from networks of tipping bucket (TB) rain gauges. TB networks are run principally by regional councils; NIWA and Metservice also have sparser national networks. TB observations are typically processed further to generate spatial estimates (e.g. NIWA's Virtual Climate Station Network, VCSN, Tait et al. 2005) which can exhibit significant biases (Tait et al. 2012). Alternative rainfall observation platforms may address shortcomings in the spatial representation of rainfall. Readily available alternatives to TBs include national radar networks (operated by MetService Ltd in New Zealand, for a description see Crouch 2003) and satellite-derived rainfall products such as CMORPH (Joyce et. al 2004) and IMERG (Hou et al. 2014).

Satellite-derived rainfall estimates are well utilised in climatological studies (Habib et al. 2012), and there is some interest in these data sources for regional hydrology applications, possibly because the cost of collecting and processing data is borne by others. In this paper, we report on inter-comparison of Quantitative Precipitation Estimates (QPE) available in the Auckland Region: rain gauge, rain radar and satellite-derived rainfall retrievals. We compare and contrast the relative error characteristics of each and comment on the suitability of each data type for stakeholder use.

Method

Auckland Council, Northland Regional Council (and associated Territorial Authorities) and Wellington Water already make use of radar data for hydrological and stormwater management. Radar data from the MetService radar is prepared using an approach that constrains uncertainties associated with many factors (e.g. calibration, ground clutter suppression, drop size distribution, vertical reflectivity profile variability, radome wetting and path integrated attenuation), followed by correction of residual errors by matching with rain gauges. The radar data has been extensively validated over a record exceeding one decade, and shown to provide rainfall estimates of comparable quality to the dense TB network in central Auckland (~1 gauge / 10km2), but all around the Auckland region, even in more sparsely gauged areas (Sutherland-Stacey et al. 2021).

For this work, we leverage the new decadal radar-derived rainfall record as ground-truth for comparison with interpolated TB results and satellite retrievals, in order to characterise the relative errors of each approach. Data is assessed at a variety of intensity/duration thresholds corresponding to the High Intensity Rainfall Design System tables (HIRDSv4, Carey-Smith et al. 2018).

Results

Satellite-derived products are found to have large transient location and intensity biases, probably due to fundamental sampling intermittency and instrument limitations. The errors make the satellite data largely unsuitable for hydrological applications. Gauge interpolation approaches on the other hand are shown to provide useful results for longer accumulation times and light-to-moderate rain events, but struggle to properly characterise high-intensity / short-duration events any distance from rain gauges. Potential benefits of using radar data for different catchment-scale applications in the Auckland, Northland and Coromandel regions are discussed.

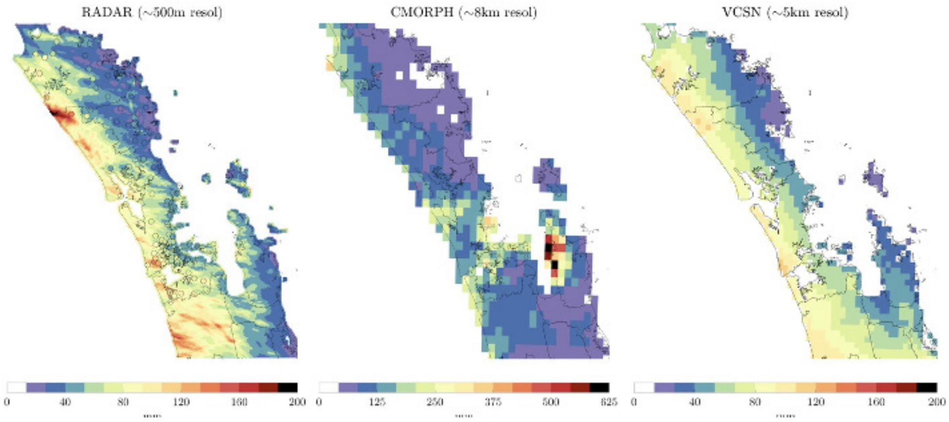

Figure 1: One month accumulations for May 2014, derived from RADAR, Satellite (CMORPH), and interpolated TB rain gauges (VCSN) respectively.

References

Carey-Smith, T., Henderson, R., and Singh, S. 2018. High Intensity Rainfall Design System V4 [https://www.niwa.co.nz/sites/niwa.co.nz/files/2018022CH_HIRDSv4_Final.pdf]

Crouch, J. 2003. Using radar to diagnose weather systems. Tephra, 20(June): 46–48.[http://www.civildefence.govt.nz/assets/Uploads/publications/tephra-june-2003.pdf]

Habib, E., Haile, A. T., Tian, Y., and Joyce, R. J. 2012. Evaluation of the High-Resolution CMORPH Satellite Rainfall Product Using Dense Rain Gauge Observations and Radar-Based Estimates. Journal of Hydrometeorology, 13(6): 1784-1798.

Hou, A. Y., Kakar, R. K., Neeck, S. S., Azarbarzin, A. A., Kummerow, C. D., Kojima, M., et al. 2014. The global precipitation measurement mission, Bulletin of the American Meteorological Society, 95: 701–722.

Joyce, R. J., Janowiak, J. E., Arkin, P. A., and Xie P. P. 2004. CMORPH: A method that produces global precipitation estimates from passive microwave and infrared data at high spatial and temporal resolution. J. Hydrometeor., 5: 487–503.

Tait, A., and Turner, R. 2005. Generating multiyear gridded daily rainfall over New Zealand. Journal of Applied Meteorology, 44(9): 1315–1323.

Tait et al. 2012. An assessment of the accuracy of interpolated daily rainfall for New Zealand. Journal of Hydrology (NZ), 51(1): 25-44.

Sutherland-Stacey, L., Reboredo, B., Nicol, J., and Brown, N. 2021. Performance Evaluation of A Decadal Rainfall Radar Record for Auckland Council. Stormwater Conference 2021, Tauranga, New Zealand, 12-14 May.

RAIN GARDENS AS STORMWATER MANAGEMENT DEVICES: ENHANCING REMOVAL CAPACITIES AND INCREASING THE LIFE CYCLE THROUGH ROUTINE INSPECTION/MAINTENANCE

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Abstract

New Zealand's urban population is growing several times faster than rural areas. Urbanization has turned many permeable surfaces impermeable. As a result, infiltration of water into the ground is reduced and the hydrological processes such as surface-runoff patterns are changed. Hence, water sensitive devices have been increasingly used to mitigate the impact of stormwater on the environment. New Zealand regional councils are using sustainable landscape devices and management practices to sequestrate pollutants in bio-retention devices like rain gardens before they flow into the subsurface and eventually to the sea. However, the system has varying success. Rain gardens frequently fail, leading to flooding or inability to hold moisture, negaitvely impacting plant health and infiltration. This failure results in siginificant costs to councils, transport agencies and our communities. In addition, high water flow rapidly exhausts rain garden devices through stormwater contaminant accumulation on device media. Sparse literature exists on the effectiveness of bioretention devices and the lifecycle of rain garden media blends.

Leveraging technology, we have developed a system to capture multiple data points from design, through installation and maintenance to identify the critical environmental variables for device success. The results of the system, loop research findings into media specification (installation), inspection and maintenance.

One area of focus has been a set of experiments to enhance hydraulic performance and sequestration potential. An avenue of enquiry investigated boosted rain garden media blends compared to basic rain garden media blend. To determine the adsorption characteristics of the blends, a series of batch adsorption isotherms were conducted on Zeolite and other adsorbents with different particle sizes using Zinc (Zn) and Copper (Cu) spiked stormwater. The data obtained from the experiments were then fitted with different kinetics models and the correlation coefficients were compared. Column tests were subsequently performed to provide insight into the effect of adsorbants particle size on the hydraulic conductivity and contaminant removal capacities.

A second area of focus has been extensive data collection to ascertain media and plant performance in relation to location and weather conditions. Analysis indicates that in the first 18 to 24 months it is critical that potential issues are identified for the rain garden to sustain plant life and reach an optimal plant coverage of 90%. Understanding the interplay of environmental variables assists with early identification of issues through targeted inspection and responsive maintenance (Yuan, 2018). Systematically capturing data across the rain garden lifecycle is assisting with future decision making, increasing accountability and reducing device fatigue.

This new information will be useful for monitoring and protecting water quality and for regulating urban planning and design practices where appropriate.

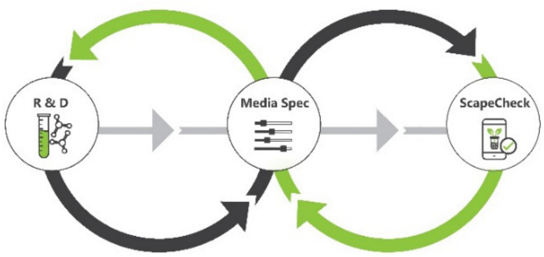

Figure 1: Graphical Abstract, The ScapeCheck Loop

References

Yuan, J. N., Dunnett, N. 2018. Plant selection for rain gardens: Response to simulated cyclical flooding of 15 perennial species. *Urban Forestry & Urban Greening*, 35: 57-65.

USING HIGH-FREQUENCY SPATIOTEMPORAL MONITORING TO IMPROVE QUANTIFICATION OF NITRATE REMOVAL AND UNDERSTANDING OF PROCESSES IN WOODCHIP BIOREACTORS

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Woodchip bioreactors as a nutrient mitigation tool for reducing nitrate load to freshwater have been gaining popularity in many countries. However, current methods for assessing performance of field bioreactors are somewhat deficient as this critical measure is generally being determined based on low frequency concurrent sampling (e.g. weekly) at the inlet and outlet. A number of hydrological studies have demonstarted that high-frequency monitoring of nitrate in tile drains and rivers improves the accuracy of load estimates and can reveal the dynamics. However, very few bioreactor studies have utilised high-frequency monitoring so far. We hypothesised that high-frequency monitoring at multiple locations within a bioreactor can improve the accuracy of the calculated nitrate removal rate (NRR) and enhance our understanding of processes occurring within a bioreactor.

For two drainage seasons (2018, 2019), we monitored nitrate concentrations at 21 locations within a pilot-scale woodchip bioreactor installed near Tatuanui in the Waikato region. Nitrate was measured using an optical nitrate sensor with porewater samples being reticulated to the sensor on a two-hourly basis. A novel method was used to account for the variable lag time between entry and exit of the sampled parcel of drainage water due to the very dynamic drainage flows. Using this data, we were able to calculate the nitrate removal rate (NRR) based on the changes in concentration for each parcel of water (e.g., parcels based on two-hourly flows). We also investigated the effect on the NRR calculated at a range of sampling frequencies (e.g., 6-, 12-, 24-hourly interval). As well as determining the nitrate removal performance between inlet and outlet, we also determined the performance of the different sections of the bioreactor, such as quarterly sections along the length of the bioreactor.

This presentation will discuss the differences in NRR calculated from different sampling frequencies to determine the benefits of high-frequency monitoring on quantifying the nitrate removal performance of bioreactors. We will also discuss the variations in performance at the different sections of the bioreactor and the factors responsible for these variations. Thus, this presentation will highlight the new insights on the hydraulic and nitrate attenuation processes occurring within the bioreactor gained from the spatiotemporal monitoring and analyses.

GROUNDWATER-SURFACE WATER INTERACTION USING RADON IN THE SELWYN RIVER BRAIDPLAIN

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Aims

Many rivers in New Zealand recharge the underlying aquifer system, assisting with groundwater storage and sustaining spring flows (White, 2001). However, in braided rivers, estimates of river-aquifer fluxes have considerable uncertainties, due to their dynamic nature (Close et al., 2014). A promising approach for characterising surface water – groundwater exchange involves environmental tracers such as radon (Bourke et al., 2014; Lamontagne & Cook, 2007; Sadat-Noori & Glamore, 2019). Radon is abundant in groundwater but degasses quickly with air contact, resulting in negligible amounts in surface water (Close et al., 2014; Stellato et al., 2008). The aim of this study was to provide baseline data to support the use of radon as a tracer for use in groundwater - surface water exchange in a braided river system, the Selwyn River, Canterbury NZ. Spatial variability of the radon activities within the saturated sediments were determined by calculating radon emanation rates of sediment samples collected during the installation of monitoring wells at the site. A relationship between the variation of lithology type, grain size and porosity was also undertaken to determine the saturated hydraulic conductivity of the sediment material.

Method

Sediment cores were sieved for grain size analysis and the fines were analysed using a Micrometrics® Saturn Digisizer, enabling a full analysis of the sediments. From this, hydraulic conductivity was calculated. Porosity and bulk density of the sediments was also measured. Radon equilibrium concentrations were measured on the different grain size fractions from the grain size analysis. In total, 276 samples were analysed. Radon equilibrium concentrations for each sample were based on the measured radon activities from the saturated samples within a known volume. These samples had been stored in sealed jars for 30 days to reach secular equilibrium (Chanyotha et al., 2014; Corbett et al., 1998; Sadat-Noori & Glamore, 2019). Radon activity was measured using the Durridge RAD7 (Durridge, 2020a), the Durridge RAD H2O (Durridge, 2020b) and a Durridge active DRYSTIK in a closed-loop system.

Results

The calculated hydraulic conductivities highlight the heterogeneity of the subsurface in such a small area. The conductivities range from 86 m/d to greater than 5000 m/d. The radon equilibrium concentrations provide detailed information on how radon varies spatially and with differing grain size fractions. The radon equilibrium concentrations range from 0.3 Bq/L to values exceeding 4 Bq/L. In summary this study provides detailed baseline data supporting the use of radon as a tracer for use in groundwater-surface water interaction in a braided river system.

References

Bourke, S., Cook, P., Shanafield, M., Dogramaci, S., & Clark, J. (2014). Characterisation of hyporheic exchange in a losing stream using radon-222. *Journal of Hydrology, 519*, 94-105. https://doi.org/10.1016/j.jhydrol.2014.06.057

Close, M., Matthews, M., Burbery, L., Abraham, P., & Scott, D. (2014). Use of radon to characterise surface water recharge to groundwater. *Journal of Hydrology, 53*(2), 113-125.

Chanyotha, S., Kranrod, C., & Burnett, W. C. (2014). Assessing diffusive fluxes and pore water radon activities via a single automated experiment. *Journal of Radioanalytical and Nuclear Chemistry, 301*(2), 581-588.

Corbett, D. R., Burnett, W. C., Cable, P. H., & Clark, S. B. (1998). A multiple approach to the determination of radon fluxes from sediments. *Journal of Radioanalytical and Nuclear Chemistry, 236*(1), 247-253.

Durridge. (2020a). *RAD7 electronic radon detector user manual*. www.durridge.com

Durridge. (2020b). *RAD H2O Radon in Water accessory for the RAD7 User Manual*. www.durridge.com

Lamontagne, S., & Cook, P. G. (2007). Estimation of hyporheic water residence time in situ using 222Rn disequilibrium. *Limnology and Oceanography: Methods, 5*(11), 407-416.

Sadat-Noori, M., & Glamore, W. (2019). Porewater exchange drives trace metal, dissolved organic carbon and total dissolved nitrogen export from a temperate mangrove wetland. *Journal of environmental management, 248*, 109264.

Stellato, L., Petrella, E., Terrasi, F., Belloni, P., Belli, M., Sansone, U., & Celico, F. (2008). Some limitations in using 222Rn to assess river–groundwater interactions: the case of Castel di Sangro alluvial plain (central Italy). *Hydrogeology Journal, 16*(4), 701-712.

White, P. A. (2001). Groundwater Resources in New Zealand in *Groundwaters of New Zealand*. Edited by Michael. R. Rosen & Paul. A. White, New Zealand Hydrological Society Inc., 45-76.

CHARACTERISING NEW ZEALAND'S NITRATE SOURCES IN FRESHWATER – A 10 YEAR SURVEY

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Aims

A national survey provides new sights into identifying the extent and origin of nitrates in New Zealand's freshwater resources using nitrogen (d^{15}N) and oxygen (d^{18}O) isotopes. More than 1000 water samples collected between 2010 to 2020 form a comprehensive nitrate isotope database to investigate freshwater type, land-use, geology, soil type and regional isotope effects across New Zealand. Nitrate contamination is the biggest threat to New Zealand's drinking water resources with almost 60 % of samples in the study having nitrate concentrations > 0.9 mg/L. Traditional nitrate isotope biplots based primarily on the Haber-Bosch cycle which integrates synthetic fertilizers into the food chain are reinterpreted to place New Zealand's unique farming nitrogen contributions from urea and ammonia into context. The majority of New Zealand's freshwater nitrate isotopes lie in a transition zone between nitrification and denitrification. Nitrate mitigation (denitrification) or sustained contamination (nitrification) depends on the ongoing level of nitrogenous source inputs and/or removal via groundwater reduction and bacterial action, which can be inferred by the isotopic signature and the nitrate-N concentration. Seasonal or climatic change influences surface to groundwater interactions, integrating multiple biochemical reactions and isotope fractionation without complete nitrate removal, unless the contamination N source is completely removed.

Method

1002 samples were collected across 14 regions around New Zealand by Regional Councils, Universities, Crown Research Institutes and industry water researchers from 2010 to 2020. These wells included national groundwater monitoring wells, and groundwater and surface water submitted to the Stable Isotope Laboratory at GNS Science, Lower Hutt, to investigate baseline and elevated nitrate responses. Water samples (250 mL) were analysed for nitrate-N concentrations according to standard methods (APHA, 2012). Our isotope method generally follows the published method by McIlvin and Altabet (2005).

Results

Nitrate-N ranged from 0.0003 to 76.3 mg/L, with a mean concentration of 2.71 ±4.97 mg/L, although the median concentration (0.99 mg/L) better reflects the average data range as the mean was skewed due to several high outliers. All but 44 samples were below the nitrate-N MAV of 11.3 mg/L. Of the 44 exceedances, 3 samples were wastewater and 41 samples were groundwater.

Nitrate isotopes show that the majority of samples lie in the Normal N retention zone, which is traditionally associated with soil organic N and low background nitrate-N concentrations. However, this work demonstrates that in the New Zealand context, this zone is also an intermediate zone for Mixed Urine and Urea samples transitioning through 15N/14N fractionation to the denitrified zone.

The data collected in this survey not only describe the current status of New Zealand's freshwater nitrate contamination but allow the impact of nitrates on our freshwater systems to be monitored in the future. Collectively this dataset provides a nation overview that can be incorporated into freshwater models and used to inform policy through understanding regional variations affected by land-use, climate and geology.

Table 1. Summary statistics for Nitrate-N concentration of different New Zealand freshwater types. GW=groundwater, SW=surface water, WW=wastewater. All concentrations are in mg/L.

Nitrate-N (mg/L)	Count	Average	Median	Standard deviation	Minimum	Maximum	Lower quartile	Upper quartile
All	1002	2.768	0.99	5.04	0.0003	76.3	0.2	3.1
GW	422	5.00	2.90	6.84	0.001	76.3	0.55	7.6
SW	528	1.10	0.69	1.56	0.0003	17	0.14	1.39
WW	17	4.01	0.84	6.51	0.01	20.2	0.61	1.80
Geothermal	16	0.20	0.175	0.18	0.005	0.61	0.03	0.33
Estuarine	18	0.14	0.08	0.18	0.02	0.66	0.03	0.138

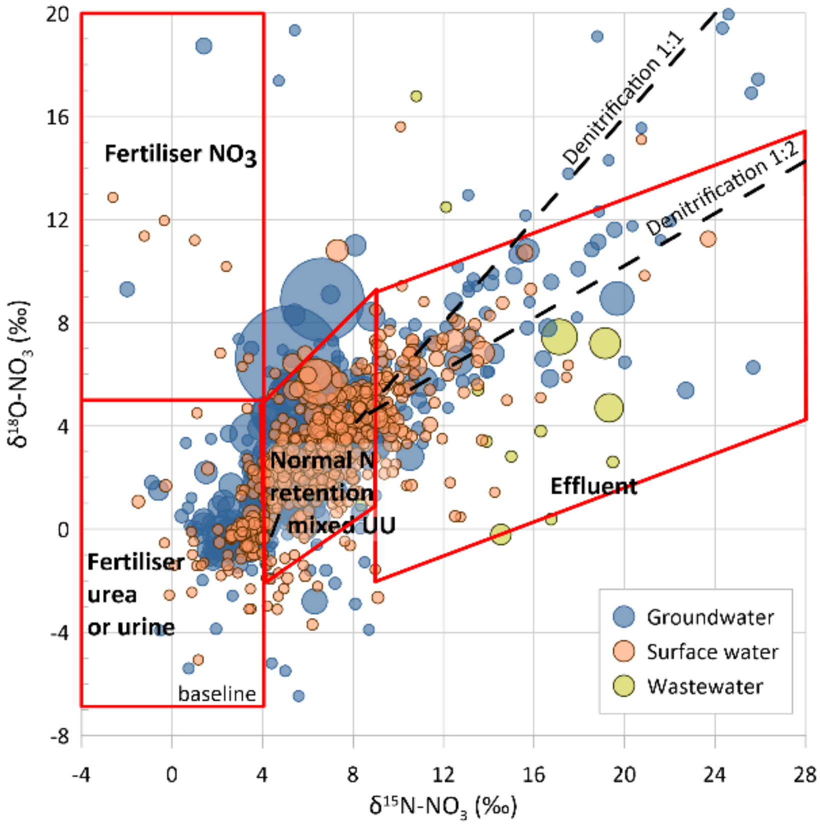

Figure 1. Nitrate Isotope biplot of 1002 freshwater samples from this study (plot format is adopted from Morgenstern et al., 2018).

References

APHA 2012. APHA Method 4500-NO3 – Standard Methods for the examination of water and wastewater. 40 CFR 136.3(a), (modified), American Public Health Association, 22st ed. 2012.

McIlvin, M.R., Altabet, M.A., 2005. Chemical conversion of nitrate and nitrite to nitrous oxide for nitrogen and oxygen isotopic analysis in freshwater and seawater. Anal. Chem., 77(17): 5589-5595

Morgenstern U, van der Raaij R, Baisden T, Stewart M, Martindale H, Stewart M, Matthews A, Collins S. 2018. Ohau and Waikawa catchments of the Horowhenua Groundwater Management Zone: groundwater dynamics, source, and hydrochemical processes as inferred from the groundwater tracer data. Lower Hutt (NZ): GNS Science. 50 p. (GNS Science report; 2018/06). doi:10.21420/G2434W.

CHRISTCHURCH COASTAL GROUNDWATER INVESTIGATION – SUMMARY OF METHODS USED AND PRELIMINARY FINDINGS

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Aims

The Christchurch Coastal Groundwater Investigation is an ongoing PhD research project undertaken at the University of Canterbury (UC) and supported by Environment Canterbury. The supervisory team includes Prof. Jarg Pettinga from the School of Earth and Environment at UC, Dr. Joshu Mountjoy from the Marine Geology Group at NIWA, and Zeb Etheridge from Kōmanawa Solutions. The project, which began in 2018 and will be completed in 2023, has two main research objectives:

1. To investigate the hydrogeology of the Christchurch coastal confined groundwater system, and
2. To assess the vulnerability to seawater intrusion of wells screened in confined aquifers along the city's coastal suburbs

This research project is targeted to investigate the Quaternary confined aquifer system in Christchurch, which comprises, from top to bottom and youngest to oldest, the Riccarton, Linwood, Burwood and Wainoni Gravels, and a sequence of older unnamed gravels that underlie the latter, with particular focus on the shallower Riccarton and Linwood Gravels.

Groundwater is a highly valued resource in Christchurch because it is the main source of drinking water supply for the city. This groundwater also feeds surface waterways that are highly cherished for their cultural, recreational, and social values. The onshore-offshore hydrogeological setting of the groundwater system that provides this high-quality water is poorly understood. The purpose of this research is to address this knowledge gap by providing an improved understanding of the onshore-offshore depositional environment, the quality and quantity of coastal groundwater, the potential location of the saltwater-freshwater interface in confined aquifers and associated vulnerability of coastal supply wells, and the implications of these findings for the management of the resource.

In this presentation, I will provide a brief summary of the methods we have used to address the first research objective, and the results we have obtained to date.

Methods

We have used a number of methods to explore the first research objective. These methods include:

- A boat-towed salinity survey conducted in Pegasus Bay to investigate whether submarine groundwater discharge is occuring somewhere along the seafloor in the shallow continental shelf,
- Interpretation of offshore seismic reflection data coupled with geological modelling to understand the onshore-offshore depositional environment,
- Collection and analysis of water chemistry data from coastal wells in Christchurch, and
- Aquifer testing of a coastal well screened in the Riccarton Gravels to determine aquifer properties

The offshore salinity survey was conducted aboard a University of Canterbury boat, and involved towing a multiparameter probe dragged along the seafloor in Pegasus Bay to measure water salinity changes that could indicate the presence of fresh submarine groundwater discharge. The offshore seismic reflection dataset was acquired by NIWA research vessel Kaharoa in 2011 following the Christchurch earthquakes to investigate the presence of offshore faults in Pegasus Bay, and is here re-evaluated to study whether the onshore aquifers extend offshore, and if they do, to define their geologic structure. Water chemistry samples, including stable isotopes of $\delta^{18}O$ and $\delta^{2}H$, were obtained from 28 coastal wells in Christchurch screened in the Riccarton, Linwood, Burwood and Wainoni Gravels. And the 4-day aquifer test was conducted in a 55 m deep well in South New Brighton, located 100 m from the coast.

Results

Results from the offshore boat-towed salinity survey show several zones where freshened groundwater may be discharging along the seafloor in Pegasus Bay, but due to the limitations of the measurement equipment, we were unable to determine with certainty whether the observed freshwater "pockets" are due to active submarine groundwater discharge or due to freshwater derived from rivers that discharge in Pegasus Bay. Results from interpretation of offshore seismic reflection data indicate that the sequence of Quaternary confined aquifers extends offshore, some as far as 20 km or more. Water chemistry results from sampled wells show predominance of alpine river recharge and little chemical differences in the composition of water found at different depths. And the results from the aquifer test suggest that the Riccarton Gravels are more transmissive near the coast than previously thought.

DRINKING WATER SAFETY: WORKING WITH COUNCILS TO DEVELOP SOLUTIONS FOR SMALL SUPPLIERS

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Under the proposed Water Services Bill, it is likely that a huge number of rural land owners will become small suppliers, as anyone providing drinking water to at least one other person is classed as a supplier. For example, a campsite supplying campers would be a drinking water supplier, as would a farmer supplying two farmhouses. There are then requirements for treatment of water, and monitoring and reporting. There may also be responsibilities for land use management within source protection zones, including implications for land owners where their land falls within a source protection zone for a public water supply.

Taumata Arowai will be responsible for making sure the output of small rural water schemes in their districts meets the drinking water standards. Councils will be expected to work with their communities to ensure they have access to safe and quality drinking water. In order to do this, councils need to understand where there are small suppliers. This, in itself is a hurdle, with the extent of the issue simply unknown. Mackenzie District Council have taken on the responsibility to attempt to identify small suppliers across its region. The approach has to be a balance, highlighting the need for small suppliers to take on board the responsibilities under the upcoming legislation, whilst being aware of the concerns about costs and responsibilities amongst many in the rural communities. The approach has had to incorporate careful messaging, and close engagement with water suppliers.

As part of this, thought was needed to work out solutions, ensuring that compliance and monitoring was at a level that is practical for small suppliers. This included consideration of options such as UV treatment at point of supply, as outlined in Taumata Arowai's "acceptable solution" for agricultural suppliers. Other options included consideration of the opportunity for extension of the council's existing supply network. At a larger scale, there may be other solutions, such as the development of multi-use storage and distribution to help with drinking water supply, that link with infrastructure solutions being considered for agricultural water, with access and security of supply for rural land owners.

We explore some of the issues around drinking water safety, and working with councils and small suppliers in the rural setting.

ASSESSING SURFACE WATER – GROUNDWATER INTERACTION IN THE WAIKIRIKIRI SELWYN RIVER USING ACTIVE DISTRIBUTED TEMPERATURE SENSING AND ELECTRICAL RESISTIVITY SURVEYS

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Aims

Braided river systems are continuously changing environments, comprising heterogeneous gravel forming meandering channels and bars, and dynamic surface water- groundwater interactions. River leakage from braided rivers is a significant source of groundwater recharge in the Canterbury Plains of New Zealand yet is not well understood (Coluccio & Morgan 2019; Larned et al. 2015). Consequently, novel and innovative field techniques are necessary to provide a better understanding of the surface water - groundwater interactions, and the processes and mechanisms of groundwater recharge in these types of systems.

The Waikirikiri Selwyn River travels from the Canterbury foothills, across the Canterbury Plains where it discharges into Te Waihora Lake Ellesmere. The upstream section of the Waikirikiri Selwyn River is primarily runoff fed with a braided morphology, whereas the downstream section is groundwater fed comprising a meandering channel. The primary mechanism of recharge to the Canterbury Plains aquifer system is leakage from the river channels as the subsurface geology is highly transmissive.

This study is part of a 5-year Ministry of Business, Innovation and Employment (MBIE) programme on Braided River research that includes national and international collaborations. The aim of this study is to investigate surface water – groundwater interaction beneath the Waikirikiri Selwyn River using two hydrogeophysical tools; temperature and electrical resistivity surveys. This will aid in improving understanding of how braided river systems recharge underlying braid plain aquifers during varying hydrological conditions and temporal scales. Specifically, we aim to conceptualise hyporheic flow beneath a braided river.

Methods

Heat can be used as a tracer to identify surface water – groundwater interaction and to detect groundwater recharge and discharge (Anderson 2005; Constantz 2008; Stonestrom & Constantz 2003). In this study, heat was used as a tracer to determine surface water loss from the Waikirikiri Selwyn River to the underlying alluvial aquifer system under various flow regimes to inform spatial variability and changes over a hydrological year.

The field study site is an active channel, approximately 70 m wide comprising one to three braids and is within a 35-km long ephemeral losing reach of the river (Larned et al 2008). Horizontal Directional Drilling (HDD) was used to construct two, 100 m long drillholes at a depth of 5 m beneath and perpendicular to the river channel at a field site of the Waikirikiri Selwyn River. The two drillholes were completed with a hybrid fibre optic cable containing four multi-mode fibres and 2x18AWG copper conductors. A Silixa XT-DTS™ distributed temperature sensor with a sample resolution of 0.25 m and temperature resolution of 0.01oC combined with a Silixa Heat Pulse System, was used to collect active distributed temperature sensing (A-DTS) measurements along both cables. An electrical resistivity tomography (ERT) cable, comprising 96 electrodes at 1 m spacings was also installed in both HDD drillholes to evaluate changes in the resistivity of the subsurface beneath the river as a result of changing river flow conditions.

For this study A-DTS and ERT surveys were conducted at monthly time intervals to capture the seasonal trends in the surface water-groundwater exchange processes. Other surface water and hydrogeological data collected at the site was used to complement the A-DTS and ERT surveys.

Results

The monthly A-DTS surveys showed distinguishable seasonal variations in temperature of the shallow braid plain aquifer. The localised temperature variations along the cable indicate spatial variation of preferential groundwater recharge pathways. The ERT surveys delineated how the subsurface resistivity structure changed in response to water saturated conditions and the extent beneath the river. Ongoing work is being done,to quantify the river leakage loss using a modified verison of the heat-flow transport equation.

The combination of A-DTS and ERT methods provide valuable insights into surface water – groundwater interaction from the braided Waikirikiri Selwyn River and how the river leakage rates change over the year and during different flow events.

References

Anderson, M. P. (2005). Heat as a Ground Water Tracer. Ground water (43): 951-968.

Coluccio, K. & Morgan, L. K. (2019). A review of methods for measuring groundwater-surface water exchange in braided rivers. Hydrology and Earth System Sciences, (23): 4397-4417.

Constantz, J. (2008). Heat as a tracer to determine streambed water exchanges. Water Resources Research 44(4).

Larned, S., Hicks, D., Schmidt, J., Davey, A., Dey, K., Scarsbrook, M., Arscott, D. & Woods, R. (2008). The Selwyn River of New Zealand: a benchmark system for alluvial plain rivers. River Research and Applications, 24(1): 1-21.

Larned, S., Unwin, M. J., & Boustead, N. C. (2015). Ecological dynamics in the riverine aquifers of a gaining and loosing river. Freshwater Science, 34(1): 245-262.

Stonestrom, D. & Constantz, J. (2003). Heat as a tool for studying the movement of ground water near streams USGS Circulation 1260.

IMPROVING PUBLIC UNDERSTANDING OF GROUNDWATER PROCESSES USING SIMPLE VISUALISATIONS

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Abstract
Groundwater is one of our most valuable resources as it provides drinking water to over ¼ of NZ's population, >30% of the water for the primary sector, while supplying approx. 80% of NZ's springs, streams and wetland baseflows, which are of central importance to Māori. Human activity is responsible for the degradation of groundwater quality worldwide, which often leads to deterioration of dependant surface water systems.

Understanding the anthropogenic effects to surface waters is straight forward. But for most people in a community, the impacts of over exploitation of the "out of sight" groundwater resource are often poorly understood. Communicating the need for sustainable management of the groundwater resource to the public is unattainable when the degradation effect (i.e. drinking water quality and safety) cannot be clearly related to a cause (i.e. human or natural activity).

Our aim is to develop new, sophisticated but easily deployable visualisation tools, that will be used to improve Māori and community perception and understanding of the groundwater movement in NZ's aquifers, and how external stresses such as water takes, climate change, point and diffuse contamination sources etc. degrade the quality and safety of groundwater supplies and freshwater bodies. Some early results will be presented, and future directions will be discussed.

Acknowledgments
This work is part of the ESR SSIF funded "*He Wai Māpuna*" and "*Securing NZ's groundwater supplies with data science and numerical tools*" programmes.

PROBABLISTIC SOURCE PROTECTION AREA DETERMINATION IN HETEROGENEOUS AQUIFERS

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[2] GNS Science

Aims

The aim of the work described in this paper is to consider how information from borehole lithology records can be used to assess the probability of contaminants reaching a pumping well from the water table. The work elaborates on the results reported by Sarris et al. (2020) which demonstrated how categorical simulations of heterogeneous hydraulic conductivity generated using the T-PROGS software package (Carle, 1999) could be used within a stochastic framework to provide a probabilistic description of source protection area.

Sarris et al. (2020) considered a range of lithology categorisation schemes to discriminate between different hydrogeological facies and to develop alternative geostatistical models. Representative hydraulic conductivities were adopted for each facies type and applied to all realisations in Monte Carlo simulations of flow and transport. That approach had two significant limitations:

- The resulting effective global hydraulic conductivities (in the x-, y- and z-directions) varied significantly between realisations for the same geostatistical model, which is likely to have led to exaggeration of the spatial variability of hydraulic conductivity.
- The adopted facies conductivities limited consideration of a range of possible relative conductivities, which is likely to have had a counter effect.

Our recent work has considered alternative methods for assigning facies conductivities in a way that provides heterogeneous hydraulic conductivity models that are comparable between multiple realisations and that allow for a less constrained exploration of possible relative conductivities.

Method

Flow and transport simulations were undertaken using an unstructured grid model to allow the assignment of heterogeneous facies hydraulic conductivities within a fine-scale inner model (cell dimensions 12.5 m square x 0.8 m) set within a more extensive, coarser-scale outer model (cell dimensions 400 m square x 0.8 m). The hydraulic conductivities in the outer model were set to represent expected values of 45 m/d in the x- and y-directions (K_x and K_y) and 4.5 m/d in the z-direction (K_z).

The general principle applied to the determination of facies hydraulic conductivities (hk_n) was that the resulting inner fine-scale model should not create an anomaly within the overall model. Four alternative approaches were developed and subsequently used to generate probabilistic source protection zones:

Cond_facies	Facies conductivities (hk_n) varied with objective of reproducing expected inner model effective hydraulic conductivities of K_x = 45, K_y = 45, K_z = 4.5 m/d Subject to condition $hk_1 > hk_2 > hk_3$
Cond_facies_tied	As for Cond_facies but with facies conductivities tied So that $hk_1 = 10*hk_2 = 10*hk_3$
Cond_k	Facies conductivities (hk_n) varied with objective of matching internal flux at the upstream boundary of the inner model with that produced with a homogeneous, anisotropic model, with facies conductivities tied, i.e. $hk_1 = 10*hk_2 = 10*hk_3$
Cond_pestfree	Facies conductivites (hk_n) fixed to match the median values identified for the Cond_facies case

Table 1: Alternative approaches to the assignment of facies hydraulic conductivities

These alternative approaches were imbedded within a workflow which, for each geostatistical model, involved:

- 200 categorical realisations of facies using the T-PROGS package
- Assignment of facies conductivities using PEST (Doherty 2016)
- Simulation of steady-state flow to partially penetrating pumping well using MODFLOW6
- Simulation of forward particle tracking (4 particles per upper layer cells) using Modpath7
- Post-processing to
  - Identify flow paths reaching pumping well ('hits') within 1 year
  - Accumulate 'hits' for all realisations to determine probabilistic SPZ

Results

Figure 1 provides examples of the probabilistic source prediction zones derived using the method outlined above. A more comprehensive set of results will be presented, and their significance discussed.

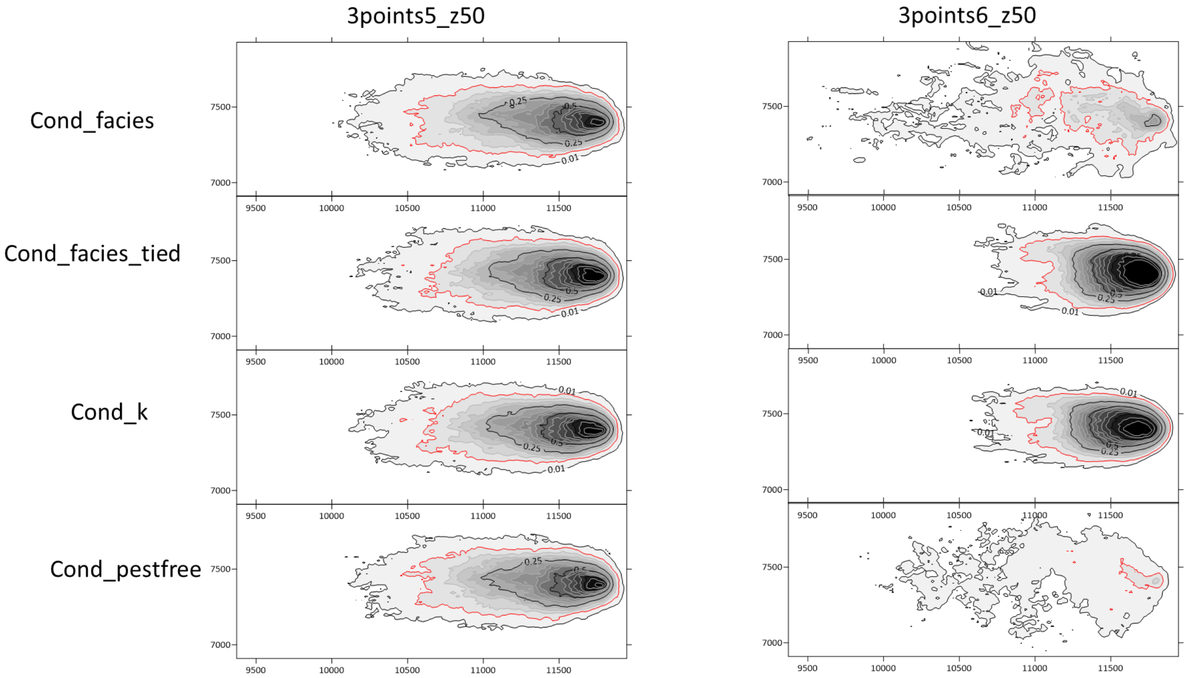

Figure 1: Probabilistic source protection zones for two of the lithology categorisation schemes and the four facies conductivity assignment approaches. The outer and red contours represent 1% and 10% probability respectively.

