WATER INFRASTRUCTURE & THE ENVIRONMENT

28 NOV - 2 DEC 2016

MILLENNIUM HOTEL, QUEENSTOWN
NEW ZEALAND

HANDBOOK

www.nzhs2016.co.nz

NEW ZEALAND HYDROLOGICAL SOCIETY

ENGINEERS AUSTRALIA

manatiaki kōawa
rivers GROUP
A joint technical interest group of IPENZ & Water NZ

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WELCOMES

NEW ZEALAND HYDROLOGICAL SOCIETY

Welcome to Queenstown for the 56th New Zealand Hydrological Society (NZHS) Conference and 37th Engineers Australia Hydrology and Water Resources Symposium (HWRS). This joint conference also includes the IPENZ Rivers Group. This is the first time a joint event of these three groups has been held. The last NZHS Conference in Queenstown was in 2004 and it is a pleasure to be back and to welcome everyone to such a beautiful part of New Zealand. A special welcome to all of our Australian colleagues and overseas visitors.

The conference theme this year is: "Water, Infrastructure and the Environment". This is a very appropriate theme considering the challenges we face in developing water infrastructure taking into account the environment and changing community values, perception and expectations, not only in New Zealand but also globally.

The enthusiasm shown for the joint conference is reflected in the large number of papers and posters submitted for the technical programme. The diversity and quality of the papers highlight the strength, depth and scope of the work in the water sciences, water engineering and river engineering arenas. An excellent and diverse range of keynote speakers have been confirmed for the conference. The Munro Oration, which is a tradition for the HWRS, is also a must, and I encourage you all to attend these sessions. I am looking forward with enthusiasm to hear the many great papers on offer and look forward to the ensuing stimulating discussions. This conference provides a great opportunity for colleagues from the three water-related organisations to be able to meet and share their knowledge, experience and research.

A big thank you to all the sponsors for the ongoing support of our Society's annual conference and the Society itself. The joint organising committee, supported by the symposium organisers On-Cue, have put in some hard work to make this event possible – a big thank you for all your efforts. I know the considerable effort and time involved in organising a conference of this scale involving overseas partners. A special acknowledgment to the co-convenors Charles Pearson and Mark Babister for their dedication and efforts. I wish everyone a great conference. I look forward to meeting as many of you delegates both from New Zealand and overseas as possible. I trust your stay in Queenstown will be enjoyable and memorable, and I hope especially for our overseas visitors that you will take this opportunity to enjoy the many attractions Queenstown has to offer.

Joseph Thomas
NZHS President

ENGINEERS AUSTRALIA

On behalf of Engineers Australia's National Committee on Water Engineering (NCWE), I am delighted to welcome you to the 37th Australian Hydrology and Water Resources Symposium component of this exciting joint conference. We are very pleased to join with the New Zealand Hydrological Society and the IPENZ Rivers Group to bring you this event in the beautiful setting of Queenstown. This is the third time that the Symposium has travelled to New Zealand, and once again we have attracted a diverse range of high quality presentations from Australia, New Zealand and the rest of the world.

The conference theme "Water, Infrastructure and the Environment" challenges all of us to consider our water infrastructure needs, the effect on the environment and the environment's effect on our infrastructure. Over the three days of this symposium, delegates will report on progress made in understanding the major uncertainties facing water resource managers and outline practical and innovative approaches for dealing with these challenges. The Munro Oration, reflecting on the evolution of hydro-climatology over the past five decades, is sure to be a highlight. We thank the sponsors and trade exhibitors, without which this excellent programme could not be presented. The authors are to be commended for the technical excellence of their papers and for their willingness to share their knowledge and expertise, and our appreciation to the large number of professionals who assisted in the paper review process.

Welcome to Queenstown, and I look forward to meeting you during the conference.

Toby McGrath
Chair, National Committee on Water Engineering
Engineers Australia

RIVERS GROUP

A warm welcome to all delegates on behalf of the IPENZ & Water New Zealand Rivers Group. We are delighted to be partnering with the New Zealand Hydrological Society and Engineers Australia's National Committee on Water Engineering to present the 2016 Water, Infrastructure and the Environment (WIE) Conference. Queenstown is a fantastic venue to gather and share knowledge with friends and colleagues from across New Zealand and Australia. I'm sure all delegates will have a fantastic time not only learning from the conference presentations but also enjoying the amazing scenery and experiences that are on offer around Queenstown and the wider Otago Region. A special thanks to Rivers Group Member Jo Hoyle from NIWA, who is on the conference organising committee and has helped bring this fantastic event together.

Kyle Christensen
Chairman IPENZ/Water NZ Rivers Group

Conference Committee Welcome

The New Zealand Hydrological Society, Engineers Australia's National Committee on Water Engineering and the IPENZ Rivers Group are pleased to welcome you to "Water, Infrastructure and the Environment", Monday 28 November to Friday 2 December 2016.

We welcome you all to Queenstown – in particular, delegates from Australia and the rest of the world!

The last occasions when the Australian Hydrology and Water Resources Symposium were staged jointly with the New Zealand Hydrological Society were in Christchurch in 1989 and Auckland in 1997 – and so we are well overdue for this event, and we are pleased to be joined by the IPENZ Rivers Group.
We have three days of concurrent conference papers prepared for you, covering all aspects of hydrology, as demonstrated by the volume of abstracts and full papers. Many of the papers relate well to the theme of "Water, Infrastructure and the Environment". There are over 230 papers in all, and over 20 poster presentations.
The conference provides an opportunity for you to make the most of communicating the latest in hydrology. It features keynote addresses on each of the three days of papers and the Munro Oration from 6–7pm on Wednesday. The conference dinner is on Thursday evening at the restaurant at the top of Queenstown's spectacular Skyline Gondola, followed by field trips on Friday. We hope you take the opportunity to make the most of the conference and the related events.

Thank you for choosing to attend and support this conference.
Thank you also to the conference sponsors for providing valuable financial support.
We would like to thank the conference organising company On-Cue and the organising and scientific committees for the hard work behind the scenes to stage this event, including reviewing the full papers and extended abstracts, and numerous other tasks – Tracy Young (On-Cue), Lea Boodee (On-Cue), James Ball (University of Technology Sydney), Tim Davie (Environment Canterbury), Monique Retallick (WMA Water), Helen Rutter (Aqualinc), Andrew Fenemor (Landcare), Lawrence Kees (Environment Southland), Jo Hoyle (NIWA), Sarah Mager (Otago University) and Tom Cochrane (University of Canterbury).

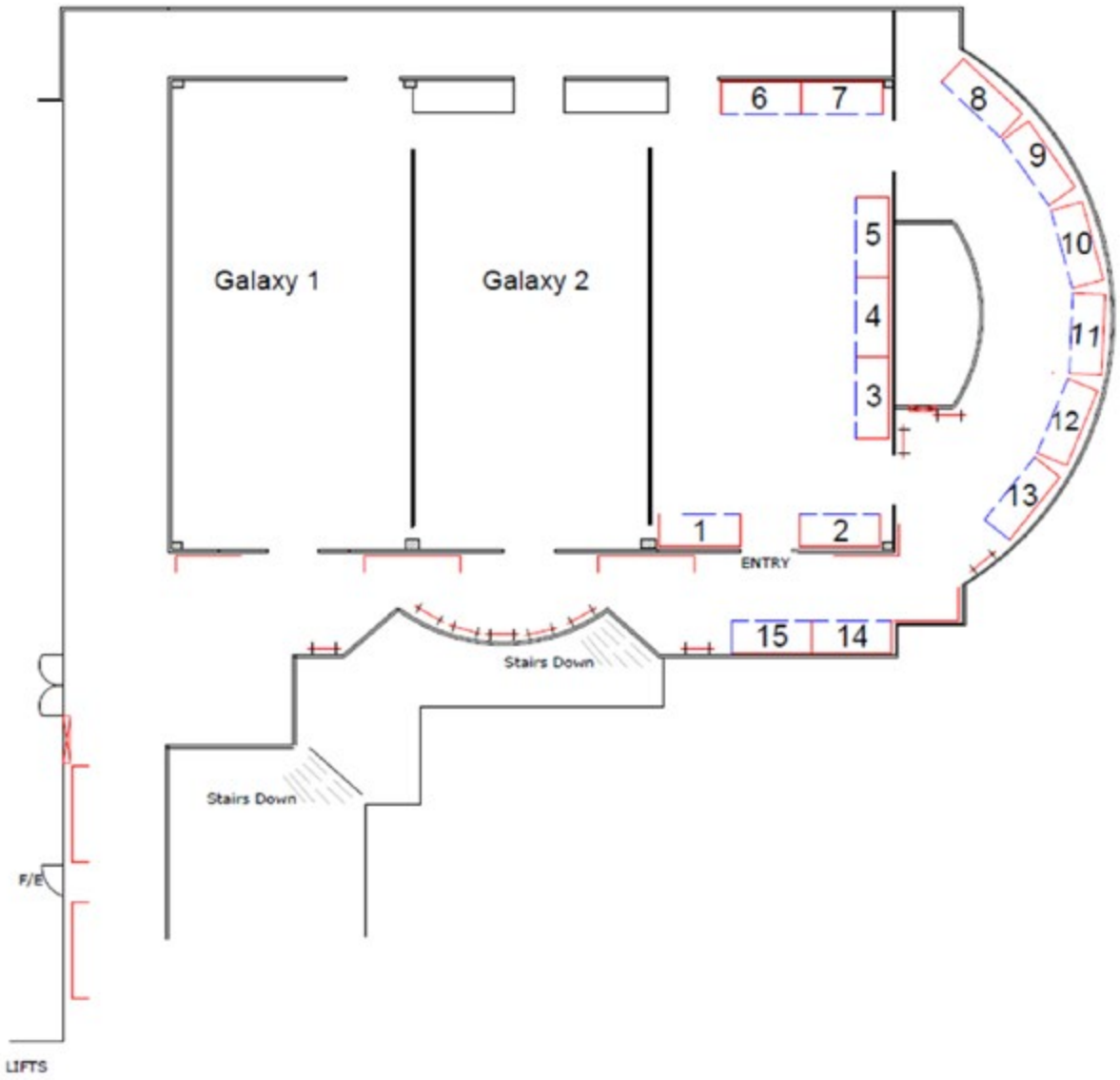
If you have any queries at any stage please do not hesitate to contact the conference office or us. Thank you.

Charles Pearson (NIWA) and Mark Babister (WMA Water)
Conference Convenors

ORGANISING COMMITTEE

- **Charles Pearson (NZ Chair)** | *NIWA*
- **Mark Babister (Australia Chair)** | *WMA Water*
- **Sarah Mager** | *Otago University*
- **Lawrence Kees** | *Environment Southland*
- **Tim Davie** | *Environment Canterbury*
- **Jo Hoyle** | *NIWA*
- **James Ball** | *University of Technology Sydney*
- **Monique Retallick** | *WMA Water*
- **Tracy Young** | *On-Cue Conferences*
- **Lea Boodee** | *On-Cue Conferences*

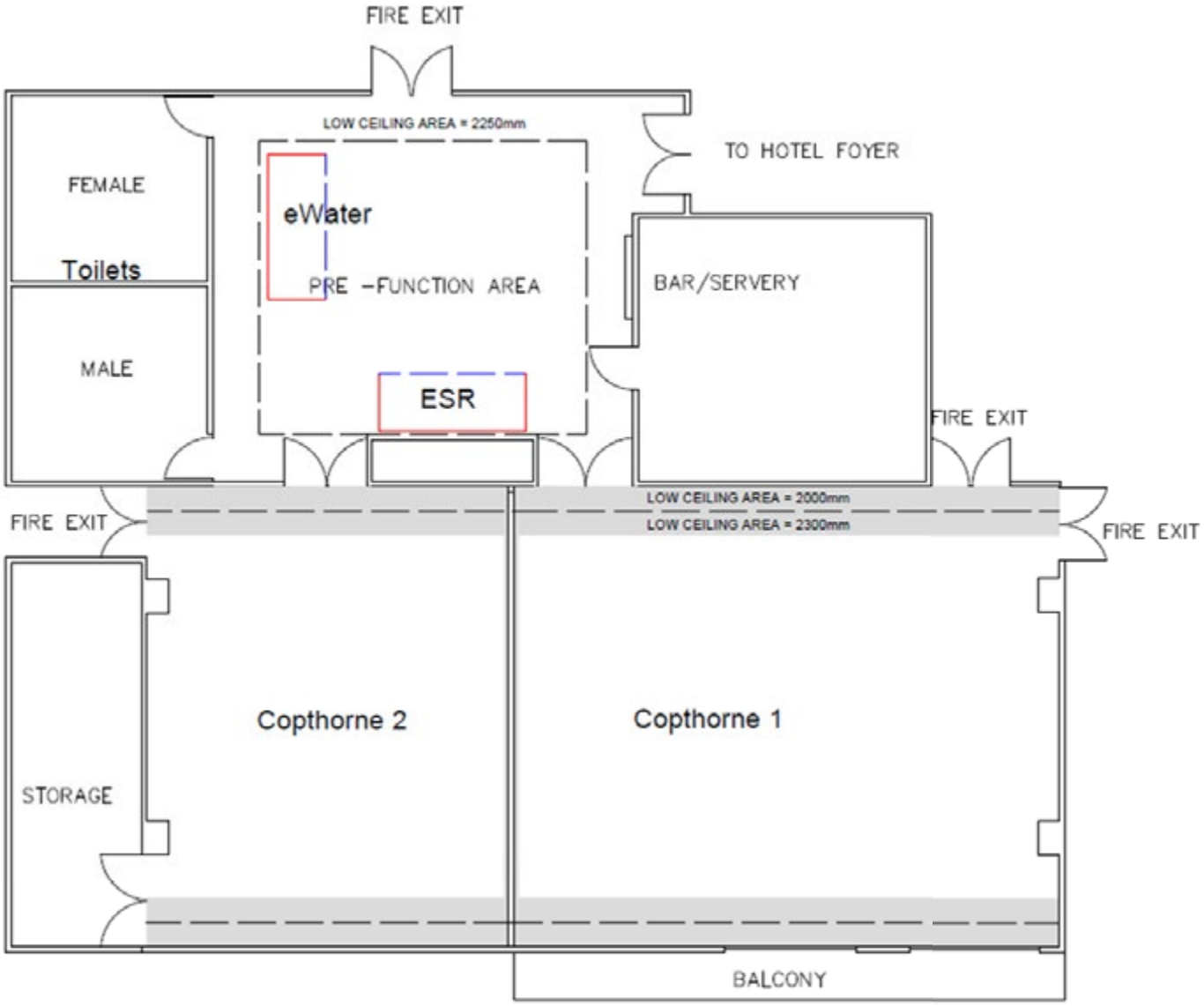
CONFERENCE VENUE MAP AND TRADE EXHIBITORS FLOOR PLAN



MILLENNIUM HOTEL

1	Jeff Booth Consulting	10	WaterRide
2	BMT TuFlow	11	Geotechnics
3	Thermofisher	12	Aquatic Informatics
4/5	Aqualinc	13	Envco
6/7	XP Solutions	14/15	NIWA
8	DHI		Copthorne 1 ESR
9	Riley Consultants		Copthorne 2 eWater Solutions

FLOOR PLAN – COPTHORNE HOTEL



Emergency Information

In the event of an emergency you will hear an alarm at the hotel, please follow staff instructions, evacuate the building and assemble outside.

In the event of an earthquake, stop, drop and cover. When the shaking stops make your way out of the building to the assembly point.

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

GENERAL INFORMATION

Registration Desk

If you require any assistance throughout the conference please see the conference organisers at the Registration Desk on the Ground Floor.

A Conference Notice Board will be placed at the Registration Desk and will be used to display conference information, programme changes, announcements and messages. Please check the board regularly.

Internet and Password

Wireless internet broadband is provided free to conference delegates in the Millennium and Copthorne hotels, the password is **WIE2016**

Stay connected with the confernce by using **#NZAUWIE2016**

Name Badges

Delegates are requested to wear their name badges to all sessions and social functions. Committee members will be wearing green lanyards, delegates have navy blue lanyards. Student helpers will be wearing yellow lanyards, please ask them for directions and local knowledge.

Meals

Morning and afternoon teas will be served downstairs in the restaurant area as well as in the trade exhibitors space in the Galaxy foyer. Lunches will be served in the restaurant area.

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 waiting 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.

Loading Presentations

Please load your presentation at the Registration Desk on the Ground Floor – this should be done at least two sessions prior to your scheduled presentation session time.

Cell Phones

Please ensure that cell phones and/or pagers are turned off, or silent, during all presentations.

Parking

Car parking is limited, please check with the hotel for availability. You can park in the surrounding streets, please observe the signposted time limits.

No Smoking

There is no smoking allowed inside the venue.

Contact Number

For assistance please call Tracy from On-Cue Conferences on **021 164 7820**

Road Crossing

Please cross between hotels using the traffic island and take care - this is a busy road.

Poster Presenters

Posters must be displayed before midday on Tuesday 29 November. Poster boards are in the Galaxy foyer area – velcro dots will be provided. Please ensure you are at the poster session by 4.30pm on Tuesday afternoon; your 2-minute presentation will be streamed live into the conference Plenary room. The session will finish by 6pm.

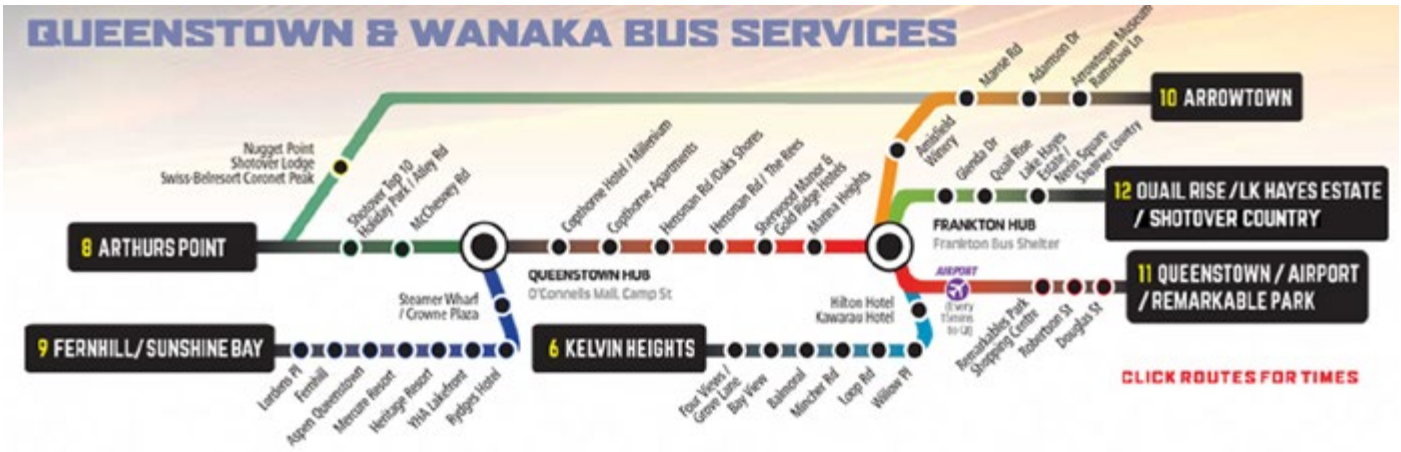
Session Chairs

Please can all session chairs be in their room at least 10 minutes prior to the start of the session. Please familiarise yourself with the AV equipment. If you have any questions, locate the student helper or AV technician, who will be close by. It is very important that presentations do not run over their allocated total of 15 minutes so please ensure presenters start and finish on time. If people want to move rooms during sessions they should do so at the start of the 3-minute question/discussion part of the presentation.

GETTING AROUND

Public Transport

Connectabus runs regularly on the following routes:



Please check their website for timetable information: ***www.connectabus.com***

Accessible Public Transport

Low-floor buses, wide aisles and reserved wheelchair seating are available on a selection of Queenstown's local bus routes. These routes pick-up and drop-off in Queenstown, Frankton and Queenstown Airport. Some other bus routes can also offer accessible services, but you should call in advance to check. Buses are operated by Connectabus on **03 441 4471**

Taxis

Queenstown Blue Bubble Taxis

Phone: 03 450 3000

Super Shuttle

Phone: +64 9 522 5100

The Queenstown Airport is approx. 15–20 minutes' drive from the Millennium Hotel, the cost is approx. NZ$40

Queenstown City Map

Upcoming Conferences

NZHS - Napier Conference Centre, 27-30 November 2017

Engineers Australia Hydrology and Water Resources conference is scheduled for 2018

Hydraulics in Water Engineering conference, Sydney, mid November 2017

Rivers Group - Claudelands Event Centre, Hamilton, 19-24 November 2017

International Society for Subsurface Microbiology - Rotorua, 6-10 November 2017 www.issm2017nz.com

QUEENSTOWN INFORMATION

Medical

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

Queenstown Police :
Phone 03 441 1600 from within Queenstown. The police station is located at 11 Camp Street, Queenstown.

Queenstown Hospital :
The Lakes District Hospital: 20 Douglas Street, Frankton. Phone 03 441 0015.

Queenstown Doctors and Medical Centres :

- Queenstown Medical Centre: 9 Isle Street, Queenstown & Remarkables Park. Phone 03 441 0500
- Arrowtown Surgery: Berkshire Street, Arrowtown. Phone 03 442 1215
- Wakatipu Medical Centre: 11 McBride Street, Frankton Phone 03 442 2288

Chemist/Pharmacy
Unichem Wilkinson's Pharmacy

Address The Mall – Queenstown Ballarat Street & Rees Street, Queenstown 9348
Phone : 03 442 7313
Hours : 8.30am – 10pm every day

SOCIAL FUNCTIONS AND MEETINGS

Welcome Function

Monday 28 November 2016
5.00pm – 7.00pm

Venue : Impressions Bar, Copthorne Hotel (opposite Millennium)
Additional Tickets : $35.00
Dress : Casual

Renew old friendships and make new acquaintances as we welcome you to Queenstown.
This function is included in the registration fee (excluding day registrations). Additional tickets may be purchased for guests.

Conference Opening/Welcome/Pōwhiri

An invitation is extended to all delegates to attend the Conference Opening.
Please meet in the Galaxy Foyer at 8.00am.

Tuesday 29 November 2016
8.00am – 9.00am

Young Professionals Function

This function is open to current full-time students and recent graduates.
The Young Professionals Function is kindly sponsored by Envco.

Tuesday 29 November 2016
7.30pm – 9.30pm
Venue : Zephyr, Searle Lane off Camp St.

Conference Dinner

The WIE 2016 Conference Dinner will be the premier event of the conference and is not to be missed by delegates and guests.

The Conference Dinner is by ticket only.

Thursday 1 December 2016
6.00pm – midnight

Venue	Skyline Restaurant
Transport	Buses depart from the Millennium from 5.45pm till 6.00pm and will return at 10.45pm and midnight, they will drop off at the Millennium/Copthorne.
Ticket	$120.00 for additional tickets
Includes	3-course meal, beverages and entertainment
Optional Dress Theme	Adventure; be adventurous!

AGMs

NZHS AGM
Tuesday 29 November 2016
6.00pm – 7.30pm
Galaxy Room 1 There will be an arrival drink available for society members.

Engineers Australia Meeting
Discussion on future directions for Australian water industry
Tuesday 29 November 2016
6.00pm – 6.30pm
Copthorne 1

Rivers Group AGM and Arch Campbell Award Presentation
Thursday 1 December 2016
1.00pm – 1.30pm
Galaxy Room 1 This meeting will take place over the lunch break.

KEYNOTE SPEAKERS

Peter Goodwin

Tuesday 29 Nov. 9.00am – 9.45am

Peter Goodwin serves as the President of the International Association for Hydro-Environment Engineering and Research (IAHR) and has just completed a federal appointment as Lead Scientist for the Science Program of the Delta Stewardship Council in California. He is the DeVlieg Presidential Professor of Civil Engineering and founding Director of the Center for Ecohydraulics Research at the University of Idaho. His research interests include systems approaches to ecological restoration of river, wetland and estuarine systems.

KEYNOTE PRESENTATION :

Balancing Water Supply Reliability and Ecosystem Restoration: Example of the San Francisco Bay-Delta in California, USA

Many of the world's large ecosystems are severely stressed due to population growth, water quality and quantity problems, vulnerability to flood and drought, and the loss of native species and cultural resources. Consequences of climate change further increase uncertainties about the future. These major societal challenges must be addressed through innovations in governance, policy, and ways of implementing management strategies. Science plays a critical role in helping define possible alternative futures that could be achieved and the possible consequences to economic development, quality of life, and sustainability of ecosystem services. Science has advanced rapidly during the past decade with the emergence of science communities coalescing around "Grand Challenges" and the maturation of how these communities function has resulted in large interdisciplinary research networks. This trend has been complemented by major advances in sensor technologies, data synthesis and mining to accelerate knowledge discovery. These factors combine to allow scientific debate to occur in a more open and transparent manner. The availability of information and improved communication of scientific and engineering issues is raising the level of dialogue at the science–policy interface. However, severe challenges persist since scientific discovery does not occur on the same timeframe as management actions, policy decisions or at the pace sometimes expected by elected officials. Common challenges include the need to make decisions in the face of considerable uncertainty, ensuring research results are actionable and preventing science being used by special interests to delay or obfuscate decisions.

These challenges are explored in the context of the California Bay-Delta system.

Jen Crawford

anderson lloyd.

Wednesday 30 Nov. 8.30am – 9.15am

Jen has 20 years' experience as a resource management and environmental law specialist, having worked in leading law firms in New Zealand and the UK. She provides strategic advice to clients on project consenting with a particular focus on large-scale water augmentation, built infrastructure, urban renewal and peri-urban planning. Jen is a regular guest lecturer in water law at the University of Canterbury School of Law and also holds an Honours Degree in History from the University of Otago.

Jen has led the consenting for a number of large-scale projects in the South Island that are focused on the interplay between water, infrastructure and the environment. Examples include the Rangitātā South Irrigation Scheme, Waimea Community Dam Project, Portlink Industrial Park and Lake Hood Extension Project. She also has a governance role at the Christchurch Arts Centre, which is undertaking what is considered to be the largest heritage restoration project of its kind in the world.

Jen is a Partner at national law firm Anderson Lloyd, Chair of The Arts Centre of Christchurch Trust Board, a Director of Regenerate Christchurch, a Chartered Member of the Institute of Directors, and a member of Heritage New Zealand Pouhere Taonga and the Resource Management Law Association of New Zealand Incorporated.

KEYNOTE PRESENTATION :
The Problem with Ponds

When considering the opportunities and challenges with water infrastructure projects in this country, it is worth looking back over the years at some of the lessons learned and identify common themes faced by proponents, local communities and decision makers.
Large-scale water storage and augmentation projects involve the interplay between water, infrastructure and the environment.

- Are such projects a win-win for the economy and the environment?
- Are we fully grasping the potential opportunities for our economy, or are we heading blindly down a path of infrastructural development without giving sufficient thought to long-term outcomes?
- Has anything really changed since New Zealand's principal environmental legislation (the Resource Management Act (RMA)) came into force in 1991?

From the Clyde Dam to Ruataniwha, we will consider several examples of large-scale water storage and augmentation projects in New Zealand. There are material differences that can make or break a project. The role of the media and the court of public opinion, the influence of technical uncertainty, potential cost/time risks resulting from litigation, and the challenges around funding to enable project delivery. Building dams is easier said than done. It is apparent that there is no easy answer or quick fix to the delivery of such projects in New Zealand.

Ultimately, there needs to be understanding and buy-in from the wider community of the benefits of water infrastructure projects. Whatever the outcome of the current debates, we need to ensure that there is still enough water to go around in the future so that the opportunities can be fully realised and the overall wellbeing of New Zealanders can be assured.

Rory Nathan

Thursday 1 Dec. 9.00am – 9.45am

Rory Nathan is Associate Professor of Hydrology and Water Resources at the University of Melbourne. He has over 30 years' experience predominately in the consulting sector, both here and overseas. He has particular expertise in the estimation of flood risk and is a co-editor and contributor to the revised Australian Rainfall and Runoff. He has received a number of national and international awards for his research publications. Engineers Australia has formally recognised his significant impact on design practice: in 2000 he was awarded national "Civil Engineer of the Year" and in 2009 he was listed as one of the nation's "most influential engineers".