Acknowledgments

This work is part of the MBIE-funded 'Te Whakaheke o Te Wai (The Pathways of the Waters)' programme led by GNS.

References

Carle, S. F. & Fogg, G. E. Transition probability-based indicator geostatistics. Mathematical Geology 28, 453-476, doi:10.1007/BF02083656 (1996).

Doherty, J., 2016., User's Manual for PEST Version 14.2, 339 pp., Watermark Numerical Computing, Brisbane, Queensland, Australia.

Sarris, T.S., Scott, D.M., Close, M.E., and C. Moore, "Transition Probability Analysis of Lithology Data: Implications for Numerical Delineation of Well Capture Zones", New Zealand Hydrological Society Conference 2020, Invercargill, New Zealand, p.212-213, 1 – 4 December, 2020

IT NEVER RAINS BUT IT POURS – WHAT HAPPENS TO ALLUVIAL AQUIFERS UNDER CLIMATE EXTREMES?

Scott, L.,[1] Aitchison-Earl, P.,[1] Scott, M.,[1] Evans, D.[1]
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Introduction

From 29 to 31 May 2021 central and southern foothill catchments in Canterbury recorded some of the heaviest three-day rainfall ever recorded causing severe flooding. This high rainfall and river flow event followed several months of well below average rainfall, low soil moisture and very low groundwater levels.

Aim

The May 2021 event provided an opportunity to improve our understanding of how the Canterbury Plains groundwater systems respond to extreme climate events. Climate change predictions for Canterbury indicate that such extremes will become more common in the future (Macara ***et al.,*** 2020).

The project aimed to investigate the effect on both the quantity and quality of groundwater in the Waimakariri, Selwyn-Waihora, Ashburton and Orari-Temuka-Opihi-Pareora zones. These were worst hit by the flooding. We were particularly interested in finding out where and how much groundwater levels recovered and how contaminants from land use, notably nitrate and ***E. coli***, were affected.

Methods

Environment Canterbury maintains a network of long-term water level monitoring wells including 15-minute interval recorders and monthly manual measurements. These monitoring sites provided data for analysis from before and after the rainfall event. Water levels from May and June 2021 were each compared with long-term median levels for the same wells in the same calendar months.

Approximately fifty long-term water quality monitoring wells, representing shallow groundwater in the catchments of interest, were selected for an intensive sampling investigation after the event. These wells all have long-term records of water quality prior to May 2021. Results from after the event were compared with historical water quality at the same monitoring sites.

In addition to the water quality sampling, four nitrate sensors installed in wells across the Canterbury region captured real time data from before, during and after the event that allowed us to look at responses and lag times in more detail (see also Wilkins, in prep).

Results

Groundwater levels before the rainfall and flooding were very low following a low recharge winter and high demand irrigation season. One in three level monitoring wells were at the lowest ever measured in May 2021. The rainfall led to a sharp rise in groundwater levels, particularly for shallow wells close to the foothills rivers that experienced the highest flows (Figure 1). The recharge was not enough to return deeper wells to average levels by June. Over 80% of monitoring wells over 30 m deep were still below June median.

Nitrate nitrogen and total coliforms showed the greatest change in concentrations before and after the floods. After a drier than average 2020 winter, Environment Canterbury's annual groundwater quality survey (samples collected in September to December) had found nitrate nitrogen concentrations across the region were slightly lower than previous years' surveys, both in terms of regional median concentration and proportion of sites exceeding the drinking-water Maximum Acceptable Value.

The heavy rainfall saturated the soil flushing nitrogen accumulated in the soil and vadose zone to the shallow groundwater. Nitrate concentrations increased by more than 1 mg/L in 60% of the wells we sampled specifically for this investigation (Figure 2). Some of the highest increases were observed in the upper plains near the Hinds/Hekeao and Ashburton/Hakatere rivers. Other sites showed little, or no change and three sites also decreased in nitrate nitrogen concentration by more than 1 mg/L, possibly due to dilution by recharge from stormwater or rivers.

The four continuous sensors all showed an increase in nitrate nitrogen concentrations after the event although one of them first decreased slightly. The time for groundwater monitored by theses sensors to reach peak nitrate concentrations varied from 4 days to 45 days after the floods.

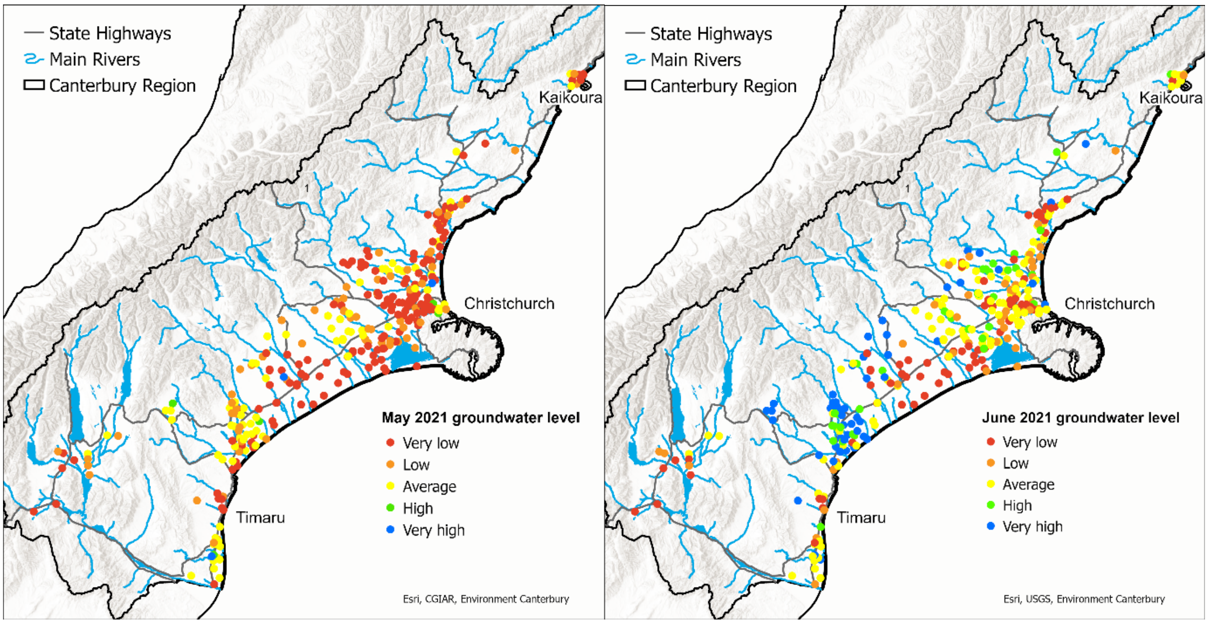

Figure 1: Comparison of May (left) and June (right) 2021 groundwater levels recorded in the Canterbury region. Symbols are categorised by how each site compared with long term median levels recorded historically in the same calendar month.

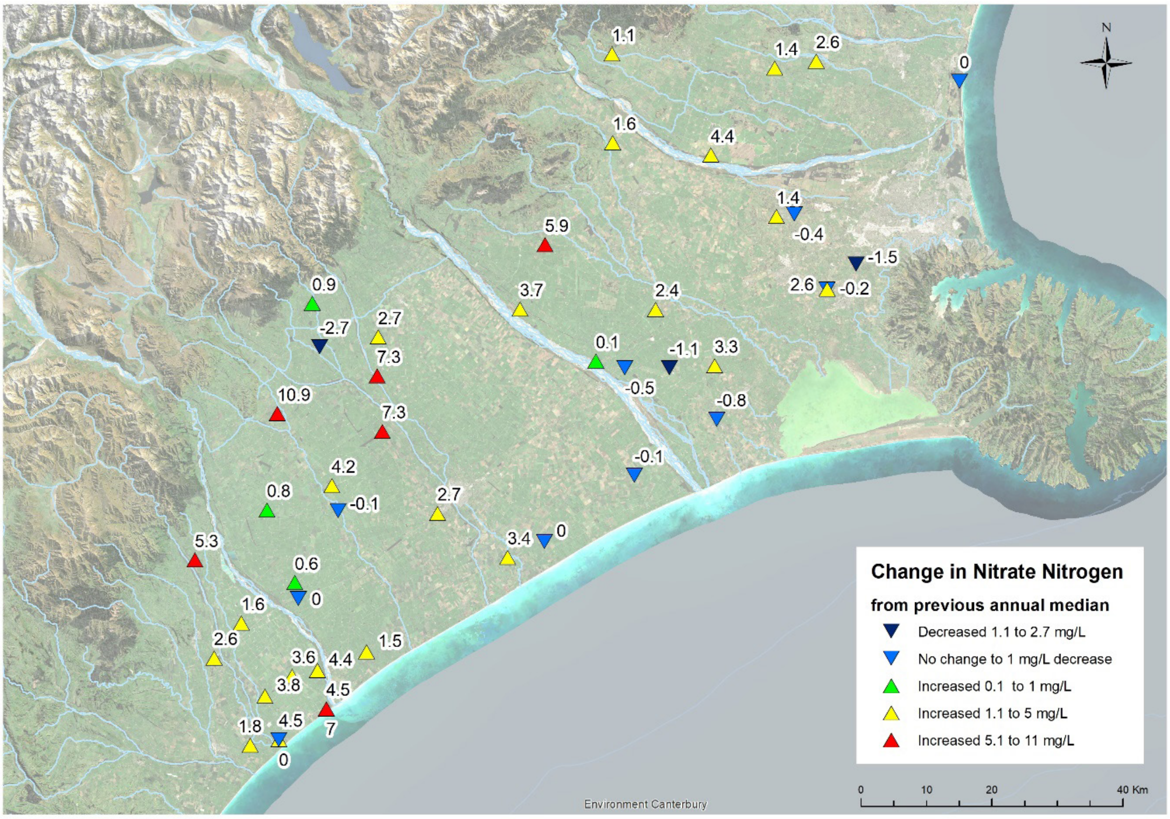

Figure 2: Change in nitrate nitrogen concentrations in groundwater samples collected mid June 2021 for the flood event investigation, compared with the median concentration over the previous year.

References

Macara, G., Woolley, J-M., Pearce, P., Wadhwa, S., Zammit, C., Sood, A., Stephens, S. 2020. *Climate change projections for the Canterbury region, NIWA client report* No. 2019339WN, Prepared for Environment Canterbury.

Wilkins, B. In prep. *Analysing nitrate nitrogen measurements in Canterbury groundwater from in-situ, UV nitrate sensors*, Abstract for 60th Annual NZHS Conference 2021: Wellington (this volume).

MAPPING SHALLOW GROUNDWATER SALINITY IN CHRISTCHURCH, NEW ZEALAND: IMPACTS ON MUNICIPAL ASSETS

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Aims

1. Sample, map, and interpolate shallow groundwater salinity in the low-lying city of Christchurch.
2. Highlight municipal assets within brackish and saline shallow groundwater areas.
3. Discuss the impacts of shallow groundwater salinization on municipal assets.

Method

In this study, 109 shallow piezometers in the Christchurch Formation surficial aquifer were measured for specific conductance (as a proxy for salinity; Jiao & Post, 2019), temperature, and pH, following the pumping of approximately three bore volumes, from 8 September to 21 October 2020. This was possible due to the extensive network of shallow piezometers installed after the 2010-11 Canterbury Earthquake Sequence to investigate liquefaction risk. In addition, spot checks of chloride concentration and alkalinity on 25% of the bores were conducted, to investigate if seawater was the source of salinity (Chang et al., 2019). The specific conductance measurements were mapped and interpolated in ArcGIS (ESRI, 2021) across the 81 km^2 study area using the Topo to Raster tool. The GIS analysis of municipal assets within the brackish and saline areas were conducted based on the data supplied by Christchurch City Council (2021).

Results

We present the results in a map showing groundwater specific conductance measurements and interpolation. We identified areas with brackish and saline shallow groundwater, and the municipal assets within them, including subsurface pipes and parks. In addition, the possibility of downward saltwater contamination into deeper aquifers is discussed, as well as the impacts of shallow groundwater salinization on wastewater treatment plant processes.

References

Chang, S. W., Chung, I.-M., Kim, M.-G., Tolera, M., & Koh, G.-W. (2019). Application of GALDIT in Assessing the Seawater Intrusion Vulnerability of Jeju Island, South Korea. *Water, 11*(9).

Christchurch City Council. (2021). *Corporate Data.* Retrieved from https://gis.ccc.govt.nz/arcgis/rest/services/CorporateData

ESRI. (2021). ArcGIS Pro: Release 2.7. Redlands, CA: Environmental Systems Research Institute

Jiao, J., & Post, V. (2019). *Coastal Hydrogeology:* Cambridge University Press.

GOING GREEN: COSTS AND BENEFITS OF LIVING ROOFS ON BUS SHELTERS IN AUCKLAND

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Introduction

Auckland Transport (AT) is trialling lightweight, living roofs on two Auckland bus shelters as part of their focus on sustainable and environmental solutions for public transport initiatives. A large bus shelter (194 m^2) at the Panmure Transport Centre, and a small bus shelter (9.5m^2) outside Redoubt North School in Manukau are being retrofitted with plants growing in a growing media up to 150 mm deep. Such roofs generally have a structural loading of 60 – 300 kg/m^2 (Hargreaves, 2006, Fassman-Beck et al 2010) and support low-growing vegetation such as herbs, rushes, grasses, sedums and other succulents, wildflowers, summer-dormant bulbs and, in Auckland, lithophytes[1] and epiphytes[2] such as bromeliads and tank lilies.

The goal of the pilot project is to design extensive living roofs which can be retrofitted, easily maintained, and which maximise four prioritised benefits:

- To contribute to the well-being of Aucklanders by providing bus stops which filter air pollutants, reduce the urban heat island effect and provide some aesthetic benefits;
- To contribute to local native biodiversity and/or pollinator pathways, increasing 'nature' in the roadside environment;
- To reduce impervious surfaces within the city and provide stormwater quantity reduction benefits; and
- Provide an opportunity to understand a climate change adaptation option.

Design and Structural Considerations

The bus stops needed to accommodate the weight of the "regular" roof, as well as the components of the living roof system under normal operating conditions (Fassman-Beck & Simcock, 2013). Both bus shelter structural loading requirements fell within the approximate saturated weight of a relatively thin and lightweight (low-profile) green roof (80-100 kg/m^2 range). The general public's (and AT's) assessment of performance of a living roof is often judged by the health and appearance of plants, hence choosing suitable plants, management and sites is important. The choice of plants depends on the sun (and wind) exposure, the availability of irrigation and water stored in the substrate. Irrigation as incorporated into the larger Panmure bus shelter to maintain plant aesthetics through summer and allow taller plants to be used. Solar panels are used on the Redoubt North School minor bus shelter. These were incorporated into the design. Lower-growing plants (sedums) were planted around the solar panels to ensure maximum sun exposure. Taller plants were planted towards the edges of the bus shelter where they could be seen by commuters. The design objectives and plant choices also have significant maintenance implications.

Understanding the Long Term Costs and Benefits of Living Roofs

Using a life cycle costing (LCC) approach, potential construction and long-term maintenance costs of the proposed living roof designs were estimated. On average, a small sized (approximately 10m^2) living roof has a low indicative LCC estimate of \$32/m^2/yr and a high indicative LCC estimate of \$62/m^2/yr over a 50 year analysis period at a 4% discount rate (2018 base date). The LCC results demonstrate a right-skewed distribution of costs (i.e., an increase in device surface area leads to a decrease in LCC). This relationship is likely caused by the predominating effect of long term maintenance costs on Total Acquisition Cost (TAC) as some of the maintenance and associated cost is device specific (e.g., inspections – individual roofs need to be inspected regardless of size) and needs to be undertaken for both small and large roof areas (i.e., it is independent of total roof area, ensuring a lesser relative cost for larger devices). This leads to clear economies of scale being achieved for larger roofs or wide-spread implementation of smaller roofs in close proximity to each other. Results show that the majority of the LCC is related to ongoing routine maintenance of the living roof (approximately 60% - 70% of the total LCC).

1 Lithophytes are plants that grow on rocky outcrops.
2 Epiphytes are plants which grow in trees.

Living roofs typically also deliver a range of environmental, economic and social benefits, many of which are non-water related. The bus shelters were designed to deliver aesthetic benefits (greening of the urban environment), air purification (by carbon sequestration), extension of roof life, reduction of ambient air temperature, increased biodiversity/ habitat, stormwater flow and volume reduction, noise reduction and support insect pollination. The “More Than Water” tool (Moores, et al., 2019) was used to graphically illustrate potential benefits of living roofs on bus shelters. “More Than Water” (MTW) was designed to enable qualitative assessments of differences in the benefits and costs of alternative green infrastructure project scenarios. As shown in Figure 1, conventional bus shelters are likely to only elicit benefits around ambient air temperature and public health (in that they keep patrons dry and shaded), other benefits would be classified as “None” in the MTW tool.   Living roofs, on the other hand, elicit numerous non-water and water-related benefits (Figure 1). The assessment assumes a cumulative effect from a wider roll-out of living roofs on bus shelters rather than individual bus shelters themselves.

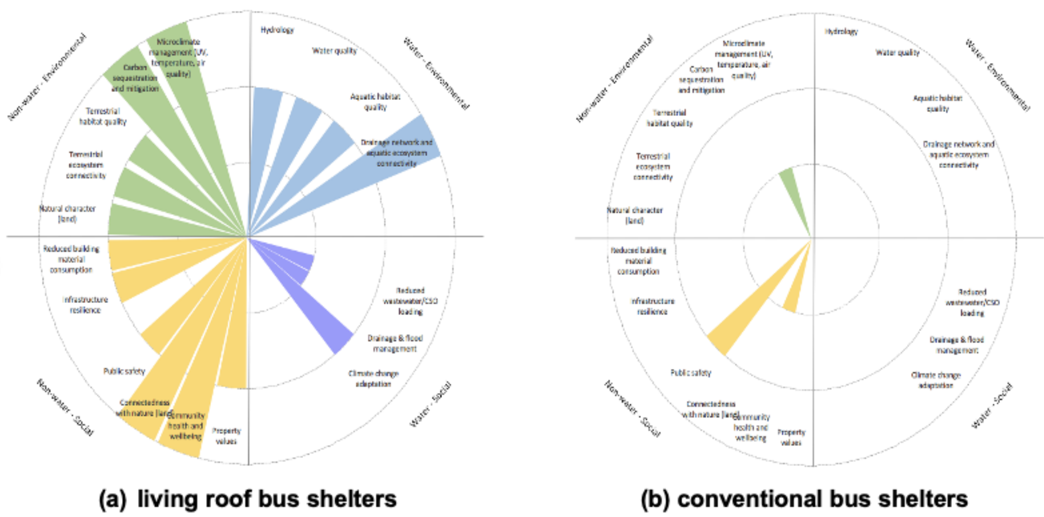

Figure 1: More Than Water benefits assessment for bus shelters with living roofs. Note benefits would differ for different designs (inclduing complementary features), locations and maintenance.

In conclusion, whilst living roofs may be more expensive than conventional roofs, they can provide a range of benefits delivered by plants and water storage (Figure 1). In addition to enhancing urban environments, these benefits can range from improving microclimates, carbon sequestration, connecting people with nature and improving community well-being to stormwater and aquatic habitat benefits. These benefits could be delivered through bus shelters if the roof area is large, the surrounding areas are bare of plants, and the plants are bulky and visible. These roofs also contribute to resilience of the road corridor by providing an option for assessment under ATs climate change adaptation approach.

References

Please contact authors for reference information.

ATMOSPHERIC RIVERS IN NEW ZEALAND: WATER RESOURCES AND EXTREME RAINFALL EVENTS

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Aim

This study quantifies hydrological impacts of landfalling Atmospheric Rivers (ARs) in New Zealand. Using an automated AR detection algorithm, daily rainfall records from 654 rain gauges and various atmospheric reanalysis datasets, we investigated the climatology of ARs, the characteristics of landfalling ARs, and the contribution of ARs to water resources and extreme rainfall events between 1979 to 2018 across the country. Results indicate that ARs play an essential role in regional water resources and producing many extreme rainfall events on the western side of mountainous areas and northern New Zealand. The west side of mountain ranges sees 40–86% of the rainfall totals and 50–98% of extreme rainfall events associated with ARs depends on the season. Interestingly, AR storms are 2-3 times the non-AR storms throughout the country. Furthermore, locally anomalously high rainfall events are related to AR's orientation and landfall direction. The results of this study extend the knowledge on the critical roles of ARs in hydrology and highlight the need for further investigation of AR climate drivers and sources to improve the ability to forecast hydrological hazards caused in New Zealand.

Method

AR detection is based on the integrated water vapour transport (IVT) magnitude from an Eulerian framework (Blamey et al., 2018; Lavers et al., 2012; Nayak & Villarini, 2017), which is given by:

$$IVT = \sqrt{\left(\frac{1}{g}\int_{1000hPa}^{300hPa} qu\, dp\right)^2 + \left(\frac{1}{g}\int_{1000hPa}^{300hPa} qv\, dp\right)^2} \qquad (1)$$

where q is specific humidity (kg kg^{-1}), u and v are zonal and meridional wind vectors (m s^{1}) respectively, g is the gravitational acceleration (9.81 m s^{-2}), and dp is the pressure difference between two adjacent atmospheric pressure levels (hPa). To compute IVT, 20 vertical pressure levels (1000hPa-300hPa) of 6-hourly specific humidity and wind vectors were retrieved from the European Centre for Medium-Range Weather Forecasts (ECMWF), ERA-5 dataset (Hersbach et al., 2016) from 1979 to 2018 with a 0.25° spatial resolution over the 0-70°S and 100°E-120°W domain. Note that only ARs which make landfall along New Zealand coastlines were considered in this study.

The AR detection algorithm developed by Guan and Waliser (2015) was employed in this study, which involves a set of conditions on the IVT grid cells to identify AR objects every time step within the specified domain. The AR object refers to the instantaneous area that meets the defined AR detection conditions. The detection conditions include grided IVT magnitude thresholding, the poleward direction of the AR object, IVT direction coherence within the AR object, consistency between the AR-object mean IVT direction and orientation, and the AR-object geometry. Detailed AR detection procedures and conditions are provided in Guan and Waliser (2015). Archived landfalling AR dates from this algorithm shows over 90% agreement with other regional-specific AR detection techniques (Gorodetskaya et al., 2014; Guan et al., 2018; Lavers et al., 2012; Neiman et al., 2008; Ralph et al., 2019; Shields et al., 2018) and this algorithm was only the one that has been validated from the dropsonde observations for the AR intensity and geometry. Thus, this algorithm has been widely used as a benchmark in different regions for AR tracking studies (Guan & Waliser, 2019; Zhou et al., 2018; Zhou & Kim, 2019) and regional-specific AR detection algorithm development (Gershunov et al., 2017; Pan & Lu, 2019; Reid et al., 2020).

We modified the method used to identify AR-induced rainfall events in Shu et al. (2021). Based on the geographical coordinate of the 4 grid points enclosing a rain gauge, the date and time that all 4 points simultaneously detected AR activities were referred to an AR event at that date and time for that rain gauge. Moreover, the peak daily rainfall amounts and the standardised index of each AR event were obtained, and the index was calculated as:

$$\text{Standardised index} = (x - \bar{x})/S, \qquad (2)$$

where x is the AR-event peak daily rain amount, $\bar{x}$ is the annual mean daily rainfall, S is the annual daily rain standardised deviation.

Results

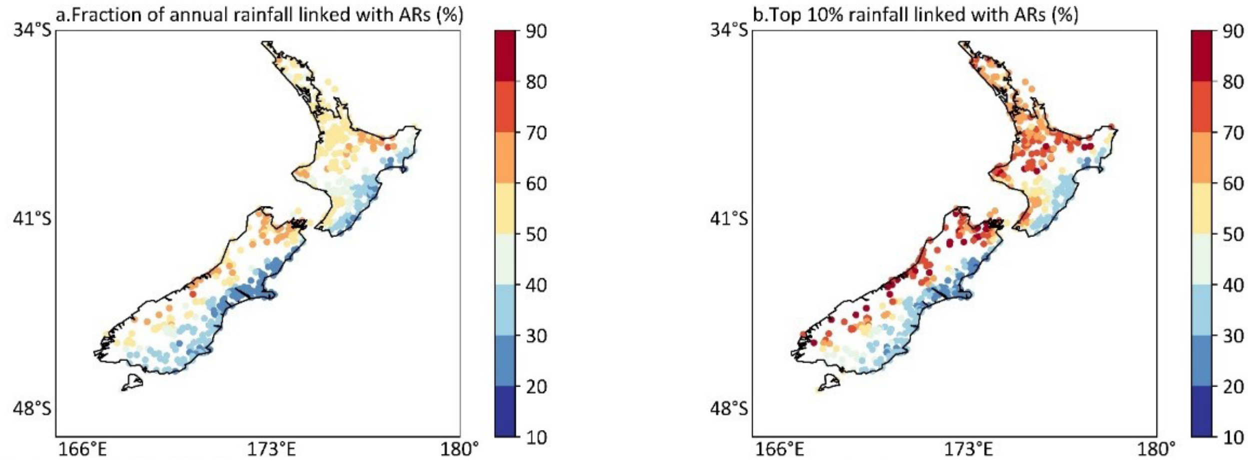

Figure 1 Contribution of ARs to annual rainfall and extreme rainfall events

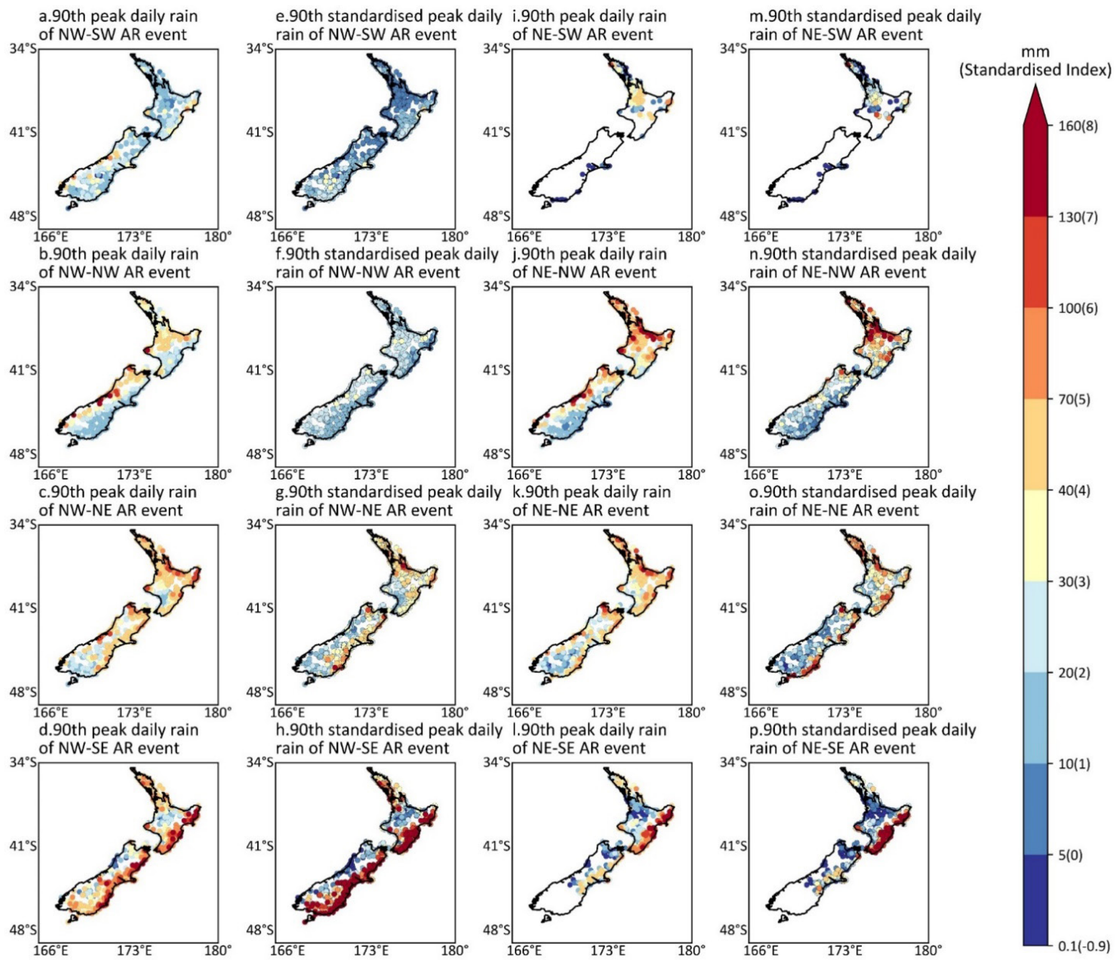

Figure 2 90th percentile value of northwesterly oriented AR-event (a-d) peak daily rainfall amount and (e-h) corresponding standardised index with different mean landfall directions. (i-l and m-p) Same as a-d and e-h but for northeasterly orientated ARs.

Reference List

Shu, J., Shamseldin, A. Y., & Weller, E. (2021). The impact of atmospheric rivers on rainfall in New Zealand. *Scientific Reports, 11*(1), 5869. https://doi.org/10.1038/s41598-021-85297-0

A VON KARMAN'S CONSTANT PROBLEM SOLUTION

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Aim

A velocity profile occurs when a moving fluid passes a solid boundary (or vice versa) - and fluid velocity adjusts to the boundary velocity as the boundary is approached. The boundary could be a boat hull, an aircraft fuselage, a riverbed or the earth's surface and the fluid is typicaly air or water. For steady, 2-dimensional turbulent flow, the local mean streamwise velocity $\boldsymbol{u}_z$ can be related directly to the boundary shear velocity u* by the logarithm of the perpendicular boundary distance z. This log law was established by Prandtl (1925) and von Karman (1930) and the inverse coefficient κ has become known as von Karman's constant:

$$u_z = (u_* / \kappa) \ln(z/z_0) \qquad (1)$$

where $u^* = \sqrt{(\tau_0 / \rho)}$ is the shear velocity, τ_0 is the shear stress on the boundary, ρ is the fluid density, z_0 is the boundary distance at which Eq. (1) indicates $u_z = 0$ and $\kappa \approx 0.4$. Eq. (1) is widely used in meteorology, river mechanics and flood modelling calculations**.**

The problem with von Karman's coefficient is that although it has been designated as a universal mixing constant (van Driest 1956, Pope 2000), it is also reported to vary. Hassan and Chauhanb (2008) found that κ is not universal and exhibits dependence on pressure gradients and channel geometry. George (2007) found a value of $\kappa \approx 0.38$ for classical boundary layer flows was not the same as $\kappa \approx 0.43$ for pipe flow and furthermore concluded that a universal log law is not supported by either theory or data. Atmospheric measurements show κ values as low as 0.35 (Businger et al., 1971) and as high as 0.46 (Sheppard, 1947). Increasing κ moves the distance at which $u_z = u^*$ further from the boundary and increases flow resistance while decreasing κ moves higher velocities closer to the boundary and the reduces drag. In Eq. (1) κ operates in an inverse manner to u* so that an error in u_* can be concealed by adjusting κ and *vice versa*. When Eq. (1) is used to calculate boundary shear stress from ρu_*^2, a 5% error in κ will result in ~ 10% error in τ_0 (other factors held constant). Such errors can have serious implications. Examples include pipeline pumping costs, calculation of flood water levels and the initiation of sediment transport. However, despite the importance of κ and the sensitivity of shear stress to κ, there has been little consensus as to whether κ is, or is not, a "constant" and, if it is, what is the correct value of the constant. The aim of this work is to provide a potential physical explanation for a fixed value of von Karman's constant and provide a base for the log law.

Method

In an ideal log law boundary layer comprising translating eddies, we make the investigative assumption that structures which govern mean streamwise velocity $\boldsymbol{u}_z$ can be represented as rolling eddies. Other than noting that horseshoe vortices and streamwise spiralling structures have a spanwise projection of downstream velocity that is rolling downstream, we focus on the implications of a rolling eddy turbulence model, rather than discussing the physical evidence. If governing eddy diameter (d) equals the distance of the eddy from the boundary and such eddies roll on their base at u* without slipping, we have the idealised situation shown in Fig. 1. A rolling cylinder moves "downstream" with its centroid rolling velocity added to its base velocity. Referring to Fig. 1 the streamwise velocity of governing eddies which have the described properties can be formulated as:

$$u_{(z)} = u^* + u_{(z - z/3)} \qquad (2)$$

Results

For a self-similar flow, the base velocity of an eddy is itself governed by eddy behaviour according to Eq. (2). Taking any arbitrary point at coordinates ($u = u_{ref}$, $z = z_{ref}$) in such a boundary layer, we can find other ($\boldsymbol{u}$, $\boldsymbol{z}$) velocity profile points at ($u_{ref} - u^*$, $(2/3)\, z_{ref}$) and ($u_{ref} - 2\,u^*$, $(2/3)^2\, z_{ref}$) and so on, leading to a general parametric profile equation:

$$(u, z) = (u_{ref} - n\, u^*,\ (2/3)^n z_{ref}) \qquad (3)$$

By eliminating *n* we convert Eq. (3) to a conventional equation:

$$u_z = u_{ref} - u_* \log_{2/3}(z/z_{ref}) \qquad (4)$$

where the log subscript indicates a log base of 2/3.

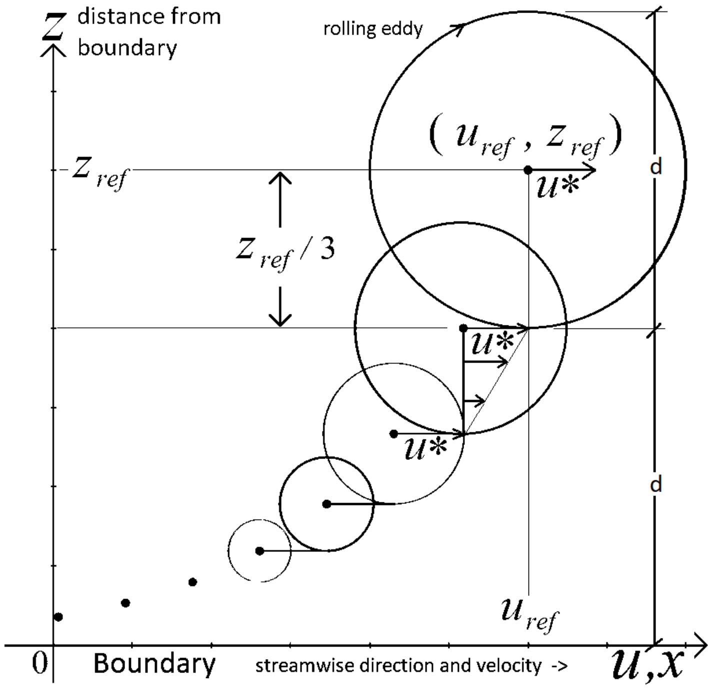

Figure 1: Conceptual model of spanwise axis eddies rolling at u* relative to their roll plane.

If z is assigned a length scale of z_0 where $u_z = 0$ then Eq. (4) shows $u_{ref} = u_* \log_{2/3}(z_0/z_{ref})$.

Substituting for u_{ref} in Eq. (4) we get:

$$u_z = u_* \log_{2/3}(z_0/z_{ref}) - u_* \log_{2/3}(z/z_{ref}) = u_* \log_{2/3}(z_0/z) = u_* \log_{3/2}(z/z_0) \quad (5)$$

Applying a change of log base to give natural logs, we arrive at:

$$u_z = (u_* / \kappa) \ln(z/z_0) \qquad \text{where } \kappa = \ln(3/2) \approx 0.4055 \quad (6)$$

which is the von Karman log law.

This rolling eddy derived log law has no empirical parameters. Seen in this light, von Karman's κ is not an elusive constant but a factor to convert a base 3/2 log to a natural (base e) log. According to this analysis the value of von Karman's constant is κ ≈ 0.406.

References

Businger, J. A., Wyngaard, J. C., Izumi, Y., Bradley, E. F. (1971). Flux profile relationships in the atmospheric surface layer. J. Atmos. Sci., 28, 181–189.

George, W. K. (2007). Is there a universal log law for turbulent wall-bounded flows? Phil. Trans. R. Soc. A 365. 789-806.

Hassan M. N and Chauhanb K. A. (2008) Variations of von Kármán coefficient in canonical flows. Physics of Fluids 20, 101518.

Pope, S. B. (2000) Turbulent Flows. Cambridge University Press.

Prandtl, L. (1925). Bericht über Untersuchungen zur ausgebildeten Turbulenz. J. App. Math. & Mech. 5 (2), 136–139.

Sheppard, P. A. (1947). The aerodynamic drag of the Earth's surface and the value of Karman's constant in the lower atmosphere. Proc. Roy. Soc. London Ser. A, 188, 208-222.

Van Driest, E. (1956). On turbulent flow near a wall. J. Aeronaut. Sci. 23, 1007–1011.

von Karman, T. (1930). Mechanische Ahnlichkeit and Turbulenz, Nachrichten der Akademie der Wissenschaften Gottingen, Math. Phys. Klasse, 58-76.

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A NATIONAL INDEX FOR SUSCEPTIBILITY TO STREAMBANK EROSION

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Aims

Accelerated erosion contributes excess fine sediment to rivers in New Zealand where it impacts water quality, ecosystem health and recreational amenity (MfE & Stats NZ, 2019). To address these impacts, the updated National Policy Statement – Freshwater Management (NPS-FM 2020) defines thresholds for freshwater attributes including suspended and deposited fine sediment, as well as regulatory planning processes that regional councils must follow to manage them.

Streambank erosion can be an importance source of fine sediment in New Zealand's rivers (Smith et al. 2019; Hughes et al. 2021). However, no data or models of streambank erosion are available at a national scale. This information is needed for prioritising management interventions to reduce streambank erosion and for evaluating the effect of those interventions. In response, the Ministry for the Environment (MfE) first commissioned a feasibility study (Smith 2020) and then work to implement a national index for susceptibility to streambank eroson (Smith et al. 2021).