KEYNOTE PRESENTATION :

Impact of Natural Variability on Design Flood Flows and Levels

Hydrologic variability has traditionally been accounted for by choosing "average" values of the inputs (the so-called "simple design event" method), though Australian Rainfall and Runoff now recommends the use of more robust approaches based on ensemble sampling and Monte Carlo simulation where possible. The studies that have been undertaken using these more sophisticated techniques have generally focused on the hydrologic rather than hydraulic aspects of the problem; that is, on estimates of the flood peak, not on the magnitude of the resulting flood depth. While the explicit treatment of hydrologic variability represents only a modest increase in computational burden for hydrologic models, it is not easily accommodated in hydraulic models. There is little information available on the manner in which hydrologic variability influences the different steps involved in the estimation of design levels, and improved understanding of this will help identify where efforts are best prioritised. This paper illustrates the manner in which natural variability influences hydrologic estimates of flood peak, and quantifies how this propagates through to estimates of flood depths using hydraulic modelling.

Munro Oration

Drinks : 5.30pm – 6.00pm
Munro Oration : Wednesday 30 Nov. 6.00pm – 7.00pm

The C.H. Munro Oration was established in 1978 in recognition of the outstanding contribution made by the late Professor Crawford Munro to the science and practice of hydrology and water resources engineering In Australia. The Orator is selected by the National Committee on Water Engineering, after receiving nomination from the symposium organising committee. The selected orator need not be an Australian or an engineer, but should be a person eminent in the field of water resources in Australia.

The Orator receives an award, which is sponsored jointly by Engineers Australia, the Hydrological Society of South Australia and the Hydrological Society of Canberra.

Emeritus Professor Crawford Munro died on 21 September 1976 at the age of 72. No man had a greater impact on the development of hydrology and water resources in Australia in his time.

Crawford Munro was a Professor of Civil Engineering at the University of New South Wales for 16 years. Crawford Munro also served the Institution with distinction. He was a member of the Stormwater Standards Committee of the Institution, which produced the first version of Australian Rainfall and Runoff, and was Chairman of the National Committee on Hydrology for six years.

The many symposia organised by these committees owed a lot to Crawford Munro, both for his organisational drive and for his many vigorous and often memorable contributions from the floor of the conference hall. It is therefore fitting that Crawford Munro be remembered at each Hydrology Symposium (held at approximately 18-month intervals) by a Memorial Oration delivered by an eminent speaker in the field of hydrology and water resources.
The Munro Oration is jointly sponsored by Engineers Australia, the Canberra Hydrological Society and the South Australian Hydrology Society. It was first given in 1978.

Munro Orators

2015 – Prof George Kuczera
2014 – Dr Bryson Bates
2012 – Dr Rob Vertessy
2011 – Dr Arthur Askew
2009 – Prof Graeme Dandy
2008 – Assoc Prof Trevor Daniell
2006 – Erwin Weinmann
2005 – Dr Allan Goyen
2003 – Don Blackmore
2002 – Assoc Prof Ian Cordery
2000 – Dr Kenneth J Langford
1999 – Prof Russell Mein
1997 – Prof Tom A McMahon
1996 – Dr Emmett O'Loughlin
1994 – Prof WD Williams
1993 – John AH Brown
1991 – Prof David Pilgrim
1989 – Assoc Prof Walter C Boughton
1988 – Prof John R Burton
1986 – Prof TG Chapman
1985 – DN Body
1983 – Prof EM Laurenson
1982 – Prof Sandford D Clark
1980 – Dr John R Philip
1979 – K Lewis
1978 – Prof HR Vallentine

Blair Fitzharris
Munro Orator 2016

Dr Blair Fitzharris is Emeritus Professor at the Department of Geography, University of Otago, New Zealand, and has held Adjunct Professor titles at Curtin and Sunshine Coast Universities, Australia. Blair has undertaken research on climate change in New Zealand, Canada, Norway, UK, Switzerland and Australia and has written over 150 refereed publications on the subjects of snow, ice, climate and impacts of climate change. He is also a consultant with 35 years of experience on climate matters related to resource development, mining, land use, energy (including hydro and wind power) and topo-climate mapping and has prepared reports for many large corporations and government agencies.

Professor Fitzharris has been a four-time Convening Lead Author for the Intergovernmental Panel on Climate Change (IPCC) from 1993 to 2007 and a Review Editor for the IPCC Fifth Assessment Report, Working Group II (Chapter 25, Australasia). He was also involved as Review Editor of the UNEP Millennium Ecosystem Assessment. Blair is a past member of Antarctica New Zealand's Research Committee and of the Royal Society of New Zealand Standing Committee on Climate Change. He is a former President of the Meteorological Society of New Zealand and former Chair of the New Zealand Mountain Safety Council.

Reflections on Climate and Water over 50 Years

Blair will reflect on some important issues in the science of climate and water over the past 50 years. He will identify changes in the way that hydro-climatology has evolved for the following: growth and analysis of big data, understanding the role of teleconnections, linking of the water and energy balances, increasing power of climate modelling, and assessment of the impacts of climate change on water resources and our vulnerability. Examples will be illustrated with case studies that Blair has been involved with from four global river basins: the Clutha (New Zealand), the Mackenzie (Canada), the Murray-Darling (Australia) and the Mekong (South East Asia). These include his occasional flirtations with engineers (some dry, but most wet).

GN ALEXANDER MEDAL

Engineers Australia awards the GN Alexander Medal for Hydrology and Water Resources to the author(s) of the best paper in hydrology and/or water resources in an Australian publication over the period from and including the previous Hydrology & Water Resources Symposium. GN Alexander was one of the greats in the early years of Australian hydrology. He was a member of the working committee which produced the first Australian Rainfall and Runoff and a regular contributor at Hydrology Symposia. The award is judged by a panel appointed by the National Committee on Water Engineering. The recipient must be a member of Engineers Australia. First awarded in 1988, the previous recipients are listed below. This medal will be presented prior to the Munro Oration.

1988	Assoc Prof WC Boughton
1989	Dr EM O'Loughlin
1991	Prof Ray Volker & Dr Wayne Read
1993	Prof ID Moore & MF Hutchinson
1994	WJC Meynink & Dr DK Brady
1996	Mark Crees
1997	Dr RJ Nathan, Dr JL Crawd, KA Austin, Dr LNN Jayasuriya
1998	Dr George Kuczera
2000	Prof Ray Volker
2002	A Rahman, PE Weinmann & Prof RG Mein
2003	Bernadette A Foley & Trevor Daniell
2005	ID Rutherd, AR Ladson & MJ Stewardson
2006	MJ Boyd & ND Bodhinayake
2008	D Misivnas
2009	B Berghout
2011	DC Verdon Kidd & AS Kiem
2012	Y Zhang & N Viney
	M Gibbs, O Thebaud & D Lorenz
2014	DL Shrestha, D Robertson, QJ Wang, T Pagano & P Hapuarachchi
2015	F Zheng, S Westra, S Sisson & M Leonard

CONFERENCE FIELD TRIPS : FRIDAY 2 DECEMBER

Each trip leaves at a different time so please be sure to check info for your trip

If you have not booked on a field trip and would like to, please enquire with the Conference Organisers at the Registration Desk before 1.00pm on Tuesday 29 November.

Clyde Dam Tour, Manuherikia Irrigation Scheme & Lunch

Departure time : 8.00am – Millennium Hotel

This trip will include a tour of the Clyde Dam, a stop at NIWA's Lauder Climate Station, and a look at the Manuherikia Irrigation Scheme. A visit to Bannockburn Winery Carrick Estate will round out the trip, and estimated arrival time back in Queenstown is 4.30pm. A winery lunch is included in the price of the field trip.

Dart River Trips

Departure time : 7.35am – Copthorne Hotel

This trip offers two options: a short trip (jet boat ride only) or a full-day trip, including a funyak (inflatable kayak) experience for part of the trip. The trip will explore the Dart River.

Wilderness Jet Boating Trip

An hour and a half of thrilling high-speed wilderness jet boating skimming across the clear waters of the Dart River into the Te Waipounamu World Heritage Area. Hear about flora, fauna and history on a 30-minute forest walk with your friendly guide as well as tales of early settlers who carved rich farms from the rugged landscape.

Funyak Trip

Enjoy an hour of high-speed wilderness jet boating through the waters of the Dart River into the Te Waipounamu World Heritage Area and your funyak launch site. Stop along the way and enjoy a wilderness picnic lunch. Travel a backcountry route to Glenorchy and put yourself in scenes and backdrops from The Lord of the Rings and The Hobbit movies.

Manapouri Field Trip

Departure time : 7am – Millennium Hotel

After a 2-hour bus trip through some stunning New Zealand scenery, you will have an hour-long cruise across Lake Manapōuri to West Arm, where you will have the opportunity to look around the visitor centre. On the return cruise you will view the power station and intakes. Expected arrival time back in Queenstown is 6pm. The trip includes a packed lunch.

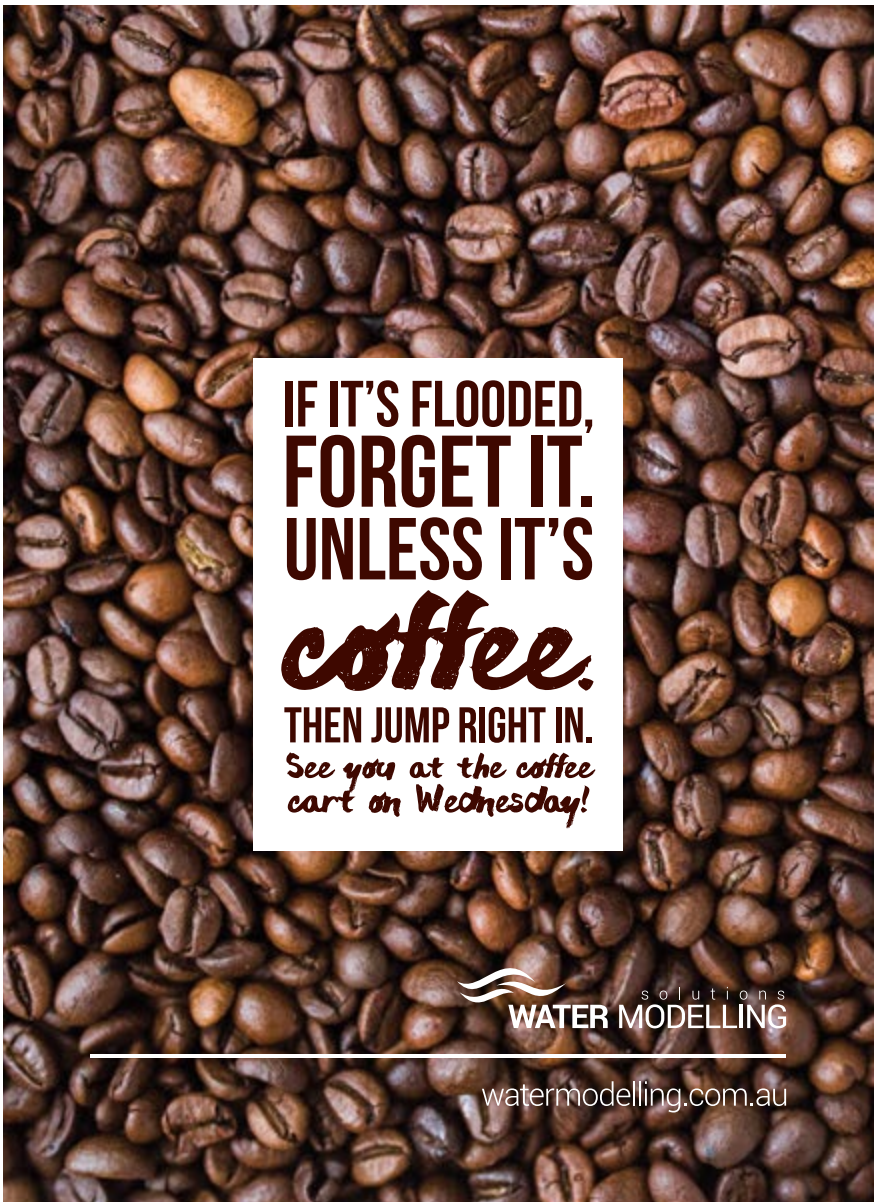
What to bring : walking shoes, rain jacket

Water and Wine Bike Tour

Estimated departure time 9am

The cost includes bike hire, lunch, and vehicle support. Wine tastings are optional extras from $5 to $15 depending on the vineyard: payable on the day. This field trip is a tour of rivers and wineries by bicycle! Attendees will be provided with mountain bikes, helmets and a safety briefing and will then set off on a scenic ride from Arrowtown along the beautiful Arrow River Trail until it meets the Kawarau River, and will then head down the Kawarau River along the Gibbston River Trail. Total riding distance is < 25 km with an expected riding time of 4–5 hours (at a leisurely pace), leaving plenty of time to stop and enjoy the scenery, wine and a picnic along the way! Planned arrival time is 5.30pm.

$120.00 per person



CONFERENCE PROGRAMME

World-class science supporting your water management goals

NIWA provides tailored research, tools and expertise to aid the effective management of New Zealand's precious freshwater resources and environments.

NIWA
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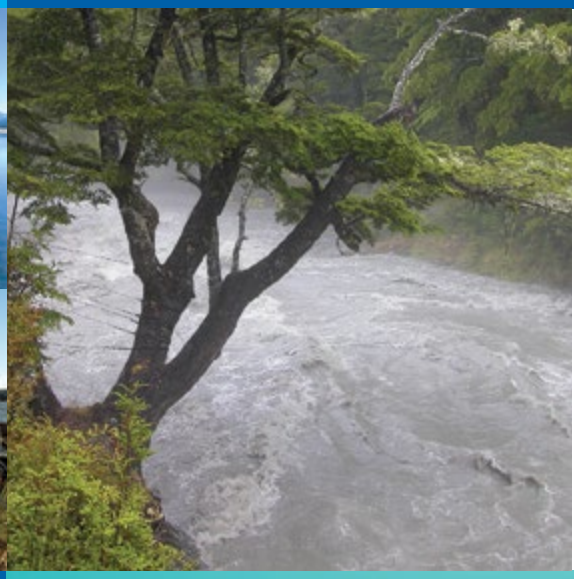
Ask us about our purpose-built tools and services.

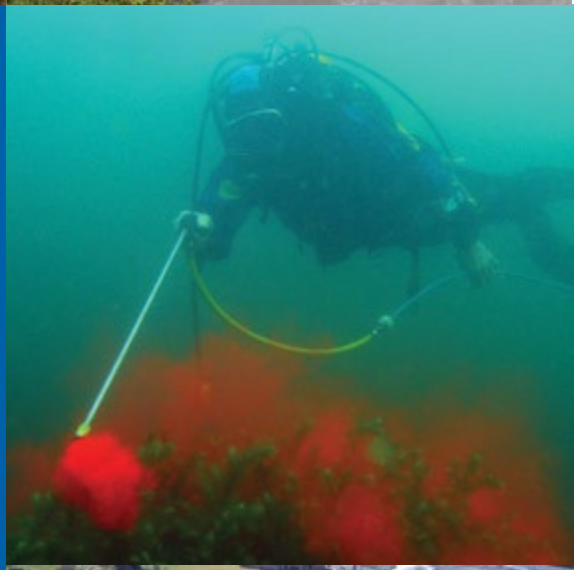


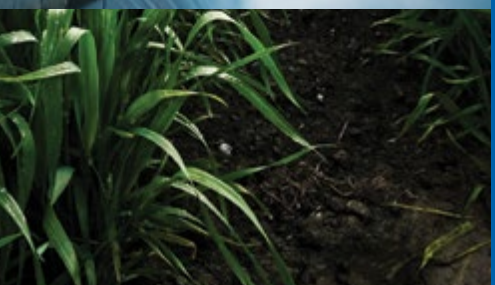
We can help you:

- assess the impacts of existing and proposed water and catchment land uses
- protect waterways from pollutants, and invasive fish and plants
- lift the efficiency, sustainability and productivity of agricultural and other water-dependent businesses
- restore waterway ecosystem health.

We achieve this using technical and natural solutions designed to:

- monitor, record and control the use, availability and quality of water
- identify the sources and reduce the impacts of pollutants
- forecast rainfall, soil moisture and river flow and their impacts on irrigation and fertiliser need, and flood and drought risk
- predict the effects of climate variability and change, and land-use change
- overcome barriers to aquatic restoration.





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MONDAY 28 NOVEMBER				
	WORKSHOPS: Groundwater Forum / WMO Hydrometry Workshop / Science Communication Workshop / Optical Nitrate Monitoring Workshop			
16.00 - 18.00	Registration Desk Open - Copthorne Hotel (opposite Millennium Hotel)			
17.00 - 19.00	Welcome Function: Copthorne Hotel - Impressions Bar			
TUESDAY 29 NOVEMBER				
7.00 - 8.00	Registration Desk Open			
8.00 - 9.00	Official Opening Ceremony Welcome Powhiri			
9.00 - 9.45	Keynote Speaker: Peter Goodwin - Idaho University Session Chair:James Ball Room: Galaxy I&II			
Room	**Galaxy I**	Galaxy II	Copthorne I	Copthorne II
	FLOODS / DESIGN	**URBAN HYDROLOGY**	**EDUCATION**	**DATA**
Chair	James Ball	Brett Phillips	Jo Hoyle	Tim Davie
10.00 - 10.15	Regional Temporal Patterns for Australian Rainfall and Runoff **Isabelle Testoni**, WMAwater	Stormwater, waterway and water resources benefits of water conservation measures in Australian cities. **Peter Coombes**, Urban Water Cycle Solutions	The rejected hypothesis - it's contribution to science success. **Stewart Cameron,** GNS Science	Integrated monitoring - can it be done? **Helen Shaw,** Environment Canterbury
10.15 - 10.30	The Australian Rainfall and Runoff DataHub **Mark Babister**, WMAwater	The journey to a Water Sensitive City - A case study of Ballarat, Victoria, Australia. **David Ebbs**, Federation University Australia	Incorporating photography to educate future hydraulic engineers. **Heide Friedrich,** University of Auckland	The value of consumer grade drones (UAVs) for river engineers. **Matthew Gardner**, Land River Sea Consulting Ltd
10.30 - 11.00	Morning Tea			
	AUSTRALIAN RAINFALL & RUNOFF	**URBAN HYDROLOGY**	**WATER RESOURCES / GROUNDWATER**	**DATA**
Chair	Mark Babister	Peter Coombes	Paul White	Helen Rutter
11.00 - 11.15	New design rainfalls for Australia – lessons learned… **Janice Green**, Bureau of Meteorology	Antecedent Rainfall prior to Significant Flows in a Small Urban Catchment. **James Ball**, UTS	Attenuation of nutrients through a ferruginous cemented sand layer in sandy soils. **Owen Hoar**, PDC	Updating a national groundwater sampling protocol. **Magali Moreau**, GNS Science
11.15 - 11.30	Technical learnings from 36th Hydrology and Water Resources Symposium Workshop on Australian Rainfall and Runoff. **Graeme Horrell**, Graeme Horrell Consultancy Limited	Is there still room for large stormwater infrastructure in the Supercity? **Lisa Dowson**, Auckland Council	Classification of the New Zealand geological map into hydrogeological and aquifer properties. **Rogier Westerhoff**, GNS Science / Deltares	Optimisation of Greater WellingtonvRegional Council's Groundwater Monitoring Networks Using Multi-Correlational and Kriging -Based Methods. **Doug Mzila**, Greater Wellington Regional Council
11.30 - 11.45	Application of AWRA-L gridded soil moisture data for flood estimation. **Peter Hill**, Hydrology and Risk Consulting (HARC)	The role of tyre crumbs as a substitute for coarse aggregates in stormwater management features. **Mitchell Sarpi**, RMIT University	Hydrogeology and groundwater analysis for the Kaituna-Maketū-Pongakawa Water Management Area, Bay of Plenty, New Zealand. **Breda Savoldelli**, Jacobs Nz Ltd	Automated Geosynthesis: A framework concept for immediate spatial-temporal decision support from e nvironmental data. **Hermann Klug**, University Of Salzburg
11.45 - 12.00	Addressing embedded bursts in design storms for flood hydrology. **Matt Scorah**, HARC	Testing the limits: methods for setting stormwater contaminant limits for urban streams. **Annette Semadeni-Davies,** NIWA	Hydrogeological study of a Fossilised Geothermal Environment: Case Study for a Gold- Silver Prospect at Puhipuhi. **Aslan Perwick**, Pattle Delamore Partners Ltd	

12.00 - 13.30	Lunch			
	Galaxy I	Galaxy II	Copthorne I	Copthorne II
	FLOODS / HISTORICAL	**URBAN HYDROLOGY**	**WATER RESOURCES / MANAGED AQUIFER RECHARGE**	**DATA**
Chair	Monique Retallick	David Ebbs	Andrew Fenemor	Lawrence Kees
13.30 -13.45	Extremes in rainfall and runoff in the Monsoonal North West of Australia from paleoclimate archives. **Danielle Verdon-Kidd**, University Of Newcastle	Rainwater Harvesting Potential in Sydney: Are We Harvesting Enough? **Ataur Rahman**, Western Sydney University	Hinds Catchment Managed Aquifer Recharge (MAR) Pilot Project Preliminary Results. **Robert Bower**, Golder Associates (NZ) Ltd	Utilisation of Non Contact Velocity Radar and Velocity Index Techniques to Validate Rating Extrapolations. **Mic Clayton**, Snowy Hydro Limited
13.45 -14.00	Extending flood series using river sedimentary archives. **Ian Fuller**, Massey University	Rainwater Harvesting Impacts on Environment. **Muhammed Bhuiyan**, RMIT University	Real-Time Groundwater Monitoring of Managed Recharge Dispersion of Groundwater at Hinds, Canterbury. **Jens Rekker**, Lincoln Agritech Ltd	Quantifying the effects of macrophyte growth on stage-discharge relationships in New Zealand lowland streams. **Jo Hoyle**, NIWA
14.00 - 14.15		Development of Generalized equations of water savings from rainwater tank for North Adelaide, Australia. **Upendra Paudel,** Swinburne University of Technology	Hinds MAR Pilot – Site Characterization Using Infiltration Test Pits. **Eric Van Nieuwkerk,** Golder Associates (NZ) Ltd	Deriving discharge with quantified uncertainty using index velocity observations: A probabilistic machine learning approach. **Stuart Hamilton**, Aquatic Informatics
14.15 - 14.30	Windsor - Australia's longest flood record. **Mark Babister**, WMAwater	Robust Supply Planning for a Metropolitan City - Portfolio Optimisation and Real Options. **Kandiah Mahadeva,** Department Of Primary Industries - Water	An Integrated Modelling Approach To The Design Of The Hinds Catchments Proposed Groundwater Replenishment Scheme. **Patrick Durney**, Canterbury Regional Council	That bloody pipe does leak – understanding the nuances of waded gaugings. **Ian Lloyd,** Golder Associates NZ Ltd
14.30 - 14.45	Bias of the Big Fella Flood - Influence of Anecdotal Floods on Mary River FFA. **Luke Toombes**, Aurecon	Multi-objective optimization and trade-off analysis for distributed stormwater harvesting systems. **Michael Di Matteo,** University Of Adelaide	Next Steps – from Pilot to Full Groundwater Replenishment Scheme based on MAR. **Bob Bower**, Golder Associates (NZ) Ltd	Hydrologists and hydrographers holding hands. **Ben Tate**, Water Technology
14.45 - 15.00	Major Floods - Random or Irregular. **Greg Mcmahon**, G M Mcmahon Consultants	Fundamentals for On-Site Stormwater Detention Design: Optimising Design Outcomes and Reducing Risk of Regional Effect. **Rodney Ronalds,** Griffith University	Managed Aquifer Recharge using a pilot to develop a Groundwater Replenishment Scheme, Poverty Bay. **Clare Houlbrooke**, Golder Associates (NZ) Ltd	Groundwater Age Distribution in the Wairau Aquifer – How the data led to understanding more complex mixing and flow processes **Uwe Morgenstern**, GNS Science
15.00 - 15.30	Afternoon Tea			

	Galaxy I	Galaxy II	Copthorne I	Copthorne II
	HYDRAULICS / BEDLOAD TRANS-PORT	**URBAN HYDROLOGY**	**WATER RESOURCES / GROUNDWATER**	**GROUNDWATER TRACING**
Chair	Richard Measures	Annette Semadeni-Davies	Ian Lloyd	Scott Wilson
15.30 - 15.45	River Load Calculator: A novel web-based tool for annual river load estimation. **Ahmed Elwan**, Massey University	Non-traditional Stabilisation of a reach of Brookvale Creek in Brookvale, NSW. **Brett Phillips**, Cardno (nsw/ act) Pty Ltd	A Hydrochemical Survey of the Groundwater Resources of South Canterbury, New Zealand. **Lee Burbery**, Institue Of Environmental Science and Research (ESR)	Using transition probabilities in combination with a smoke tracer test. **Catherine Moore**, GNS Science
15.45 - 16.00	Modelling of bio-morphodynamics in braided rivers: applications to the Waitaki river. **Guglielmo Stecca,** NIWA	Testing models for simulating urban hydrology. **Robin Connolly,** Hydrologia	Water budget of the Heretaunga Plains. **Paul White**, GNS Science	Smart Aquifer Characterisation of the Hutt Valley aquifer using novel age tracers. **Mike Toews**, GNS Science
16.00 - 16.15	Gravel transport and aggradation in the Kauerenga River. **Graham Macky**, DHI	Calibrating an Urban Catchment Modelling System with a Genetic Algorithm. **James Ball**, UTS	Spring depletion potential in the Heretaunga Plains semiconfined aquifer zone, implications for water permit consenting. **Susan Rabbitte,** Lattey Group	Modelling Heat As A Groundwater Tracer In Heterogeneous Aquifers. **Murray Close**, ESR
16.15 - 16.30	TUFLOW GPU – Best Practice Advice for Hydrologic and Hydraulic Model Simulations. **Chris Huxley**, Tuflow	Changing flow regimes in the springs of Christ-church. **Jenny Webster-Brown,** Waterways Centre For Freshwater Management		Aggregation bias in tritium-based transit times **Michael Stewart,** Aquifer Dynamics & GNS Science
16.45 - 18.00	**Poster Session** **Galaxy Rooms - Chair: Charles Pearson**			
18.00 - 19.30	**NZHS AGM** **(Millennium Galaxy I & II)**		**Engineers Australia Meeting** Discussion on future directions for Australian water industry **(Copthorne I & II)**	
19.30 - Late	**Envco Young Professionals Function - Zephyr**			