The national index provides a relative measure of reach-scale susceptibility based on the spatial variation in factors that influence streambank erosion. The requirement for a nationwide susceptibility index means that only spatial data sets available on a national scale may be used as inputs. As a result, the balance between model complexity, spatial resolution, and the level of available data were key considerations for index development. Here, we describe the susceptibility index for streambank erosion and provide recommendations on appropriate use of the index and future work.

Methods

An empirical approach for representing reach-average bank migration rate (M_j) forms the basis for computing the index of susceptibility to streambank erosion (Smith 2020). M_j can be calculated for each link in the digital river network (REC v2.5) as follows:

$$M_j = SP_j Sn_j T_j V_j (1 - PR_j)(1 - PL_j)$$

where SP_j is the stream power of the mean annual flood (MAF) for the *j*-th stream link, Sn_j is the channel sinuosity rate factor of the *j*-th link, T_j is the soil texture-based erodibility factor of the j-th link, V_j is the valley confinement factor of the j-th link, PR_j is the proportional extent of riparian woody vegetation of the j-th link, and PL_j is the proportional extent of intersection with mapped lakes for the *j*-th link.

The basis for including and calculating each term used in computing M_j is described by Smith et al. (2019; 2020). Previous studies report increasing bank migration with increasing bankfull discharge, mean annual flood, and stream power (Walker & Rutherfurd 1999; Dymond et al. 2016; Alber & Piégay 2017). Other factors, such as the cohesiveness of bank materials (Julian & Torres 2006), channel sinuosity (Nanson & Hicken 1983), valley confinement (Hall et al. 2007), and riparian woody vegetation (Abernethy & Rutherfurd 2000) are also important and result in high levels of spatial variability in bank erosion.

The dimensionless index of susceptibility (I_j, range 0 – 100) is computed as:

$$I_j = \left(\frac{M_j - M_{min}}{M_{max} - M_{min}}\right) \times 100$$

where M_{max} is set to the mean of the 10 highest values for M_j (for which I_j is set to 100) to avoid dependence on a single large value of M_j for calculating all index values. M_{min} corresponds to the minimum value (zero).

Results

The streambank erosion susceptibility index is available for download from the MfE Data Service ([Streambank Erosion Susceptibility Index - Freshwater directorate | | GIS Map Data | MfE Data Service]). Most index values are low and correspond with the large number of first and second order stream links in the digital river network. Index values tend to increase with stream order, which reflect the general downstream trends of increasing MAF, decreasing valley confinement, and the decreasing extent of riparian woody vegetation.

Comparison of index values should not focus on individual stream links. This is because index values for individual links may be uncertain due to a) errors in underlying spatial data and b) the potential for missing spatial information (e.g. erosion control works) to result in predicted susceptibility that is not fully representative of contemporary conditions. Limitations associated with the derivation of the index are described in detail by Smith et al. (2021) for consideration when evaluating results.

Higher levels of spatial aggregation reduce the sensitivity to index values for individual stream links. We recommend that sea-draining catchments and stream order be used as a basis for summarising index values for the purpose of comparison. Percent exceedance thresholds may also form a basis for ranking bank erosion susceptibility by catchment. Stream links that equal or exceed a pre-defined threshold value (e.g. the upper 1% of stream links that correspond to 4,375 km of channel nationally) may be identified and the proportion of threshold-exceeding stream length computed relative to the total stream length by stream order present within each sea-draining catchment.

Our study presents the first national estimate of susceptibility to streambank erosion for New Zealand. The index provides a quantitative basis for comparing and prioritising catchments for management interventions to reduce bank erosion. We consider the index of susceptibility an important step in the longer-term effort to quantify the contribution of bank erosion to catchment suspended sediment loads. This requires future investment to acquire a) bank migraton rate, b) bank height, and c) bank accretation rate data for a range of river channel forms and conditions to enable model development and national scale prediction of sediment loads from bank erosion.

References

Abernethy, B., Rutherfurd, I.D. 2000. The effect of riparian tree roots on the mass-stability of riverbanks. *Earth Surface Processes and Landforms*, 25: 921–937.

Alber, A., Piégay, H. 2017. Characterizing and modelling river channel migration rates at a regional scale: case study of south-east France. *Journal of Environmental Management*, 202: 479–493.

Dymond, J.R., Herzig, A., Basher, L., Betts, H.D., Marden, M., Phillips, C.J., et al. 2016. Development of a New Zealand SedNet model for assessment of catchment-wide soil-conservation works. *Geomorphology*, 257: 85–93.

Hall, J.E., Holzer, D.M., Beechie, T.J. 2007. Predicting river floodplain and lateral channel migration for salmon habitat conservation. *Journal of the American Water Resources Association,* 43: 786–797.

Hughes, A.O., Huirama, M.K., Owens, P.N., Petticrew, E.L. 2021. Stream bank erosion as a source of sediment within New Zealand catchments. *New Zealand Journal of Marine and Freshwater Management* https://doi.org/10.1080/00288330.2021.1929352

Julian, J.P., Torres, R. 2006. Hydraulic erosion of cohesive riverbanks. *Geomorphology,* 76: 193–206.

Ministry for the Environment & Stats NZ. 2019. New Zealand's Environmental Reporting Series: Environment Aotearoa 2019. Ministry for the Environment and Stats NZ Publication No. ME 1416.

Nanson, G.C., Hicken, E.J. 1983. Channel migration and incision on the Beatton River. *Journal of Hydraulic Engineering,* 109: 327–337.

Smith, H.G. 2020. Memorandum on the technical feasibility of developing a national index for susceptibility to streambank erosion. Manaaki Whenua − Landcare Research Contract Report LC3769 prepared for the Ministry for the Environment.

Smith, H.G., Betts, H. 2021. Memorandum on implementing a national index for susceptibiltiy to streambank erosion. Manaaki Whenua − Landcare Research Contract Report LC3998 prepared for the Ministry for the Environment. https://environment.govt.nz/publications/national-index-streambank-erosion

Smith, H.G., Spiekermann, R., Dymond, J., Basher, L. 2019. Predicting spatial patterns in riverbank erosion for catchment sediment budgets. *New Zealand Journal of Marine and Freshwater Management,* 53: 338–362.

Walker, M., Rutherfurd, I.D. 1999. An approach to predicting rates of bend migration in meandering alluvial streams, in *Proceedings of the Second Australian Stream Management Conference,* edited by Rutherfurd, I.D., Bartley, R. eds: Cooperative Research Centre for Catchment Hydrology. Pp. 659–665.

DATA DRIVEN ANALYSIS OF TEMPORAL STORM DESIGN PATTERNS FOR USE IN CLIMATE CHANGE SCENARIOS

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[1] NIWA, Wellington

Aim

Design storms are often used in flood inundation modelling to inject rainfall in a realistic way. There are a variety of ways to disaggregrate a total storm rainfall depth to simulate the temporal evolution of event. These include for example, a simple triangle shape, a parameterised functional form (French and Jones, 2012), or a nested design storm (Keifer and Chu, 1957). In this study we use a data driven approach to investigate historic storm shapes and explore the use of machine learning to generate synthetic storm shapes that capture the key observed properties. In addition, we analyse the relationship between temperature and temporal storm shape for possible application in climate change scenarios.

Method

Using historical rainrate breakpoint data from 10 selected sites in the lower North Island, the top 50 storms by volume, were found for each site and used to assemble a database of approximately 500 storms. To create a standard design storm, we then used a version of the average variability method (Pilgrim and Cordery, 1975) to construct a nested storm based on the typical proportion and rank of the observed sub-storm components.

A Variational Auto Encoder (VAE) model was trained on a subset of the 500 storms and, based on a manual classification of the observed storms, a relationship between storm type and latent space was found. This VAE model was then to generate synthetic storm shapes with different temporal characteristics which were shown to have similar properties to the standard design storm, but with more realistic temporal structure.

Following the method of Wasko et al. (2015), the relationship between daily mean temperature and storm shape was analysed. By regressing the proportion of rain that fell during the most intense segment of a storm against temperature, it is possible to estimate how temporal storm shape might be impacted by climate change (Hettiarachchi.,2018).

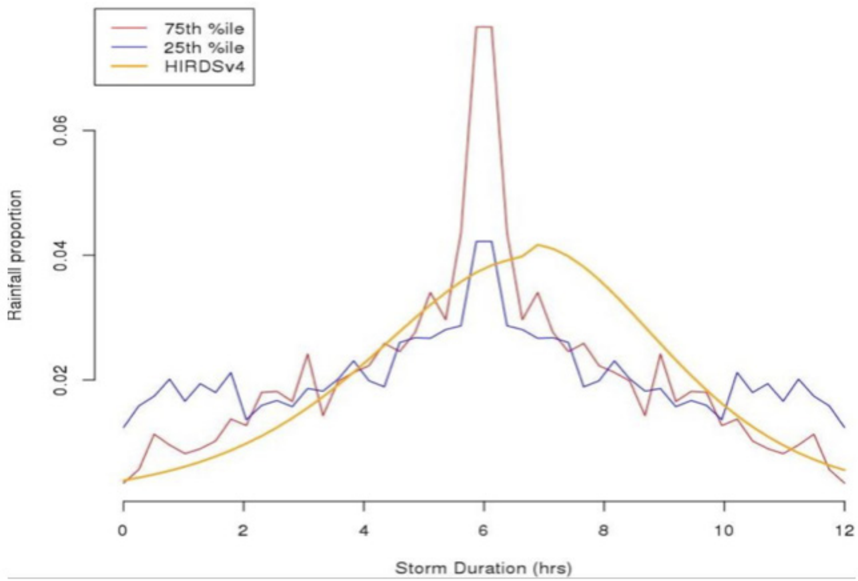

Figure 1 – Standardised storm shape (25 and 75 %ile)

Results

Figure 1 shows the standardised temporal design storm for a 12-hour storm using a nested storm approach based on the ranked proportions at the 25th and 75th percentile of the full 500 storm dataset. Also shown for comparison is the asymmetric hyperbolic tangent hyetograph from the HIRDSv4 report (Carey-Smith et al., 2018). Figure 2 shows a set of 16 different storm shapes generated using the VAE model which span the model's latent space.

Finally, after fitting an exponential regression of a storms divided into 6 sections with corresponding mean daily temperature it was found that the more intense storm segments became more intense with increasing temperature (see Figure 3).

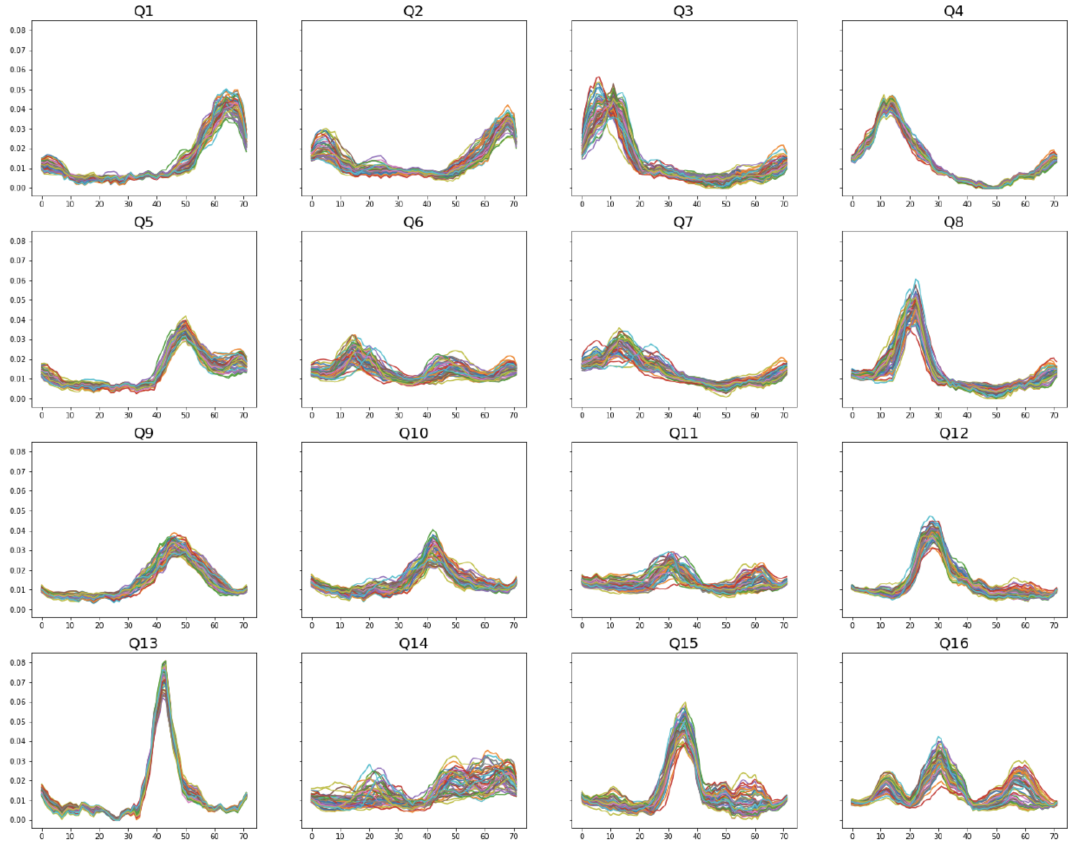

Figure 2: Examples of VAE simulated temporal storm shapes. Each panel contains 50 synthetic generated storms sampled from 1 of 16 different parts of the model latent space.

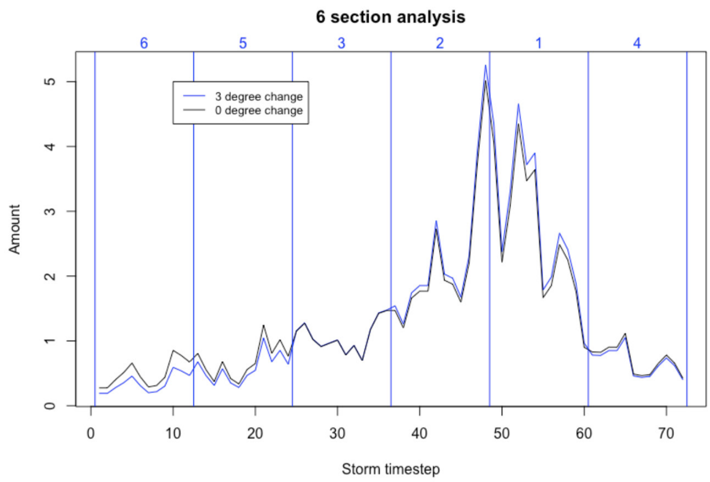

Figure 3: Six section temporal storm shape with 3 degree temperature change compared with 0 degree temperature change.

References

Carey-Smith, T., R. Henderson and S. Singh, 2018, High Intensity Rainfall Design System Version 4, NIWA Client Report 2018022CH prepared for Envirolink, retrieved from https://niwa.co.nz/information-services/hirds

French, R., and M. Jones, 2012, Design rainfall temporal patterns in Australian Rainfall and Runoff: durations exceeding one hour, Australasian Journal of Water Resources, 16(1), 21-27.

Hettiarachchi, S., Wasko, C., and Sharma, A., 2018, Increase in flood risk resulting from climate change in a developed urban watershed – the role of storm temporal patterns, Hydrol. Earth Syst. Sci., 22, 2041–2056, https://doi.org/10.5194/hess-22-2041-2018.

Keifer, D.J. and Chu, H.H., 1957, Synthetic Storm Pattern for Drainage Design. ASCE, Journal of the Hydraulics Division. Vol. 83 (HY4), pp: 1332.1-1332.25.

Pilgrim, D. H., and I. Cordery, 1975, Rainfall Temporal Patterns for Design Floods, J Hydr Eng Div-Asce,

101(Nhy1), 81-95.

Wasko, C., Sharma, A. 2015, Steeper temporal distribution of rain intensity at higher temperatures within Australian storms. Nature Geosci 8, 527–529. https://doi.org/10.1038/ngeo2456

DATA TO INFORMATION TO IMPACT: CO-LEARNING FROM END-USER ENGAGEMENTS

Srinivasan, MS.,[1] Measures, R.,[1] Fear, A.,[1] Elley, G.[1]
[1] NIWA

Aim:

Uptake of irrigation scheduling tools among New Zealand pastoral farmers has long been reported as poor, but recent studies suggest that end-user inclusive participatory approaches could improve the adaptation. We aimed to co-develop an operational irrigation decision support tool using a participatory approach that would facilitate improved environmental and economic outcomes for NZ farms.

Methods:

Using a co-learning based participatory approach, we engaged with a selection of pastoral farmers from the Canterbury region along with regional council (Environment Canterbury) regulators and land managers, and industry professionals. We followed a set of co-learning principles to guide the engagement process: (1) take time to understand the problem from multiple (stakeholder) perspectives; (2) apply equal value to all sources of knowledge; (3) provide an atmosphere that fosters learning among stakeholders (co-learning); (4) be aware of wider (problem) context; and (5) remain flexible and adaptable throughout the engagement process.

Results:

The co-learning process revealed an over-lapping and distinct understanding of the meaning of efficient irrigation water use. Researchers described efficient water use as a practice that justifies the application of each irrigation event by taking into account current crop water demand and forecast rainfall (water supply). Regulators and land managers described it as a practice that avoids over irrigation and prevents drainage of excess irrigation water and leaching of nutrients below the root zone. Producers described it as a practice that mitigates crop water stress and supports and maximises productivity. The co-developed tool included all three perspectives to efficient water use: it includes current demand and forecast weather conditions; near-real time depiction of irrigation applied; soil water conditions within and below the rootzone, signalling the occurrence of drainage; and modelled daily pasture growth directly linked to available soil water within the root zone. The presentation will follow the evolution of co-learning process and the eventual design and development of the operational irrigation decision support tool.

MEASURE.MODEL.MANAGE – LINCOLN AGRITECH'S CONTRIBUTION TO WATER SCIENCE

Stenger, R.,[1]
[1] Lincoln Agritech

Aims

The Hydrological Society of New Zealand and the pedecessor organisations of Lincoln Agritech were founded around the same time. Celebrating the Society's 60th anniversary therefore seems an opportune occasion to reflect on Lincoln Agritech's contribution to hydrological science in Aotearoa/New Zealand, with an emphasis on the last 25 years.

Methods

Lincoln Agritech officially adopted the strapline 'Measure.Model.Manage' only in 2012, but this trifecta had informally been used much earlier within its Environmental Group, focussing on water-related science and consulting. Accordingly, 'Measure.Model.Manage' provides a useful structure for this presentation on water science contributions made by Lincoln Agritech and their collaborators in other research organisations and Regional Councils.

Results

The 'Measure' section will contain examples of advances in measurement technology (e.g. Aquaflex), innovative measurement facilities (e.g. 'Spydia' vadose zone research station), and fit-for-purpose investigation approaches (incl. geophysics, isotopes, tritium) to increase process understanding (e.g. on groundwater redox gradients and denitrification, groundwater recharge from braided rivers, transfer pathways through catchments, and performance of denitrifying bioreactors).

Under the 'Model' headline, an overview of model and software developments will be given. In the context of resource investigations for irrigation scheme establishments, hydrological models and computer-aided design packages (IRRICAD) have been developed since the 1970s. The Eigen-model approach was pioneered by a team member and has subsequently been adapted for multiple groundwater applications and expanded to surface waters (e.g. StreamGEM). Closely linked to our innovative measurements, noteworthy advances in process-based vadose zone water flow and contaminant transport and transformation modelling were achieved (e.g. mixing cell modelling, inverse parameter estimation). The development of Bayesian chemistry-assisted hydrograph separation (BACH) and nutrient load partitioning enabled to extract greater value from existing Regional Council surface water chemistry and flow data. Utilising machine learning techniques and data oversampling made it possible to achieve unbiased groundwater redox predictions at the regional and national scales. Current research demonstrates that the smart incorporation of information deducible from geophysical surveys (e.g. SkyTEM) has the potential to substantially improve the hydrological modelling of meso-scale catchments.

'Manage'. Utilising the advances made in the 'Measure' and 'Model' areas for better land and water management is largely out of the realm of scientists and engineers, and due to long planning processes, it may well take a decade until science advances are incorporated into policy and/or actual management on the ground. However, continual engagement with major stakeholders (e.g. Environment Canterbury, Waikato Regional Council, Marlborough District Council) have ensured that our science advances and tools derived from them have influenced the Canterbury Water Management Strategy, the Wai ora – Healthy Rivers process, and the future management of the Wairau River, to name just a few.

SPATIOTEMPORAL VARIATION OF PATHWAY CONTRIBUTIONS AND MEAN TRANSIT TIMES IN WAIKATO RIVERS

Stenger, R.,[1] Park, J.,[1] Morgenstern, U.,[2] Hadfield, J.,[3] Rivas, A.,[1] Clague, J.,[1]
[1] Lincoln Agritech
[2] GNS Science
[3] Waikato Regional Council

Aims

To defensibly establish the link between currently observed surface water quality and past and present land use, we aimed to quantify the seasonally changing contributions of the key transfer pathways and the resulting temporal dynamics of the mean transit time (MTT) of the sampled water for a number of long-term monitoring sites.

Concerning spatial variation, we were particularly interested in comparing rivers with highly dynamic flow to rivers with more stable flow. Gaining this understanding will also inform how long it will take between a land use change and a detectable effect on surface water quality, and how big the potential 'load to come' from previous land use might be in a particular catchment.

Methods

Our pilot study focussed on five Waikato Regional Council river monitoring sites in the Hauraki and Upper Waikato sub-regions, for which long-term water quality and flow data is available (Piako@Kiwitahi, Waitoa@Landsdowne Rd, Waihou@Okauia, Pokaiwhenua@Putaruru Rd, Waiotapu@Homestead Rd). Piako and Waitoa represented rivers with very dynamic flow, while Waiotapu, Pokaiwhenua, and Waihou are characterised by modest relative flow variation.

We complemented the existing data with 5-8 tritium analyses, strategically carried out between 2016 and 2021 with the aim to capture the range of flows typically observed at these sites (cf. Fig. 1). For each sampled flow, the mean transit time was estimated applying an exponential-piston flow model to the measured tritium concentration (cf. Morgenstern et al., 2010). The BACH hydrograph separation approach (Woodward & Stenger, 2018) was used to estimate the flow contributions made by fast, medium, and slow flow components, representing near-surface flows (NS, i.e. surface runoff, interflow, artificial drainage), shallow (local, seasonal) groundwater (SGW), and deeper (regional, continual) groundwater (DGW), respectively.

Results

All five rivers showed a substantial MTT variation within the range of sampled flow rates. MTTs varied between 24 and 70 years at the lowest, and between 1 and 9 years at the highest sampled flows. The temporal MTT variation observed at individual rivers was mainly between 23 and 36 years, but 67 years for the flashy Piako River.

Very strong MTT variation with stream flow, resulting in very young water leaving the catchment at high flows, has previously been described for the neighbouring Toenepi Stream (Morgenstern et al., 2010). However, it is noteworthy that the MTTs at the highest sampled flows also decreased to ≤9 years in the three rivers with relatively little flow variation (Waiotapu, Pokaiwhenua, Waihou). This suggests that relatively young water, reflecting recent land use intensity, represents a substantial proportion of the water leaving these catchments under high-flow conditions.

Correspondingly, at least tentatively increasing nitrate+nitrite nitrogen (NNN) concentrations with increasing flow were observed at all sites, with the steepest increases at Piako and the most gentle ones at Pokaiwhenua and Waiotapu. Figure 1 illustrates these results, using Piako as an example for a very dynamic river and Pokaiwhenua to respresent the rivers with modest relative flow variation.

Figure 2 shows how estimated pathway contributions change with decreasing flow/increasing MTT. The stream water MTT is most closely related to the deep groundwater (DGW) contribution, which reflects the wide range of physically realistic DGW-MTTs (years to decades), relative to SGW-MTTs (months to years) and NS-MTTs (hours to months).

Comparison of the Piako samples 2 and 3 in Figure 2 also illustrates that different combinations of pathway contributions can result in similar MTTs, reflecting that obtaining the actual age-distribution of a water sample would be more informative than the MTT alone. Sample 2 was taken in July when the catchment was gradually wetting up and groundwater levels were rising following prolonged dry conditions. In contrast, sample 3 originates from November, when groundwater levels were dropping again after their peak in early spring and river flow was generally decreasing. Near-surface flow was triggered by a rain event preceding the sampling.

We conclude that integrating flow, chemistry, age-dating data and BACH modelling provides a powerful tool to elucidate water and contaminant fluxes through catchments.

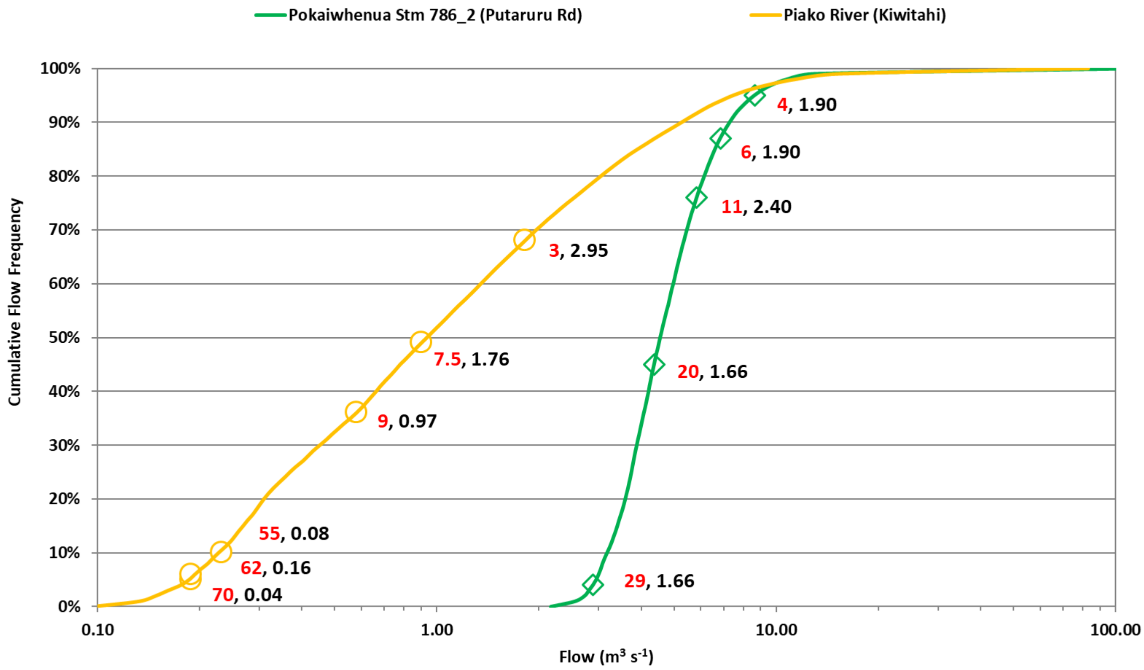

Figure 1: Cumulative flow frequency graphs for the highly dynamic Piako River and Pokaiwhenua Stream with modest relative flow variation (note the log scale). Mean transit times (in years) determined for 5 or 6 flows are shown in red numbers and NNN concentrations (in mg l-1) in black numbers next to the sampling symbols.

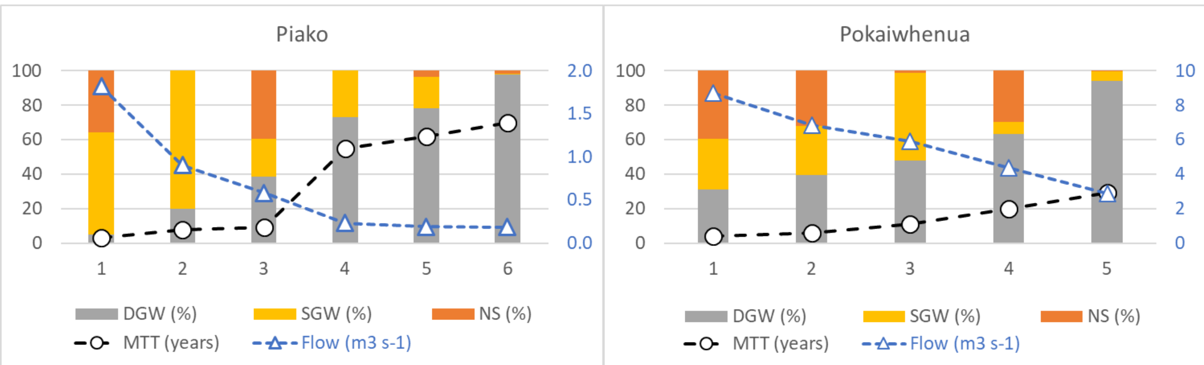

Figure 2: Flow contributions by the three pathways, as estimated by the BACH model for each sampling date and corresponding flows and MTT estimates (data sorted for decreasing flow). Flow contributions (%) by deep groundwater (DGW), shallow groundwater (SGW), and near-surface (NS) flows.

References

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

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

NATURE OF THE CHRISTCHURCH GROUNDWATER SYSTEM

Stewart, M. K.,[1] van der Raaij, R. W.,[2]
[1] Aquifer Dynamics & GNS Science
[2] GNS Science

The Christchurch aquifer system is an excellent water resource for the city of Christchurch. Preserving the high quality of the system to meet the future needs of the city is of utmost importance. Plans to scale up abstraction will require good understanding of the system and how it is likely to respond to increasing exploitation. Previous work with environmental tracers (isotopes and chemistry) have shown that big changes have taken place in system flows due to exploitation (Stewart, 2012). Current samples (2017-2020) are adding to the picture, including observation of:

- Strong age gradients from west to east across Christchurch showing deep-sourced old waters on the east
- Younger waters on the western side of the system
- ^{3}H and ^{14}C measurements that show discordant ages on the western side indicating two (or more) water sources feeding the wells (these are classed as shallow and deep sources respectively)
- Wells near the Waimakariri River are showing rapid penetration of river water to depth, and also indications of deep flow from the northwest (Ashley-Waimakariri plains) towards Christchurch
- Wells with two water sources (near and southeast of the Waimakariri River) are fed by river water with low nitrate (the shallow source) and plains recharge with low but higher nitrate (the deep source). The nitrate concentration of the latter water source is likely to increase in coming years.

The talk will enlarge on these observations.

References

Stewart, M.K. 2012. A 40-year record of carbon-14 and tritium in the Christchurch groundwater system, New Zealand: Dating of young samples with carbon-14. *Journal of Hydrology*, 430-431: 50-68.

UNDERSTANDING TE WAIKOROPUPU SPRINGS CHEMICAL SOURCES

Stewart, M. K.,[1] Thomas, J. T.,[2]
[1] Aquifer Dynamics & GNS Science
[2] Tasman District Council

Te Waikoropupu Springs are a jewel of Golden Bay. Preservation of the springs requires that both the springs themselves and the karst aquifers that feed them remain healthy. For this, an understanding of how the springs work is essential. Rrecharge to and flow from the springs are described by a mass balance model based on estimated inflows and outflows, and their stable isotope compositions (Stewart and Thomas, 2008). This model has been extended to include chloride concentrations in the flows which makes the model unique (see Fig. 1).

			Flows			
Recharge Source	**$\delta^{18}O$**	**Cl**	**Inputs**	**Main Spring**	**Fish Springs**	**Remainder**
	‰	mg/L	L/s	L/s	L/s	L/s
Karst uplands	-7.20	124	9,200	7,624	649	926
Upper Takaka River	-8.67	2	8,350	1,741	1,735	4,875
Valley rainfall	-6.00	2	2,200	635	916	649
Total flows (L/s) calculated				10,000	3,300	
Total flows (L/s) measured			19,750	10,000	3,300	6,450
Differences				0.0	0.0	
$\delta^{18}O$ (‰) calculated				-7.38	-7.64	
$\delta^{18}O$ (‰) measured				-7.38	-7.64	
Differences				0.00	0.00	
Cl mg/L calculated				95.0	26.0	
Cl mg/L measured				95.0	26.0	
Differences				0.0	0.0	

Figure 1: Improved model of flows within the Arthur Marble Aquifer.

Other chemical balances for which the inputs are less clear can be examined using this model. The talk will elaborate the consequences for the springs.

References

Stewart, M.K., Thomas, J.T. 2008. A conceptual model of flow to the Waikoropupu Springs, NW Nelson, New Zealand, based on hydrometric and tracer (18O, Cl, 3H and CFC) evidence. *Hydrology and Earth System Sciences* 12(1), 1-19.

ESTIMATING ADDITIONAL GROUNDWATER ALLOCATION WITH THE KAITUNA-MAKETŪ-PONGAKAWA GROUNDWATER MODEL

Taulis, M.E.,[1] Fernandes, R.[2]
[1] Beca Ltd, Auckland (previously at Jacobs New Zealand Ltd)
[2] Bay of Plenty Regional Council

Aims
Jacobs New Zealand Limited (Jacobs) has developed a regional groundwater flow model of the Kaituna-Maketū-Pongakawa Water Management Area (Kaituna WMA) for Bay of Plenty Regional Council (BoPRC) (Jacobs, 2020). This model has been used to predict potential long-term impacts of augmented groundwater abstraction on groundwater levels and baseflow to rivers in the area, and this information has been used to inform on groundwater allocation for groundwater management zones within the Kaituna WMA catchment.

Method
A Zone of No Further Abstraction (ZNFA) has been defined as the area in which drawdown exceeds 0.5 m during a 30-year simulation run with pumping at the current level of allocation (Qmax). A preliminary analysis established that the baseflow reduction criteria is at its upper limit with pumping at Qmax. The new predictive scenario includes additional pumping from existing wells and potential new wells outside the ZNFA. The starting point was to assess potential impacts caused by the current level of groundwater extraction against the following sustainability criteria, prescribed by BoPRC:

- Minimal (less than 1%) baseflow reduction at streamflow gauging stations reported when pumping at Qmax, as specified by BoPRC at locations on the Pongakawa, Mangorewa, and Kaituna rivers within the Kaituna WMA, and
- Heads near the coast remaining above -0.5 masl (meters above sea level)

The pumping rates assigned to each of the new pumping wells corresponds to the pumping rate of the nearest existing pumping well. The model was then run with both the new pumping wells and the existing wells pumping at Qmax. It was verified that neither baseflow nor heads by the coast breached the prescribed environmental conditions.

To estimate additional groundwater extraction the model was then run by progressively increasing Qmax, but only for wells outside of the ZNFA, until the prescribed environmental conditions were just exceeded. Virtual observation bores (at about 1 km from the coast) were incorporated in the model to report heads by the coast (Figure 1). To monitor baseflow, river cells in the reaches upgradient of the gauging station were analysed using a mass balance approach.

Results
It was determined that groundwater extraction outside of the ZNFA could increase to pumping at five times Qmax (5Qmax). Table 1 shows average annual well production for both the Qmax scenario and the 5Qmax scenario, in mega litres per year (ML/year), from each of the model layers. The additional annual pumping with 5Qmax is about 26,720 ML/year which corresponds to a groundwater production increase of about 78%.

Table 1: Well production per model layer for the Qmax and 5Qmax scenarios.

Layer	**Well production at 5Qmax**	**Well production at Qmax (ML/year)**
1	16,442	7,842
2	28,110	16,535
3	0	0
4	5,659	2,395
5	10,888	7,609
Total	61,100	34,380

Predicted baseflow reduction for surface water gauging stations varies seasonally but the average baseflow reduction is less than 0.4% when comparing the 5Qmax scenario against the Qmax scenario. As a result of this additional pumping, the drawdown cone expands but heads at model reporting locations at 1 km from the coast remain above -0.5 masl except for few existing pumping wells in the north east (Figure 1).

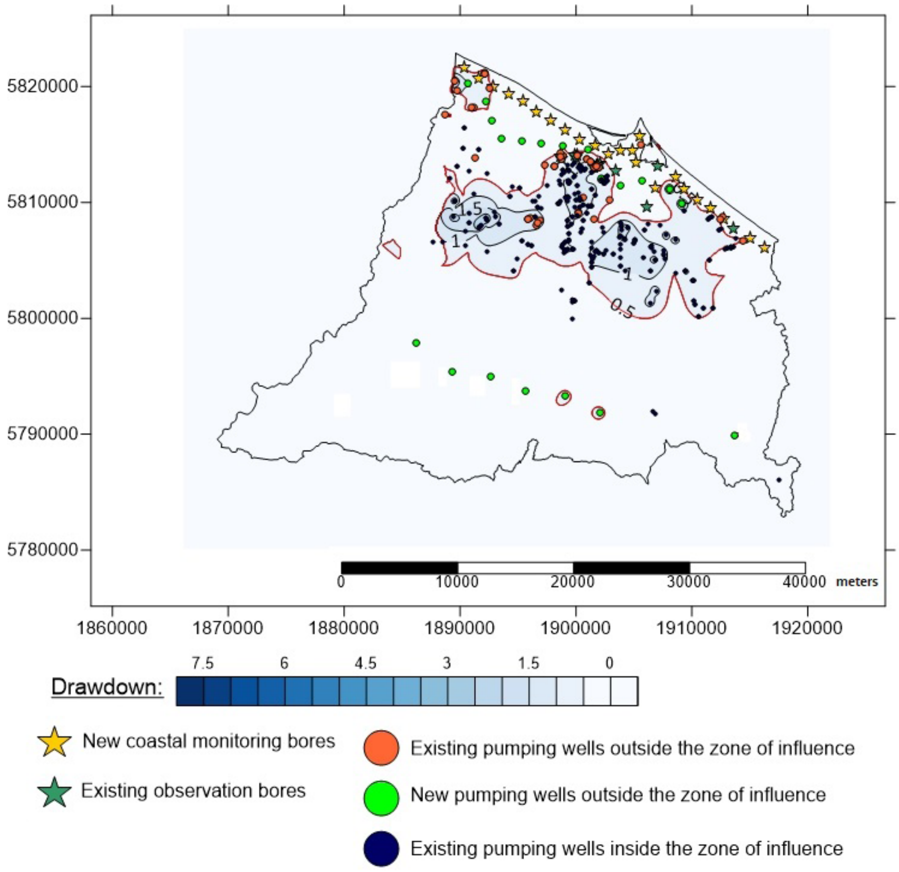

Figure 1: Kaituna model area showing the location of monitoring and pumping bores as well as drawdown results for when pumping at 5Qmax. Drawdown contours are drawn at 0.5 m intervals (the 0.5 m contour line is drawn in red).

This work also reports groundwater fluxes in and out of management zones, and for the whole Kaituna WMA:

- On average, the total recharge contribution for the months of winter (June to August) is about 4,474 ML/day whereas for summer (December to February) recharge is about 1,312 ML/day.
- In general, river baseflow contribution tends to be steady for all months in each zone, but is a bit lower in January, February, and March.
- The currently consented groundwater allocation is about 34,380 ML/year (on an annual basis), and the maximum modelled allocation is 61,100 ML/year. The increased extraction scenario represents an additional 26,720 ML/year of groundwater extraction.