WEDNESDAY 30 NOVEMBER				
7.30 - 8.30	Registration Desk Open			
8.30 - 9.15	Keynote Speaker: Jen Crawford - Anderson Lloyd Session Chair: Joseph Thomas Room: Galaxy I&II			
Room	**Galaxy I**	Galaxy II	Copthorne I	Copthorne II
	RIVER / FLOOD PROTECTION	**WATER RESOURCES / GROUNDWATER / SEISMIC**	**WATER ALLOCATION / MANAGEMENT**	**KOREAN WATER RESOURCES ASSOCIATION**
Chair	Peter Hill	Mike Stewart	Katherine Daniell	Joseph Thomas
9.30 -9.45	We've got how many of these things? Rediscovery of Lost River Protection. **Hamish Smith**, Kiwirail	Increase in vertical permeability after the Mw7.1 Canterbury Earthquake. **Helen Rutter**, Aqualinc Research Ltd	Measuring Success: Horizons' Water Allocation Framework In The Rear-view Mirror. **Raelene Mercer**, Horizons Regional Council	Selecting Representative GCMs to Preserve Uncertainties **Young-Oh Kim,** Seoul National University
9.45 - 10.00	Defensive Engineering or Engineering A Defence. **Greg McMahon**, G M Mcmahon Consultants	Thresholds for earthquake-induced hydrological changes in New Zealand aquifers. **Konrad Weaver**, Victoria University Of Wellington	Role Of Consistent And Transparent Water Accounting Modelling For Sustainable Water Resources Management. **Uttam Manandhar,** Department of Environment, Land, Water and Planning	Development Of Hydro Economic Water Allocation Model. **Gunhui Chung**, Hoseo University
10.00 - 10.15	Comparing Design Storm Burst and Embedded Design Storm Approaches in the Narellan Creek Catchment, NSW. **Brett Phillips**, Cardno (nsw/act) Pty Ltd	Variables controlling the sustained groundwater level change after the Darfield Mw 7.1 earthquake. **Helen Rutter**, Aqualinc Research Ltd	Hydrological modelling to assist community decision making Manuherikia Catchment Water Strategy Optimisation Process. **Eric Van Nieuwkerk**, Golder Associates (NZ) Ltd	
10.15 - 10.45	**Morning Tea**			
	WATER INFRASTRUCTURE	**WATER RESOURCES / GROUDWATER**	**WATER RESOURCES / MANAGAMENT**	**CLIMATE**
Chair	Dennis Jamieson	Jon Williamson	Helen Rouse	Janice Green
10.45 - 11.00		Strategies To Overcome Unavailability Of Landuse And N Loading Inputs In Groundwater Modelling. **Channa Rajanayaka**, Aqualinc Research	Serious Fun for Tomorrow's Catchment Managers. **Carl Johnson**, DHI	How big was the January 2016 Geelong storm really? A novel use of radar data. **Doerte Jakob**, Bureau of Meteorology
11.00 - 11.15	A multiproxy 1000-year hydroclimate reconstruction for eastern Australia, and implications for water management and infrastructure. **Anna Flack**, University Of Newcastle	Calibration of a complex groundwater model using modern computation techniques, example of Heretaunga Plains model. **Pawel Rakowski**, HBRC	Back to basics – Water inventories to implement water sharing in páramo catchments of Colombia and Ecuador. **Andrew Fenemor**, Landcare Research	What is the best source of precipitation forecasts for a hydrological forecasting system? A potted exploration. **James Bennett**, CSIRO Land & Water
11.15 - 11.30	A methodology for optimisation of mine water management infrastructure **Amir Hedjripour,** WSP / Parsons Brinckerhoff	Machine-Learning Based Assistance for Groundwater Model Calibration. **Michael Friedel**, GNS Science	The role of Integrated Continental Hydrological Model (AWRA Modelling System) to Inform Water Resources Assessment. **Amgard Elmahdi**, Bureau of Meteorology	Assessing the potential impacts of climate change on the Clutha catchment. **Andreas Jobst**, Otago University
11.30 - 11.45		Can recharge be reliably estimated through regional-scale groundwater model calibration? **Matthew Knowling**, GNS Science	CHES for the Grey River Catchment. **Jan Diettrich,** NIWA	Finding spatial climate-oceanic precursors of hydro-lake inflows: Waitaki catchment, New Zealand. **Varvara Vetrova**, University of Waikato

	Galaxy I	Galaxy II	Copthorne I	Copthorne II
	WATER INFRASTRUCTURE	**WATER RESOURCES / GROUDWATER**	**WATER RESOURCES / MANAGAMENT**	**CLIMATE**
	Dennis Jamieson	Jon Williamson	Helen Rouse	Janice Green
11.45 - 12.00	Dambreak Analysis To Evaluate Downstream Hazard Potential – Several Case Studies. **David Leong**, Tonkin & Taylor Ltd	Using Best-Available Data for Robust Groundwater Model Development: An Example. **Julian Weir,** Aqualinc	UTSA Decision Support System for Burrinjuck Dam Flood Operations and Airspace Management. **Ajantha Prathab**, Water NSW	Design flood estimation in a warmer climate. **Conrad Wasko**, University of New South Wales
12.00 - 12.15	Mangorei Power Station Flood Harvesting of the Waiwhakaiho River. **Michelle Hitchcock,** Trustpower	Sensitivity of groundwater recharge estimates to distribution of intensities in satellite and reanalysis precipitation products **Rogier Westerhoff** Deltares / GNS Science	Generalized equations for rainwater tank savings under different climatic conditions: A case study for Sydney. **Upendra Paudel**, Swinburne University Of Technology	Evaluation of a model for disaggregating daily rainfall into hourly rainfields: the Logan-Albert case study. **Yeboah Gyasi-agyei,** Central Queensland University
12.15 - 13.30	**Lunch**			
	WATER USE EFFICIENCY / DROUGHT	**WATER RESOURCES / GROUDWATER**	**FLOODS**	**CLIMATE**
Chair	Trevol Daniell	John Hadfield	Robin Connolly	Graeme Horell
13.30 - 13.45	Water use efficiency and infrastructure**.** **Dennis Jamieson**, Environment Canterbury	Hawke's Bay Lysimeter Project: Installation to Data Collection - What have we learnt so far. **Abigail Lovett**, GNS Science	The Australian Government's role in reducing community flood risk: the National Flood Risk Information Project. **Martyn Hazelwood.** Geoscience Australia	Trends In Rainfall Data in New South Wales, Australia. **Himadri Paul**, Western Sydney University
13.45 - 14.00	The Irrigation Efficiency Dilemma. **Ian McIndoe**, Aqualinc Research Ltd	Methods for mapping uncertainty in modelled groundwater age. **Chris Daughney**, GNS Science	The state of hydrologic practice in Victoria, Australia. **Anthony Ladson**, Moroka Pty Ltd	Long-term Rainfall Prediction using Large Scale Climate Variables through Linear and Non-linear Methods. **H.M Rasel**, Swinburne University Of Technology
14.00 - 14.15	Water use efficiency – What's working and what's not: An update from a field study. **M.S. Srinivasan,** NIWA	Mine Pit Lake Water Level Recovery. **James Dommisse,** MWH	Developing a consistent floodplain risk assessment process for Tasmania. **Chris White**, University Of Tasmania	Relationship between Meteorological and Hydrological Drought Characteristics. **Chandi Shakila Dissanayake,** Rmit University
14.15 - 14.30	Lake Coleridge Power Scheme: enhancement initiatives. **Lennie Palmer,** Trustpower NZ Ltd	Managed Aquifer Re-charge: A Multi Criteria Feasability Assessment Tool. **Dave Stafford**, Pattle Delamore Partners	The future of flood hazard mapping. **Mark Hooker**, Greater Wellington Regional Council	Disparity between observed rainfall trends in Canterbury and climate change guidelines. **Tim Kerr,** Aqualinc Research Ltd
14.30 - 14.45	How low will they go? Diminishing summer flows in the Wairarapa. **Mike Thompson**, Greater Wellington Regional Council	Wairau Aquifer recharge pathways. **Scott Wilson**, Lincoln Agritech Limited	No rain recorded - why did it flood? **Jon Rix**, Tonkin + Taylor Ltd	Atmospheric controls on snow and ice melt on Brewster Glacier, South Westland. **Jonathan Conway**, Bodeker Scientific
14.45 - 15.00	Evaluation of hydrological drought severity. **Sadia Rahman**, Rmit University	Development of a ground-water model for a tropical eogenetic karst aquifer in Rote Island, Indonesia. **Dua Klaas**, Swinburne University of Technology	20-21 June 2015 major lower Whanganui flood – determination of size, frequency and other characteristics. **Jon Bell**, Horizons Regional Council	An improved interpolated daily climate record for New Zealand. **Peter Brown,** Aqualinc Research Ltd
15.00 - 15.30	**Afternoon Tea**			

	Galaxy I	Galaxy II	Copthorne I	Copthorne II
	WATER QUALITY	**WATER RESOURCES / SURFACE WATER / GROUNDWATER**	**FLOODS**	**CLIMATE**
Chair	Murray Close	Michael Stewart	Toby McGrath	MS Srinivasan
15.30 - 15.45	The seasonal dynamics of the stream source waters and flowpaths in an Austrian headwater catchment. **Michael Exner-Kittridge,** Environment Canterbury	Groundwater surface water interaction in the vicinity of the Blue Spring. **John Hadfield,** Waikato Regional Council	Flood Forecasting by scenario lookup. **Richard Measures**, NZ Nat. Inst. Water & Atmospheric Research	Chasing The Significance Of Fog Deposition In Otago's Tussock Grasslands. **Sarah Mager**, University Of Otago
15.45 - 16.00	Groundwater Chemistry And Residence Time In The Lower Hutt Aquifer: The Relationship To Iron Bacteria. **Rob van der Raaij,** GNS Science	Estimating the change in stream flow resulting from groundwater takes. **Tim Kerr**, Aqualinc Research Ltd	Experiences Exploring The Feasibility of Constructing a Very Large Scale 2D Flood Model Of Tasmania. **Ted Rigby**, Rienco Consulting	Uncertainty in future rainfall and river flows in New Zealand under changes in climate. **Chris Cameron**, Bodeker Scientific
16.00 - 16.15	Edaphic and Geological Controls over Redox Processes in Southland's Ground & Surface Water. **Monique Beyer,** Environment Southland	Long term variability of proglacial groundwater-fed hydrological systems in an area of rapid glacier retreat. **Amir Levy**, Lattey Civil and Precast	Assess Flooding Potential in the Vicinity of the Myponga Reservoir Area. **Guna Hewa**, University of South Australia	Climate change impacts on hourly precipitation across New Zealand; potential downstream impacts. **Christian Zammit**, NIWA
16.15 - 16.30	Groundwater microbial community assessment - can shifts in composition predict contamination? **Lousie Weaver**, Institute Of Environmental Science & Research (ESR) Ltd	Surface water and groundwater dynamics in the Ohau and Waikawa catchments, Horowhenua. **Abby Matthews**, Horizons Regional Council	Constraining the Ensemble Kalman Filter for improved streamflow forecasting. **Deborah Maxwell**, Victoria University of Wellington	How effective is quantile mapping for post-processing GCM ensemble forecasts. **QJ Wang**, CSIRO Land and Water
16.30 - 16.45		Modelling Groundwater-Surface Water Balance Dynamics for Water Allocation. **Blair Thornburrow**, Pattle Delamore Partners	A Review of Stream Gauge Records for Design Flood Estimation. **James Ball**, UTS	Water Balance of the Upper to Middle Niger Basin and the Impact of Climate Change. **Boubacar Seydou Coulibaly,** UTS
16.45 - 17.00		Modelling surface water - groundwater interaction using a newly developed conceptual surface water-groundwater model. **Jing Yang**, NIWA	Approaches for a Pilot Catchment Flood Study in Qatar. **Benjamin Regan**, GHDGlobal Pty Ltd	Combined Regression Modelling of Winter Rainfall in Western Australia Using Potential Climate Indices. **Farhana Islam**, Swinburne University of Technology
17.30 - 19.00	Drinks on arrival followed by the Munro Oration Galaxy Rooms: Chair - Toby McGrath			

THURSDAY 01 DECEMBER				
8.00 - 9.00	Registration Desk Open			
9.00 - 9.45	Keynote: Rory Nathan - University of Melbourne Session Chair: Mark Babister Room: Galaxy I&II			
Room	**Galaxy I**	Galaxy II	Copthorne I	Copthorne II
	FLOODS / DESIGN	**CATCHMENT HYDROLOGY**	**WATER RESOURCES**	**WATER QUALITY / SEDIMENT**
Chair	Charles Pearson	Daniel Collins	Tim Kerr	Sarah Mager
10.00 - 10.15	Interdependence of design losses and temporal patterns in design flood estimation. **Melanie Loveridge**, Water NSW	Uncertainty analysis of hydrologic model parameters through Monte Carlo Methods in XPRAFTS. **Sophia Buchanan**, XP Solutions	Investigating the challenges of water governance in Oceania. **Katherine Daniell,** The Australian National University	How does uncertainty in land use change influence flow and sediment projections? **Bikesh Shrestha**, University Of Canterbury
10.15 - 10.30	A review of the capabilities of RORBwin: an enabling tool for application of ARR2016. **David Stephens**, HARC	Understanding mean transit times of river water in Australian headwater catchments using tritium. **Ian Cartwright**, Monash University	Modelling to support water resource management of the Hakataramea catchment in South Canterbury. **Mike Law,** BECA Ltd	Application of daily SedNet for modelling catchment-scale sediment generation and transport: New Zealand case study. **Lydia Cetin**, Jacobs
10.30 - 10.45	Novel Methods for Improved Filtering of Rain on Grid Results for Flood Mapping. **Elliot Jones**, GHD	A modern perspective on hydrology processes of two catchments in regional Victoria. **Peter Coombes**, Urban Water Cycle Solutions	eWater Source as an integrated modelling tool supporting policy and management in SE Asia. **Juanita Moolman**, eWater Ltd	Why do suspended sediment-turbidity relationships fail? **Christina Bright** and **Sarah Mager**
10.45 - 11.15	**Morning Tea**			
	FLOODS / DESIGN	**WATER RESOURCES / SURFACE WATER**	**WATER RESOURCES / SURFACE WATER / GROUNDWATER**	**WATER QUALITY**
Chair	Mike Law	Kyle Christensen	Joseph Thomas	Chris Daughney
11.15 - 11.30	Stuck in the 1960s – the Need for Fundamental Change in Flood Hydrology in Australia. **David Kemp**, University Of South Australia	Regionalisation of the parameters of a rainfall runoff model: A case study adopting Australian Water Balance Model. **Ataur Rahman,** Western Sydney University	An evaluation of analytical stream to groundwater exchange models based on spatial flow assumptions. **Michael Exner-Kittridge,** Environment Canterbury	Nutrient Variability Over Short Time Scales in Pristine Alpine Catchments. **Emily Diack**, Williamson Water Advisory
11.30 - 11.45	ARR Blockage: Numerical Implementation and Three Case Studies. **Paul Ollett**, Hydralinc Pty Ltd	Estimating the incremental increase in inflows due to cloud seeding over the Australian Snowy Mountains. **James Pirozzi**, Snowy Hydro	Modelling groundwater – surface water interactions with the Double-Averaged Navier-Stokes Equations. **Andrew Dark**, Aqualinc Research Ltd	Investigation of nitrogen loads and transport pathways in the Kaiapoi River catchment. **Zeb Etheridge**, Environment Canterbury
11.45 - 12.00	Blockage is random! A probabilistic framework to estimate blockage factors for design flood modelling. **Rhys Hardwick-Jones,** WMAwater	Accounting for water at a national level. **Janice Green**, Bureau Of Meteorology	Changes in the hydrological regime of the Wairau Plains Aquifer. **Thomas Wöhling,** Technische Universität Dresden / Lincoln Agritech Ltd.	Investigating nutrient pathways in groundwater to meet community expectations. **Marta Scott**, Environment Canterbury
12.00 - 12.15	Flood frequency models of New Zealand: Past, present and future. **Daniel Collins,** NIWA	Impact of spatial and temporal averages on prediction of water security using systems analysis. **Peter Coombes**, Urban Water Cycle Solutions	Using three dimensional groundwater flow models for major infrastructure projects: from consenting to construction. **Dora Avanidou**, BECA	Modelling the impact of Denitrification on N removal in the Reporoa catchment. **Murray Close**, ESR