References

Jacobs, 2020. Kaituna-Maketu-Pongakawa Management Area, Groundwater flow model Phase 1. Jacobs report IZ013400-RP-004, Jacobs, Auckland.

EXTENSION OF SURFACE WATER NETWORK PYTHON TOOL

Taves, M. W.,[1] Hemmings, B.,[1] Kitlasten, W.[1]
[1] GNS Science, Avalon, Lower Hutt, New Zealand

Aims

This work describes further development of a surface water network method presented at the Hydrological Society Conference in 2019 (Toews and Hemmings, 2019). This Python tool processes vector representations of streams and includes functionality to export the stream network as MODFLOW input files using flopy (Bakker et al., 2016). Several versions of this software have been published on the Python Package Index (PyPI). This presentation describes new capabilities of the software tool, and how they are applied to groundwater modelling projects.

This software package was developed as part of the Te Whakaheke o Te Wai research programme, which aims to provide a suite of rapid model building tools to allow building of robust issue specific models and sub-models in matter of hours rather than weeks. These tools represent a step change in providing a cost effective method that enables model based decision support where it is needed.

The design goal throughout this software project is to provide simplicity, but allow complexity, if required, using object-oriented design. The first step in creating a surface water network only requires stream line geometries, which can be loaded from a shapefile (Figure 1). After creating the surface water network object (Figure 2), it can be used for different purposes, such as evaluating catchment hypsometry or creating a SFR package for a MODFLOW model (Figure 3).

Method

The primary enhancement to the software is to support embedding a SFR package to a MODFLOW 6 model (Langevin et al., 2017). A Groundwater Transport Model was added for version 6.2.0, released October 2020, which supersedes reliance on older MODFLOW and MT3D releases from the past decade. It is anticipated that a large proportion of future groundwater modelling projects that simulate groundwater flow and transport will be based on the MODFLOW 6 framework. Support for the SFR package in older versions of MODFLOW is still supported using a different subclass.

The MODFLOW Stream-Flow Routing (SFR) package has complex inputs, such as routing tables and stream top elevations. These properties are seamlessly derived from a surface water network. However, due to the resolution of DEMs used to define the top elevation of the model some stream reaches are located in model cells with elevations higher than the elevation of the cell containing the upstream reach. If the reach elevation is set based on the cell elevation the direction of flow will be violated. If the reach elevation is set to honour the direction of flow the reach will fall below the bottom of the cell, causing a fatal error in the MODFLOW model run. New methods have been developed to address this issue and adjust the elevations of the grid and/or reach top elevations to ensure each reach flows to a reach of lower elevation while still remaining within the top layer of the model.

Documentation is available at https://mwtoews.github.io/surface-water-network/

which has a “quickstart” guide with an simple dataset, and detailed API description with examples.

Other improvements to note are better use of spatial indexes for quicker operations, and the ability to “save” the Python objects so they can be loaded quickly while running as part of a script.

Results

Further extensions to the framework are possible, as the software tool is built using object-oriented principals. For instance, a surface water network can be adapted to support other mesh types used by other groundwater modelling software.

```python
import geopandas
# Read shapefiles and set unique index
lines_gdf = geopandas.read_file("lines.shp")
lines_gdf.set_index("catno", inplace=True)
polygons_gdf = geopandas.read_file("polygons.shp")
polygons_gdf.set_index("catno", inplace=True)
# Get GeoSeries -- other attributes are not needed
lines = lines_gdf.geometry
poly = polygons_gdf.geometry
```

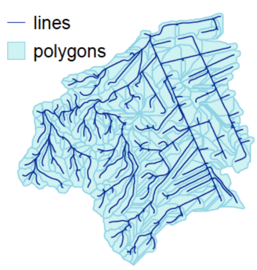

Figure 1: Python code to read lines and polygons from shapefiles. Polygons are not required, but can enhance information used for methods, e.g., estimating stream widths based on upstream catchment areas.

```python
import swn

n = swn.SurfaceWaterNetwork.from_lines(lines, poly)
# A few properties/methods to explore ...
n.plot()  # basic image, similar to one on right
n.segments  # GeoDataFrame of derived attributes
n.query(upstream=3046456)  # find upstream segments
n.adjust_elevation_profile() # ensure sloping down
n.estimate_width(a=1.3, b=0.5)
```

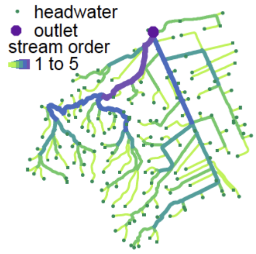

Figure 2: Python code to create a basic surface water network, followed by a few object properties and methods provided by the object. Stream order is illustrated in the map, along with headwater and outlet points.

```python
import flopy
sim = flopy.mf6.MFSimulation.load(sim_ws="path")
gwf = sim.get_model("gwflow")
nm = swn.SwnMf6.from_swn_flopy(n, gwf)
nm.default_packagedata(hyd_cond1=2.0)
nm.fix_reach_elevs()
nm.set_sfr_obj(unit_conversion=86400.0)
# Write files and run MODFLOW 6
sim.write_simulation()
success, buff = sim.run_simulation()
```

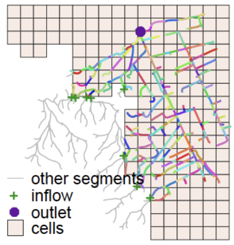

Figure 3: Python code to load a MODFLOW 6 model and add a SFR package based on the surface water network. Map shows finite difference grid and reaches derived from segments. Inflow locations are marked where external upstream flow may be routed to SFR package.

Acknowledgments

This work is part of the MBIE-funded 'Te Whakaheke o Te Wai (The Pathways of the Waters)' programme led by GNS Science.

References

Bakker, M., Post, V., Langevin, C.D., Hughes, J.D., White, J.T., Starn, J.J., Fienen, M.N., 2016. Scripting MODFLOW model development using Python and FloPy. Groundwater 54, 733–739. doi:10.1111/gwat. 12413.

Langevin, C.D., Hughes, J.D., Banta, E.R., Niswonger, R.G., Panday, S., Provost, A.M., 2017. Documentation for the MODFLOW 6 Groundwater Flow Model. Techniques and Methods 6-A55. U.S. Geological Survey. doi:10.3133/tm6A55.

Toews, M.W., Hemmings, B., 2019. A surface water network method for generalising streams and rapid groundwater model development, in: New Zealand Hydrological Society Conference, Rotorua, 3-6 December, 2019, Rotorua. pp. 166–169.

GISBORNE WWTP DEWATERING: FOCUSSED MODELLING WHEN YOU NEED RESULTS FAST!

Thornburrow, B.,[1]
[1] Pattle Delamore Partners

Background and Aims

Gisborne District Council (GDC) applied for resource consents to enable upgrade construction works at the Gisborne Wastewater Treatment Plant (WWTP). The works require dewatering to enable construction of several below ground elements to be completed in sequence. In response to the applications, requirement for an additional consent to take groundwater was identified by the regulator and further information was sought regarding the associated effects.

Gisborne WWTP is located on Banks Street, Awapuni, approximately 1.5 km west of the town centre. The site is bounded to the north by the Waikanae Stream, which is tidal (Lidar indicates the channel is below 0 mRL near the site; NZVD2016). The main coastline is around 500 m south of the site. Ground elevation at the site ranges between 1 and 4 mRL based on GDC Lidar data.

The site is underlain by Holocene ocean beach and dune deposits comprising sands. These sands host the locally described Te Hapara Sands Aquifer which has been identified as a higher risk for coastal saline intrusion. Groundwater levels in the nearest monitoring bore (245 m to the south) from about 2014 have fluctuated seasonally between approximately 0.8 and 1.4 mRL.

Dewatering is proposed to drawdown the water table to a minimum -5 mRL for the Clarifier Pump Station (CPS) and shallower for the other elements. In total, dewatering works are proposed to span up to 195 calendar days (about 6.5 months). Given the topography, hydrogeology, location, and nature of the works, a careful and considered assessment of effects was required.

Pattle Delamore Partners (PDP) was engaged by GDC to prepare the technical assessment of effects on the aquifer, neighbouring bores, surface water depletion and saline intrusion. Under statutory timeframes, a response was sought within 2 weeks of the request for further information and construction of the WWTP was due to commence within two months.

Method

An assessment method was required that could meet the following requirements:

- Estimate dewatering rates and volumes for each construction stage
- Assess drawdown in the aquifer
- Assess stream depletion effects
- Assess saline intrusion risk
- Consider dewatering works staging (timing)
- Consider the location and extent of dewatering works
- Consider seasonality in groundwater recharge and flows
- Complete within a two-week timeframe

Considering these requirements and the location of surface water features around this site, available analytical methods were considered less able to capture sufficient detail to provide a realistic assessment for this site. Use of such methods may have led to overly conservative predictions due to their inherent simplifications in this instance. A comprehensive/detailed numerical modelling approach was considered able to meet technical objectives, but difficult to deliver within timeframe requirements.

Instead, a methodology was developed which took advantage of the capabilities of numerical modelling tools, namely the ability to consider both spatial and temporal variations. However, the approach was simplified as much as possible while focussing efforts on developing aspects of the model most pertinent to the key predictions of interest. Where simplifications and generalisations were made, they were done in such a way that the model would be conservative regarding key predictions.

A simple, single layer, unconfined 3D numerical groundwater flow model was developed using FEFLOW with mesh refinement maximised around the dewatering features. Constant head boundary conditions were used to represent the coastline and Waikanae Creek. A transient model was developed, and seasonally variable rainfall recharge was estimated from climate data as part of the model calibration process. A long-term groundwater level monitoring record from a bore near the site was used to inform a basic transient calibration. Staged seepage face boundary conditions were used to simulate dewatering during three sequential stages of construction.

Model simulations included transient historic recharge conditions but considered works occurring in a dry winter based on 2019 rainfall (the driest winter of the 2010s). The effects were assessed during low recharge conditions as this relates scenario to lower predicted water levels and higher predicted stream depletion. A targeted sensitivity assessment based on a higher global hydraulic conductivity was also included to address uncertainties in the model predictions and provide an upper bound effects scenario.

Results

Key results of the assessment included:

- Estimated dewatering rates and volumes over the duration of the works, including an upper bound based on a high conductivity scenario
- Maps showing drawdown magnitude and extent at key stages of dewatering
- Hydrographs showing the duration of drawdown effects at distance from the works, followed by a recovery period
- Predicted drawdown effects in neighbouring bores
- Rates and volumes of potential leakage from Waikanae Stream (including an upper bound uncertainty prediction)
- Results of a transient particle tracking assessment illustrating the maximum transit of groundwater from Waikanae Stream toward the dewatering works

Conclusions

Use of a numerical modelling approach enabled consideration of critical factors constraining the magnitude and extent of dewatering effects, namely:

- The temporary nature of the activity, timing of effects onset, duration of effects and subsequent recovery
- The size, configuration, and geometry of dewatered features
- The spatial extent of effects both on groundwater levels and potential surface water leakage

A targeted approach to model development, calibration and simulation enabled completion of the assessment within a short timeframe. Numerical models can be developed in this way to support pragmatic outcomes while obtaining the required level of confidence in predictions. This can be achieved by balancing model simplicity and conservatism with realistic representation of the key hydrogeological processes with the greatest influence on key outcomes or decisions.

The ultimate outcome for GDC was that the consent application enabling the dewatering works was advanced while avoiding potentially significant delays. The insights and confidence gained through modelling helped in the development of consent conditions to satisfy both the applicant's and regulator's objectives.

SURFACE WATER NETWORK TOOL - IMPROVING UTILISATION OF EXISTING DATA TO MEET FRESHWATER OBJECTIVES

Throssell, B.,[1] Jasper, M.,[2] Be, S.[3]
[1] Pattle Delamore Partners
[2] Environment Canterbury
[3] Auckland Council

The National Policy Statement for Freshwater Management 2020 requires regional councils to assess current pressure on their water bodies via accounting systems. Good organisation of existing data is critical for this. In partnership with ECan, PDP has developed a geospatial tool to assist with the management and sharing of surface water allocation data. The tool integrates planning information from regional plans, geospatial databases, and various algorithms to create a visualisation layer for surface water allocation.

The tool links the river network to a database containing the regional planning rules, attaches relevant allocation rules to the geospatial river layer, and outputs a visual representation of the river network. Upon interrogation of the geospatial layer, the user can identify all allocation blocks that apply and the associated geographic extent. The user also has options to run the tool for a future date, which returns rules for proposed plans, or to run for other limit types and plan statuses (e.g. proposed, notified, operative).

In conjunction with Auckland Council, we are also in the process of applying our tool to the problem of delineating urban stormwater catchments for the Auckland region. The stormwater reticulation network is critical to the definition of an urban Catchment with boundaries not necessarily completely following topographical drainage catchments. Piped networks can pass water forward from parts of one Catchment to a neighbouring Catchment, thus altering internal flow characteristics and potentially contaminant loads. We are in the process of using our tool to validate and geometrically correct the stormwater asset data and then extend the functionality of the tool to delineate catchments which reflect the urban stormwater reticulation patterns present in those catchments. The geospatial catchment data can then be used to identify proportional land use type (heavy industry, commercial, light industry etc) as well as stormwater flows and expected contaminant loads. This data can be used to investigate targeted treatment options to help improve water quality in the urban environment.

The ongoing development of this tool demonstrates how geospatial technology forms an integral part of effective freshwater management that can be applied to different water use types and land use types.

IMPROVING METAMODEL PREDICTIVE OUTCOMES THROUGH SUPPLEMENTING TRAINING DATASETS WITH NUMERICAL MODEL OUTPUTS

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[1] GNS Science

Aims

Metamodels are statistical models, trained on observed data, that can be used to extrapolate relationships that enable predictions to be made at unsampled locations. Therefore, metamodels can make relatively rapid predictions of system behaviour or characteristics based on the relationships that are established with more easily observable data. By definition, these data-driven techniques are sensitive to data availability, with predictive capacity suffering when the data sets are limited and sparse.

Using Gradient Boosting Regression (GBR), we have developed a model to predict groundwater age distributions from common chemical analytes. This work confirms the promising predictive correlations recently established using symbolic regression (Daughney 2020). However, the spatial coverage of predictions is limited to locations where groundwater chemistry has been analysed (Figure 1). To provide a broader predictive coverage of water age predictions, we also developed a metamodel to predict groundwater age distributions from mappable physical variables with higher spatial density (e.g. position within catchment, relative elevation, water table elevation), that can be used in areas where there is no chemical data. This provides a higher coverage of predictor variables. In both cases however, the availability of training data remains limited and reliant on lumped parameter model estimation of age distributions from tracer observations (e.g. tritium and chlorofluorocarbons).

To address the limited training data, we explore the use of a hybrid meta-model and physically based approach, wherein the outputs of a regional numerical model are used to supplement metamodel training data and facilitate the prediction of age distributions with national coverage. This extends the approach used in Fienen ***et al.*** (2018), where the outputs of a numerical model were used as additional training data for a meta-model of the 'young water fraction' in Michigan.

Method

We used GBR, a sequential ensemble learning technique, to develop the metamodel. The GBR models were trained using mappable predictor variables to predict groundwater age distributions at different locations. Data from the Heretaunga Plains, Hawke's Bay, combined with regional model simulated age distributions provided dense training data (Figure 2). The regional model simulated outputs include a combination of groundwater flow, tritium transport, young water fraction, and zero-order-growth age using MODFLOW 6. Highly parametrised inversion implemented with PEST++ IES is used to history match (calibrate) the flow and transport models to historical system observations, including groundwater tritium concentrations. The young water fraction simulation outputs were processed to provide simulated groundwater age distributions at a high spatial density, suitable for metamodel training. Repeated K-fold cross-validation of data from within the training region is used to evaluate and test the performance of the GBR model during the training process. This includes repeat tests of the accuracy of model predictions of data held-out from the training process, during model construction. Predictions with the selected metamodel were then attempted outside the training region and compared to available lumped parameter model estimates.

Results

While recent metamodel developments highlight strong and extractable relationships between groundwater chemistry and age, the relatively limited availability of groundwater chemistry measurements limits the utility of such models, especially where national coverage of groundwater age is desired. Using mappable physical predictor variables provides the opportunity to improve the coverage of groundwater age prediction. However, the relationships between mappable parameters and sparse estimates of groundwater age distributions are less strong. The relatively sparse training dataset provided by lumped parameter estimates of age limits the predictive capacity of the model. Metamodel training and predictive power is improved by including simulated outputs for groundwater age to supplement that training datasets. This results in a hybrid approach, where the statistical meta-model is able to also harness information generated on the basis of the laws of physics.

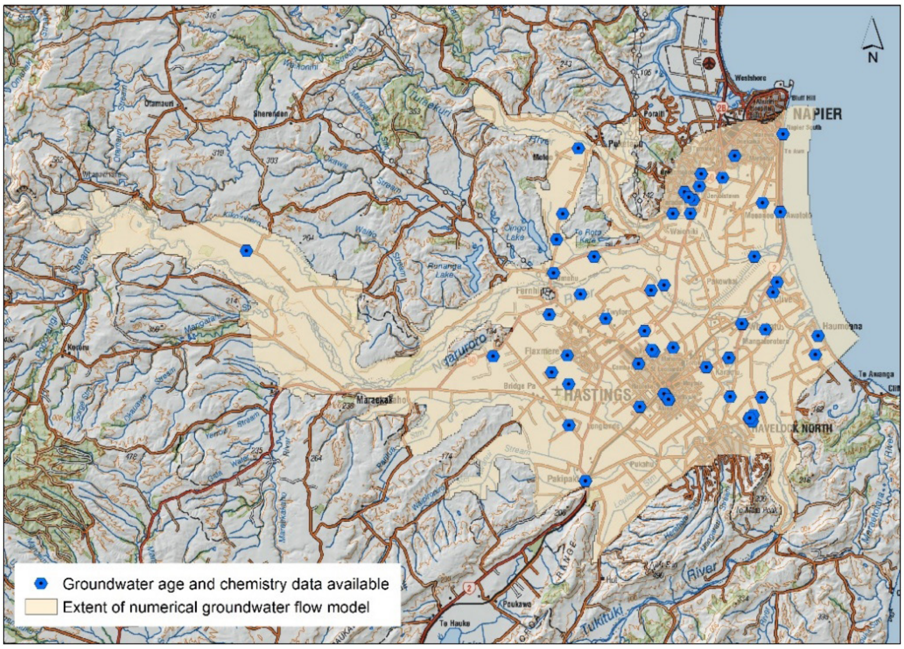

Figure 1Spatial distribution of metamodel age prediction training data, derived from lumped parameter model interpretations of tracer measurements.

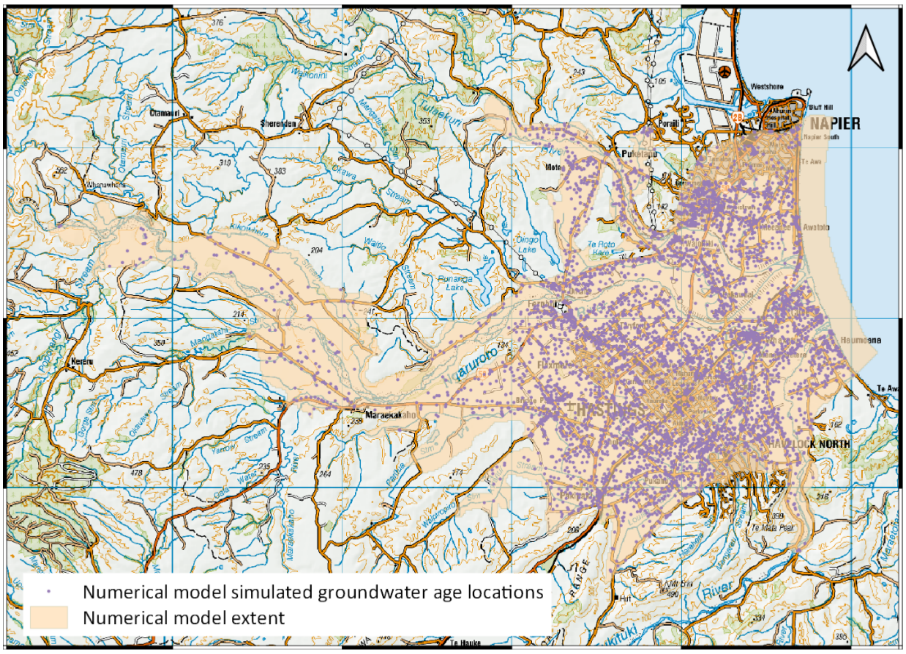

Figure 2 Spatial distribution of metamodel age prediction training data, derived from numerical model simulated outputs.

Acknowledgments

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References

Daughney, C.J., Morgenstern, U., 2020. Use of symbolic regression to estimate groundwater age distributions from hydrochemistry, Heretaunga Plains. New Zealand Hydrological Society Conference, Invercargill.

Fienen, M.N., Nolan, B.T., Kauffman, L.J., Feinstein, D.T., 2018. Metamodeling for Groundwater Age Forecasting in the Lake Michigan Basin. Water Resour. Res. 54, 4750–4766. doi:10.1029/2017WR022387

QUATERNARY DEPOSITION CHRONOLOGY OF NGARURORO RIVER GRAVELS IN THE MAJOR RECHARGE ZONE, HERETAUNGA PLAINS

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Aims

New Zealand's first modern hydrogeological investigation, the Heretaunga Project, led by Hugh Thorpe from 1975, drilled 71 wells in the major recharge zone of the Heretaunga Plains aquifer, Hawkes Bay (Figure 1). This is a unique dataset as all the wells were drilled in a short time frame and were logged to a good standard by only three drillers. The wells were drilled within alluvial gravels deposited by the Ngaruroro River on the Ngaruroro River fan; this area provides most of the groundwater recharge to the Heretaunga Plains aquifer system. The well logs offer a unique insight to gravel deposition by braided, gravel-bed rivers and to the structure of similar aquifers in New Zealand.

This work has three aims. Well-log quality was compared for the two drilling methods (i.e., cable tool and air rotary) used in the investigation. The project aimed to assess lithological markers (e.g., pumice, organics and sediment colour) in this gravel-dominated system to illuminate the difficult problem of identifying gravel deposition chronology and post-deposition alteration. Lastly, alluvial gravel deposition chronology was assessed with a 3-D model of four geomorphological zones in the Ngaruroro River gravel fan.

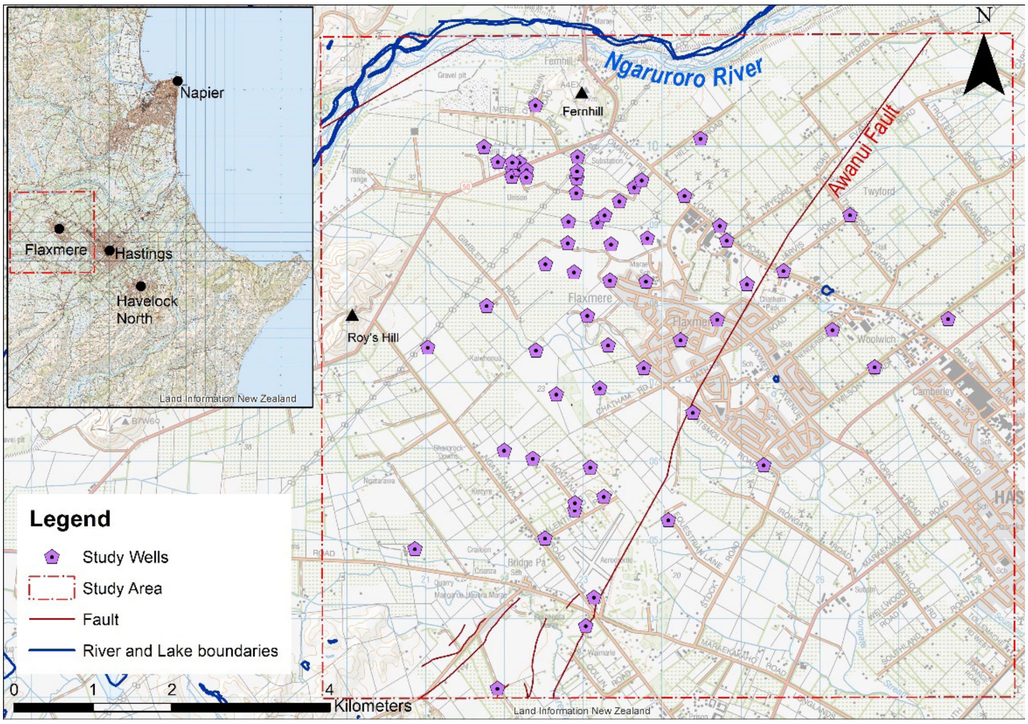

Figure 1. Topographic map of the study area displayed in Flaxmere, east of North Island.

Method

Well logs and a digital terrain model (DTM) were used in this project. Wells logs were digitised from the original Heretaunga Project paper records. Information taken from these records include well number, drilling method, driller's names, geological descriptions (i.e. tops and bottoms of units, lithology, markers and colours) and, sample descriptions. Out of the 71 wells, there were 45 drilled by cable tool, 25 drilled by air rotary and 1 drilled by both drilling methods. Logging was completed by three drillers, with one driller logging all the air-rotary wells.

Well logs were processed according to White and Reeves (1996), with the aim to produce Quaternary sedimentary markers in a 3-D dataset of sediment type and sedimentary markers (Table 1). To create the datasets, sediment type and markers were assigned a numerical value indicating presence and absence in the well log.

The DTM was used to calculate elevations of well log units and identify four depositional zones within the study area (Figure 2). Then, Ngaruroro River depositional units within the study area were identified and modelled in 3-D. Sedimentary markers were used to identify features of age (pumice) and flow conditions (colour and organics).

Lithology	Sedimentary Markers
Clay	Pumice
Silt	Organic Material
Sand	Red
Gravels	Blue
Clay-Silt	Black
	Yellow

Table 1. Lithologies and sedimentary markers identified in well logs.

Results

The advantages of cable-tool drilling over air-rotary drilling for delineation of lithological markers was demonstrated. In particular, geological descriptions in cable-tool well logs were more expressive than the logs of air-rotary wells, For example, cable-tool log descriptions of organic material were described in detail (such as 'tree stump', 'peat', and 'rotten wood fragments') whereas logs of similar materials simply described them as 'organic'. Typically, cable-tool drilling generally keeps samples intact which allow loggers to accurately record sediments and markers. In comparison, air-rotary drilling provides mixed cuttings from wells.

Pumice was recorded in the well logs. Two pumice depositional events (possibly Taupo Eruption and Waimihia Eruption, approximately 1.8k years old and 3.4k years old, respectively) indicated the age of the most recent gravel layers. The pumice was reworked and mixed with sediments suggesting alluvial deposition but, some layers are solely pumice, indicating potential airfall deposition. Colour markers indicate chemical alteration before or after deposition, signifying oxidised and reduced conditions. Oxidised conditions are indicated by red, yellow and brown markers; reduced conditions are indicated by blue and black markers. Typically, oxidising conditions are indicated towards the northwest of the study area (i.e., near the Ngaruroro River) with reducing conditions towards the south and southeast of the study area.

The chronology of sedimentation is demonstrated in Zone 1 of the Ngaruroro River gravel, which was probably the last main channel of the Ngaruroro River that was abandoned after the 1867 flood (Figure 2). Sediment deposition identified in the model includes a sequence of four gravel-sand units interspersed with silts and clays. The two shallowest gravel layers probably post-date the Waimihia Eruption, with a sand layer near the ground surface.

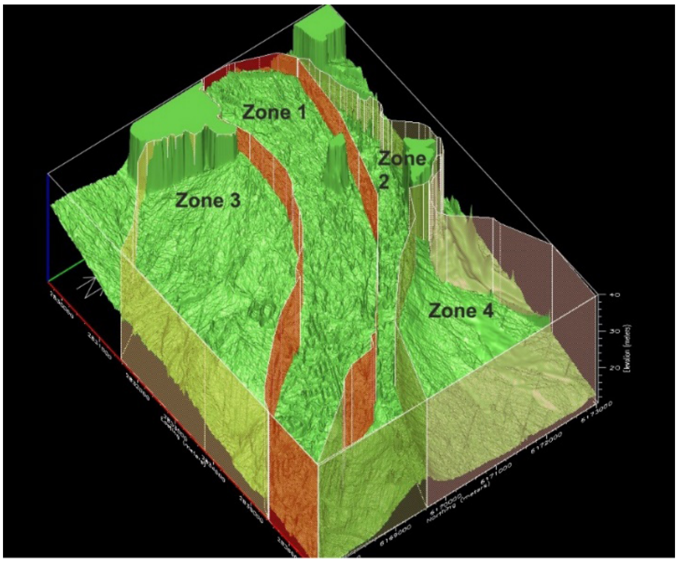

Figure 2. Four depositional zones within the study area, modelled in 3-D.

References:

White, P.A. and Reeves, R. 1996. Computer modelling of Waimea Plains aquifer geology. New Zealand Hydrological Society Conference, Wellington.

Farrier T. 2020. 3D Aquifer Mapping Project DEM Version 2. Napier: Hawke's Bay Regional Council.

EVALUATING THE ACCURACY AND SENSITIVITY OF CATCHMENT SEDIMENT SOURCE APPORTIONMENT USING SEDIMENT FINGERPRINTING.

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Aims

Sediment fingerprinting is a technique for determining the proportional contributions of sediment from erosion sources in river catchments. Tracers such as geochemical, fallout radionuclide and compound specific stable isotopes (CSSI) properties of soils and sediments are used to discriminate sources and determine contributions to sediment deposited in downstream receiving environments. While the basis for discriminating sediment sources is well understood, research has drawn increasing attention to limitations and uncertainties associated with source apportionment using mixing models. Numerical mixtures provide a way to test model performance using idealized mixtures with known source proportions. Although this approach has been applied previously (e.g. Haddadchi et al., 2014), it has not been used to systematically test and compare model performance across a range of tracer types with variations in source contribution dominance and number of sources. Here, we use numerical mixtures to examine the ability of two different tracer sets (i.e., geochemical and CSSI), each with two tracer selection methods, to discriminate sources using a common source dataset.

Methods

Sources were sampled according to erosion process and land cover in the Aroaro catchment (22 km^2), Auckland, New Zealand. This involved sampling top-soils (0-2 cm) and sub-soils (40-50 cm) from pasture, harvested pine, kanuka scrub and native forest. We focus on using numerical mixtures with geochemical and CSSI tracers for an increasing number of sources (i.e., 3 to 6) where each individual source and pairwise combination of sources were systematically set as the dominant source (Table 1). Since unmixing CSSI tracers produces isotopic proportions (Iso%) instead of soil proportion (Soil%) (Gibbs, 2013), numerical mixtures were created for both Iso% and Soil% to assess the impact of the correction on model performance which relies on the percent of organic carbon. In total, over 400 model scenarios were tested.

Table 1: Summary of numerical mixture scenarios, tracer sets, and tracer selections used. KW-DFA refers to tracer selection using a combination of Kruskal-Wallis and stepwise discriminant function analysis; NC refers to a tracer selection using a non-conservative approach which removes tracers showing evidence of non-conservativeness

<table>
<tr><th>Source Groups</th><th>Source groups (n)</th><th>Tracer Set</th><th>Selection Criteria</th><th>Name</th></tr>
<tr><td rowspan="2">3-source
Erosion process</td><td rowspan="2">Surface (35)
Subsoil (27)
Channel bank (10)</td><td rowspan="2">Geo</td><td>KW-DFA</td><td>3_GEO_KWD</td></tr>
<tr><td>Non-Conservative</td><td>3_GEO_NC</td></tr>
<tr><td rowspan="3">4-source
Landcover sources</td><td rowspan="3">Harvested pine surface (12)
Native Forest surface (4)
Pasture surface (12)
Scrub surface (7)</td><td rowspan="3">CSSI</td><td>Long-chain =>18</td><td>4_CSSI_L1</td></tr>
<tr><td>Long-chain =>22</td><td>4_CSSI_L2</td></tr>
<tr><td>KW-DFA</td><td>4_CSSI_KWD</td></tr>
<tr><td rowspan="5">5-source
Channel bank +
Landcover surface</td><td rowspan="5">Harvested pine surface (12)
Native Forest surface (4)
Pasture surface (12)
Scrub surface (7)
Channel bank (10)</td><td rowspan="2">Geo</td><td>KW-DFA</td><td>5_GEO_KWD</td></tr>
<tr><td>Non-Conservative</td><td>5_GEO_NC</td></tr>
<tr><td rowspan="3">CSSI</td><td>Long-chain =>18</td><td>5_CSSI_L1</td></tr>
<tr><td>Long-chain =>22</td><td>5_CSSI_L2</td></tr>
<tr><td>KW-DFA</td><td>5_CSSI_KWD</td></tr>
<tr><td rowspan="5">6-source
Erosion process +
Landcover surface</td><td rowspan="5">Harvested pine surface (12)
Native Forest surface (4)
Pasture surface (12)
Scrub surface (7)
Channel bank (10)
Subsoil (27)</td><td rowspan="2">Geo</td><td>KW-DFA</td><td>6_GEO_KWD</td></tr>
<tr><td>Non-Conservative</td><td>6_GEO_NC</td></tr>
<tr><td rowspan="3">CSSI</td><td>Long-chain =>18</td><td>6_CSSI_L1</td></tr>
<tr><td>Long-chain =>22</td><td>6_CSSI_L2</td></tr>
<tr><td>KW-DFA</td><td>6_CSSI_KWD</td></tr>
</table>

Results

Numerical mixture testing indicates that the dominant source can have a significant impact on model performance. If the dominant source is well discriminated, then the model performs well but accuracy declines significantly as discrimination of the dominant source reduces. For instance, channel bank is well discriminated for Geo-KWD (Figure 1) scenario which corresponds to a lower Mean Absolute Error (MAE) of 5.6 when channel bank is dominant (Table 2). Poor source discrimination also tends to occur more frequently as the number of sources increase.

The geochemical dataset performed well for erosion-based sources while both tracer sets produced larger apportionment errors for land cover sources. Mean MAE shows CSSI model performance was generally poorer for Soil% (15.2 – 16.3%) than Iso% (11 – 11.4%) for the 6-source scenario, indicating high sensitivity to the percent of soil organic carbon in each source, especially when there are large differences in organic matter between sources (Table 2).

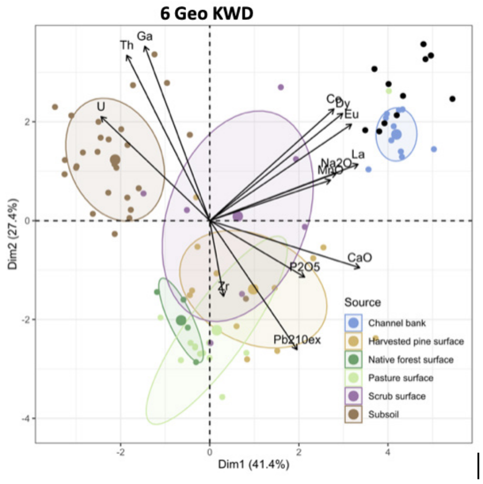

Figure 1: Geo_KWD PCA plot of source discrimination for 6-source scenario.

Table 2: Summary of MAE for each scenario for the 6 sources; channel bank (CB), harvest pine surface (HPS), native forest surface (NFS), pasture surface (PSS), scrub surface (ScS), and subsoil (Sub)

Dominant Source	Mean Absolute Error (MAE)								Mean
	GEO		CSSI Soil%			CSSI Iso%			
	NC	KWD	L1	L2	KWD	L1	L2	KWD	
Equal	2.9	6.3	14.3	12.1	15.3	6.9	5.8	5.7	**8.7**
CB	0.8	0.8	4.2	5.5	6.7	9.7	7.8	9.5	**5.6**
HPS	9	10.1	19.7	19.7	16.5	12.1	11.5	6.6	**13.1**
NFS	6.7	2.2	22	22.5	21.7	18.8	20	18.7	**16.6**
PS	6.5	9	23.2	24.7	25.6	18	18.2	18.8	**18**
ScS	13.7	16	14.4	11	13.5	3.4	5.1	4.3	**10.2**
Sub	2.4	1.1	15.9	13.8	12	8.5	9.3	12	**9.4**
CB/HPS	7.7	8	12	11.6	11.1	8.6	12.5	9.2	**10.1**
CB/NFS	3.5	1.6	13	11.8	12.3	10.4	13.3	13.5	**9.9**
CB/PSS	4.8	5.4	13.6	14	14.4	8.7	10.3	9.5	**10.1**
CB/SCS	7.7	9.2	8.6	6	5	6.1	8.2	3.9	**6.8**
CB/Sub	1.5	1.7	8.1	7	7.1	5.4	3.9	10.2	**5.6**
HPS/NFS	8.4	5.8	20.8	19.8	21.2	15.5	11.3	12.8	**14.4**
HPS/PSS	5.5	10.9	24.4	21.4	24.5	13.3	10.7	11.9	**15.3**
HPS/ScS	8.8	16.8	16.5	19.7	16.6	11.3	5.8	6.9	**12.8**
HPS/Sub	11.7	11.4	12	9.5	9.6	6.4	7.4	6.4	**9.3**
NFS/PSS	6.4	5.9	25.1	26.8	23.8	18.7	19.8	19.1	**18.2**
NFS/ScS	7.9	10.4	21.1	18.3	18.3	11.1	10.4	10.3	**13.5**
NFS/Sub	5.4	1.9	15.2	16.4	14	15.4	15.2	13.9	**12.2**
PSS/ScS	13.1	14.8	23.6	22.8	17.8	14.4	9.8	15.9	**16.5**
PSS/Sub	5.6	7.4	14	16.8	12.9	12.6	10.3	8.9	**11.1**
ScS/Sub	6.4	8.8	16.9	10.9	15.6	16.4	17	13.4	**13.2**
Mean	**6.6**	**7.5**	**16.3**	**15.5**	**15.2**	**11.4**	**11.1**	**11**	

References

GIBBS, M. 2013. Protocols on the use of the CSSI technique to identify and apportion soil sources from land use. Prepared for the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture CRP Number D1. 20.11. 126 pages.

HADDADCHI, A., OLLEY, J. & LACEBY, P. 2014. Accuracy of mixing models in predicting sediment source contributions. Science of The Total Environment, 497–498, 139–152.

GROUNDWATER NITRATE TRENDS: WHAT DO THEY TELL US, WHAT DON'T THEY TELL US, AND WHAT CAN THEY TELL US?

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[1] Environment Canterbury

Aims

State and trend have become critical elements in environmental reporting and are widely used to help communicate science to the public and decision-makers. The methods used to generate state and trend have not changed significantly in the past 20+ years, but recent publications have suggested that nitrate concentrations in drinking water that are well below the World Health Organization guideline value of 50 mg/L (11.3 mg/L as nitrate-nitrogen) lead to a significant increase in the chance of negative health effects. This has led to a significant increase in the interest of nitrate trends which provides an opportunity and need to improve how trends are reported to the public and decision-makers.