	Galaxy I	Galaxy II	Copthorne I	Copthorne II
	FLOODS / DESIGN cont..	**WATER RESOURCES / SURFACE cont..**	**WATER RESOURCES / SURFACE WATER / GROUNDWATER cont..**	**WATER QUALITY cont..**
	Mike Law	Kyle Christensen	Joseph Thomas	Chris Daughney
12.15 - 12.30	Efficacy of a storm-based Monte Carlo approach in modelling flood volumes. **Melanie Loveridge,** Water NSW	Using Calibration Strategies to Emulate a Complex River Basin Model with a Simplified Fit-For-Purpose Model. **Rebecca Borwell**, University Of Newcastle	Towards collaborative groundwater – surface water interaction models from catchment to regional and national scales. **Christian Zammit**, NIWA	Low-gradient streams need more flow for oxygen. **Thomas Wilding,** Hawke's Bay Regional Council
12.30 - 12.45	Incorporation of snowmelt into joint probability event based rainfall-runoff modelling. **David Stephens**, HARC	SUMMA time in the Waikato – Rainfallrunoff modelling in ungauged catchments. **Bevan Jenkins**, Waikato Regional Council	Assessing Groundwater and Surface Water interactions in Sukhuma District, Champasak Province, Southern Laos. **Sinxay Vongphachanh**, University Of Technology Sydney	Stratification of groundwater age and quality at Lake Taupo from Push-drill tests. **Uwe Morgenstern,** GNS Science
12.45 - 13.30	**Lunch + Rivers Group AGM**			
	FLOODS / DESIGN	**WATER RESOURCES / SURFACE WATER**	**WATER RESOURCES / MANAGEMENT**	**WATER QUALITY**
Chair	Roddy Henderson	Mike Thompson	Helen Shaw	Catherine Moore
13.30 - 13.45	Deriving Temporal Patterns for Areal Rainfall Bursts. **Scott Podger**, WMAwater	Bayesian Calibration Of A Lumped Model To Estimate Catchment Nitrate Fluxes From Monthly Monitoring Data. **Simon Woodward**, Lincoln Agritech Limited	New approaches to water management in Otago. **Peter Wilson**, Otago Fish And Game Council	Sedimentary anisotropy and its effects on solute mixing in groundwater. **Jeremy Bennett**, University of Tübingen
13.45 - 14.00	Estimation of Plotting Position for Flood Frequency Analysis. **Rob Connell**, Independent Researcher	Streamflow Forecasting Based on Ensemble Streamflow Prediction Technique: A Case Study in New Zealand. **Shailesh Kumar Singh**, NIWA	Scenario Planning As A Tool For Integrated, Collaborative Freshwater Management Decision Making. **Helen Rouse**, NIWA	Geochemical modeling of electron donors involved in denitrification in the Lake Taupo catchment. **Scott Korom**, Barr Engineering Company
14.00 - 14.15	Application of ARR FLIKE for At-site Flood Frequency Analysis in New South Wales, Australia. **Himadri Paul**, Western Sydney University	Water resources opportunities from near real time national soil moisture assessment. **Adam Smith**, Bureau Of Meteorology	Using leading-edge research to inform freshwater management policies: example of the Southland region, NZ. **Magali Moreau**, GNS Science	Automated detection of (missing) buffer stripes surrounding rivers in the Mondsee catchment. **Hermann Klug,** University Of Salzburg
14.15 - 14.30	Regional Flood Modelling in Tasmania: Comparison of ARR RFFE Model and Kriging. **Ataur Rahman**, Western Sydney University		Strategic Water Resource Planning using eWater Source in Port Macquarie, Australia. **Mahala McLindin and Andrew Herron**, Jacobs	Spatial prediction of groundwater redox status. **Scott Wilson**, Lincoln Agritech Limited
14.30 - 14.45	KiwiRail Main South Line – Bridge 190 Shag River Hydraulic Assessment. **Daniel Mcmullan**, Opus International Consultants Ltd	Hydrological applications of Australian and New Zealand atmospheric reanalysis. **Adam Smith**, Bureau Of Meteorology	Understanding the value of reconstructing environmental history of reservoirs for improved water supply management. **Neeraj Mall**, Federation University Australia	Parameterisation and simulation of the SMWBM within the Source catchment model. **Jon Williamson**, Williamson Water Advisory

	Galaxy I	Galaxy II	Copthorne I	Copthorne II
	FLOODS / DESIGN cont..	**WATER RESOURCES / SURFACE WATER cont..**	**WATER RESOURCES / MANAGEMENT cont..**	**WATER QUALITY cont..**
	Roddy Henderson	Mike Thompson	Helen Shaw	Catherine Moore
14.45 - 15.00	Incorporation of snowmelt into joint probability event based rainfall-runoff modelling. **David Stephens**, HARC	Assessment of AWAP large-scale hydrological model to detect influence of climate drivers on runoff variability. **Lanying Zhang**, University Of Newcastle	Satellite Remote Sensing For Water Resources Management and Groundwater Modelling In the Waimakariri Zone. **Fouad Alkhaier**, Environment Canterbury	The practicalities of managing catchments to fixed nutrient limits: a case study from the Hurunui. **Peter Brown**, Aqualinc Research Ltd
15.00 - 15.15	Standardising hydrological modelling for the Wellington region (Wellington's own TP108). **Charlotte Lockyer**, Cardno	Development and calibration of HEC-RAS model for the Juqueriquerê river basin in São Paulo, Brazil. **Vassiliki Terezinha Galvão Boulomytis,** Swinburne University of Technology	Policy responses to the identification by Maori of flows necessary to maintain their cultural values. **Gail Tipa**, Tipa and Associates Ltd	National Sea Outfall Assessment in Qatar: Opportunities and Challenges. **Abdullah Al Mamoon**, Ministry Of Municipality And Environment
15.15 - 15.45	**Afternoon Tea**			
	FORECASTING	**WATER RESOURCES / MODELLING**	**WATER RESOURCES / GROUNDWATER**	**WATER QUALITY**
Chair	Fiona Ling	Jan Diettrich	Abigail Lovett	Michael Exner-Kittridge
15.45 - 16.00	Operational flood forecasting with a bias corrected high resolution weather forecast. **Celine Cattoen-Gilbert**, NIWA	Hydrological analysis: are we modelling or muddling? **Earl Bardsley**, University Of Waikato	Conceptual model of groundwater movement through the Ohau and Waikawa groundwater catchments. **Neil Thomas,** Pattle Delamore Partners	Building wider engagement through creative interfaces to water quality models developed in Source. **Phillip Jordan** Hydrology And Risk Consulting Pty Ltd
16.00 - 16.15	Real-Time Flood Forecasting – You Probably Already Have What You Need. **Cameron Drurey**, WorleyParsons	Hydraulic modelling to inform physical constraints on environmental flows in the Gwydir floodplain. **Monika Balicki**, Water Modelling Solutions	Sam and Decision Crash Testing Models. **Catherine Moore**, GNS Science	Improving aquatic community health with the help of big data bedload transport studies. **Andrew Neverman**, Massey University
16.15 - 16.30	Stochastic updating for ensemble hydrological forecasting. **QJ Wang**, CSIRO Land and Water	Waipaoa River Catchment Modelling, Gisborne. **James Blyth**, Jacobs	Modeling and calibration of groundwater flow for Qatar aquifer. **Husam Baalousha**, Qatar Environment And Energy Research Institute (QEERI)	Kopeopeo Canal Remediation - Community Engagement and Dredging Trial. **Ken Tarboton**, Aqueus Consulting
16.30 - 16.45	Quantifying total uncertainty in short-term streamflow forecasts through pre & post-processing. **James Benett**, CSIRO Land & Water	A national pressure-state-impact model for freshwater flows. **Doug Booker**, NIWA	An integrated catchment modelling approach to set and review New Zealand water and nutrient policies. **Andrew Herron**, Eco Logical Australia	Real-time measuring and modelling phosphorus runoff using SWAT and AGNPS. **Hermann Klug**, University Of Salzburg
16.45 - 17.00	Forecasting the Hutt. **Greg Whyte**, DHI Water & Environment	Modelling to support planning, in a lowflow, rapidly developing environment in Western Australia. **Stephan Suter**, DHI Water & Environment		Physiographic Controls over Southland's Ground & Surface Water Chemistry – Lessons Learnt. **Clint Rissman**, Environment Southland
17.00	**Conference Close**			
18.00	**Buses depart from Millennium for Conference Dinner - Skyline Gondola**			

FRIDAY 16 DECEMBER

Field Trips

PLEASE SEE PAGE 23 FOR DETAILS

ORAL ABSTRACTS

In order of presenters Last Name

National sea outfall assessment in Qatar: Opportunities and challenges

Abdullah Al Mamoon[1], Ataur Rahman[2], Khalifa Hassn JH Buhazzaa[1], Subhi Almasri[3]
[1]*Ministry of Municipality and Environment,* [2]*Western Sydney University,* [3]*ASCO Consulting Qatar*

Most of the pollutants that originate in land areas end up in the sea through different routes, including sea outfalls. This paper presents an overview of the ongoing national sea outfall study in Qatar. Except for a small span of land border with Saudi Arabia, Qatar is surrounded by the Arabian Gulf, which is a semi-enclosed but shallow water body with a sensitive marine environment. The Arabian Gulf is characterised by a low energy environment with a limited water exchange capacity, and hence, pollutants entering into this water body via sea outfalls are unlikely to be dispersed quickly similar to deep sea outfalls. In this paper, an overview is presented of the Arabian Gulf as a sea outfall location for Qatar where significant infrastructure developments have been happening for the last 20 years or so. These rapid developments may impact its fragile marine environment if not well managed. In this paper, the previous sea outfall studies in the Arabian Gulf are reviewed. The ambient marine water quality and effluent standards in Qatar are compared with the nearby Gulf countries. Finally, important issues in relation to the ongoing national sea outfall study in Qatar are highlighted in relation to its national vision.

Satellite remote sensing for water resources management and groundwater modelling in the Waimakariri Zone

Fouad Alkhaier[1]
[1]*Environment Canterbury*

Data from earth observation satellites have been demonstrated to be valuable for water resources management worldwide. Some technical applications include:

- Retrieving surface temperature and vegetation indices
- Crops classification, irrigated area mapping
- Soil moisture and actual evapotranspiration calculations: these calculations are useful to estimate recharge and feed into the water balance estimations
- Using thermal anomalies in land and sea to detect groundwater discharge
- Observing lake water quality indicators such as suspended particulate matter (SPM), coloured dissolved organic matter (CDOM), Chlorophyll-a absorption and turbidity.

Recently, two types of high-resolution multi-spectral satellite imagery have become available to the scientific community free of charge: ASTER and Landsat 8. ASTER is an imaging instrument on board the Terra satellite launched in late 1999. Landsat 8 is an Earth observation satellite launched in early 2013. Both ASTER and Landsat 8 sensors operate in the visible, near-infrared, shortwave infrared and thermal infrared spectra. Their spatial resolution ranges between 15 and 100 metres.

The no-cost availability of these satellite data provides the ideal opportunity to increase their use for water resources management and groundwater modelling in our catchments. This paper investigates these data use possibilities in the Waimakariri Zone on the northern Canterbury Plains. Initially, the data will be used to monitor irrigated area and to estimate actual evapotranspiration. Other applications include monitoring possible thermal anomalies to show potential groundwater discharges.

Using three-dimensional groundwater flow models for major infrastructure projects: From consenting to construction

Theo Sarris[1], **Theodora Avanidou**[1]
[1]*Beca Ltd*

A robust groundwater flow model can be a valuable tool for better understanding impacts of infrastructure projects on groundwater systems and the associated environment. Construction activities that extend below the groundwater table have had significant effects in the past, including cease or significant reduction of stream baseflows, drying of wetlands, water quality degradation of riparian ecosystems, and induced land subsidence and ground cracks. In major infrastructure projects, decision-makers require adequate information on how construction activities may interact with the groundwater flow regime in order to better understand, manage and formulate sustainable mitigation strategies, throughout the project cycle, starting from planning to consenting and construction.

This paper presents an overview of the regional groundwater flow modelling work that was undertaken as part of the MacKays to Peka Peka Expressway project in Kāpiti Coast, and how this work evolved and was used through the various project phases. The Expressway is a road of national significance that crosses a highly valuable and sensitive coastal ecosystem. The model that was initially developed at the consenting phase for the Assessment of Environment Effects was further refined with additional information obtained through detailed field investigations and long-term monitoring, and was constantly updated throughout the project cycle to guide swale construction design, construction water supply development, manage dewatering effects and provide reliable and sustainable mitigation options.

Modelling and calibration of groundwater flow for the Qatar aquifer

Husam Baalousha[1]
[1]*Qatar Environment and Energy Research Institute (QEERI)*

Groundwater models are good tools for water resources management and protection. The problem with models is the data requirement and calibration. As the number of calibrated parameters increases, so does the computational time and effort.

The Qatar aquifer is the only natural source of water supply, which is being used for irrigation. Due to heavy pumping, the aquifer storage has sharply dropped and the seawater intrusion – brackish water upconing – becomes very common. In the light of Qatar Vision 2030, water security was identified as one of the country's main Grand Challenges. The Aquifer Storage and Recovery Project was initiated to artificially recharge the over-exploited aquifer and to counter the environmental impacts resulting from over-pumping.

A groundwater flow model was developed for aquifers in Qatar to understand the steady-state flow regime, and to be used as a basis for a transient state model. The model covers the entire area of the country (11,500km^2) and was discretised into a 500 × 500m grid comprising 208 columns and 390 rows. The model contains three layers representing the main geological formations of the aquifers.