Methods

Many current methods of reporting on nitrate state and trend look at a single aspect for each. For state, this is often an annual median or 5-year median concentration; for trends, this is often the 10-year trend direction (increasing or decreasing). When these different elements are reported on independently, we tend to lose a significant amount of information that is necessary for resource management decisions. You can imagine that areas with low nitrate concentrations and decreasing trends would require different management solutions than areas with high concentrations and decreasing trends. The former does not show immediate need for concern whereas the latter should raise some consideration on whether the decreasing trend rate or slope is acceptable.

This leads to a frequently overlooked component of state and trend: the trend slope. Often, trends are reported on by their direction; however, the slope can be just as important as the direction in providing information to the public and decision makers. It is not uncommon for trend slopes to be near zero or to be below a detectable amount of change over the trend period. These areas should likely be managed differently than areas that have trends with more significant slopes, regardless of direction.

The past few years have seen an increase in research around the reporting of trends and potential ways in which state, trend direction, and trend slope can be incorporated together (McBride, 2019; Moreau & Daughney, 2021). Despite this, Aotearoa is not at a point where slope is included at the national reporting level on LAWA nor within the Ministry of the Environment's Our Freshwater 2020. This may be attributed to the additional decisions that are required, including whether to report on absolute versus relative slopes and on what slope magnitudes are considered relevant.

Results

This presentation will discuss the topics described above using examples of nitrate-nitrogen time series from the Canterbury region. It will include examples of success with current methods, flaws with current methods, and some alternatives to how state and trend can be visualised together on a regional (or national) scale.

References

McBride, G. 2019. Has Water Quality Improved or Been Maintained? A Quantitative Assessment Procedure. *Journal of Environmental Quality,* 48(2): 412-420.

Moreau, M. & Daughney, C. 2021. Defining natural baselines for rates of change in New Zealand's groundwater quality: Dealing with incomplete or disparate datasets, accounting for impacted sites, and merging into state of the-environment reporting. *Science of the Total Environment,* 755(2): 143292.

HOW DOES DIVERSITY CHANGE ALONG A TRANSECT THROUGH A PERMEABLE REACTIVE BARRIER?

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Aims

To establish microbial changes in groundwater upstream, within and downstream of a permeable reactive bioreactor treating nitrate contaminated groundwater.

Method

As part of a larger investigation into the use of permeable reactive barrier (PRB) to remediate nitrate, we undertook an investigation into the microbial taxa present upstream, within and downstream of a denitrifying PRB installed in Canterbury, South Island, NZ. Denitrifying PRB's are nitrate remediation technologies that enhance the removal of nitrate in shallow groundwater systems. Solid organic matter is mixed with aquifer material in trenches within an aquifer so that nitrate-contaminated groundwater is passively intercepted. The organic matter then stimulates microbial activity, and nitrate is used by microbes and is converted to inert di-nitrogen gas which is released into the atmosphere.

The denitrifying PRB was installed November 2018 at Silverstream site in Canterbury. The PRB contains a 50:50 mix of wood chip and clean open framework gravel. Wells have been installed with various screen depths across the site. The characterisitcs of the wells sampled for this research are described in Table 1. When the wells were being drilled, intact core sediment samples were taken from of the wells PX1 to 5, S7, S8.

Table 1 Well characteristics.

Well identifier	**Well diameter (mm)**	**Depth (m)**	**Field position**	**Biobag type & position**
PX1	100	1.5 – 2.5 m screen	Upstream	Round gravel biobags. Place top of sampler 1.5 m deep.
PX2	100	1.5 – 2.5 m screen	Start of PRB	Round gravel biobags. Place top of sampler 1.5 m deep.
PX3	100	1.5 – 2.5 m screen	Mid PRB	Round gravel biobags and woodchip biobags. Place top of sampler 1.5 m deep.
PX4	100	3 – 4 m screen	Mid PRB below reactor	Round gravel biobag. Place top of sampler 3 m deep.
PX5	100	1.5 – 2.5 m screen	Downstream	Round gravel biobag. Place top of sampler 1.5 m deep.
S7	50	1 m screen top and bottom	Downstream	Oblong gravel biobags. Place top of sampler 1.5 m deep.
S8	50	1 m screen top and bottom	Downstream	Oblong gravel biobags. Place top of sampler 1.5 m deep.

After installation of the PRB, samples of the groundwater was taken (Winter 2019) and biobags were installed into the wells. Samples were then taken at four monthly intervals over a period of one year. Sample collection was according to Weaver et al. 2018.

Results

We can see changes occuring in the dominant phyla present along the transect through the PRB and downstream of the PRB (Figure 1A-F). Changes within the bioreactor coincide with the shift to microaerobic or anaerobic conditions and this could be seen in the increase in anaerobic organisms identified. This enabled the denitrifying organisms to effectively remove nitrate both within the PRB, under the reactor and downstream of the PRB. Seasonal changes could also be observed which will be discussed in relation to water chemistry and other parameters tested.The appearance of sulphate reducing organisms (e.g.Desulfovibrio), iron reducers (e.g. Geothrix), and methane oxidisers (e.g. Candidatis methylomirabilis) linked to methane coupled denitrification point to a complex number of metabolic pathways present both within and downstream of the PRB.

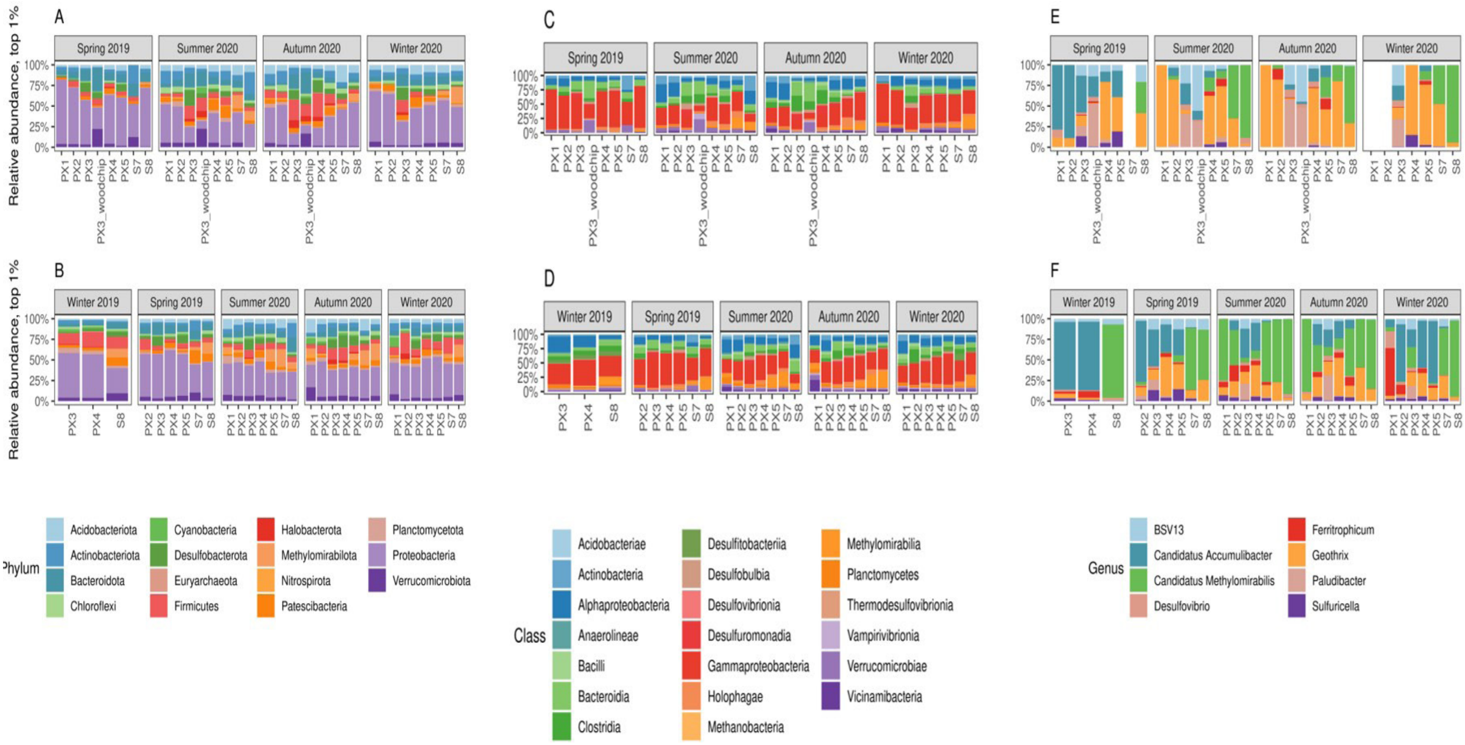

Figure 1 Phyla present along the transect sampled. Stacked Bars represent phyla present over 1% abundance in each well. ***A*** *shows the phyla present in the biobag samples (and woodchip for PX3 samples);* ***B*** *shows the phyla present in the groundwater;* ***C*** *shows the classes present in the biobag samples (and woodchip for PX3 samples);* ***D*** *shows the classes present in the groundwater;* ***E*** *shows the genera present in the biobag samples (and woodchip for PX3 samples);* ***F*** *shows the genera present in the groundwater. Absent (white) bars occur where that level of taxa description could not be made.*

Discussion

The results demonstrate that PRB can effectively removel nitrate and that there are distinct taxa present that undertake denitrification. The dominant process appears to be heterotrophic denitrification It is also evident, however, from the communites identified that other processes are occurring such as annamox and dissimilatory nitrate reduction to ammonium (DNRA). The results that will be presented will complement the previously published assessment of the PRB and provide more evidence to the pathways for nitrate removal (Burbery et al. 2020).

References

Burbery, L., Sarris, T., Mellis, R., Abraham, P., Sutton, R., Finnemore, M., Close, M. 2020. Woodchip denitrification wall technology trialled in a shallow alluvial gravel aquifer. Ecological Engineering, Vol 157, doi.org/10.1016/j.ecoleng.2020.105996.

Weaver, L., Bolton, A., Abraham, P. 2018. Sampling considerations and protocols for assessing groundwater ecosystems. Envirolink report CSC18008, prepared for Tasman District Council under Envirolink contract 1861-TSDC143.

MOVING TOWARDS A PROACTIVE WAY OF PREDICTING WATER QUALITY

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Aims

Groundwater provides vital services, including drinking water, irrigation and source water. It is, therefore, important that groundwater is monitored for harmful contaminants and pathogens to protect human health. Groundwater is monitored by testing specific water quality parameters, including major ions, nitrate nitrogen, ammonia nitrogen, silica, iron, manganese, and faecal indicator bacteria. Currently, these tests are reactive and indicate a past problem if 'issues' are detected. There is a need for a fast, proactive method to assess the status of groundwater to give an early warning of groundwater contamination. Microbes can respond quickly to subtle changes in their environments and offer the potential to be an early warning of a change in water quality. Our aim was to model microbial diversity with water chemistry using Random Forest, a predictive modelling tool, to find key organisms that could predict contaminant presence. The detection of specific microbes or changes in their abundance could ultimately be used for inline sensors, automated to signal water quality changes.

Method

Groundwater data, including water chemistry, field parameters (pH, temperature, depth, conductivity) and microbial diversity (eDNA), was collected from 58 wells across New Zealand. Datasets were combined in RStudio (RStudio Team, 2021), nitrate results were categorised according to the WHO MAV guidelines (World Health Organisation, 2017), and microbial diversity data was classified according to the Phyla level. The dataset was then run through a Random Forest package in RStudio.

Results

When the groundwater dataset was classified according to Phyla present (Proteobacteria and Thaumarchaeota), Random Forest correctly predicted 83 % of pristine groundwater (<1 mg/L nitrate) as correct and 96 % of groundwater below MAV (<11.3 mg/L nitrate) as correct (Figure 1:). These model predictions, while simple, indicate that it is possible to predict nitrate levels from microbial diversity data. We are now beginning to look at the other key predictors for overall groundwater health and test the robustness of using these predictors over a range of regions across New Zealand.

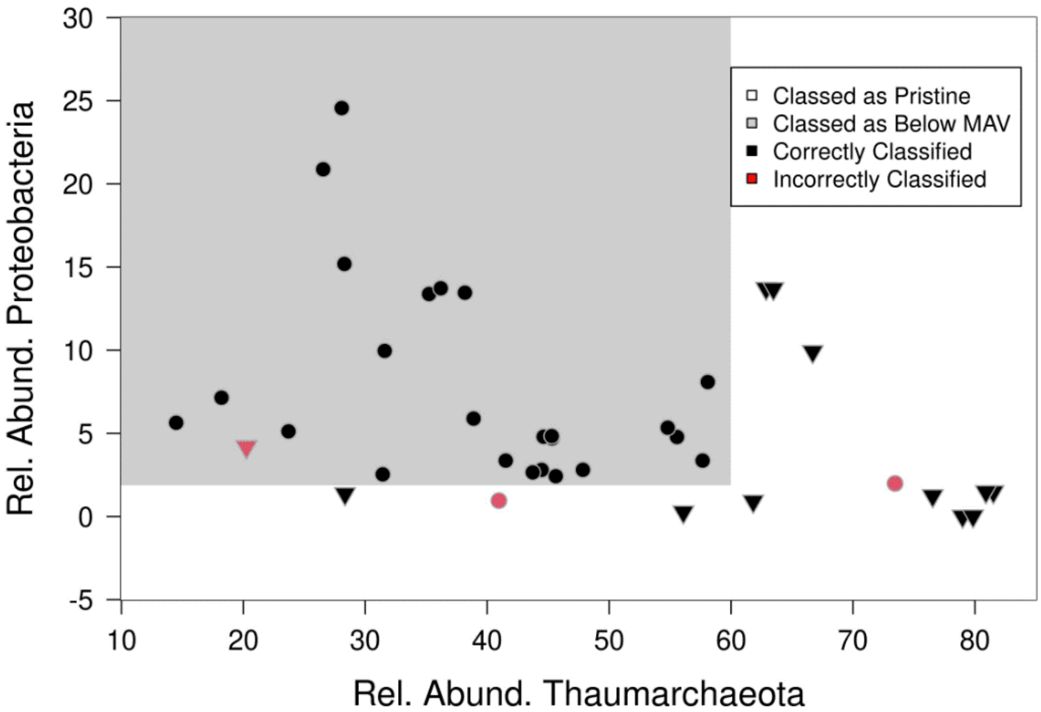

Figure 1: Predictions using Random Forest. The triangles indicate pristine groundwater in terms of nitrate levels, and circles indicate groundwater below MAV. Black indicates when the prediction was correct looking at Proteobacteria and Thaumarchaeota present, and red indicates incorrect prediction.

References

RStudio Team. 2021. RStudio: Integrated Development Environment for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/.

World Health Organization. 2017. Guidelines for drinking-water quality: fourth edition incorporating first addendum, 4th ed + 1st add. World Health Organization. https://apps.who.int/iris/handle/10665/254637. License: CC BY-NC-SA 3.0 IGO

ENVIROSATTOOLS – A COLLABORATIVE SATELLITE DATA WORKSPACE FOR REGIONAL COUNCILS

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Aims

Regional councils (RCs) follow national policy direction, but decision-making processes across RCs can differ due to regional variability in landscapes, climate, population, resources, industry demands, and information availability across each region. Therefore, there is a lack of consistency in decision-making tools and underlying spatial data (e.g., land-use change, wetland dynamics, flood plain dynamics, drought assessment, vegetation growth) across regions and at the national level.

Global-scale studies show that satellite data can improve the understanding and monitoring of our natural environment. Additionally, there have been significant advances in online geoprocessing toolboxes that utilise cloud-based services (to spread computational load away from the computer of the user). New Zealand agricultural and environmental science under-utilises modern satellite data because many scientists (at CRIs, regional councils and central government) still believe satellite data is too costly and time-consuming. For instance, RCs do not have the funding nor capability to systematically employ satellite data in their resource management activities.

This project aims to develop a platform where RCs can develop satellite applications 'in the Cloud' and a collaborative space that allows participants to share their findings to improve intra- and inter-council collaboration.

Methods

The Envirolink Tools project 'A collaborative satellite data workspace for regional councils' developed a suite of standard processing methods ('EnviroSatTools') that apply satellite data to identify and map land, soil, vegetation and inland water consistently across New Zealand. The suite employs the Google Earth Engine (GEE) Cloud computing service for satellite data processing - alongside a web forum and a project wiki (https://tinyurl.com/envirosattools) with guidelines, tutorials and workshop material - so methods are easily shareable between all RCs. The project embraced a coordinated approach with concurrent one-on-one training and six-monthly national training workshops for RCs and Central Government staff. Training was provided by the project consortium: domain experts across New Zealand.

Results and conclusion

A key output of the project is the EnviroSatTools collaborative workspace, a suite of methods and GEE scripts in the Cloud, with associated communication tools. The suite of methods consisted of mapping applications at national and regional scales for land-use change; wetlands; flood and drought impacts; forestry; and coastal change. These outputs support and enhance resource monitoring, management and better informed decision making.

Our presentation will demonstrate the workspace and, more specifically, explain its hydrological and hydrogeological applications (e.g. as shown in Figures 1 and 2).

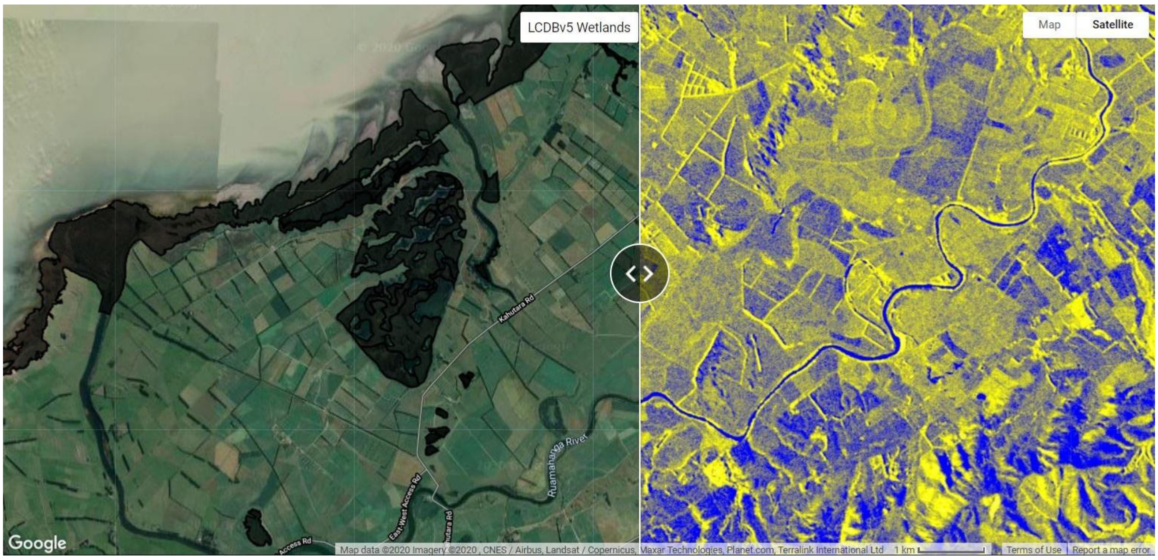

Figure 1: Example of a wetland mapping tool interface, where different 'satellite layers' can be accessed and viewed with sliding windows. Left window, LCDB wetlands in dark green overlaying visual imagery; Right window: Sentinel-1 satellite radar imagery showing radar backscatter, at 10 m spatial resolution.

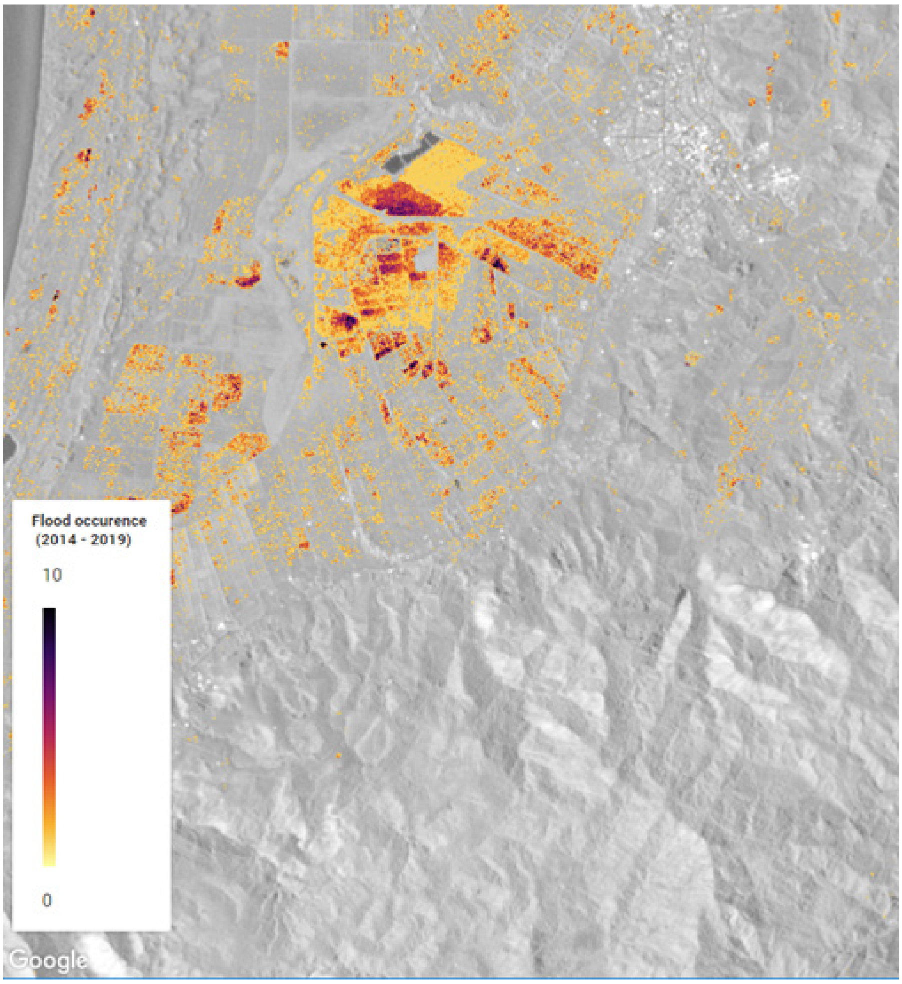

Figure 2: 'Flood occurrence' example near Kaitaia, Northland. Satellite radar anomalies are compared with long-term mean values and applied iteratively for all satellite images in the collection (e.g. from 2014-2019). The amount of times the satellite radar picks up anomalous water is interpreted as a proxy for flood occurrence.

PRELIMINARY GROUNDWATER QUALITY ASSESSMENT IN THE AORERE/WEST COAST CATCHMENT

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Aims

The Aorere/West Coast catchment is in the north-west of the South Island, on the western side of Golden Bay. The catchment is one of the Freshwater Management Units (FMU) for the Tasman District. It extends from Parapara Inlet to Farewell Spit in the east and along the Tasman Bay coastline to Kahurangi Point in the west. The Aorere River is the largest river in the catchment. It originates in Kahurangi National Park, with the floodplains forming the Aorere valley. The eastern mountain range (Haupiri) separates the catchment from the rest of Golden Bay. The Wakamarama Range separates the Aorere valley from the west coast, with the Burnett Range separating the Whanganui Inlet from the eastern coastal settlements.

The majority of the catchment is native forest and conservation land. Primary human land use is dairy farming, particularly in the Aorere valley. The coastal settlements are mostly a mixture of farming, permanent residents, tourism related businesses and holiday homes. The largest settlement is Collingwood, with properties connected to Tasman District Council water supply (groundwater piped in from the lower Aorere valley) and a wastewater treatment plant for the township located just outside of Collingwood. Outside of Collingwood, properties source water from bores/wells, rainwater collection or surface water abstraction. They also rely on private wastewater disposal systems (such as septic tanks).

Current knowledge on groundwater resources in the Aorere/West Coast catchment is limited. The catchment experiences high annual rainfall (> 2,000 mm per year) so groundwater demand is limited. The main aquifer is in the Aorere valley river alluvial terraces. It is unconfined/semiconfined (leaky), and generally flows to the northeast. Recent drilling and testing data show water bearing gravels in this area between 6 – 20 m deep. The Aorere River provides considerable recharge. Away from the river, the aquifer is recharged from rainfall and localised rivers in the side contributing valleys (such as the Kaituna). Groundwater exits the aquifer system by subsurface flow into Golden Bay, springs in the lower Aorere valley with water also abstracted from the rivers and groundwater.

In the eastern coastal settlements (from Ruataniwha Inlet to Farewell Spit), the majority of bores/wells source from shallow unconfined aquifers in localised river outwash alluvial gravels and coastal sand/gravel deposits. Shallow aquifers in these areas are recharged from the local rivers/streams with some going dry in their lower coastal reaches in summer. The local aquifers also get rainfall recharge/overland infiltration. Some of the bores north of Pakawau indicate deeper alluvial outwash gravel (> 20 m) and water in these are mineralised (with high iron and manganese content).

In April 2021, a synoptic water quality survey was undertaken in Aorere/West Coast catchment. The aim was to improve understanding of the groundwater quality and recharge waters in the area.

Method

A water quality survey was undertaken in the Aorere/West Coast catchment in April 2021 and is the first wide-scale water quality survey to be undertaken. 29 groundwater, 16 river and 5 spring sites were sampled (see Figure 1). Of the groundwater sites, 21 were shallow wells or driven bores (generally 2 – 8 m deep). 8 were drilled bores which access deeper groundwater (the deepest bore sampled abstracted from 135 m below the ground).

Results

Water quality results were compared against the Drinking Water Standards for New Zealand 2005 (Revised 2018) (DWSNZ) for both health significant maximum acceptable values (MAV) and aesthetic guideline values (GV). The results of the water quality survey including groundwater and surface water hydrological investigations will be incorporated into an Aorere/West Coast FMU Water Resources Report that will inform the development of a water quality and quantity management plan.

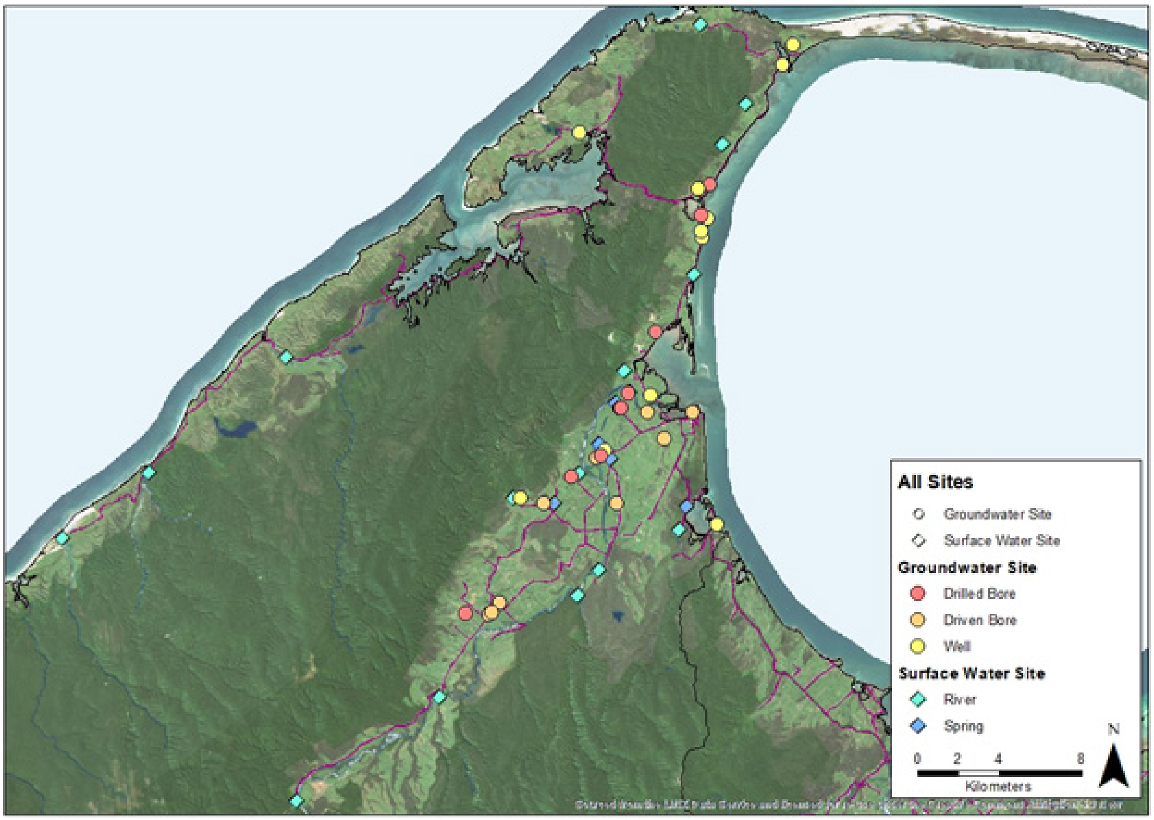

Figure 1: Location of all bores, wells, river and spring sites sampled in the 2021 Aorere and West Coast water quality survey.

The delta where the Aorere River discharges into Golden Bay is swampy and the groundwater (both shallow and deep) has a low pH (between 5.5 and 6) and elevated iron (most near or exceeding the GV). Manganese was also elevated in this area (concentrations above the staining of laundry and some above the taste threshold GV). Surface water near the delta was less impacted by the swampy conditions, with pH between 6 and 7.5, slight elevation in iron (detected but not above the GV), and manganese detected but at very low concentrations (between 0.0007 - 0.0030 g/m3). Nitrates were all below MAV. In groundwater, nitrates were generally higher (between 10% and 50% of MAV) than surface water (all lower than 10% of MAV).

Inland, pH in groundwater (both shallow and deep) remains low (between 5.5 and 6) while the pH in rivers was slightly higher (between 7 and 8). Iron and manganese are lower than the delta (most at or below detection limits) for groundwater and surface water. Nitrates were all below MAV. Groundwater was generally higher in nitrates (most below 50% of MAV) compared to rivers (all below 10% of MAV). Inland spring sites were slight worse in quality, with nitrates between 10% and 50% of MAV.

Coastally, both shallow and deep groundwater sites have higher pH than inland sites (between 6 and 7.5). Rivers had slightly higher pH (between 6.5 and 8.5). Iron and manganese were virtually undetectable (most below the detection limit) for groundwater and rivers. Nitrates for both groundwater and surface water were mostly below 10% of MAV.

Localised contamination of *Escherichia coli* (E.coli) was common in the shallow groundwater sites, both inland and coastal. E.coli contamination is likely occurring due to inappropriate bore/well siting where the bore/well was in close proximity with activities involving faecal matter (e.g. runoff from milking sheds or seepage from septic tanks). Poor bore/well head protection could also be a pathway for contamination to enter into the aquifer. Groundwater abstracted from deeper in the aquifer (bores deeper than 10 m below ground level) did not have detections of E.coli at the time of sampling. All of the deep bores had good bore head protection and were appropriately sited away from potential contamination sources. E.coli was the only DWSNZ parameter in the rivers and springs to be exceeded. Inland rivers had lower E.coli concentrations compared to coastal rivers. Inland springs had the highest E.coli concentrations out of the surface water sites.

THREE-DIMENSIONAL MODEL OF SEDIMENTARY FACIES IN THE LOWER WAIRAU PLAIN: NEW INSIGHTS INTO HOLOCENE COASTAL AQUIFER DEVELOPMENT

White, P.A.,[1] Crundwell, M.P.,[1] Davidson, P.[2]
[1] GNS Science
[2] Marlborough District Council

Background

Three-dimensional facies models have the potential to improve the understanding of aquifers including 3D structure and hydraulic properties. The Lower Wairau Plain is an ideal area to test technical approaches with the local importance of groundwater, the history of model development and the national importance of coastal aquifer systems.

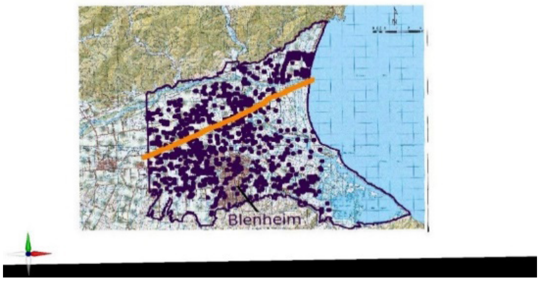

Figure 1: The lower Wairau Plain study area, the position of the Wairau Fault (orange line) in the area, and the locations of well logs.

The Wairau Plains aquifer system is a key water resource for the Marlborough district as it supplies drinking water to the local population, provides much of the water for agricultural irrigation, and is the source of water for Blenheim's spring-fed streams (Davidson and Wilson, 2011; White et al., 2016), Figure 1.

Characterisation of the Wairau Plains aquifer system has included a geostatistical approach to model the sediment distribution in the lower Wairau Plain, based on well logs and a 4D representation of geological development in the last 20 k years at a 1 k timestep (White et al., 2016 and 2017).

The modelling approach of this paper is relevant to other coastal aquifer systems as this work is part of GNS Science's programme that is currently characterising all coastal aquifer systems in New Zealand in consultation with local experts. The work is also relevant to the development of a new 4D database for hydrogeological information, which will be demonstrated during the talk.

Method

LiDAR terrain data was used to produce a Digital Terrain Model (DTM) of the study area on a 5 m grid by 2D gridding and smoothing. An analysis of topographic patterns (e.g., beach ridges and dunes) informed the distribution of surface facies, building on Brown (1981).

Marlborough District Council's database of logs from 1070 wells were assembled for the study area (Figure 1). Facies were interpreted from well-log lithologies, and supporting field work (principally, sediment sampling in shallow auger holes), i.e.: nearshore-marine, beach-to-nearshore, beach, estuary, plains-fluvial; plains-other and basement. The distribution of these facies was then modelled in 3D to 50 m depth according to the method of White and Reeves (1999).

Results

Analysis of the DTM identifies numerous features of the surface facies (Figure 2). For example, the DTM identifies: a pre-historic ridge (A-A'; Figure 3) that probably represents the high-stand Holocene beach position; and multiple dune deposits with lateral continuity indicating the location of palaeo-estuary boundaries (Figure 4).

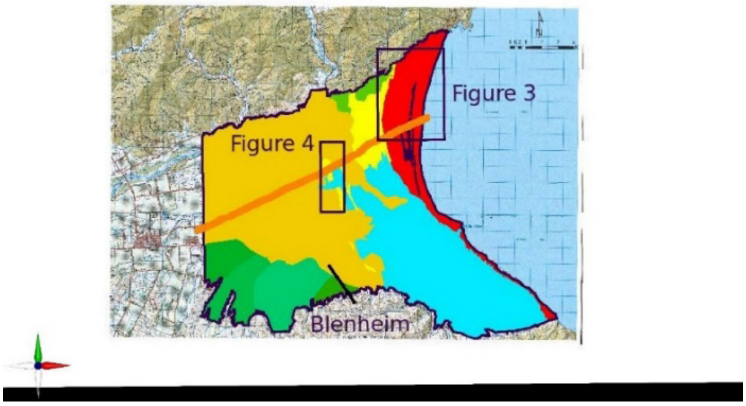

Figure 2: Surface facies of the lower Wairau Plain, including: swamp (black); beach (red); dune (yellow); northern and southern alluvial fans (green); Wairau Plain fluvial and other (ochre) and estuary (blue). The positions of the Wairau Fault (orange line) and figures 3 and 4) are indicated.

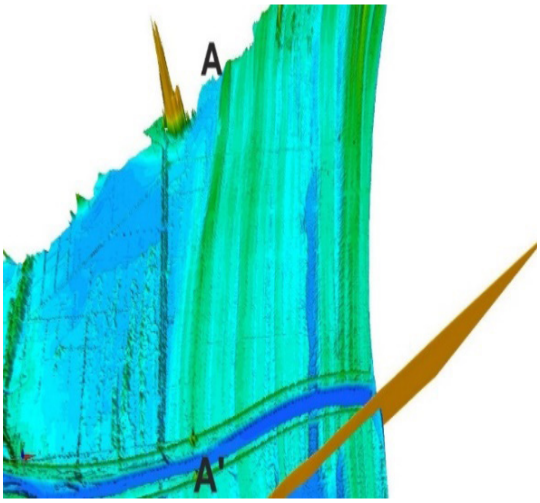

Figure 3: The DTM, looking north showing beach ridges including the Holocene high-stand ridge (A-A') and the Wairau Fault position (orange fence).

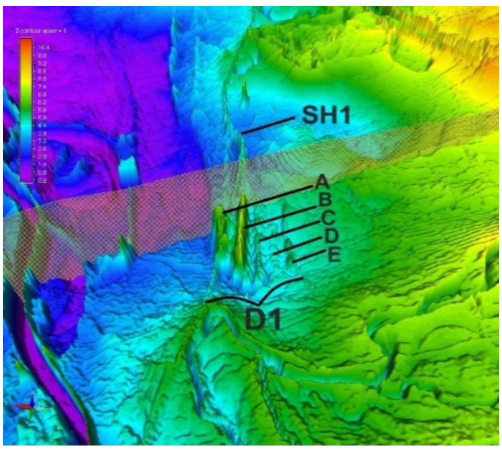

Figure 4: The DTM, looking south from Spring Creek down State Highway One (SH1) showing the Spring Creek set (D1), a multiple-dune system (A to E), with the Wairau Fault position (transparent fence).

The 3D facies model indicates the depositional history, e.g., north of the Wairau Fault (Figure 5):

- Sea level rose in the early Holocene and deposited beach sediments on the Pleistocene gravel fan.
- During the high-stand sea level (approximately 6,000 years ago), the estuary formed with estuarine sediments depositing as far inland as 'D1' (Figure 4) with the high-stand beach ridge (Figure 3) forming a proto-Wairau Bar.
- Since the high-stand sea level, the estuary has been filled with Holocene gravels, silts and sands.
- Holocene beach gravels were then deposited in ridges, until today, as the coastline regressed.

Together, a facies interpretation provides information on how the main aquifer (i.e., Holocene and Pleistocene gravels ('4') interfinger with estuarine sediments, e.g., the estuary appears as an erosional feature within Pleistocene sediments generally forcing groundwater flow from the west to the ground surface.

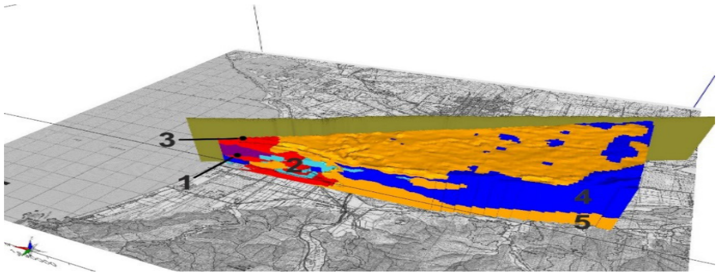

Figure 5: Facies in the area north of the Wairau Fault, showing facies: nearshore-marine (purple), beach (red), estuary (teal), plains-other (ochre) and plains- fluvial (royal blue) and the Wairau Fault (transparent fence).

References

Brown, L.J. 1981. Late Quaternary geology of the Wairau Plain, Marlborough, New Zealand. New Zealand Journal of Geology and geophysics, 24(4): 477-490.

Davidson, P. & Wilson, S. 2011. Groundwaters of Marlborough. Blenheim, NZ: Marlborough District Council, 302p.

White, P.A. & Reeves, R.R. 1999. Waimea Plains aquifer structure as determined by three-dimensional computer modelling. Journal of Hydrology, New Zealand, 38(1): 49-75.

White, P.A., Tschritter, C. & Davidson, P. 2016. Groundwater-surface water interaction in a coastal aquifer system, lower Wairau Plain, Marlborough. Journal of Hydrology, New Zealand, 55(1): 25-43.

White, P.A., Davidson, P. & Tschritter, C. 2017. A geomorphic model to describe key geological units for groundwater flow in the Wairau Plains. New Zealand Hydrological Society annual conference, 28 November – 1 December 2017, Napier Conference Centre. Wellington, NZ: New Zealand Hydrological Society: 236-237.

ANALYSING NITRATE NITROGEN MEASUREMENTS IN CANTERBURY GROUNDWATER FROM IN-SITU, UV NITRATE SENSORS

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Aims

Environment Canterbury has six groundwater nitrate sensors throughout Canterbury that are used for monitoring purposes. In addition to monitoring the concentration, the nitrate sensors can be used to gain a greater understanding of nitrate processes in the subsurface (Pellerin *et al*., 2013; Huebsch *et al*., 2015). The data provides unique insights into nitrate responses to rainfall events, lag times and the effectiveness of discrete sampling programmes in dynamic groundwater environments. One nitrate sensor is installed at Balmoral, near Culverden, to monitor the effects of land use change from forestry to irrigated beef farming.

Method

The Canterbury sensors have been set up to measure nitrate nitrogen concentrations in groundwater at 15-minute intervals and convey that data via a telemetry system, so that both high frequency and real time measurements are possible. The sensors measure the transmittance of light in water and use that to calculate the concentration of nitrate nitrogen based on its absorbance of light between 200-250nm. Monitoring bores equipped with sensors have various co-located instruments for the collection of rainfall and/or groundwater level data that assist in the interpretation. Regular maintenance of the sensors and validation by grab samples ensure the quality of the nitrate data collected. Time series data from the sensors has been analysed here with particular attention to the patterns of response after large rainfall recharge events.

Results

The nitrate sensor at Balmoral shows that there is a hysteresis relationship between groundwater level and nitrate nitrogen concentration, after rainfall events. During initial rainfall or first flush events there is a rapid increase in the concentration of nitrate nitrogen but very little change in water level. This suggests that there is a pressure response of localised nitrate nitrogen stored in the vadose zone that reaches the well screens when rainfall recharge begins to infiltrate from above. Although there is an immediate nitrate nitrogen response to rainfall, it takes significantly longer for concentrations to return to baseline levels after the event. As winter progresses the degree of hysteresis decreases, suggesting that there is a depletion of nitrate storage in the catchment and increased rates of transport from the soil to the aquifer (Figure 1). Additionally, the results from Balmoral show that lag times for nitrate nitrogen can be relatively short in highly permeable, shallow systems.

Nitrate sensors at other locations in Canterbury show very different responses of nitrate nitrogen to rainfall events based on hydrogeological conditions and sources of nitrate nitrogen. The Balmoral sensor shows rapid changes in nitrate concentrations within hours of a rain event, while another sensor at Seadown in South Canterbury showed a delayed response where nitrate concentrations began to increase three to four days after a significant rain event and only peaked more than a month later. In this case much of the nitrate is thought to be travelling through the aquifer from an upgradient discharge location.

The results obtained from the nitrate sensors can also be used to compare the results of continuous samples compared to discrete sampling methods. The data collected so far suggests that many peak nitrate concentrations are not captured by less frequent sampling. In some locations, particularly for shallow wells where land surface recharge is dominant, such as Balmoral, continuous sampling programs offer the benefit of capturing significant variability in nitrate nitrogen concentrations that would be missed by quarterly or less frequent sampling, that most regional councils use for groundwater monitoring.

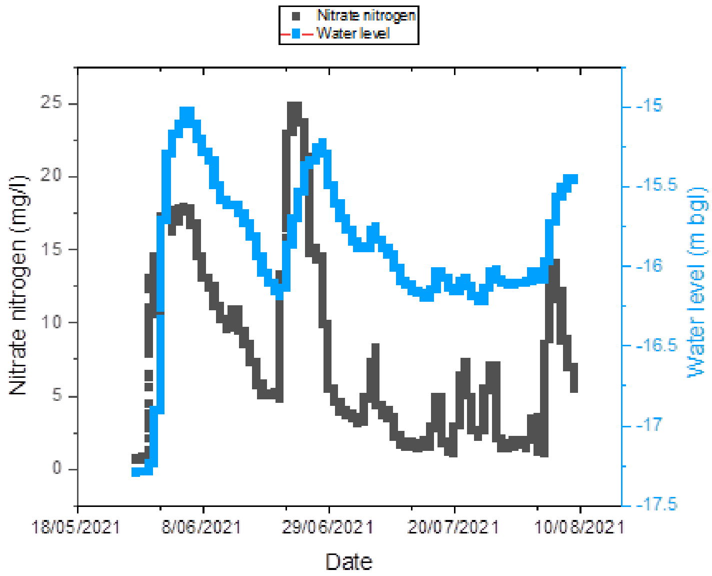

Figure 1: Nitrate nitrogen and groundwater level measured at the Balmoral site.

References

Huebsch, M., Grimmeisen, F., Zemann, M., Fenton, O., Richards, K.G., Jordan, P., Sawarieh, A., Blum, P. and Goldscheider, N., 2015. Field experiences using UV/VIS sensors for high-resolution monitoring of nitrate in groundwater. *Hydrology and Earth System Sciences*, 19(4), 1589-1598.

Pellerin, B.A., Bergamaschi, B.A., Downing, B.D., Saraceno, J.F., Garrett, J.D. and Olsen, L.D., 2013. Optical techniques for the determination of nitrate in environmental waters: Guidelines for instrument selection, operation, deployment, maintenance, quality assurance, and data reporting. *US Geological Survey Techniques and Methods*, 1-D5.

INFORMING CATCHMENT CONCEPTUALISATION AND MODELLING WITH SKYTEM DATA

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Aims

This study aims to use geophysical data to improve the conceptualisation of catchment flow pathways and improve groundwater model structure. SkyTEM surveys were flown in February 2019 for the upper Piako and Waiotapu catchments of the Waikato region as part of the MBIE-funded "Critical Pathways" programme. Interpretation of the SkyTEM resistivity results is hampered by a lack of reliable drill hole data for ground-truthing, and available bore logs are mostly restricted to the valley floors. Also, Qmap only represents the surface geology, and may not be a reflection of what is present at depth, for example at depths where groundwater may be found. The difficulty in interpretation in the absence of ground-truthing data results from the fact that earth resistivity is determined by several physical factors, namely porosity, water content, water total dissolved solids, and matrix conduction (in the presence of clays). A single resistivity value can be derived from different combinations of these physical factors, which makes derivation of geological units from resistivity data extremely challenging, and in the absence of good borehole coverage, nearly impossible.

Method

The data captured by the two SkyTEM surveys was resistivity, total magnetic intensity (TMI) and spatial positioning. The resistivity data were inverted by our collaborators at Aarhus University using smooth and sharp inversion models. The spatial positioning data (E, N, elevation) were transformed to positional eigenvalues using principal components analysis. The combined data provides four spatially varying datasets in 3D space which can be queried using statistical models. An initial model was applied to remove the unsaturated material from the raw dataset. This initial filtering provided us with two datasets, an estimate of the water table elevation, and a dataset of saturated material to be used for estimating hydrogeophysical units.

In applying a statistical model, we assume that physical data with similar characteristics represent groups of data with similar hydrogeophysical properties. Of the analysis methods available, only unsupervised learning methods are suitable, since there is inadequate data for use as a model training dataset. To select an appropriate method, we tested self-organising maps and several forms of K-means clustering to partition the data into groups or clusters. Of the methods tested, the CLARA algorithm produced the best results, with both superior partitioning and representation of the known near-surface geology. CLARA is an extension of K-means clustering which partitions a dataset into a set of K clusters, with each observation attributed to the cluster with the nearest median value to remove outlier bias. CLARA is an efficient method for large datasets since it takes a random sample of the dataset, finds medoids for those values, clusters the observations based on those medoids, and repeats.

Estimation of the water table depth used a simple algebraic approach. The estimate was based on the assumption that the maximum negative change from average resistivity in a particular sounding represents the point where the transition from saturated to unsaturated conditions occurred. Estimates were made on a sounding by sounding basis, the results then kriged across the study domain.

Results

For the Waiotapu catchment, the clustering process produced an optimum of seven clusters or hydrogeophysical classes. These seven classes were subsequently refined into ten classes based on their physical location in the cathment (Paeroa Ranges vs. Kaingaroa Plateau). The first saturated layer matched the mapped geology reasonably well, while deeper layers corresponded well with the logs from the two boreholes we drilled for ground-truthing the SkyTEM data. In general, the catchment can be seen to consist of low permeability units in the Paeroa Range, alluvial fans on the valley flanks, low permeability silt on the valley floor, and moderate permeability fractured ignimbrite on the Kaingaroa Plateau.

The water table depth estimate was made with an uncertainty of plus or minus one sounding depth, generally totalling less than plus or minus three metres error. The resulting dataset is particularly powerful for groundwater flow modelling since it provides a water table estimate for each cell in our MODFLOW model.

For the upper Piako catchment, Qmap (Leonard et al. 2010) shows the widespread presence of Early Pleistocene alluvium. However, these sediments could not be identified in either the SkyTEM data, or bore logs. A field check was carried out, which revealed minor thin lenses of alluvium at some localities on the valley floor, barely distinguishable from the underlying ignimbrite. Conversely, significant deposits of sediment were found just to the east in the Mangapapa catchment. Our conclusion is that much of the Piako catchment has been incorrectly represented by Qmap (Leonard et al. 2010) as Early Pleistocene alluvium. The 1964 geolgical map (Healy et al. 1964) is a more accurate representation of upper Piako geology, dominantly consisting of ignimbrite subjected to various degrees of weathering. Within the valley floor, the stream bed has dissected down to a strongly welded ignimbrite horizon ~10m thick, with the material above and below this horizon being deeply weathered to clay, and therefore not conducive to groundwater flow.

The clustering process for Piako data could only distinguish four hydrogeophysical classes, and could not distinguish between weathered greywacke and weathered ignibrite. However, the SkyTEM data confirms that the majority of the catchment consists of low permeability material, the majority comprising ignimbrite, deeply weathered to clay. The extent of fractured Basaltic Andesite of the Kiwitahi Group is clearly identified as being extensive in the Piakonui headwaters. This unit is also presnt in the Piakoiti headwaters, but is more limited in it's extent. The substrate distribution provides a conceptualisation that matches our flow gauging data, with considerable baseflow being sourced from the Piakonui, and to a lesser extent Piakoiti, headwaters. The remainder of the catchment (including Piaokiti) being dominated by quickflow with only a minor groundwater contribution. This conceptualisation lends the catchment to a surface water modelling approach rather than a groundwater model.

References

Healy, J.; Schofield, J.C.; Thompson, B.N. 1964: Sheet 5 Rotorua. Geological map of New Zealand 1:250 000. Wellington, Department of Scientific and Industrial Research. 1 sheet.

Leonard, G.S.; Begg, J.G.; Wilson, C.J.N. (compilers) 2010: Geology of the Rotorua area. Institute of Geological & Nuclear Sciences 1:250 000 geological map 5. 1 sheet + 102 p. Lower Hutt, New Zealand. GNS Science.

CONCEPTUALISING SURFACE WATER-GROUNDWATER INTERACTION IN BRAIDED RIVERS

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Aims

This study aims to provide a conceptualisation of how braided rivers work in the subsurface. This knowledge will support how groundwater-surface water interaction occurs, how it can be measured, and how river management practices can affect the river water balance.

Method

Field sites were established on three braided rivers, the Selwyn/Waikirikiri, Wairau, and Ngaruroro. All three of the river study reaches are known to have considerable flow loss, which contibutes significant recharge to groundwater. This hydrological setting is advantageous for understanding how braided rivers work in the subsurface, since a dominantly losing river reach is elevated to some degree above the underlying aquifer(s) (Brunner et al. 2009). This elevation difference creates a degree of physical separation between the river and underlying aquifers, and is often associated with variable saturation conditions, which impact on the surface water-groundwater exchange. This makes the identification of any subsurface structural controls on groundwater-surface water exchange by drilling or geophysics easier to identify than for a gaining river.

A number of field methods have been applied to understand the relationship between the river and the nature of its subsurface saturation. A multi-method approach is necessary since each method has advantages and disadvantages, and is scale- and process-dependant (González-Pinzón et al. 2015, Coluccio & Morgan 2019). Some of these methods were applied in our field investigations, which includes surface and subsurface hydrological characterisation, sedimentology, recconaisance geophysics, radon and temperature as environmental tracers of water movement in the subsurface.

Results

Each of the three rivers has been found to be closely associated with a near-surface reservoir, which we propose to call the “braidplain aquifer”. Water visible at the river-bed surface is hydrologically inseperable from the underlying braidplain aquifer, with the two exchanging water at multiple spatial and temporal scales.

The function of the braidplain aquifer is to mediate the exchange of water between the river and regional aquifer system. It facilitates hyporheic and parafluvial return flow, and these processes sustain river flow and cool temperatures during the dry season. When storage in the braidplain aquifer is high, there is an increase in the rate of hyporheic and parafluvial exchange. We expect that river flows will be higher, and temperatures cooler, during the summer period if the braiplain aquifer has sufficient antecedent storage. The braidplain aquifer also provides a steady source of recharge to the regional aquifer, with the rate of recharge depending on the lateral extent of the braidplain aquifer and its storage volume.

Differential flow gauging is a method commonly used to estimate groundwater recharge from rivers. But it is important to note that what is actually measured by this approach is the water exchanged between the river and braidplain aquifer, and a lumped term for groundwater recharge and the change in storage of the braidplain aquifer. Local exchange between the river and braidplain aquifer is the reason why repeated concurrent gaugings show variable results and large uncertainty in gaugings. As such, the differential flow value obtained from this approach is not necessarily the same as the rate of recharge to the regional aquifer.

The river and braidplain aquifer can generally be considered to be hydrologically connected, although there are some exceptions. River braids can locally become perched above the braidplain aquifer along riffles. In this situtation, low vertical conductance combined with elevated the bed topography forces the river away from the water table, creating an unsaturated zone beanth the bed. Further downstream, the same channel will become hydraulically connected to the braidplain aquifer at the next pool. The Selwyn/Waikiriri is an example of an ephemeral river where during the dry season the rate of leakage to the regional aquifer exceeds the rate of storage replenishment in the braidplain aquifer. This reduction in storage and associated lowering of the braidplain aquifer water table creates a hydraulic disconnection between the river and its braidplain aquifer. At such a time, the river loses the benefit of any supplementary return flow from the braidplain aquifer, and the river eventually dries up at a position where the rate of vertical infiltration to the braidplain aquifer exceeds flow in the river.

The braidplain aquifers associated with each of our study rivers are thin, on the order of 2-5m. However, they are wide, and extend beyond the contemporary braidplain in each case. The lateral extent of subsurface saturation increases when river flow is high, and diminishes when river flow is low. The physical dimensions of the braidplain aquifer are also largely controlled by the high degree of stratification that is associated with braided river deposits. The base of the braidplain aquifer is formed by a structural control which limits the rate of vertical percolation.

For the Selwyn/Waikirikiri, the braidplain aquifer is hosted by highly stratified postglacial sediments, with the base marked by a change in depositional enviroment in the underlying poorly sorted glacial outwash gravels, which creates a 10m partially sturated zone between the braidplain aquifer and regional water table. In the Wairau and Ngaruroro, the basal control appears to be a more subtle transition from actively reworked alluvium overlying older postglacial alluvium and there are bounding hills on the north banks of these rivers. Both of these factors result in a lesser degree of separation between the braidplain aquifer and regional water table, although the braidplain aquifer can be readily identified beneath both of these rivers. For each of the studied rivers, the dominant control on exchange between the river, braidplain aquifer, and regional aquifer, is the degree of stratification, and it's associated vertical hydraulic conductivity.

References

Brunner, P., Cook, P.G., Simmons, C.T., 2009. Hydrogeologic controls on disconnection between surface water and groundwater. Water Resources Research 45 (1), W01422.

Coluccio, K., Morgan, L.k., 2019. A review of methods for measuring groundwater–surface water exchange in braided rivers. Hydrol. Earth Syst. Sci., 23, 4397–4417.

González-Pinzón, R., Ward, A.S., Hatch, C.E., Wlostowski, A.N., Singha, K., Gooseff, M.N., Haggerty, R., Harvey, J.W., Cirpka, O.A., Brock, J.T., 2015. A field comparison of multiple techniques to quantify groundwater-surface-water interactions. Freshwater Science 34 (1): 139-160.

COMMUNICATING UNCERTAINTY AND VARIABILITY IN WATER FLOW AND NUTRIENT LOADS TO LAKE TARAWERA FROM CONNECTED LAKE CATCHMENTS

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Introduction

Lake Tarawera is a large, deep lake located within the Taupo Volcanic zone, 12 km south-east of Rotorua. It occupies a surface area of 41.44 km^2, and has mean and maximum depths of 50 m and 88 m respectively (Abell et al., 2020). Seven smaller lakes within the "Greater Tarawera Lakes" catchment (Ōkareka, Ōkaro, Ōkataina, Rerewhakaaitu, Rotokakahi, Rotomahana and Tikitapu) contribute flows to Lake Tarawera via groundwater and/or surface water (Figure 1). The quantity and quality of flows from these connected lakes is important in assessing hydrological inputs to Lake Tarawera.

Numerous legislative documents, community processes and stakeholders support or require managing nutrient loads to Lake Tarawera to improve water quality. The Tarawera Lakes Restoration Plan (Bay of Plenty Regional Council, 2015) sets a target Trophic Level Index (TLI) of 2.6 for Lake Tarawera which is not currently met.

Groundwater is recognised as a large component of the flow to Lake Tarawera, estimated to be approximately 45% of total inflows (White et al, 2016). Previous investigations have been undertaken in the Greater Lake Tarawera catchment to assess groundwater resources and groundwater quality (Gillon et al., 2009; White et al., 2016, 2020). Despite the extensive work of these past researchers, there remain substantial uncertainties on the hydrology and chemistry of groundwater fluxes to Lake Tarawera (Abell et al., 2020).

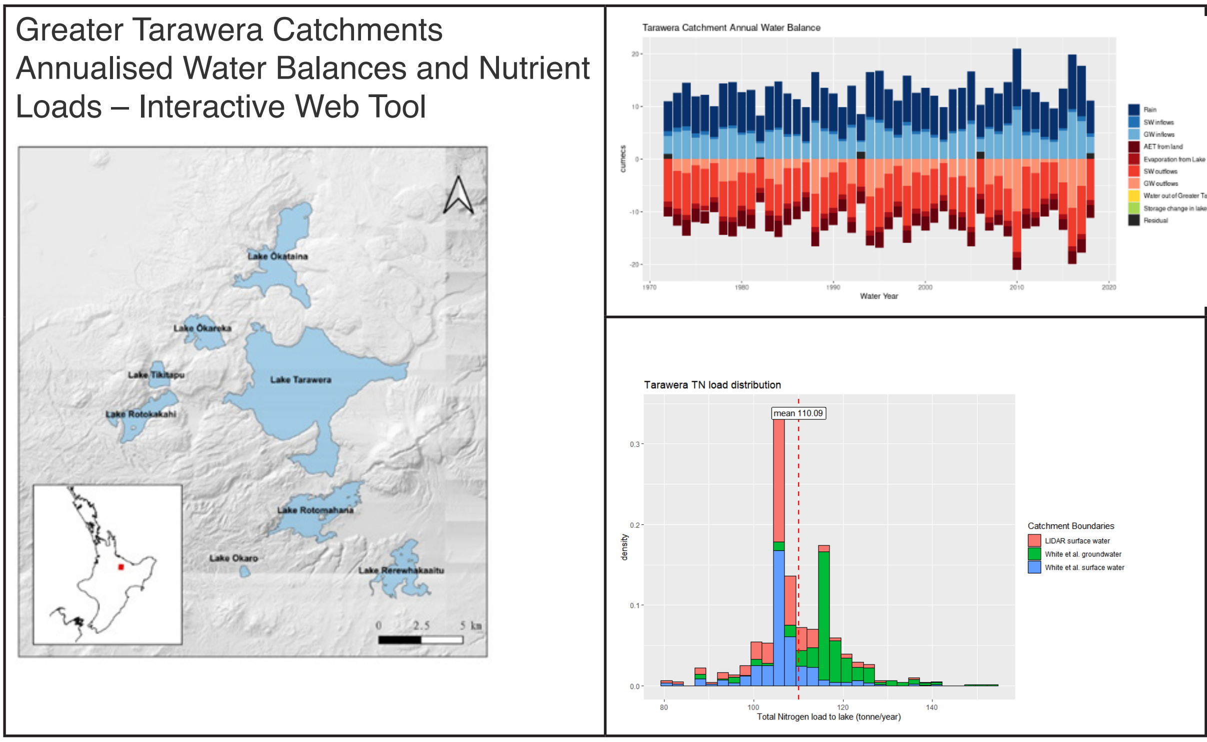

Figure 1: Screen shots from an interactive web-based tool showing a map of the eight lakes of the Greater Tarawera Lakes Catchment and outputs for Lake Tarawera

Aim
This research aims to communicate uncertainties and variabilities in water flows and nutrient load estimates to the Greater Tarawera Lakes using a water balance approach and an interactive web visualisation tool.

Method
Annualised water balances from 1972 to 2018 have been calculated for the Greater Tarawera Lakes and their catchments. Different data options and calculation methods for water balance components and nutrient load estimates are used in the calculations. Uncertainties are presented as range estimates with underlying distributions.

The workflow has been automated using the R statistical computing language. A web-based tool that performs water balance calculations and nutrient load estimates has been developed using Shiny R technology (Figure 1). This tool is a useful for visualising, exploring, and communicating uncertainties in the estimates water flow and nutrient loads.

Results
The web-based tool will be demonstrated and is available for viewing at https://nickiwilson.shinyapps.io/tarawera/. Ranges of groundwater flows and nutrient loads to Lake Tarawera have been estimated and are presented in Figure 1 and Table 1.

Table 1: Total Nitrogen and Total Phosphorus load statistics to Lake Tarawera

Lake Tarawera Load Statistics (tonnes/year)		
	TN	TP
Mean	110.09	11.09
Standard Deviation	9.20	1.05
IQR	10.06	1.35
25th percentile	106.58	10.62
75th percentile	116.64	11.97
95% CI. lower limit	88.75	8.94
95% CI. upper limit	130.95	13.48

References

Abell, J., McBride, C., & Baisden, T. 2020. Assessing effects of changes to nutrient loads on Lake Tarawera water quality: Model simulations for 2010 to 2020. Environmental Research Institute, University of Waikato, Report No. 144, prepared for Bay of Plenty Regional Council: p. 55 + appendices. https://www.waikato.ac.nz/__data/assets/pdf_file/0004/715099/ERI144_2021_TaraweraModelling.pdf

Bay of Plenty Regional Council. 2015. Tarawera Lakes Restoration Plan. Environmental Publication No. 2014/2.

Gillon, N., White, P., Hamilton, D., & Silvester, W. 2009. Groundwater in the Okataina caldera: Model of future nitrogen loads to Lake Tarawera. Centre for Biodiversity and Ecology Research, University of Waikato. Report No. 94: p. 75.

NIWA. 2021. Climate Dataset created as part of NIWA Strategic Science Investment Fund Regional Hydrological modelling and New Zealand Water Model projects. Data provided by NIWA February 2021.

White, P., Mourot, F., Toews, M., & Davids, B. 2020. Catchment boundaries of lakes in the greater Lake Tarawera area. GNS Science, Consultancy Report No. 2018/188: p. 39.

White, P., Toews, M., Tschritter, C., & Lovett, A. 2016. Nitrogen discharge from the groundwater system to lakes and streams in the greater Lake Tarawera catchment. GNS Science, Consultancy Report No. 2015/108: p. 88. GNS Science.

FACING THE CHALLENGE OF MANAGING GROUNDWATER OF THE WAIRAU PLAIN AQUIFER

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Aims

Managing the important groundwater resources of the unconfined Wairau Plain Aquifer is increasingly challenging because of observed multi-decadal trends of declining groundwater levels and spring flows combined with a natural strong seasonality and an expected high vulnerability of the river-aquifer system to climate change, overexploitation or other significant alterations.

In this contribution we aim to examine the impact on groundwater storage of one of the most influential knowledge gaps, namely the actual groundwater abstraction. Current abstraction rates are estimated to be much lower than the consented abstraction rates. We investigate current groundwater management policy in the hypothetical case of full abstraction as a kind of a worst-case scenario and discuss alternative management options that could embrace expected future conditions of the river-aquifer system.

Method

We have previously set up a detailed, three-dimensional surface water – groundwater model of the Wairau River and Wairau Plain aquifer on the South Island of New Zealand (Wöhling et al., 2018). Inputs to this model are, among others, daily values of spatially distributed groundwater abstraction rates (crop water requirement) and land surface recharge on the Wairau Plain. These quantities are computed by the Rushton soil water balance model. Since Rushton model parameters (e.g. readily and total available water in the soil profile) and meteorological inputs are highly uncertain and the data to calibrate these parameters is very limited, the estimates of actual groundwater abstraction are also uncertain. We have revised the Rushton model and tested results at six vineyards where actual abstraction data was available to provide a best-estimate simulation of current Wairau Aquifer groundwater abstraction for vineyard irrigation.

In addition, scenario simulations are performed that scale current abstraction rates up by a factor to mimic future demands and a dryer, warmer climate. Further, a full abstraction scenario was performed that considers a constant basal abstraction rate throughout the year in addition to the seasonal demands that peak in summer.

Results

The scenario simulations show that current groundwater level limits will be exceeded more regularly in the future under current groundwater management rules and an increased abstraction demand. Carry-over effects of groundwater storage from one year to the next are likely to occur, particularly in years with dry summers and certainly for a succession of such years.

Instead of imposing hard cut-offs at specified groundwater levels, groundwater management could be based on an annual sustainable fluctuation of groundwater storage which is roughly estimated to be around 15 million m^3. This volume should not be confused with abstractable storage. Instead, it is a sustainable annual depletion of aquifer storage resulting from the combined effect of the natural balance between aquifer recharge, groundwater abstraction and aquifer discharge.

Limit setting could be based on the sustainable abstraction volume being exceeded with a flexible upper reference level for that volume being determined annually in spring when aquifer levels are high (i.e., after the recharge season). This would take into account the hydrological variability between years and prevent hard cut-offs after (a series of) dry years.

Mitigation measures against excess aquifer depletion would be an ideal supplement to groundwater management of the Wairau Plain Aquifer. Such measures are maintaining Wairau River flows above ~20 m^3/s, enhanced recharge (e.g., widening the river bed in the recharge sector), sustainable sediment control and prevention of river-bed erosion.

References

Wöhling T., Gosses, M. Wilson, S., Davidson, P. (2018). Quantifying river-groundwater interactions of New Zealand's gravel-bed rivers: The Wairau Plain. Groundwater, 56(4), 647-666.

NATIONAL IMPLEMENTATION OF TOPNET-GW IN NEW ZEALAND

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Aims

New Zealand has a variety of hydrologic phenomena, resulting from different hydrogeologic setting, landscapes and climate system. These hydrologic phenomena range from glacial and snow in the mountains, floods, droughts, springs, etc. This requires a holistic consideration when developing a national hydrologic model in New Zealand, among which is taking surface and groundwater as an integrated component (especially in the lowland area where people relies on). These requirements have been recently embodied as *Te Mana o te Wai (integrated and holistic well-being of a freshwater body)* in the National Policy Statement for Freshwater Management (NPS-FM; MfE, 2020). Application of Te Mana o te Wai concepts to water management is supported through the development of an integrated surface-groundwater model TopNet-Groundwater (Topnet-GW; Yang *et al*., 2017), as part of the New Zealand Water Model (NZWaM-Hydro) framework. This paper presents an update on recent progress of implementing TopNet-GW for the entire New Zealand, as one of the major tasks of NZWaM in this year.

Method

National implementation of an integrated surface-groundwater model is a challenging task which involves the development of the conceptual model of the hydrological processes of i) surface and groundwater, and their interaction, ii) collection of different land surface and hydrogeologic data, and iii) a-prior parameterisation of the integrated hydrological model. In the past several years, we have developed the conceptual groundwater model for application in New Zealand (Griffiths et al., 2021), collected and/or developed hydrologic national datasets for model parameterisation, developed *a-priori* parameterisation method for New Zealand, through a wide range of collaborations with scientists from regional/district councils, GNS, and University of Bristol, UK. These datasets include: national losing and gaining streams (Yang et al., 2019); national equilibrium groundwater table (Westerhoff et al, 2019); QMAP (Rattenbury and Isaac, 2012), national geologic data for aquifers (Tschritter et al., 2016), etc. This national implementation of TopNet-GW is a parameterisation of TopNet-GW for New Zealand based on the conceptual model and collected data, using the method developed between NIWA and University of Bristol.

To facilitate the implementation, we have developed different tools, from geospatial operation in ArcGIS to different scripting in R. The realisation is being carried out region by region.

Results

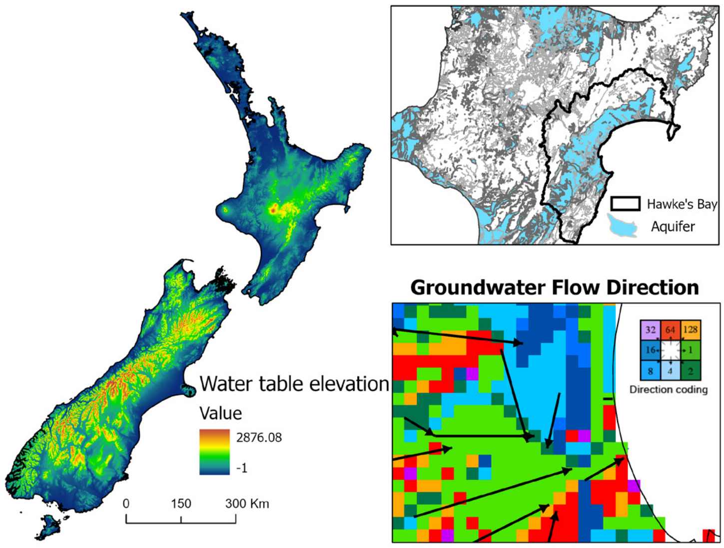

Figure 1: Groundwater flow direction tool developed in ArcGIS to facilitate the groundwater flow simulation in TopNet-GW.

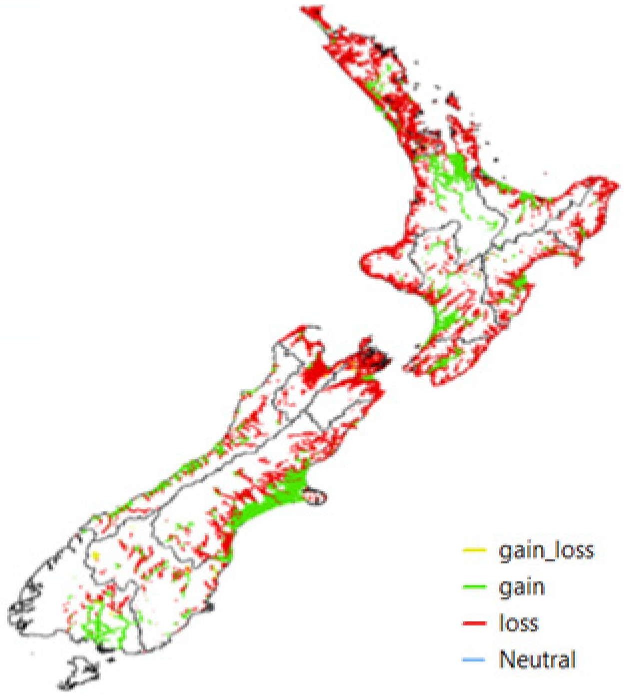

Figure 2: National dataset of losing and gaining streams in New Zealand to signify the interaction between surface and groundwater in TopNet-GW.

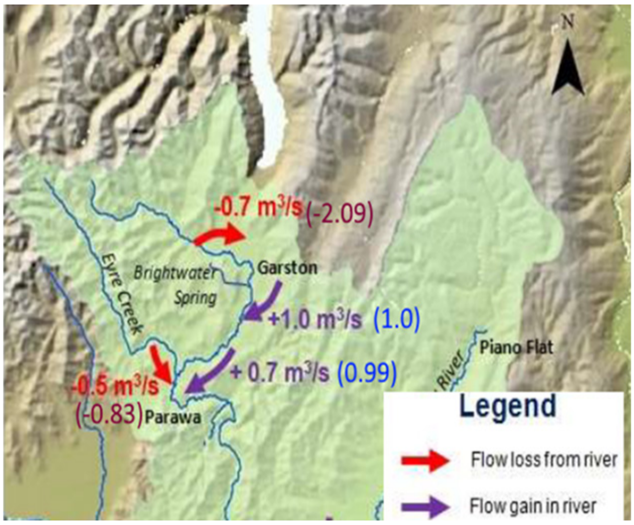

Figure 3: A TopNet-GW application in Pawara (Southland) to simulate the losing and gaining rates of streams (bracketed) as a comparison to the one in Hughes et al., 2011.

We expect the first version of the model application in New Zealand will be completed by June 2022 and the model results will support different water management across New Zealand.

References

MfE, 2020. National Policy Statement for Freshwater Management 2020. Ministry for the Environment document.

Griffiths et al., 2021, Parameterizing a national groundwater model for New Zealand (in prep).

Hughes, B., Harris, S., Brown P., 2011. Mataura Catchment Strategic Water Study. Report Prepared for Environment Southland.

Rattenbury, M. S., & Isaac, M. J. (2012). The QMAP 1: 250 000 geological map of New Zealand project. New Zealand Journal of Geology and Geophysics, 55(4), 393–405.

Tschritter, C., Rawlison, Z., Westerhoff, R., White, P.: Aquifer classification and mapping at the national scale – Phase 1: Identification of hydrogeological units, GNS Science Report SR2016-51, GNS Science, Wellington, New Zealand, 2016.

Westhoff, 2019. National Water table for New Zealand. Data provided to NIWA.

Yang, J., McMillan, H. and Zammit, C., 2017. Modeling surface water–groundwater interaction in New Zealand: Model development and application. Hydrological Processes, 31(4), pp.925-934

Yang, J., Griffiths, J., Zammit, C., 2019. National classification of surface–groundwater interaction using random forest machine learning technique. River Research and Applications. https://doi.org/10.1002/rra.3449.

MODELLING DYNAMIC SURFACE - GROUNDWATER INTERACTION IN RUATANIWHA

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Aims

Over the past decades, there has been a conflict between the increasing water demand for economic production and domestic consumption, and environmental conservation, across New Zealand. This will pose a big challenge for regional/district councils to manage surface and groundwater resources, as stated by the National Policy Statement for Freshwater Management (NPS-FM; MfE, 2020). Future climate change will exacerbate this challenge as it increases the uncertainty in the availability and dynamics of surface and groundwater. It is therefore crucial to understand the dynamics of surface and groundwater interaction processes.

In this study, we are presenting a study to model the surface-groundwater dynamic processes in the Ruataniwha catchment, which has shown strong surface-groundwater interaction, and increasing concerns on water availability for domestic and economic consumption, and environment conservation problems.

Method

TopNet-GW (Yang et al., 2017) is a groundwater version from TopNet family. This model was developed to simulate the cross-boundary groundwater flow and interaction of surface and groundwater, and is typically designed for lowland area where groundwater plays a big role in the hydrologic process.

Application of TopNet-GW requires climate data, land information (e.g. DEM, soil, land cover), groundwater zone boundary, information on losing and gaining streams (Yang et al., 2019) for model setup, and observed river flow data for model calibration and validation.

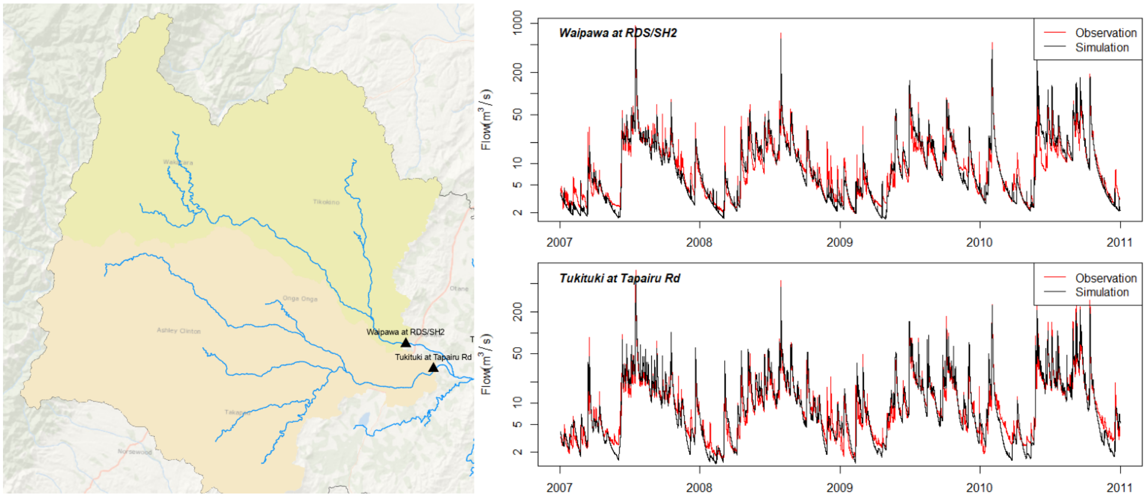
We used two steps to apply TopNet-GW in Ruataniwha catchment. The first step was to set up and calibrate TopNet model (rainfall-runoff) at the two watershed outlets namely Waipawa at RDS/SH2 and Tukituki at Tapairu Rd (Figure 1 and Table 1). This step is to ensure general water balance for the catchments by assuming all groundwater will eventually come out and pass these two outlets. The second step was to set up groundwater components on TopNet and calibrate flows within the catchment where there are losing and gaining streams.