To overcome the problem of high parameterisation, the pilot-points approach with regularisation was utilised. This approach uses calibrated parameter values at pilot points and interpolates them on the model domain.

Results of this study include a calibrated steady-state flow model, and calibrated hydraulic conductivities and rainfall recharge. Water budget analysis revealed that the current groundwater abstraction is around five times more than the natural rainfall recharge.

Windsor: Australia's longest flood record

Mark Babister[1], Terry McKeown[2], Monique Retallick[1]
[1]*WMA Water,* [2]*Retired*

The flood record at Windsor on the Hawkesbury Nepean dates back to 1799 and is Australia's longest flood record. This long record is very important for understanding the flood behaviour on the east coast of Australia, including the climate cycles that drive flooding. The flood range at Windsor is very large and has been causing problems with floodplain management since the settlement of Australia. Floodplain management in Australia started at Windsor with a series of proclamations by Governor Macquarie in the early 1800s. Over 200 years later we are still grappling with how to manage this enormous flooding and risk to people. The long record also contains some key lessons on incorporating correctly interpreted historical flood records and incorporating this historical flood information in frequency analysis. Early colonial records contain a lot of flood level estimates that should not be accepted on face value and certainly do not accord with other records that compare the relative height of events. This paper also sets out to correct some flood levels that are often taken at face value from historical records with validation.

The Australian Rainfall and Runoff DataHub

Isabelle Testoni[1], **Mark Babister**[1], Monique Retallick[1], Melanie Loverigde[1]
[1]*WMA Water*

As part of the Australian Rainfall and Runoff (ARR) 2016, updated regional patterns for Australia have been developed. ARR Research Project 3: Temporal Patterns of Rainfall investigated a number of different methods of temporal patterns selection and created an Australia-wide storm database.

The final recommended regional temporal patterns for ARR have been through a rigorous testing process. These temporal patterns have been sourced from pluviographs within the region and/or adjoining regions. The patterns were then sorted into three Annual Exceedance Probability (AEP) "bins". Temporal patterns were then selected based on criteria set. The evolution of this criteria and the lessons learnt from this project are discussed in this paper. Final testing and quality control of the patterns has also been undertaken and is presented herein.

Hydraulic modelling to inform physical constraints on environmental flows in the Gwydir floodplain

Monika Balicki[1], Daniel Knott[1], Neal Albert[2]
[1]*Water Modelling Solutions Pty Ltd,* [2]*Office of Environment and Heritage*

As part of implementing the Basin Plan, the Murray-Darling Basin Authority (MDBA) is proposing to develop a Constraints Management Strategy to investigate and implement ways to get better environmental watering results for wetlands and rivers through addressing physical and operational management constraints. Seven focus areas in the Basin have been identified where the relaxation of constraints needs detailed consideration, including the Gwydir floodplain.

Most of the land within the Gwydir focus area is used for agriculture – mainly cotton, wheat and grazing. The Office of Environment and Heritage currently delivers environmental flows to high-value ecological assets along the system and wetlands in the Gwydir. Due to the small channel capacity of the rivers and creeks, some environmental water is carried overbank and has the potential to inundate agricultural land, which can have positive or negative impacts.

This paper details the use of hydraulic modelling to inform the Constraints Management Strategy. Specifically, how hydraulic modelling was used to determine inundation extents for a range of flow scenarios and inform where physical constraints are causing flood redistribution impacts. The modelling will also assist in identifying proposals, such as easements, to aid delivery of environmental flows in the Gwydir focus area

A review of stream gauge records for design flood estimation

Prof James Ball[1], Annabel Kerr[1], Guilherme Carneiro Rocha[1]
[1]*University of Technology Sydney*

Design flood estimation remains a problem for many professionals involved in the management of rural and urban catchments. Recorded flood data provides the basis for most design flood estimation; the recorded flood data is used in application of the design flood estimation technique (FFA) or in the development of the technique (RFFE). In general, data used for design flood estimation is the peak flow of the flood hydrograph. However, the data recorded at most gauging stations is the water level in the channel (the channel stage). To convert these stages to an equivalent flood flow, a rating curve or a stage–discharge relationship is used. For most design flood problems, extrapolation of the stage–discharge relationship usually is required to enable the desired translation. There is a need to consider the magnitude of this extrapolation of the stage–discharge relationship. Furthermore, there is a need to consider the data used for development of the stage–discharge relationship and the impact of this data on the subsequent extrapolation. Presented herein will be the results of an investigation into stage–discharge relationships and their basis.

Calibrating an urban catchment modelling system with a genetic algorithm

Prof James Ball[1], Linh Than Ngyuen[1]
[1]*University of Technology Sydney*

Estimation and management of flows in urban catchments remains an issue for many urban catchment managers. Catchment modelling is one approach that has received widespread usage by the profession. There are numerous catchment modelling systems that have been applied for the purpose of simulating flows in urban catchments. The Storm Water Management Model (SWMM) is one modelling system that has achieved widespread usage throughout the world. As a distributed catchment modelling system, application of SWMM requires users to deal with a large number of spatially variable parameters which describe subcatchment characteristics. In implementing a physically distributed catchment modelling system, a variety of uncertainties arise from the imperfect model structures, the assumptions regarding input variables, and measurement errors. Identifying a unique optimal parameter set in a complex catchment modelling system is extremely difficult, if not impossible, due to these uncertainties and also the unknown parameter interactions. The "equifinality" concept recognises sets of behavioural parameter values applied within a given model structure can generate similar simulation performance. The study reported herein used a real-value coding genetic algorithm as a tool to search for behavioural parameter sets in the application of SWMM for simulating runoff from the Powells Creek catchment in Sydney.

Antecedent rainfall prior to significant flows in a small urban catchment

Prof James Ball[1], Vegard Osthus[1]
[1]*University of Technology Sydney*

Estimation and management of flows in urban catchments remains an issue for many urban catchment managers. Catchment modelling is one approach that has received widespread usage by the profession. While rainfall is the dominant process influencing the magnitude of the predicted flows, there are many other processes that also influence the predicted flow. Among these processes are those incorporated in the generic loss model; these processes include the infiltration model. One factor that influences the infiltration model is the antecedent wetness of the catchment. Presented herein are the results of an investigation into the antecedent rainfall for the Powells Creek catchment in Sydney. This investigation considered the rainfall 6 hours, 12 hours, 1 day, 2 days, and 5 days prior to the occurrence of the top 150 events recorded at the Powells Creek gauging station.

Hydrological analysis: Are we modelling or muddling?

Earl Bardsley[1], Varvara Vetrova[1]
[1]*University of Waikato, Faculty of Science & Engineering*

Hydrological journal articles have ever-increasing numbers of cited references, but is hydrological science and hydrological knowledge really advancing? A common feature of many hydrological models is the illusion of mathematical sophistication and misleading graphical displays. The presentation will cover a range of selected topics, including wavelet forecast methodology, which requires the forecast value to be known in advance, good forecasts from random numbers, high river flow being less probable on July 20 than July 25, and distributions of flood maxima with zero discharge as the most frequent event. The use of mathematical formalism in distribution estimation is also questioned when subjective estimation may give a better result by any pragmatic measure. Ending on a more constructive note, an alternative model of extreme value theoretical analysis is proposed to replace the three asymptotic extreme value distributions (and the GEV equivalent) and their silly notions of upper and lower discharge bounds appearing and disappearing with a minor change in a data value.

What is the best source of precipitation forecasts for a hydrological forecasting system? A potted exploration

Durga Lal Shrestha[1], David Robertson[1], **James Bennett**[1], QJ Wang[1]
[1]*CSIRO Land and Water*

In recent years a substantial research effort has aimed to incorporate precipitation predictions from numerical weather prediction (NWP) models into streamflow forecasts. We assess two NWP forecast products for their suitability in streamflow forecasting: 1) the deterministic ACCESS-G NWP, operated by the Bureau of Meteorology, and 2) the "Poor Man's Ensemble" (PME), an ensemble of eight deterministic NWP models, which forms the basis of operational weather forecasting in Australia.

We first compare the mean of the PME precipitation forecasts to ACCESS-G forecasts over 21 Australian catchments. In general, the mean PME forecasts exhibit lower errors and biases than ACCESS-G. We extend the analysis by applying a post-processing algorithm to both ACCESS-G forecasts and the mean PME forecasts. The post-processor is based on a Bayesian joint probability approach, and is very effective at correcting biases at the catchment scale, removing noise and quantifying forecast uncertainty. Forecast uncertainty is represented in the form of an ensemble, and we use the Schaake shuffle to ensure each ensemble member has realistic spatial and temporal properties. Post-processing improved both ACCESS-G and PME forecasts: post-processed forecasts are unbiased and have substantially lower errors than unprocessed forecasts. After post-processing, the performance of ACCESS-G was all but indistinguishable from that of PME. In addition, the statistical properties of the mean PME forecasts made them less amenable to post-processing. We conclude that simple ensembles like PME offer advantages over deterministic forecasts like ACCESS-G for use in hydrological forecasting, but that these advantages are obviated by robust post-processing methods.

Quantifying total uncertainty in short-term streamflow forecasts through pre- and post-processing

James Bennett[1], David Robertson[1], QJ Wang[1], Ming Li[2], Durga Lal Shrestha[1]
[1]*CSIRO Land and Water,* [2]*Data61*

Ensemble streamflow forecasts offer the promise of higher accuracy and explicit quantification of forecast uncertainty. Uncertainties arise from observations, precipitation forecasts and hydrological models. Ideally, we would understand and be able to quantify the uncertainty from each source, and these would sum together to accurately represent total forecast uncertainty. In practice, correctly quantifying the forecast uncertainties is very challenging and many ensemble forecasting systems opt simply to quantify rainfall forecast uncertainty, leading to poor representations of total forecast uncertainty. We present a new method that is able to reliably quantify total streamflow forecast uncertainty.

The method treats uncertainties arising from weather observations and forecasts separately from those arising from hydrological models and observations. We pre-process precipitation forecasts from a deterministic Numerical Weather Prediction (NWP) model with a Bayesian joint probability method that i) corrects forecasts biases, ii) removes noise, and iii) reliably represents forecast uncertainty. We use the Schaake shuffle to instil correct temporal and spatial properties in the forecasts to produce an ensemble . Ensemble precipitation forecasts are then run through the GR4H hydrological model and a 3-stage hydrological error model. The hydrological error model corrects biases, and quantifies and propagates uncertainty through the streamflow forecast.

We show in a case study of the Murray River that the forecasts are highly accurate at short lead-times. Our forecast ensemble correctly quantifies the increase in uncertainty with lead-time: forecasts are statistically reliable at all lead-times. The forecasting method proposed here will form the basis of an operational ensemble forecasting service in Australia.

Sedimentary anisotropy and its effects on solute mixing in groundwater

Jeremy Bennett[1], Claus Haslauer[1], Prof Olaf Cirpka[1]
[1]*University of Tübingen*

Transverse mixing has been proven to control the length of steady-state contaminant plumes in situations where solutes are degraded through interaction with ambient groundwater. Numerical modelling has demonstrated that changes in the orientation of hydraulic anisotropy can cause complex groundwater velocity flow fields which impact transverse mixing and thus the length of mixing-controlled contaminant plumes. However, these studies are implemented in idealised porous media that are not geologically plausible.

Sedimentary anisotropy occurs due to variations in streamflow over a wide range of spatial and temporal scales. For example, Quaternary trough cross-stratified gravel deposits in the Canterbury Plains showed strong orientation differences. Such internal anisotropy of sedimentary units (i.e. orientation variability) has been largely neglected in hydrogeological modelling.

In this study, we consider a virtual, three-dimensional gravel aquifer composed of trough-fill structures, with blockwise homogeneous anisotropic hydraulic conductivity, mimicking trough features observed in glaciofluvial sediments of the upper Rhine Valley, Germany. We generate multiple realisations, perform flow simulations in such a way that the mean flow velocity is identical among all realisations in all cases, and conduct transport simulations on streamline-oriented grids.

The results clearly show that variability in the orientation of anisotropy is the key factor for variability in transverse flow components and thus controls transverse mixing. The results of this study are relevant to practitioners considering natural attenuation of contaminants in groundwater in a New Zealand context.

Edaphic and geological controls over redox processes in Southland's ground and surface water

Monique Beyer[1,2], Clint Rissmann[1,2,3,4], Michael Killick[1], Ewen Rodway[1], Janet Hodgetts[1], Tapuwa Marapara[1], Karen Wilson[1], Brydon Hughes[1], Rachael Millar[1], Lisa Pearson[1], Roger Hodson[1], Abbas Akbaripasand[1], James Dare[1], Tim Ellis[1], Maggie Lawton[1], Nick Ward[1], Jane McMecking[1], Darren May[1], Lawrence Kees[1]

[1]Environment Southland, [2]Land and Water Science, [3]GNS Science, [4]Waterways Centre for Freshwater Management

Many studies have shown that redox processes are the main determining factor for the variability in water chemistry and quality. For example, some hydrogeological settings may enhance the removal, or natural attenuation, of nitrate from the soil zone or water-bearing layers.

Spatial variability in the redox processes responsible for nitrate removal are a factor of biogeochemical and physical processes that include electron donor abundance, temperature control and hydrological factors such as natural vertical bypass of the soil zone and intrinsic permeability of subsurface material, as well as recharge mechanism.

The aim of this study is to classify and map soil and geological materials according to their varying potential to reduce terminal electron accepting species (e.g. O_2, NO_3^-, Mn(IV), Fe(III)) across Southland. As a basis for this assessment, we used qualitative soil and geological denitrification assessments of (1) and (2), respectively.

The primary output is a regional-scale map of Combined Soil and Geological Redox Potential (CRP) that constitutes one of the four key drivers of hydrochemical variation of regional surface and groundwaters (as part of the Physiographics of Southland project).

We found that CRP was a good estimator of redox state and concentration of redox-sensitive species but was most precise when combined with the hydrological driver layer. A key finding of this work is that the soil zone is the dominant site of reduction across Southland. However, only when both soil and geological reduction are combined can the spatial variation in redox signatures freshwaters be explained.