The model was set up at hourly time step and the simulation period (from 2001 to 2012) was split into calibration period and validation period (Table 1), where data from 2005 to 2008 were used for calibration, and the rest were used for model validation.

Results

We used the Nash-Sutcliffe on hourly flow series (NS) and log transformed hourly flow series (NSlog) to assess the model performance.

Model results show that the calibration of TopNet at both two outlets in the Ruataniwha catchment (Figure 1(a)) are satisfactory; for both calibration and validation period, as indicated by NS and NSlog are over 0.8. Figure 1(b) corroborates this by showing the close match between hourly observed and modelled time series of flow.



(a) (b)

Figure 1: (a) Location of the the Ruataniwha catchment with the two outlets, (b) Hourly TopNet simulations at the two outlets.

Table 1: Flow site information and TopNet flow calibration results

Site	Area (km^2)	Calibration (2005-2008)		Validation (2001-2004, 2009-2012)	
		NS	NSlog	NS	NSlog
Waipawa at RDS/SH2	689	0.88	0.88	0.83	0.81
Tukituki at Tapairu Rd	762	0.88	0.88	0.88	0.86

This presentation will outline extended results and analysis based on both TopNet and TopNet-GW models. We will also assess the impact of climate change on the flow and hope it will be useful to support the water management in this catchment.

References

MfE, 2020. National Policy Statement for Freshwater Management 2020. Ministry for the Environment, document.

Yang, J., McMillan, H. and Zammit, C., 2017. Modeling surface water–groundwater interaction in New Zealand: Model development and application. Hydrological Processes, 31(4), pp.925-934

Yang, J., Griffiths, J., Zammit, C., 2019. National classification of surface–groundwater interaction using random forest machine learning technique. River Research and Applications. https://doi.org/10.1002/rra.3449.

Poster Abstracts

IN ORDER OF PRESENTERS LAST NAME

DEVELOPMENT OF AN EXTREME HYDROMETEOROLOGICAL EVENT INDEX

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Aims

Extreme weather events cause billions of dollars in damages globally, costing the lives of thousands and having devasting effects on fauna and flora. Anthropogenic climate change is frequently linked to both an increase in frequency and severity of these extreme weather events, alongside increased exposure from land use change. These factors contribute to critical areas of research on extreme weather events. Droughts and floods are two types of weather events whose effects are widely felt, with research remaining focused in regards to their impacts on society, development and termination mechanisms, and expected changes under various climate change scenarios.

Droughts and floods both result from significant perturbations to the water cycle. While precipitation clearly plays a significant role in floods and droughts, how this precipitaiton moves through the hydrological cycle to cause these events can be of more importance than simply the excess or deficiency in precipitaiton itself. Similarly, the relationship amongst variables within the hydrological cycle can play a significant role in the development of these events. As such, it is critical to identify how different parts of the atmospheric and terrestrial hydrological cycle interact to fully understand the controls of the causes and characteristics of these damaging extreme events.

The following work aims to develop new insights into these extreme events by investigating the relationship amongst variables within the hydrological cycle. Changes to event behaviour under a joint probability framework, and connections to wider atmospheric drivers and/or teleconnections, will be investigated by asking questions on the co-variability and joint probability of occurrence amongst selected climatic and hydrological variables. In particular, the role of land-atmosphere coupling during these extreme events will be examined.

Here these research questions are tackled by examining how both new and existing methods are able to capture multivariate relationship between different parts of the hydrological cycle associated with extreme event occurrence.

Method

The focus of this analysis was the 2012/2013 North Island drought. Data were obtained from version 2 of the Modern-Era Retrospective analysis for Research and Applications (MERRA-2). Precipitation, evapotranspiration and soil moisture were obtained for the period 1 January 1980 to 31 December 2013 for the New Zealand region. Data were aggregated to a monthly time step, before the time series was decomposed for seasonality using Loess regression. Exceedance probabilities for each variable were then defined based on the 20^{th} quantile of each grid cell, with evaporation quantiles inverted to match the other variable distributions (80th quantile became 20th quantile).

Frank copulas were used to derive the joint probability distribution of the variables, after goodness of fit tests were used to assess the performance of a range of copulas (Frank, Clayton and Gumbel). The following joint probabilities were therefore constructed: Precipitation-Soil Moisture, Precipitation-Evaporation and Evaporation-Soil Moisture.

A pair-copula was then constructed to obtain the multivariate distribution, which will be used to develop a multivariate drought index. Further multivariate analysis will be performed using kernal principal component analysis (kPCA) to construct another multivariate drought index. These indices will also be compared against more commonly used drought metrics such as the Standardised Precipitation Index (SPI), Standardised Precipitation-Evaporation Index (SPEI) and New Zealand Drought Index (NZDI).

Results

Severe drought conditions were experienced across the North Island and parts of the South Island during the summer of 2012/2013 (Porteous and Mullan, 2013). Onset of conditions are shown in November 2012 across three variables (precipitation, evaporation and soil moisture) (Fig. 1).

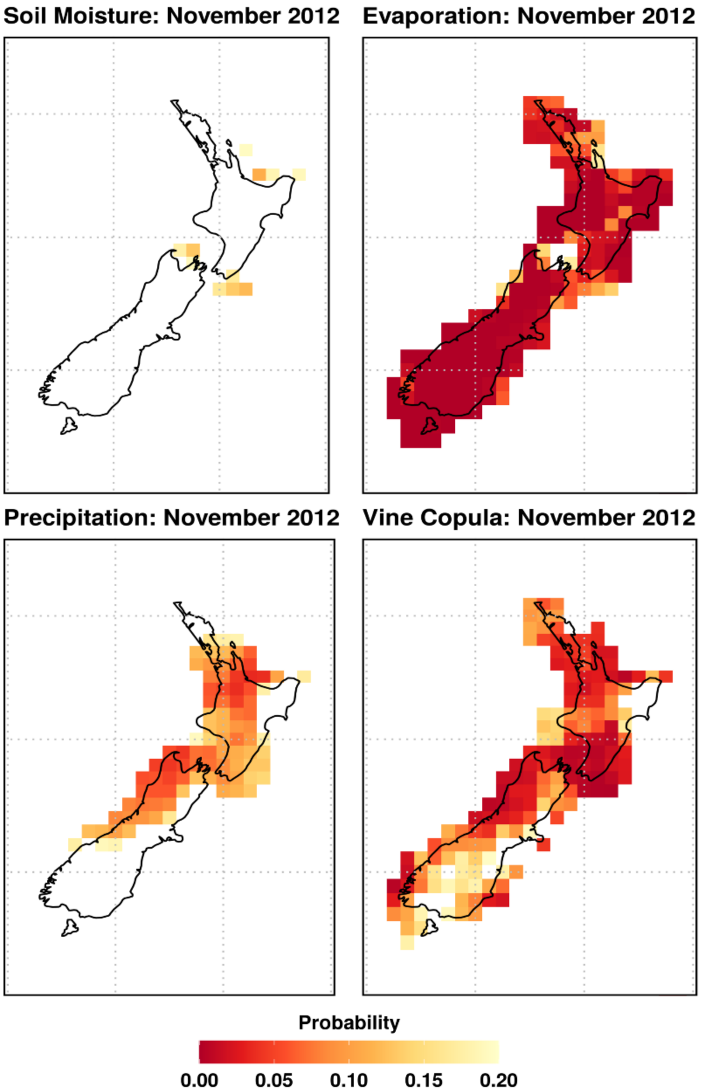

Figure 1: Precipitation, Evaporation, Soil Moisture and pair-copula during the lead up to the 2012/2013 summer drought (November 2012). Grid cells below the 20th quantile are highlighted. The pair-copula highlights the multivariate probability across the three variables (Precipitation, Evaporation and Soil Moisture).

Drought conditions are not yet manifested through soil moisture, with onset in this part of the hydrological cycle occurring in December. Evaporation reveals severe, widespread increases across the entire country, while precipitation highlights decreases to the lowest 10th quantile across the west coast of the North Island and top of the South Island (Fig. 1). Utilising the multivariate probabilities, the pair-copula (Vine Copula) reveals a spatial distribution similar to that of precipitation, with increased coverage across the north of the North Island and lower probability of occurrence across the Wellington and Waikato regions than shown by precipitation alone (Fig. 1). The results highlight the increased insight pair-copulas can provide when investigating extreme weather events, revealing more extreme conditions, earlier onset and wider spatial distribution than univariate analysis.

References

Porteous, A. and Mullan, B. (2013). The 2012-13 drought: an assessment and historical perspective. Ministry for Primary Industries. 57 pp. Wellington, New Zealand.

TURBIDITY IS A FLAWED METRIC – THAT SHOULD BE REPLACED BY LIGHT BEAM ATTENUATION

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Aims

- To raise awareness of the numerical 'ambiguity' of turbidity measurements, including those made with sensors complying with the ISO-7027 standard
- To outline the ramifications for the application of field and laboratory turbidity data and introduce a superior metric.

Background

Nephelometric turbidity, an index of cloudiness in water due to light scattering, is commonly measured in erosion-sediment management and water quality. Turbidity provides a valuable index of concentration of suspended particulate matter (SPM) which dominates light scattering in natural waters (e.g., Davies-Colley & Smith 2001). Turbidity also provides a useful index of water clarity, although the relationship is seldom quantified.

Turbidity sensors are traditionally calibrated (arbitrarily) to the intensely light-scattering material formazin. However, turbidity measurements in 'informal' units based on formazin (FNU, NTU, etc) cannot be converted to light scattering in proper (SI) units of scattering (m^{-1}) – or to visual clarity – because the optical properties of SPM vary widely – depending on particle size, shape and composition. This arbitrary and informal character of turbidity seems to have gone largely unrecognized by water quality practitioners for many decades.

Sediment researchers and managers routinely (locally) calibrate continuous turbidity records in rivers to SPM concentration. But turbidity data is often reported *uncalibrated* in water quality monitoring. This is problematic because different sensors have long been known to give numerically different outputs despite their identical calibration to formazin. For example, Rymszewicz et al. (2017) reported a 5-fold numerical range for twelve different turbidity sensors – and warned against use of turbidity in environmental standards.

Methods

With funding through Envirolink, we compared four different field-type (*in situ*) turbidity sensors plus two cuvette turbidity instruments (all compliant with the ISO-7027 standard specifying 90^{o} scattering of near infrared radiation) in a 170 litre well-mixed tank. Three optically diverse 'natural' suspensions were used for the comparative tests over a 100-fold range of concentration: river stormflow silt, kaolinite (layer clay), and pond water laden with green algae. Sensors were calibrated prior to the experiment with freshly-made formazin standards in order to put all the comparisons on the same basis. Tank samples were analysed for SPM concentration, and the beam attenuation coefficient (beam-c) was measured by c-star beam transmissometer operated in flow-through mode. Further methodological detail is given in the Envirolink report (Davies-Colley et al. 2021).

Results

Results of the tank experiments have been reported by Davies-Colley et al. (2021) and summarised in a previous conference presentation (Davies-Colley et al. 2020).

Briefly, we found that output of different ISO-7027-compliant turbidity sensors ranged about two-fold in magnitude for all three test materials (Figure 1 shows results for kaolinite). Our results demonstrate that even sensors meeting the ISO-7027 design standard are only roughly numerically comparable. The range in sensor response seems to reflect design differences interacting with light scattering characteristics of natural suspensoids – which contrast optically with formazin.

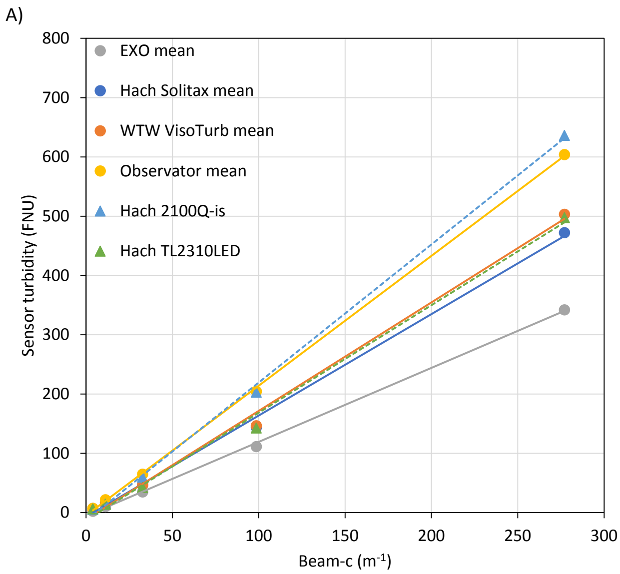

Figure 1. Formazin-standardised response of (ISO 7027-compliant) turbidity sensors in kaolinite at different concentrations in a 170 litre tank. The beam attenuation coefficient (beam-c) is used as the reference optical concentration. (Field *in situ* sensors – dots with solid lines; cuvette instruments – triangles and dashed lines.)

Discussion and ramifications

The weak numerical comparability of turbidity sensors, even those compliant with the ISO-7027 design standard, has some important ramifications. Clearly turbidity is merely a *relative* measure of light scattering that usefully indicates SPM concentration or water clarity *with suitable local calibration.* But turbidity should not be treated as if it were an absolute quantity; that is reporting of turbidity in FNU, NTU or other 'informal' units, should be avoided. Further ramifications include:

- Turbidity is unsuitable for environmental standards, and
- Studies of tolerance of aquatic organisms to SPM should not use turbidity as a metric.

Fortunately, laboratory turbidity measurement is easily replaced by absolute measurement of the light beam attenuation coefficient (beam-c = total light scattering plus light absorption) – the reference quantity in our experiments (Figure 1). Beam-c, measured by beam transmissometry in SI units (m^{-1}), is accurately convertible to visual clarity (Zanevald & Pegau 2003) which, in marked contrast to turbidity, gives the metric immediate meaning for policy-makers and lay people.

Beam transmissometers are not very practical for continuous monitoring in the field, at least not in rivers, because: i) their collimated beams are extremely vulnerable to window fouling, and ii) they have insufficient dynamic range (only 60-fold compared to several 100-fold for nephelometers). However, it is entirely practical to ***locally*** calibrate field turbidity sensors to beam-c measured on laboratory water samples. We recommend abandoning turbidity as a water quality metric and replacing it by beam-c measured in the laboratory or, equivalently, field measurement of visual clarity.

References

Davies-Colley RJ, Heubeck S, Ovenden R, Vincent A, Hughes AO 2021. Comparison of the responses of ISO-7027-compliant turbidity sensors commonly used in NZ. NIWA NIWA Report 61 p.

Davies-Colley RJ, Smith DG 2001. Turbidity, suspended sediment, and water clarity: A review. Journal of the American Water Resources Association 37: 1085-1101.

Davies-Colley RJ, Vincent A, Hughes A, Heubeck S 2020. NEPHELOMETRIC TURBIDITY APPLICATIONS IN WATER QUALITY – RAMIFICATIONS OF POOR SENSOR COMPARABILITY. Weathering the Storm conference NZHS/Rivers/NZFSS. Invercargill,

Rymszewicz A, O'Sullivan JJ, Bruen M, Turner JN, Lawler DM, Conroy E, Kelly-Quinn M 2017. Measurement differences between turbidity instruments, and their implications for suspended sediment concentration and load calculations: A sensor inter-comparison study. Journal of Environmental Management 199: 99-108.

Zanevald JRV, Pegau WS 2003. Robust underwater visibility parameter. Optics express 11: 2997-3009.

CLIMATE-SHOCK RESILIENCE AND ADAPTATION FOR NORTH CANTERBURY FARMS

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[2] Water Strategies
[3] Bodeker Scientific
[4] University of Canterbury

Aims

Farming is vulnerable to financial shocks associated with extreme weather events. The likelihood of multiple extreme events occurring within a compressed period is increasing but the compounding impact of increased event frequencies on the primary sector under current climate conditions has not been investigated.

This poster summarises the methodology and findings of the first year of work on our two-year Sustainable Land Management and Climate Change (SLMACC) research project: a North Canterbury case study which aims to better understand the risk and impact of adverse weather and water availability sequences under current climate conditions.

We analysed a range of possible weather and river flow-based water take restriction sequences (referred to as storylines) to understand the cumulative exposure of different farming systems to clusters of adverse events. We extended the features of an open source pasture growth model (BASGRA_NZ_PY) to quantify the impacts and therefore the risk of our storylines.

Method

To produce and assess the impacts of our climate storylines we:

- Engaged with local North Canterbury farmers to help develop our understanding and definitions of adverse events.
- Developed a classification scheme to simplify the myriad climatic conditions into sets of temperature states (Cold – Average – Hot), precipitation states (Wet – Average – Dry) and average restriction states (0-100% restrictions) for each month.
- Developed tools to produce weather and irrigation restriction time series for a given storyline:
    - Stochastic Weather Generator (SWG).
    - Stochastic Irrigation Restriction Generator (SIRG).
- Developed a tool to assess the probability of any given storyline.
    - Infinite Improbability Drive (IID).
- Extend and bias correct a pasture growth model (BASGRA_NZ_PY).
- Developed a suite of climatic storylines.
- Assessed the impact on farm pasture production for each storyline on multiple farm systems.

Results

Here we present the process and assumptions used to develop the tools required for this analysis; the solutions to a number of problems we encountered; and results. Our analysis of a suite of storylines has allowed us to estimate the probability of, and the exceedance probability of, pasture production yields for a number of different North Canterbury farms, understand the correlation between production on different farm systems and understand the key drivers of reduced production for each farm system. These results will be used in economic investigations and to help identify areas where additional resilience can be built into the North Canterbury farm systems.

Farm and water allocation policy mitigations and adaptations will be explored in the next phase of work to identify how farm and water allocation systems can be designed to reduce risk and build resilience to climate related shock-events.

TOWARD EVALUATION OF ENERGY STORAGE CAPACITY

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Introduction

As part of the NZ Battery Project, Cabinet has approved funding to research pumped hydro against other possible energy storage solutions to New Zealand's dry year electricity problem (Ministry of Business, Innovation and Employment 2021). Pumped storage schemes majorly serve to offset hourly variations in power demand in conjunction with constant fossil fuel stations. Such systems have not been needed in New Zealand because our large hydro power component enables rapid changes in power output.

However, pumped storage on the seasonal scale would be a definite advantage here because climate change brings uncertainty over whether existing hydro storage capacity can maintain power through a dry year. Another important factor is the move toward increased wind power is being constrained presently by limited hydro storage capacity.

Furthermore, South Island power generation is presently wasteful of water. The waste factor is that high South Island Lake levels in summer can lead to water loss for all downstream users through hydro spill in the event of significant flood inflows to the lakes. Another factor is that potentially useful water is held back during spring and summer in the South Island hydro lakes to provide necessary additional winter power; for example, the mean January discharge in the lower Waitaki River is now 200 m^3s^{-1} less than pre-hydro times, meaning reduced water availability for summer irrigation and recreation. There is also an environmental component because the current significant seasonal fluctuation of lake water levels leads to shoreline erosion in some of our most scenic hydro lakes like Pukaki, Tekapo, and Hawea; and create dust in areas such as Hawea.

A single large, pumped storage scheme could operate so that South Island hydro lake inflows in spring and summer would no longer be held back for winter generation, but instead released downstream for power generation and other uses. The surplus power would be used to pump water into a high reservoir, thus shifting energy storage away from the hydro lakes. In winter, much of the power demand would then be contributed from pumped storage as water is shifted to a lower reservoir. Simulations indicate hydro lake operation is best at near-constant water levels kept around the mid-range of the present seasonal cycle. This has the advantage of reduced hydro spill losses and reduced flood risk with respect to both rivers and lake townships. There is also a return to more natural lake shorelines and the creation of equilibrium lake beaches for the main hydro lakes.

Results

The potential New Zealand seasonal pumped storage scheme have been previously investigated, with the upper reservoir being an expansion of Lake Onslow in Central Otago (Bardsley 2005). The energy storage capacity of the upper reservoir is twice the national hydro energy storage capacity. Based on the simulation model between 1998 – 2012, showed the maximum energy storage capacity is 7,000 GWh. While the current research (see Figure 1), through a statistical analysis between 1992 - 2020 showed a maximum national energy storage estimate of 8,000 GWh with a chance of use of the maximum storage capacity is 3.4%. This study will therefore focus on the optimum required energy storage capacity. The major observation of Figure 1A showed the country faced a sequence of dry years from 2004 – 2009, while a sequence of wet years occurred from 1993- 96, and 2014 -19.

Simulations indicate the Onslow scheme would operate in excess of 100% energy efficiency because of the extra power generated from existing hydro stations from reduced spill loss. There are multiple advantages of this scheme, such as: solving the dry year issue, easily support wind power developments, operate the reservoir in mid-range, such as Lake's; Tekapo, Pukaki and Taupo, increase irrigation within Waitaki scheme in summer months, etcetera.

Based on research the only viable option based on large energy storage capacity is the Onslow scheme, which can be supported by smaller schemes such as another Pumped Hydro Storage and Advanced Rail Energy Storage (ARES).

Two Options of the proposed Onslow pumped storage configuration, has been discussed in previous research (Majeed 2019), as shown in the schematic (Figure 2). This research will also focus on the economic feasibility of these options. Option A is a 24 km tunnel connecting Lake Roxburgh at 120 masl to the existing Lake Onslow at 695 masl. Option B is a 13.5 km tunnel connecting a proposed Lake Teviot at 80 masl to an expanded Lake Onslow at 695 masl, by digging a 5.5 km open channel.

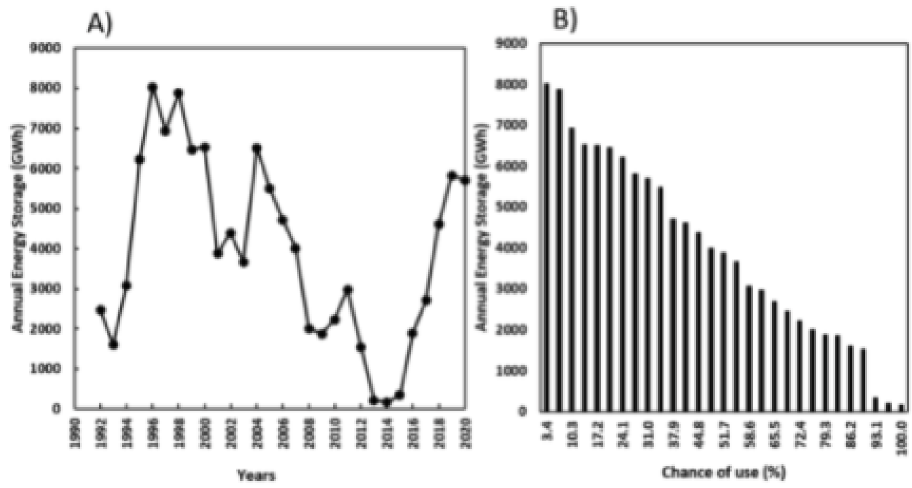

Figure 1: Anual Energy Storage: A) years; B) chance of use (%)

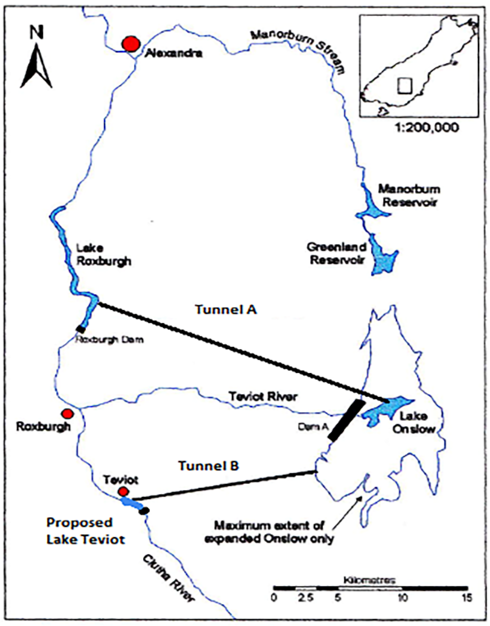

Figure 2: Onslow Schematic

References

Majeed, M. K. 2019, Evaluating the potential for a multi-use seasonal pumped storage scheme in New Zealand's South Island. PhD. Thesis, University of Waikato, Hamilton, New Zealand.

Bardsley, W. E. 2005, Note on the pumped storage potential of the Onslow-Manorburn depression, New Zealand. Journal of Hydrology New Zealand, v.44 p.131-135.

MINISTRY OF BUSINESS, INNOVATION AND EMPLOYMENT, 2021-last update, NZ Battery Project. Available: https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/low-emissions-economy/nz-battery/.

TOO MANY ROCKS: MODELLING THE INFLUENCE OF RIVER CONFINEMENT ON AGGRADATION IN THE WAIHO RIVER

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[1] NIWA

Aims

Flooding of the Waiho river is a well-known problem with several recent highly publicized flood events damaging the Mueller Hotel and SH 6 bridge. The river is currently confined with stop banks, limiting the riverbed to ~1/3 the historic area, in an attempt to protect local infrastructure from the damaging effects of flooding. However, sediment deposition in the braided section of the Waiho river, downstream of the SH 6 bridge, have resulted in riverbed elevation increasing at ~30 cm per year for several decades (Beagley et al., 2020) necessitating frequent increases in stop bank heights to maintain flood protection.

Traditional river engineering theory suggests that reducing river width with stop banks should result in increased flow velocities and increased sediment transport, thereby reducing bed aggradation. However, confinement of the Waiho river has been correlated with increased rates of bed aggradation, exacerbating flood risk. Traditional river engineering theory estimates bedload sediment transport through cross-sections by applying one-dimensional hydraulics over a static riverbed. In braided rivers such as the Waiho, two-dimensional morphological evolution of the riverbed occurs as transient morphological events that alter flow patterns and rapidly mobilize sediment, resulting in bedload pulses. The simplified one-dimensional theory fails to capture these transient morphological events that are a key driver of sediment transport in braided rivers. Here, we explore the impact of river confinement on braiding processes and sediment transport and seek to identify an optimum width of the Waiho to maximize these events and increase sediment transport to reduce bed aggradation.

Method

The importance of transient morphological events on sediment movement in the Waiho river is investigated with a two-dimensional morphodynamic numerical model developed in Delft3D. The domain of the model stretches from the SH 6 bridge near Franz Josef, downstream to the loop moraine (Figure 1). The morphodynamic model was developed with similar slope, grain size distribution, and dimensions as the Waiho River. Starting with a planar bed, the model was run with fixed flow (~mean annual flood) to generate an initial morphology. This developed morphology was compared to LiDAR data collected in 2016. Tuning of flow dependent sediment input at the upstream boundary was achieved by comparing actual river aggradation observed between LiDAR surveys in 2016 and 2019 and model predicted aggradation.

The importance of river confinement on transient morphological events and sediment transport in the Waiho river is explored with the calibrated model by systematically varying modelled river width and analysing the effect on downstream sediment transport. Additionally, work is ongoing to develop algorithms to isolate the importance of transient morphological events from tradition sediment transport.

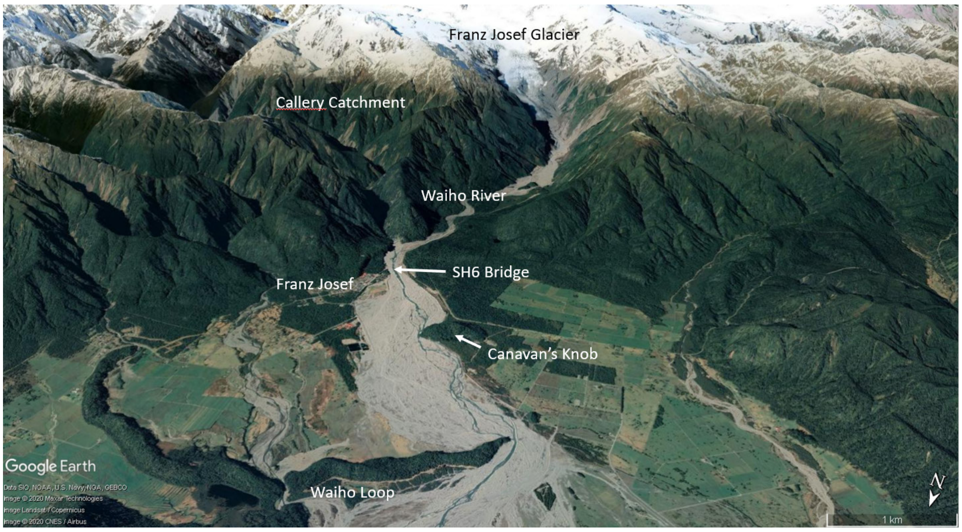

Figure 1: Waiho river with features identified. Model domain extends from the SH 6 bridge to the Waiho Loop.

Results

The morphodynamic model of the Waiho river has been able to reasonably reproduce metrics observed in static bed models developed with LiDAR data. Morphodynamic model validation has included braiding index across a range of flows, general aggradation patterns, and water depth distribution at mean annual flood (~1350 m^3/s). Comparison of the bed elevation of the morphodynamics model (Figure 2A) and LiDAR based model (Figure 2B) are shown for qualitative assessment of the model fit to observations of river morphology and to demonstrate the capacity of the model to reproduce aggradation patterns.

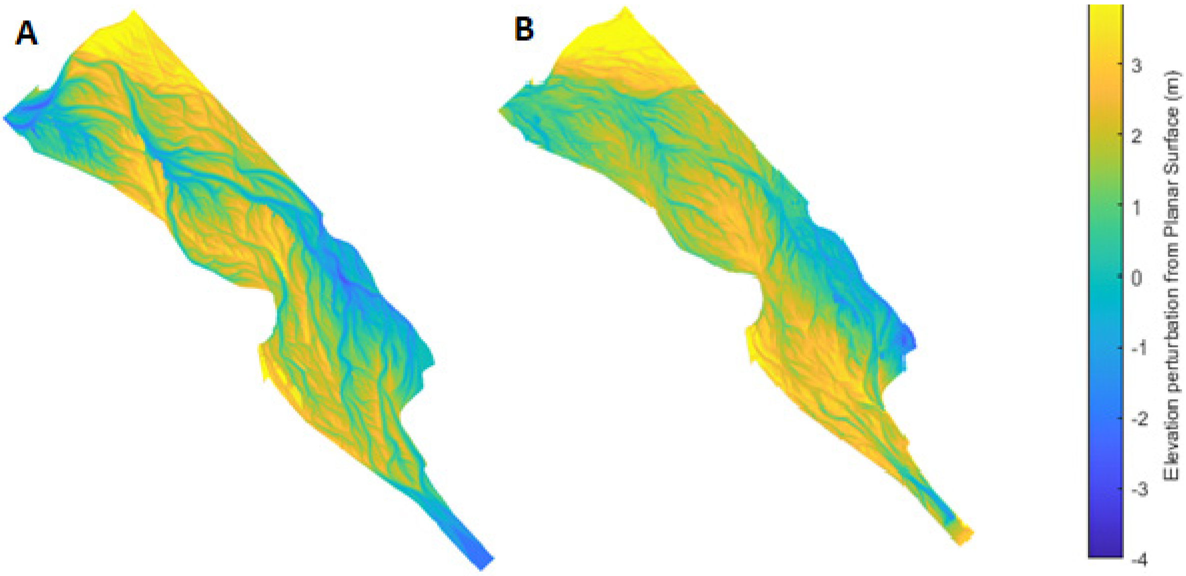

Figure 2: Deviation of bed elevation from a planar surface for (A) morphodynamic modeal developed from a planar bed initial condition and (B) LiDAR observations collected in 2016.

Work is underway to use the well calibrated model of the Waiho to investigate the effect of river confinement and stop bank arrangement on sediment transport.

References

Beagley, R., T. Davies, and B. Eaton (2020), Past, present and future behaviour of the Waiho River, Westland, New Zealand: a new perspective, *Journal of Hydrology, 59*(1), 41-61.

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SPATIO-TEMPORAL DISTRIBUTION OF FLOOD EVENT TYPES IN NEW ZEALAND

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[3] NIWA

Aims

Flood events can have very different generating processes such as high intensity rainfall, long-duration rainfall or snowmelt. The objective of this study are

1. to classify flood events across New Zealand and

2. to investigate the changes of the frequency of occurrence of flood event types, their spatial patterns and the consequences for estimating extreme events.

Methods

We apply a causative classification of flood events with statistical analyses of flood peaks for the classification of floods into different categories (Fischer et al., 2019). A peak-over-threshold (POT) approach is used to specify single flood events based on an automated flood event separation. These events are classified into groups according to the flood type (types mostly generated by precipitation and types mostly generated by snowmelt) based on their hydrographs and the peak-volume relationship, the so-called flood timescale (Gaál et al., 2012). The frequencies of these types are estimated. To estimate the impact of changing frequencies, the annual flood statistic is synthesised by a statistical mixing model to validate the representativeness of the probabilities, derived from the analyses of time series of floods from several gauges within one river basin. Data from 482 gauged catchments across New Zealand were used. The coherence between flood types and catchment characteristics such as topography and geology was analysed in order to obtain the probability of occurrence of each flood type in different regions.

Results

Figure 1 shows the spatial distribution of the flood type that dominates the largest floods in New Zealand. Type 1 refers to floods with high peak but small volume associated with heavy rainfall, flood type 2 refers to flood events with moderate peak and moderate volume associated with 3-5 days of moderate rainfall and Type 3 refers to flood events with small peak but high volume associated with long-duration rainfall or snowmelt.

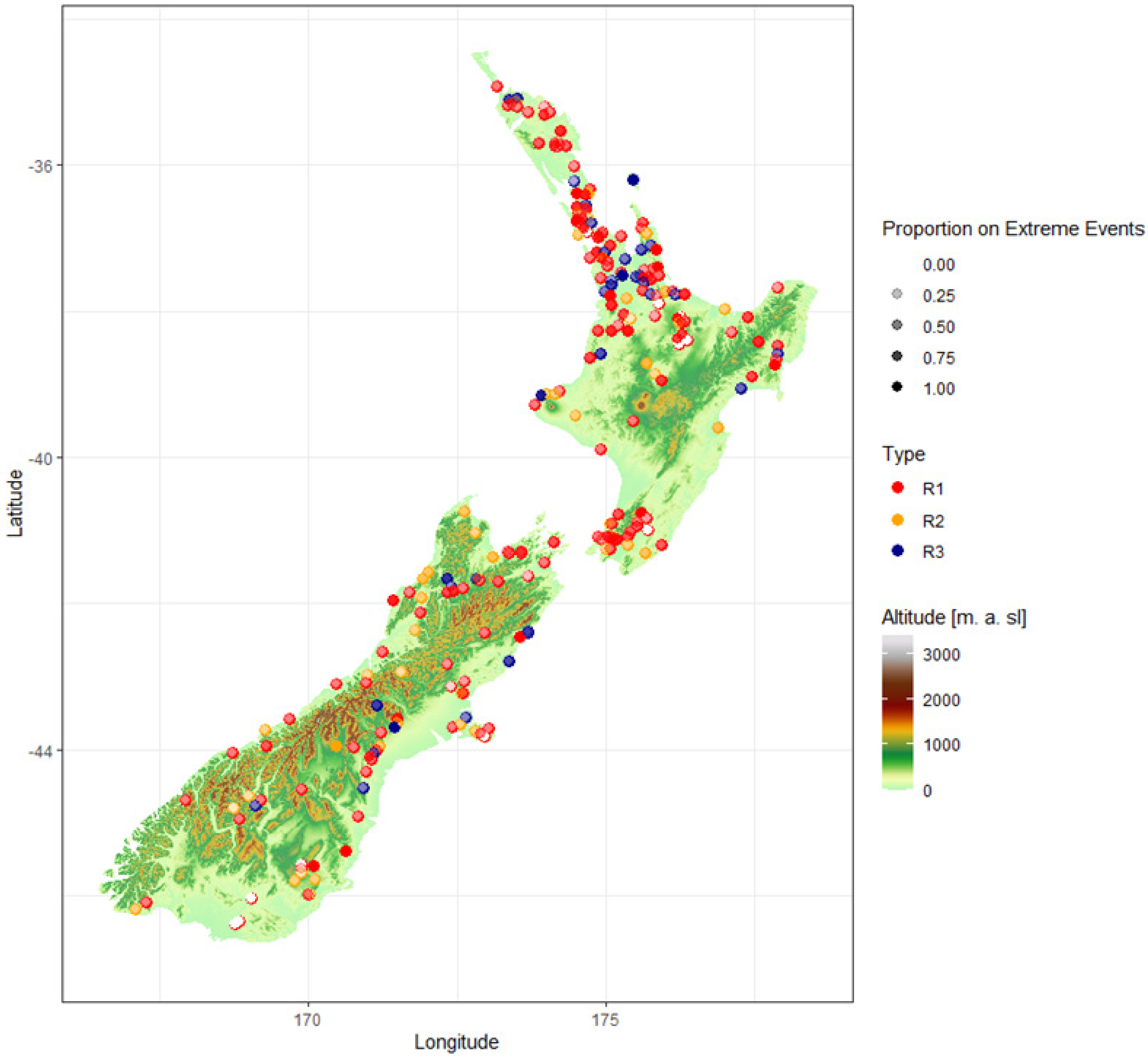

Figure 1. Spatial distribution of flood types identified across New Zealand.

References

Fischer, S., Schumann, A. and Bühler, P. 2019. Timescale-based flood typing to estimate temporal changes in flood frequencies, *Hydrological Sciences Journal*, 64(15), 1867-1892.

Gaál, L., Szolgay, J., Kohnová, S., Parajka, J., Merz, R., Viglione, A. and Blöschl, G. 2012. Flood timescales: understanding the interplay of climate and catchment processes through comparative hydrology. *Water Resources Research*, 48 (1), 1-21.

WAIMAKARIRI DEEP MONITORING WELL

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Aims

Drilling and installation of a deep well was carried out near the Waimakariri river to;

- assess potential deep groundwater flow from the Waimakariri zone to the Christchurch aquifers in the area of McLeans Island,
- provide a monitoring point for water quality and groundater levels in the deep aquifer upstream of the Christchurch aquifers, an area where we have limited data, and
- provide information on the deeper geological profile of the Waimakariri fan at this location to help support and better define geophysical interpretation of the area. Existing drilling information >150 m depth within the Waimakariri fan is very sparse.

Method

The bore location was selected to intersect potential deep flow paths from north of the Waimakariri river towards the Christchurch aquifer system. The general area of this potential flow path was identified in previous groundwater age studies *(Stewart et al 2002)* and numerical modelling**.** The precise location was selected near existing monitoring wells installed between 50 and 150 mbgl to allow comparison with data from these sites. The target installation depth for the monitoring well was the depth at which the downward hydraulic gradient flattened out or in gravels above any thick layers of low permeabiliy strata encountered. Previous geophysical studies suggested the base of quaternary sediment would be encountered at approximately 250 mbgl *(Jongens 2011)*.

Results

Morning water level measurements made during drilling showed the downward hydraulic gradient flattened off from approximately 190 m depth. Clays were present from 294 m depth and most likely correspond to a reflective surface seen in seismic survey made near the site. Drilling continued to 324 m to confirm the clay deposit was significantly thick. The monitoring well was completed with screens at 290 to 292 metres below ground surface, which is within the gravels immediately above the clay. Groundwater quality samples were collected in the final stages of well development and the well was added to the regional groundwater monitoring network.

References

Stewart, M. Trompetter, V. van der Raaij, R. April 2002. Age and source of Canterbury plains groundwater. Environment Canterbury report No. U02/30, prepared by GNS

Jongens, R. May 2011. Contours for the base Quaternary sediments under the Canterbury plains between the Ashley and Rakaia rivers. GNS Science consultancy report 2011/132

ESTIMATING SECTION 14(3)(B) GROUNDWATER TAKES IN AUCKLAND

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[2]Auckland Council

The National Policy Statement for Freshwater Management requires Councils to set and apply limits and to establish and operate a freshwater accounting system. The difficulty is that not all allocation can be quantified. Section 14(3)(b) of the the Resource Management Act (RMA) allows for water to be taken for reasonable domestic and stock drinking water use, provided that the use does not, or is not likely to have, an adverse effect on the environment. These "Section 14(3)(b)" takes can be difficult to quantify, as councils have not historically required the measurement, recording and reporting of the take.

In some areas, Section 14(3)(b) takes could represent a substantial proportion of the total water abstraction. For example, Waikato Regional Council estimated that Section 14(3)(b) takes could represent as much as 20% of the total surface water take in the Region, illustrating the magnitude of Section 14(3)(b) takes relative to consented takes in some areas.

This paper describes a project for Auckland Council, which aimed to evaluate and model water use that had not been consented or allowed under permitted activity rules, known as Section 14(3)(b) takes.

The project involved

- Identifying bores that could be Section 14(3)(b) bores from the Council's database. Where these were known, they could be attributed to individual properties. Where there was no record of a bore, it was recognised that, in many cases, there would still be a bore, if there were likely to be stock on the land.
- Estimating domestic and stock water needs for each property. This reuqired an estimate of stock numbers for each. Moving away from a previous approach which relied on a subscription based model, the new model adopts a open source approach that utlises publicly available information. For this project, stock numbers were estimated from StatsNZ data and "Land Cover Database (LCDB). It was recognised that the numbers will not be correct on a property-by-property basis, but they should provide a reasonable estimate over larger areas.
- Assiging an aquifer to each bore or property, allowing for the fact that, in many parts of the Region, there may be shallow and deep aquifers.
- Identifying properties based on ratings data that were likely to be used for agricultural activities, and excluding non-agricultural properties.
- Summarising results based on Aquifer Management Area.

The model outputs enable the Council to include potential Section 14(3)(b) takes when assessing the allocation status of aquifers. However, it was recognised that the input datasets were static and contain inherent uncertaintly. Regular review of the model inputs was considered important for ongoing use of the model. On-the-ground surveys of actual 14(3)(b) takes to validate the model results is essential for the accounting process, particularly for any aqufiers shown to be fully or over-allocated.

DEALING WITH CHANGING BEST-PRACTICE WITHIN A LONG-TERM MONITORING PROGRAMME: COMPARISON OF AMMONIA-NITROGEN MEASUREMENTS BETWEEN UNPRESERVED AND ACID-SULFURIC PRESERVED GROUNDWATER SAMPLES

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[1] GNS Science, New Zealand

Aims

In 2016, as part of developing the National Environmental Monitoring Standards for the collection of groundwater quality samples, operations of the National Groundwater Monitoring Programme (NGMP) were reviewed using the Standard Methods of Rice et al. (2012). The only operational change resulting from this review was switch from an unpreserved filtered bottle collection for the analysis of ammonia-nitrogen to the use of a sulfuric acid (H_2SO_4) preserved filter bottle. This acid is used as a preservative for collecting water samples as it acts as bacterial inhibitor and prevents salt formation with organic bases. To investigate the impact of this change on measured ammonia-nitrogen concentrations, duplicate samples were collected for ammonia-nitrogen over three sampling rounds. We present the duplicate sampling results and possible difference in measurements. It will inform on future NGMP operations with consideration for cost-effectiveness.

Method

Duplicate groundwater samples were collected by regional council staff over the NGMP network between May and December 2016. A selection of these duplicate samples was analysed, selected to encompass a range of ammonia-nitrogen concentrations (<0.003 to 13.7 mg/L). In total, 255 duplicate samples were analysed at the New Zealand Geothermal Analytical (NZGAL) laboratory for ammonia-nitrogen, using a flow injection analyser (APHA 4500-NH3-H method; Baird et al. 2017).

The dataset was first reviewed as part of the Quality Assurance programme to identify non valid analyses. Subsequently, the cleaned dataset was grouped under different conditions for comparison purposes (e.g.: pair data ammonia-nitrogen; pair data, valid arrival temperature and valid sampling holding time). The paired datasets were analysed by graphical examination and tested for significant difference using the non-parametric sign ranked text (Helsel et al. 2020).

Results

No statistical difference was observed between ammonia-nitrogen concentrations measured on unpreserved samples (2006-2016 sampling protocol) and the sulfuric-acid preserved samples (2016 onwards protocol) at NGMP sites. Based on this result, it is recommended to revert sampling to unpreserved samples, with consideration for cost-effectiveness in both the field and the laboratories for NGMP.

The design, methodology and statistical tests used to investigate the impact of change in sample preservation here are transferable to other operational changes and will be made available publicly (Santamaria and Moreau 2021).

References

Baird, R., Eaton, A., Rice, E. W. (eds). 2017. Standard methods for the examination of water and wastewater. 23rd ed. Washington, DC: American Public Health Association. 1391 p.

Helsel, D., Archfield, S., Gilroy, E., Ryberg, K., Hirsch, R. and Helsel, D. 2020. Statistical methods in water resources. Reston, VA: U.S. Geological Survey. 458 p.

Rice, E., Baird R. B. Eaton A. D., Clesceri L. S. (eds). 2012. Standard methods for the examination of water and wastewater. 22nd ed. Washington, D.C: American Public Health Association. 1496 p.

Santamaria Cerrutti, M.E.; Moreau, M. 2021. Comparison of ammonia-nitrogen measurements between unpreserved and acid-sulfuric preserved groundwater samples. GNS Science: in prep. (GNS Science Report, 2021/27)

STRATEGIC PLANNING FOR DYNAMIC WATER SUPPLY SYSTEM

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Water utility organisations have to deal with both short term and long term issues affecting supply and demand. In the short term they have to deal with changes in day-to-day supply caused by weather dependent demands, planned outages for scheduled maintenance, and emergency situations. Over the longer term, there are issues related to gradual changes in demand, both temporal and spatial, changes in supply caused potential changes to the climate, the introduction of new sources of supply and the discontinuation of old facilities. Some of the long term changes are multi-faceted. For example, changes consequent on climate change may involve allowing for increased demand because of higher temperatures, changes in supply availability where sea-level rise impacts on aquifers, and changes in the seasonal distribution of rainfall affecting the availability of river sources.

Wellington Water Ltd has a dynamic water supply system that relies heavily on water drawn from three rivers and an aquifer. This presents unique challenges when assessing the long term ability of the system to withstand drought or the operational risk of supply shortfall during summer. Wellington Water uses a strategic planning tool called the Sustainable Yield Model (SYM) to support this decision making. The tool incorporates the entire water supply system including resource consent and infrastructure constraints

The SYM is currently being comprehensively upgraded through a project with the National Institute of Water and Atmospheric Research (NIWA). The purpose of the upgrade is to enable significant strategic challenges to be addressed. These include preparing for proposed water allocation changes that will progressively reduce water available over the next 50 years, disaggregating the demand models into sectoral components to improve assessment of demand reduction scenarios, downscaling IPCC climate change datasets consistent with AR6, addition of wastewater treatment plants to the network to enable assessment of integrated water resources scenarios, automation improvements to enable robust decision making and support preparation of an adaptive plan for the next investment cycle. This paper outlines how the SYM is being improved for purpose of strategic and operational planning at Wellington Water.

STREAMFLOW RECESSION CURVES IN GAUGES AND UNGAUGED BASIN

Singh, S, K.,[1] Griffiths, G, A.,[1]
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Low flow statistics are used for various activities such as planning water supply, hydropower, and irrigation systems; designing cooling plant facilities, treatment plants and sanitary landfills; determining waste-load allocations, and making decisions regarding interbasin transfers of water and allowable basin withdrawals. In addition, low streamflow events are often critical periods for aquatic habitats due to potentially low dissolved oxygen concentrations and/or high pollutant concentrations. Low flows are also important for water quality management where they provide critical dilution of nonpoint source and point source pollution discharges during dry periods; and in water quantity management where low flows greatly influence water use policy.

Prediction of the time for perennial outflow from a natural basin to recede from the mean to some low flow value is an important practical and difficult problem in water resource management. This study aims to gain further understanding of this complex problem and to put forward new practical and accurate methods for predicting flow recessions between nominated limits in both gauged and ungauged basins. For a gauged basin a three parameter recession model is employed to estimate the recession time, from day-to-day, as flow recedes from mean flow using previously measured site recession curves and a library of recession curve shapes generated by the ROPE algorithm. The model is tested using data from ten New Zealand basins which are diverse in low flow hydrological behavior. Another model is also developed to predict recession time in an ungauged basin using catchment characteristics and information from master recession curves in a suite of ten reference basins geologically and hydrologically similar to the ungauged basin, as assessed by a Random Forest Model. Model performance is robust and accurate and the models can be applied elsewhere with confidence although further testing is desirable.

SPATIAL AND TEMPORAL ANALYSIS OF WELL DEPTHS OVER TIME IN CANTERBURY, NEW ZEALAND

Tregurtha, J.[1]
[1] Environment Canterbury

Aims

We wanted to see if there were any spatial and/or temporal patterns that could be seen in well depths over time. This would give us a better understanding of how groundwater use has developed and the pressures on groundwater resources in the region.

Method

The Environment Canterbury Wells Database contains information about more than 54,000 wells in the Canterbury region. All wells that had adequate information in the database about well depth and date drilled were analysed by decade. ArcGIS Pro was used to map decadal well depth for all wells, and for sub-groups of irrigation and domestic wells.

Results

The mapping of wells by depth and decade allowed many interesting patterns to be seen, such as a rapid increase in well numbers in the Ashburton District in the 2000s when large scale conversion from sheep and beef farming to dairy farming land use occurred (See Figure 1). This required new sources of water for irrigation (Engelbrecht, 2005). As drilling technology improved, wells were able to access the deeper water tables further inland on the Canterbury Plains. The spatial analysis shows this depth gradient both spatially and temporally. Increased abstraction and climate variability can cause large fluctuations in groundwater levels in some parts of the Canterbury Plains, making shallower wells less reliable, and further encouraging well owners to drill deeper.

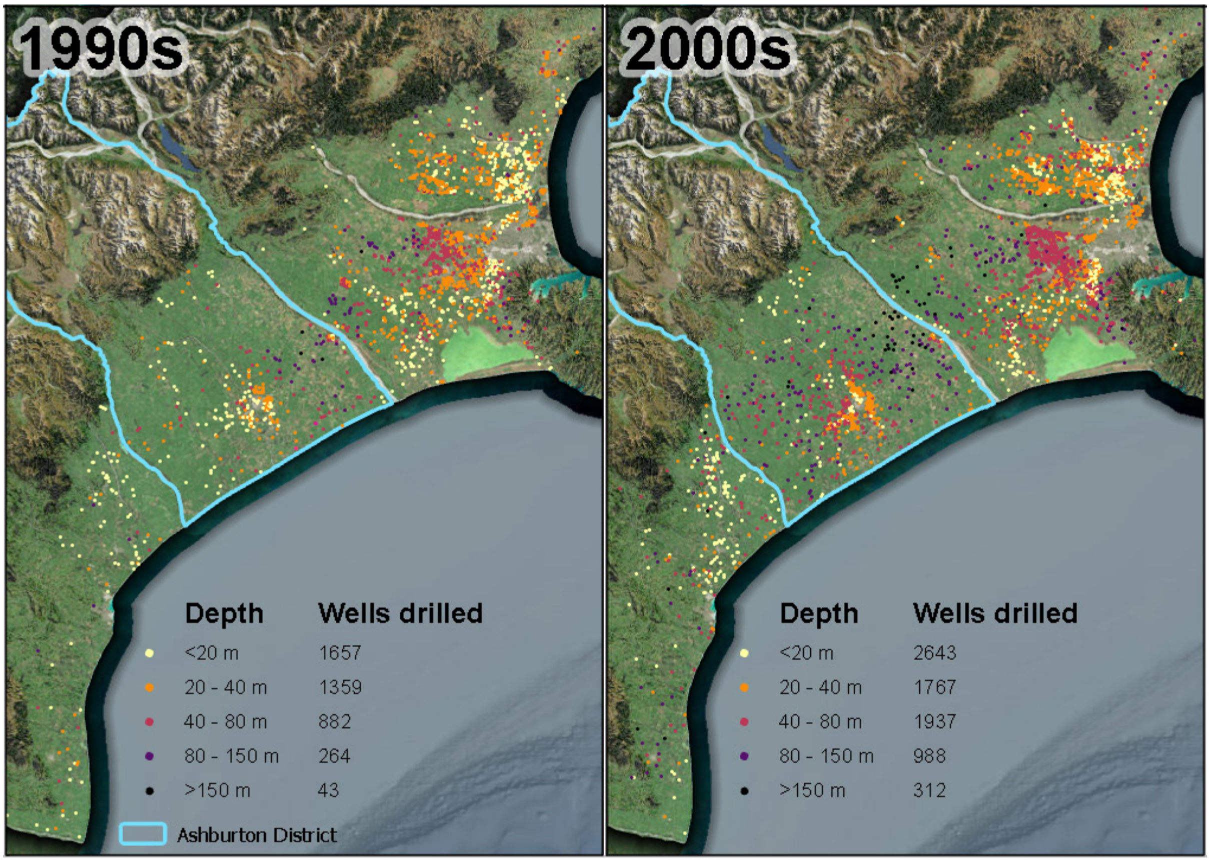

Figure 1: Comparison of Well Numbers in the Ashburton District in the 1990s and 2000s. Note the numbers refer to the whole region, not just Ashburton.

Numbers of irrigation wells increased across the plains in the early 2000s, and decreased from 2010, which may be related to groundwater allocation limits coming into force from 2004 slowing development of the groundwater resource. Domestic well numbers also increased from the early 2000s but were clustered mainly into areas around Christchurch and Ashburton, as self-supplied lifestyle blocks became more common.

Fewer shallow irrigation wells have been drilled in the last decade. Irrigation wells often have to be drilled deeper to ensure adequate supply for the higher pumping rates and volumes required. Recent low water tables in many areas of Canterbury have added to the necessity to drill deep. Another driver behind the move to deeper irrigation wells is the potential to avoid stream depletion effects and resulting restrictions on water take consents. Wells for private domestic use do not show the same pattern, but instead have a more even spread across the range of well depths that we see. Small domestic takes are usually a permitted activity, unaffected by any stream depletion restrictions. This means there isn't as much incentive to drill deeper as there is for the larger takes. Shallow wells are also cheaper for individual households to drill, so are often the preferred option for domestic wells. However, shallow wells are more vulnerable to contamination, which is a concern for safe drinking water supply. This has resulted in some domestic wells being deepened over time to improve security of supply.

References

Engelbrecht, B., 2005. *Land Use History - Ashburton District Plains*

EVALUATING THE IMPACT OF EROSION PROCESS ON SEDIMENT RELATED WATER QUALITY

Vale, S.S.,[1] Smith, H.G.,[1] Dymond, J.D.,[1] Davies-Colley, R.J.,[2] Hughes, A.,[2] Phillips, C.J.[1]
[1] Manaaki Whenua – Landcare Research
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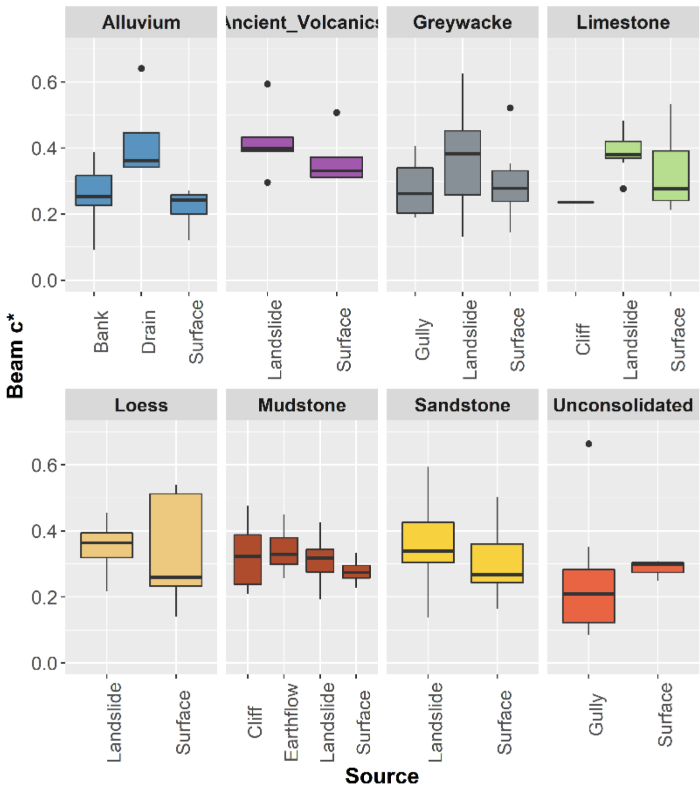
Aims

Accelerated erosion of fine sediment and its delivery to river channels pose a significant issue for freshwater quality. At present, a range of modelling, monitoring, and measurement techniques are employed to inform spatial and temporal understanding of erosion processes and guide the targeting of erosion mitigation strategies. These approaches focus largely on the mass or quantity of sediment, while quality aspects, notably particle size and its impact on water quality, are often not evaluated. This is problematic, as the attributes of sediment that affect environmental behavior and water quality vary across catchments, geological parent materials, and erosion processes. Here, we aim to evaluate the impact of different erosion processes and their impact sediment related water quality across a range of New Zealand landscapes.

Methods

Sediment sources were sampled *in situ* to represent a range of parent materials and erosion processes across four New Zealand catchments. Erosion processes included, surficial, earthflow, cliff, channel bank, shallow landslide, and gully erosion, while parent materials included alluvium, greywacke, limestone, loess, mudstone, sandstone, ancient volcanics and unconsolidated sandstone/siltstone. Samples collected from these sources were analysed for a set of sediment quality attributes including particle size represented by D10, D50, and D90 in combination with Particulate Organic Carbon (POC), Particulate Organic Nitrogen (PON), Inorganic Suspended Solids (Inorg SS), Volatile Suspended Solids (VSS), Suspended Solids (SS), and light beam attenuation (Beam c) – which controls visual clarity of waters (Davies-Colley and Nagels, 2008).



These quality attributes and their relationship to spatial data on parent material and Erosion Terrains (Dymond et al., 2010) were evaluated to determine the range of sources that can be discriminated and whether this can be generalized for different Erosion Terrains. The sampled erosion sources were then used to run scenarios using 'Beam c' to determine expected visual water clarity across a range of suspended sediment concentrations (SSC). This assumes that the light-attenuating nature of particles does not change due to in-channel 'processing' – which may not be realistic (e.g. Droppo et al., 2005).The scenarios included modelling the impact of individual erosion sources on visual water clarity, as well as mixture modelling using a combination of sources to model expected visual clarity as function of relative source contribution.

Results

The sediment quality attributes show significant variation between specific erosion processes while some show significant overlap. For example, Beam c* (m^2/g), which is inversely related to water clarity (Davies-Colley and Nagels, 2008) shows lower values for surface erosion relative to shallow landslide sources for most parent materials, while gully and surficial erosion occurring on unconsolidated sandstone/siltstone terrain has a significantly lower value (Figure 1).

At high concentrations (>500 mg/litre), visual clarity is low, and the range is small across all erosion sources (0.02m to 0.06m). However, as SSC lowers, the relative difference in Beam c* across the erosion processes, and its effect on visual clarity, becomes more evident. At 5 – 10 mg/litre, which approximates concentrations experienced at low flow (e.g. Dymond et al., 2017), and ignoring attenuation by water and humics, the visual clarity range in is large (2.4m to 5.6m, and 1.2m to 2.8m for 5 and 10 mg/litre respectively). As an erosion process example, at 5 mg/litre gully erosion on unconsolidated sandstone/siltstone displays a visual clarity over ≈5.5m, while shallow landslides (subsoil source) on grewacke or mudstone is approximately ≈3.2m (Figure 2).

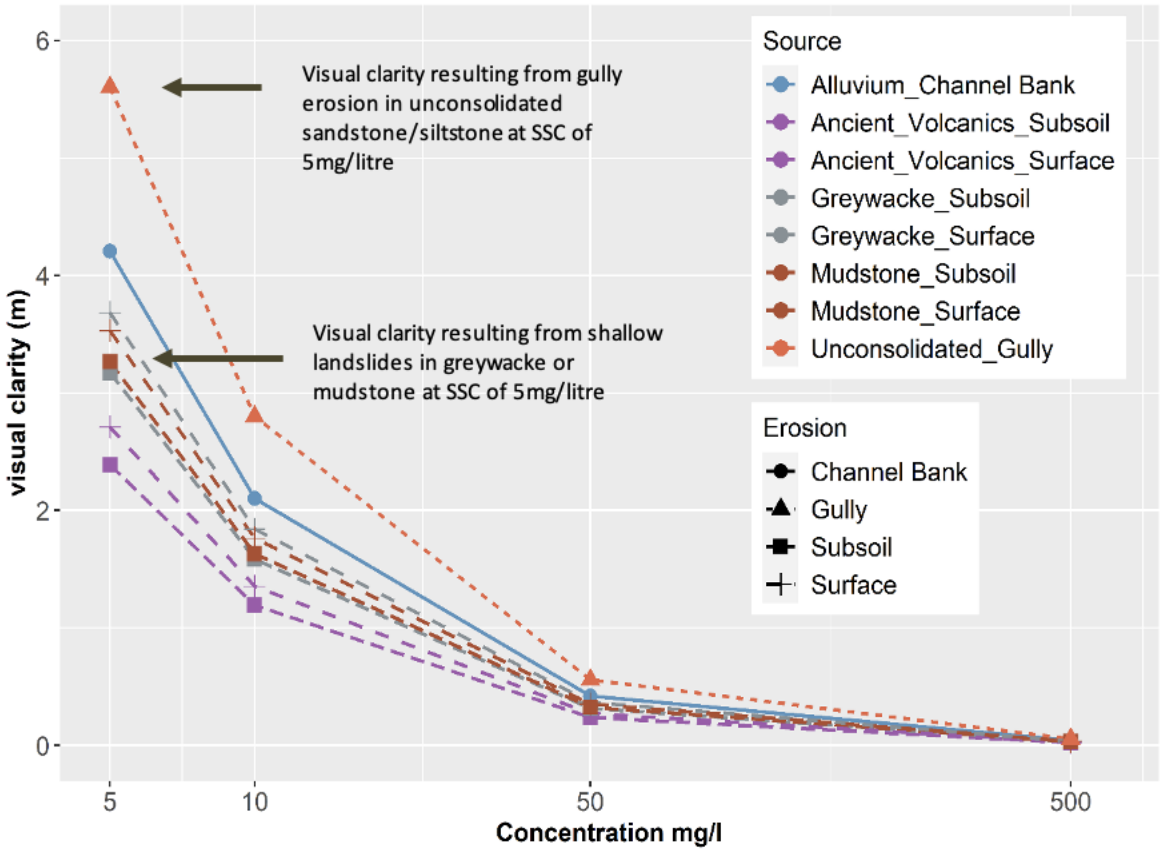


Figure 2: Estimated mean visual clarity for each erosion source across a range of suspended sediment concentrations arising from Beam c* variation across the erosion sources.

References

DAVIES-COLLEY, R. J. & NAGELS, J. W. 2008. Predicting light penetration into river waters. Journal of Geophysical Research: Biogeosciences, 113.

DROPPO, I. G., NACKAERTS, K., WALLING, D. E. & WILLIAMS, N. 2005. Can flocs and water stable soil aggregates be differentiated within fluvial systems? CATENA, 60, 1-18.

DYMOND, J. R., BETTS, H. D. & SCHIERLITZ, C. S. 2010. An erosion model for evaluating regional land-use scenarios. Journal of Environmental Modelling Software, 25, 289-298.

DYMOND, J. R., DAVIES-COLLEY, R. J., HUGHES, A. O. & MATTHAEI, C. D. 2017. Predicting improved optical water quality in rivers resulting from soil conservation actions on land. Science of The Total Environment, 603-604, 584-592.

GROUNDWATER-SURFACE WATER INTERACTIONS IN THE KAURU RIVER AND IMPLICATIONS TO THE LOWLAND LONGJAW GALAXIAS

Yeo, S.,[1] Rekker, J.,[1] Ravenscroft, P.,[1] Levy, A.[1]
[1] Otago Regional Council

The Kauru River (North Otago) plays a significant role in the behaviour and habitat of the threatened lowland longjaw galaxias (Galaxias cobitinis). Studies carried out by the Department of Conservation (DOC, 2004) have shown that the fish generally inhabit loosely packed gravels and coarse gravel to cobble substrate with high porosity. Therefore, due to the ephemeral nature of the stream, fish can burrow down or through the substrate in order to survive periods of drought when water levels fall below the stream bed. The fish can then inhabit the hyporheic zone until water levels increase. This project aims to understand the complex interaction between groundwater and surface water and investigate the reasons why river and groundwater levels in the middle reaches of the Kauru River have been declining over recent years.

The Kauru river has a complex interaction with the Kakanui-Kauru Alluvial aquifer. Groundwater levels change seasonally and with high flow events when groundwater storage is filled in the upper reaches of the Kauru River, above the confluence with the Kakanui River. Conversely, during periods of low inflow and drought, groundwater storage is decreased, when flow can disappear beneath the stream bed along sections of the river and in sections between Kauru Hill bridge at Ewings and Kinnimont Valley Road. River level gauging carried out by the Otago Regional Council (ORC) show that the Kauru River loses approximately half of its flow, or ~150-250l/s, to the underlying gravels and to groundwater within this ~4km section (ORC, 2003). Inflow and outflow measurements from river gauging have not decreased, and in recent years have even shown increasing trends. Conversely the middle reaches of the Kauru River, as seen in both the Kauru River stage at a perennial pool and a groundwater bore measured for levels, show a declining trend. Therefore, there is a dilemma presented where inflow and outflow are increasing, whereas levels in the middle reaches are decreasing. These increasingly drying reaches within the habitat of the Lowland longjaw galaxias pose a risk to the survival of the already critically endangered species.

The work programme in development to explore the nature of groundwater-surface water interaction in the Kauru River will include the following steps:

1. A temperature survey to determine locations of groundwater upwellings in the stream bed
2. Compare fish distribution with upwelling locations
3. Implement a transect of piezometers across the river to get direct measurements of hydraulic head in the aquifer and compare to river stage
4. Differential gauging down the Kauru River to determine flow losses/gains
5. Use modelling (e.g MODFLOW) to look for a correlation between stream flow and groundwater levels in order to identify suitable river management

References

Otago Regional Council, 2003. The Kauru River: A report prepared for the Department of Conservation Workshop on the Long jaw galaxiid.

Department of Conservation, 2005. BACI Study – Kauru River. Unpublished Department of Conservation Report. Otago Conservancy, New Zealand

Attendee List

IN-PERSON ATTENDEES - AS AT 17.11.21

First Name	Last Name	Organisation
Nariefa	Abrahim	University Of Otago
Darcy	Aker	Lincoln Agritech
Louise	Algeo	GWRC
Lindsay	Annear	Greater Wellington Regional Council
Sujani	Ariyadasa	Institute of Environmental Science and Research (ESR)
Alexandra	Badenhop	E3scientific Limited
Troy	Baisden	University Of Waikato
Mahina-a-rangi	Baker	Te Kōnae
Tim	Baker	SLR Consulting
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stefan	Beaumont	Nelson City Council
Morgan	Bennet	University Of Otago
Ivan	Berra	Hydrogeoex Ltd
Hamish	Biggs	NIWA
Benjamin	Bishop	Meridian Energy
Gillian	Blythe	Water NZ
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Annette	Bolton	ESR Ltd
Marinus	Boon	Pattle Delamore Partners
Amandine	Bosserelle	University of Canterbury
Courtenay	Bremner	WSP
John	Bright	Aqualinc Research
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Lee	Burbery	Dairy NZ
Stewart	Cameron	GNS Science
Rose	Cantwell	GNS Science
Trevor	Carey-smith	NIWA
Celine	Cattoen	NIWA
Lee	Chambers	GNS Science
Damon	Clarke	GNS Science
Murray	Close	ESR
Matthew	Coble	GNS Science
Will	Conley	Massey University, Geosciences Group
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Ethan	Coulston	Greater wellington regional council
Simon	Cox	GNS Science
Martin	Crundwell	GNS Science
Jay	Curtis	GNS Science
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Nguyet	Dang	Victoria University Of Wellington
Chris	Daughney	NIWA
Peter	Davidson	Marlborough District Council
Rob	Davies-Colley	NIWA
William	Dench	Wallbridge Gilbert Aztec

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James	Dommisse	Stantec
Patrick	Durney	Lincoln Agritech Ltd
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Graham	Elley	NIWA
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Lizzie	Fox	WSP
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Susana	Guzman	GNS Science
Arman	Haddadchi	NIWA
John	Hadfield	Waikato Regional Council
Matt	Hanson	Komanawa Solutions Ltd.
Mike	Harkness	Greater Wellington
Richard	Hawke	Toitū Te Whenua Land Information New Zealand
Greg	Hawkins	Trustpower
Ross	Hector	Aqualinc Research Limited
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Graeme	Horrell	GHCL
Karen	Houghton	GNS Science
Jo	Hoyle	NIWA
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Sarah	Johnstone	e3 Scientific
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Allanah	Kenny	ESR
Tim	Kerr	Rainfall.nz
Wes	Kitlasten	GNS Science
Mike	Kittridge	Headwaters Hydrology
brian	Kouvelis	Sustainable Futures Nz Ltd
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Richard	Levy	GNS Science
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Abigail	Lovett	Earth & Environmental Science Ltd.
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Betsan	Martin	Response Trust, Victoria University
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Raelene	Mercer	NEMS
Florence	Mills	Pattle Delamore Partners Ltd
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John	Montgomery	NIWA
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Magali	Moreau	GNS Science

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Sunday	Nwoba	University Of Canterbury
Stephanie	Patchett	University Of Cantebury
Rasool	Porhemmat	NIWA
Channa	Rajanayaka	NIWA
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Abi	Robison	GNS Science
Karyne	Rogers	GNS Science
Lucia	Roncaglia	GNS Science
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Graeme	Smart	NIWA
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MS	Srinivasan	NIWA
Raghav	Srinivasan	NIWA
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Mike	Taves	GNS Science
Alicia	Taylor	WSP
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Mike	Thompson	Great Wellington Regional Council
Blair	Thornburrow	Pattle Delamore Partners
Hugh	Thorpe	Retired
Ben	Throssell	Pattle Delamore Partners
Vanessa	Trompetter	GNS Science
Conny	Tschritter	GNS Science
Simon	Vale	Manaaki Whenua Landcare Research
Rob	Van Der Raaij	Greater Wellington Regional Council
John	Waugh	Retired Hydrologist
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Judith	Webber	ESR
Julian	Weir	Aqualinc
Rogier	Westerhoff	GNS Science
Melanie	Westley	Tasman District Council
Matai	Wetere	Greater Wellington Regional Council
Paul	White	GNS Science
Scott	Wilson	Lincoln Agritech
Nicola	Wilson	University Of Waikato
Chris	Worts	GNS Science
Jing	Yang	NIWA
Sam	Yeo	Otago Regional Council
Christian	Zammit	NIWA

Attendee List

VIRTUAL ATTENDEES - AS AT 17.11.21

First Name	Last Name	Organisation
Philippa	Aitchison-earl	Environment Canterbury
Greg	Barkle	Land And Water Research
Jeremy	Bennett	Tonkin & Taylor Ltd
Simon	Bloomberg	e3 Scientific
Christina	Bright	Landpro Limited
Troy	Brockbank	Pattle Delamore Partners Ltd
Kalyan	Chakravarthy	DHI Water And Environment
Ed	Clayton	University Of Auckland
Mic	Clayton	Snowy Hydro Limited
Andrew	Dark	Aqualinc Research
Bruce	Dudley	NIWA
Bapon	Fakhruddin	Tonkin + Taylor
Suzanne	Gabites	Environment Canterbury
Moritz	Gosses	Technische Universität Dresden
Hamish	Graham	Environment Canterbury
Phil	Hall	Greater Wellington Regional Council
Carl	Hanson	Environment Canterbury
Erin	Harvie	Bowden Environmental
Maiwenn	Herpe	GNS Science
Krystal	Hoult	ALS Hydrographics
Brian	Jackson	Water Technology Pty Ltd
Kolt	Johnson	Auckland Council
Charlene	Joubert	Beca Ltd
Lucy	Just	Environment Canterbury
Philip	Kelsey	Earthtech Consulting Limited
Samuel	Kelsey	Earthtech Consulting Limited
Cameron	King	Waikato Regional Council
Daniel	Kingston	University Of Otago
Amber	Kreleger	Environment Canterbury
Andrew	Lester	Watercare Services Limited
Carey	Lintott	Environment Canterbury
Sally	Lochhead	Tonkin + Taylor
Sarah	Mager	University Of Otago
Mohammed	Majeed	Manukau Institute Of Technology
Adam	Martin	Environment Canterbury
Mandy	McDavitt	Beca Ltd
Brian	Mcglynn	E3 Scientific
Paul	Murphy	Gisborne District Council
Jungho	Park	Lincoln Agritech
Andrew	Pearson	Environment Canterbury
Andrew	Raj	Environment Canterbury
Zara	Rawlinson	GNS Science
Beatriz	Reboredo Viso	Weather Radar New Zealand
Dean	Rissetto	Scapespec

Aldrin	Rivas	Lincoln Agritech Ltd.
Carlos	Rosado	Environment Canterbury
Lisa	Scott	Environment Canterbury
Linda	Shamrock	Pattle Delamore Partners
Matt	Silver	Environmental Geochemist
Roland	Stenger	Lincoln Agritech
Mauricio	Taulis	Beca
Sharon	Tenger	Engeo Ltd.
Jeanine	Topelen	Environment Canterbury
Jennifer	Tregurtha	Environment Canterbury
Nimthara	Udawatta	GNS Science
Kurt	van Ness	Environment Canterbury
Lucy	Whitlock-Bell	Tonkin + Taylor
Ben	Wilkins	Environment Canterbury
Thomas	Wöhling	Tud / Lal
Lucy	Brown	University Of Otago
Carlos	Carvajal	Earthtech Consulting Limited
Daniel	Collins	Lincoln University
Kate	Hodgson	University Of Otago
Michael	Knopick	The University Of Otago
Jingxiang	Shu	University Of Auckland

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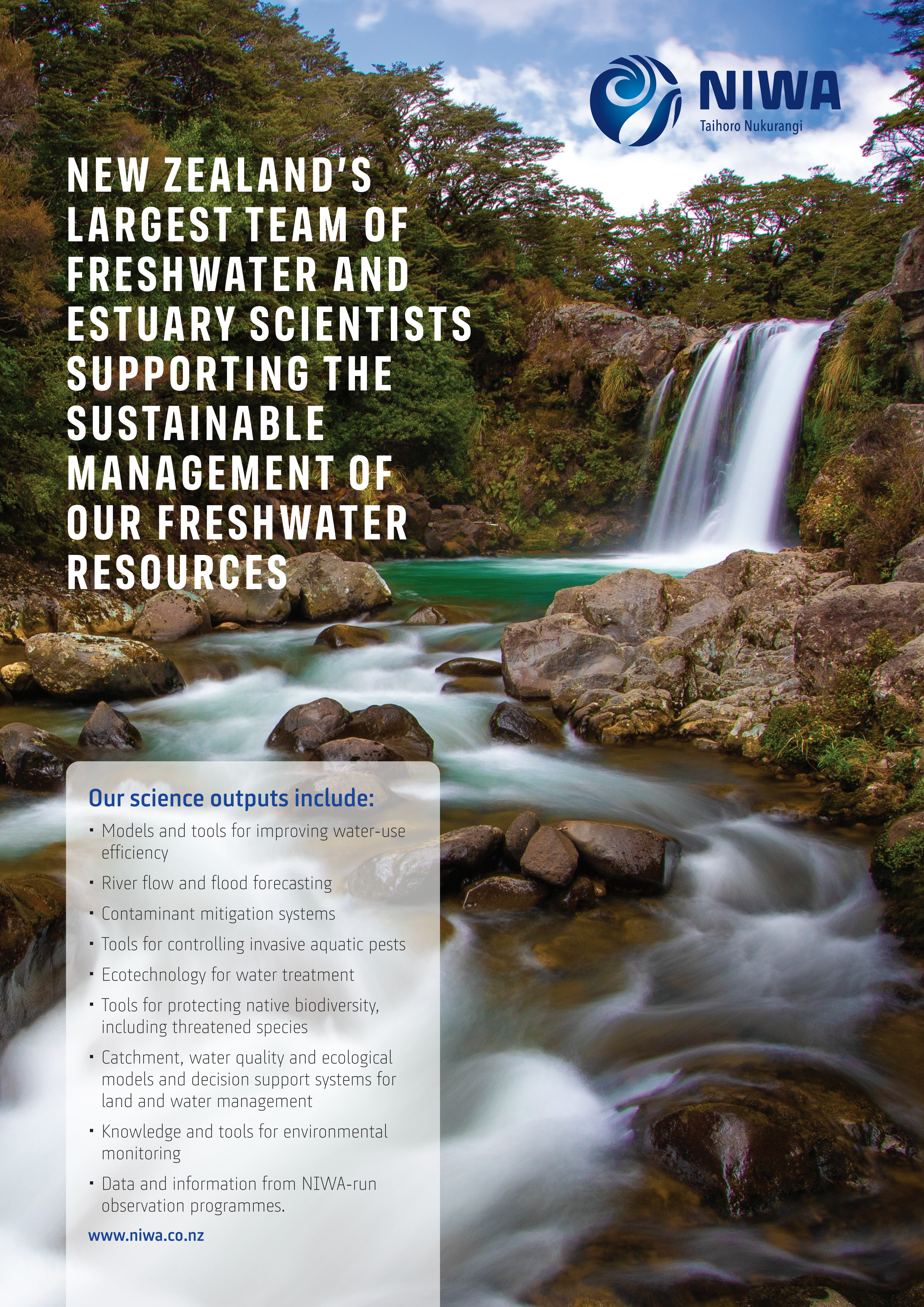
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