20–21 June 2015 major lower Whanganui flood: Determination of size, frequency and other characteristics

Peter Blackwood[1], **Jon Bell**[1]

[1]Horizons Regional Council

During 19 to 21 June 2015 the western area of the Manawatū-Wanganui Region experienced a very major rainfall event. This resulted in flood frequencies close to or exceeding 1% AEP (1 in 100 year) in several rivers. Substantial flooding occurred through the city of Whanganui, with water flooding numerous houses reaching depths of up to 2 metres in some.

The lower Whanganui River peaked at a stage of 21.975 metres and flow of 4,755 cumecs or 1.18% AEP (1 in 85 year) at the Te Rewa gauge. This flow is understood to be the second highest flood flow ever recorded in the North Island – behind only the famous Mōhaka Flood flow of 1938, estimated at 225,000 cusecs (6,370 cumecs).

In the lower reaches this flood was characterised by well above normal tributary flows. These were due to high rainfalls occurring upon wet antecedent conditions, with the 48-hour rainfalls exceeding 1% AEP frequency for almost the entire area downstream of Te Rewa. The final blow was a significant heavy burst of rain near the tail of the storm.

This paper presents:

1. The revised flood frequency at Te Rewa
1. The possible influence of the Interdecadal Pacific Oscillation (IPO), with nine out of the top ten floods during the period 1957 to 2015 occurring in the negative phase
2. The estimation of ungauged tributary flows
3. The size of the June 2015 flood at Whanganui City – 5,150 cumecs, 0.77% AEP (1 in 130 years) at the City Bridge
4. The determination of the appropriate tributary flows to be included in the design flood hydraulic model
5. Commentary on aspects of flood levels attained, including particularly the mitigating impact of mouth scour on lower river levels.

Rainwater harvesting impacts on the environment

Abu Reza Rashid[1], **Muhammed Bhuiyan**[1], Niranjali Jayasuriya[1]
[1]*RMIT University*

There are 6 aspects of impact analysis available on rainwater harvesting (RWH): water savings, energy savings, life cycle analysis (LCA), life cycle costing (LCC), runoff reduction, and pollutant load reduction. So far, all of these aspects were neither considered fully nor analysed rigorously to evaluate the net environmental impacts of RWH on a catchment scale. Particularly, direct impacts of runoff and pollutant load reductions on the environment were not evaluated in general. In this research, runoff and pollutant load reductions are estimated through field observation and simulation using a storm water management model (SWMM). Water and energy savings and runoff and pollutant reductions in LCA are used to estimate the net impacts on the environment. Findings of this study are: i) RWH (with pump) has more negative environmental impacts than the system without RWH in all the considered impact categories; ii) systems with RWH (without pump) of 2kL and 3kL tank sizes have less negative environmental impacts than the systems without RWH in all the impact categories except ozone layer depletion; iii) more the non-potable water demand met by RWH (without pump) showing less environmental impact; iv) annual rainfall amount has no effect on considered impact categories except eutrophication and freshwater eco-toxicity; however, these categories exhibit less negative impacts in dry years; and v) recycling of RWH system components contributes positively to the net environmental impact. This study would help to remove uncertainty related to performances of RWH in Australia and elsewhere on a catchment scale.

Waipaoa River catchment modelling, Gisborne

James Blyth[1], Lydia Cetin[1], Phil Pedruco[1]
[1]*Jacobs,* [2]*Horticulture New Zealand,* [3]*Gisborne District Council,* [4]*Federated Farmers,* [5]*Eastland Wood Council*

A collaborative surface water modelling study has been undertaken for the Waipaoa River catchment near Gisborne. A surface water and water quality model is being developed for the catchment using the eWater's Source modelling platform, which evaluates a range of development and nutrient load scenarios that may occur in the catchment.

The model utilises a 40-year climate dataset gridded across the 50 sub-catchments. Functional units have been developed through utilisation of GIS information derived from Agribase farming units, Gisborne District Council (GDC) Cropping units and national S Map data. This provides a spatially distributed land use and soil drainage layer, which is important for flow calibration, but even more so for simulation of nutrient leaching and runoff. The first phase of calibration/validation has a focus on one of the main downstream stations, for which currently a good fit has been achieved with a Nash Sutcliffe Efficiency (NSE) of 0.76. Future refinements will look at calibrating to the other upstream gauges.

Water quality calibrations are underway, utilising an event mean concentration and dry weather concentration approach. The outputs will focus on calibrating to annual average loads and median concentrations, due to current data limitations. A number of scenarios will then be run to evaluate land use change, irrigation expansion and adoption of best management practices. The Waipaoa Source model provides GDC and Horticulture NZ with a flexible tool that can be further developed to include groundwater connectivity through inclusion of analytical stream depletion functions or through integration with MODFLOW.

A national pressure-state-impact model for freshwater flows

Doug Booker[1]
[1]*NIWA*

The New Zealand government has adopted a pressure-state-impact framework for national environmental reporting. In this framework, pressures are indicators of human activities that influence the environment. States are indicators of the resulting conditions in the environment. Impacts are indicators of the implications for ecosystems health. Application of this framework to the freshwater environment requires estimates of how much water is being abstracted from rivers and the impacts of these takes on the freshwater environment, as well as the reliability of supply and potential for headroom in respect of water use. A pressure-state-impact model for freshwater flows has been devised that can provide these estimates on a daily basis across New Zealand using a national digital river network. A national rainfall-runoff model is used to estimate naturalised flows (flows without any abstractions) for each segment. A database of collated regional council data is used to collate information describing, for each abstraction, from where the water is being taken, the purpose of abstraction, total recorded water use, maximum allowable water use and any associated environmental flow rules. A model is applied to position each take on the river network, accumulate its downstream effects, and therefore calculate total recorded water use and maximum allowable water use upstream of each river segment. Results quantify nationally the trade-off between water availability and pressure from water abstraction for various purposes such as for agricultural and hydroelectricity production.

Using calibration strategies to emulate a complex river basin model with a simplified fit-for-purpose model

Rebecca Borwell[1], Prof George Kuczera[1], Jose F Rodriguez[1]
[1]*University of Newcastle*

This study is part of a larger study pursuing multi-criterion optimisation to identify the strategies that make best use of regulated water in the Macquarie River basin to support the Macquarie Marshes ecosystem. The Macquarie Valley Integrated Quantity and Quality Management (IQQM) model is a complex model simulating the Macquarie River catchment in considerable detail, including environmental and irrigation demands, river losses and routing relationships. However, it is not capable of optimising the environmental flow regime using information about the state of the Macquarie Marshes. Achieving this goal requires a model capable of using information about the current state of the Marshes to inform regulated water releases and capable of searching for the optimal strategy. Complex details of the existing IQQM model were not needed to realise this goal.

The primary objective of this study is to present and illustrate a calibration strategy to emulate a complex model with a fit-for-purpose simplified river basin model. The strategy uses a free body diagram concept in which a subset of the complex model is isolated and calibrated to parameterise the simplified model to closely reproduce behaviours of the complex model at key locations. This strategy is illustrated by the development of a fit-for-purpose WATHNET5 model emulating the IQQM model at key locations within the Macquarie basin upstream of the Marshes. It shows that irrigation demands, river losses, hydraulic routing and hydraulic structures can be accommodated within the simplified model to produce behaviours that closely match the more complex model at key locations.

Hinds catchment Managed Aquifer Recharge (MAR) pilot project preliminary results

Catherine Howell[1], **Bob Bower[1]**, Brett Sinclair[1]
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Investigations at the Hinds MAR pilot site near Ashburton indicated an infiltration basin of 0.9ha should be sufficient to generate recharge flows to the underlying aquifer of 0.5 cumec. The site infrastructure was designed accordingly and construction of the infiltration basins and monitoring systems was completed in May 2016. Pilot trial operations were initiated shortly afterward.

The aims of the pilot are to demonstrate the viability of MAR in:

1. Diluting nitrate concentrations in shallow groundwater
6. Supporting minimum flows in spring-fed streams
7. Increasing water supply reliability for existing groundwater and surface water users
8. Reducing the on-farm mitigations needed to achieve community objectives in groundwater nutrient management.

Four resource consents have been granted for the project and one condition of these is adaptive management through a trigger condition based on certain hydrological parameters. The trial therefore incorporates adaptive operational management procedures that respond to a number of physical factors, including rainfall patterns, flows in down-gradient coastal drains, and the source water race capacity during peak irrigation season.

The progress of the trial is tracked using an extensive programme of both continuous and regular water quantity and quality monitoring (groundwater, surface water) and ecological monitoring.

Ongoing analysis of data from the monitoring programme results started early in the trial with a view to providing preliminary results to Canterbury Regional Council and other groups supporting the trial. This paper introduces preliminary results from the trial and their relevance to the trial objectives.

Next steps: From pilot to full groundwater replenishment scheme based on MAR

Bob Bower[1]
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The Phase 1 results of the Hinds MAR trial running from June 2016 to August 2017 will provide useful insight into the feasibility of the MAR approach and design criteria to develop a full Groundwater Replenishment Scheme (GRS) on the Hinds Plains. This concluding presentation of the MAR and IWMS session emphasises the challenges to infiltrating sufficient water continuously into the aquifer during the irrigation off-season in order to replenish the aquifer with clean water. The preliminary results of comprehensive ongoing monitoring of groundwater levels, flow and quality are presented and interpreted to show how water quality and quantity goals can be met in a full-scale GRS.

The talk also covers the conceptual structure for developing a GRS for the Hinds Plains catchment, including the following critical elements of upscaling to a fully functional scheme:

1. Governance – community led
9. Integrated systems – surface and groundwater storage
10. Goals and targets
11. Scheme designs and catchment scale modelling
12. Costs and scheme funding structures
13. Consenting
14. Community outreach and education

Key to achieving a fully functional GRS is good stakeholder participation and leadership. This is of particular importance in a farming area in which many irrigators need to “buy in” to the benefits but also be prepared to take ownership of the scheme.

Many of the lessons learned will serve further development of a GRS and be of great value to other MAR initiatives throughout Australasia.

Digital signal processing for fast computation of hydrologic variables

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Summation and averaging of spatial and temporal variables is a common operation in hydrologic studies and, in most circumstances, the naïve approach of basic arithmetic is good enough. However, for the Australian Rainfall and Runoff Areal Temporal Patterns project there are approximately 1.5M grid cells, each with 108 time sequences of fifty years of thirty-minute periods, which are in turn themselves the result of spatial averages. Each of those time sequences was further processed through ten moving average windows for event identification. Given that a naïve spatial average is an $O(n^2)$ hard computation, the required computational time is prohibitive. GPUs can speed up these computations but, by themselves, the computational time is still large. Fortunately, summation and averaging operations can be mathematically recast into a digital signal-processing convolution. There has been significant research conducted into improving the speed of convolution operations as they form a core component in the field of digital signal processing – for example, Fourier space convolutions are an $O(n\log^2 n)$ operation; certain filters can be classed as separable, which are trivial to compute as vector operations; as well as from the recognition that a convolution is a form of finite impulse response filter a suite of image processing tools specifically optimised for computation on GPUs. This paper explores some of the methods that can be extracted from digital signal processing with application to the Australian Rainfall and Runoff Areal Temporal Patterns project. Specifically, the application of these tools reduced the computation run times such that project was completed.

Modelling to support planning in a low-flow, rapidly developing environment in Western Australia

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The Metropolitan Redevelopment Authority (MRA), in partnership with local government, communities and industry, is redeveloping parts of Armadale (located 28km south-east of Perth), including the 1,580-hectare Wungong Urban Water (WUW) project. A key goal of the project is to ensure the quality of surface water and groundwater discharging from the project area following development is improved, all while delivering a community for some 40,000 future residents.

To help achieve this, MRA and the Department of Water are working together to produce a revised flood model and drainage and water management plan for the WUW Master Plan area. The vision is to create water sensitive communities, which can only be delivered by a state of the art flood model to define and inform how water moves through the landscape.

This paper outlines the development of the flood model of the developing area surrounding the Wungong River and associated tributaries. Rainfall characteristics of the catchment, together with the dominant sandy soils that have a high capacity to infiltrate, result in a very low flow environment where channel storage/conveyance and in-channel regulating structures dominate the flow behaviour. The FM approach applied in this study, specifically a variable resolution element mix dynamically coupled with complex hydraulic structures, provides the necessary flexibility to accommodate the changing flow characteristics from urbanisation of natural or semi-rural catchments. Furthermore, specific post-development geometries such as rehabilitated “Living Streams”, flood corridors and ephemeral storage areas can be more accurately represented within a mesh compared to a grid based approach.

An improved interpolated daily climate record for New Zealand

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We present a new method for interpolating daily climate data for New Zealand. Interpolation occurs first in the temporal rather than spatial domain. Gap filling and series extension uses linear regression, with a unique relationship calculated for each calendar month. The method provides a number of benefits over current methods that interpolate first in the spatial domain (such as the Virtual Climate Station Network), including not introducing artificial time series step changes and making greater utilisation of shorter climate records. The greater data utilisation means time series can be reliably extended further back in time. For example, we could extend 2,700 rainfall sites from 1915 to present, while for minimum and maximum temperature, 350 sites could be extended for the same period. We discuss data accuracy and some of the insights that the data provide into observed climate change over the last 100 years.

The practicalities of managing catchments to fixed nutrient limits: A case study from the Hurunui

Peter Brown[1]
[1]*Aqualinc Research Ltd*

The Hurunui catchment has had fixed catchment nutrient limits for nitrogen and phosphorus since December 2013. This was the first major catchment in Canterbury to have clear limits in an operative plan. These limits have highlighted three challenges: the accuracy that loads can be measured within rivers; the extent that catchment limits constrain growth; and the practicalities of allocating and tracking changes in nitrogen losses at a farm scale. We present the results of the calculated uncertainty in in-stream measurements of nitrogen and phosphorus loads. We discuss how the limit has constrained irrigation growth. We also discuss the nitrogen accounting system that has been implemented by the main emitters, and the practicalities of ensuring good farm-scale data and consistency from year to year in root zone nitrogen accounting.

Uncertainty analysis of hydrologic model parameters through Monte Carlo methods in XPRAFTS

Laurence Allan[1], Jonathan Klaric[2] , **Sophia Buchanan[3]**
[1]Cardno, [2]XP Solutions

Despite initially being proposed over two decades ago, the use of Monte Carlo methods (MCMs) in hydrology and water engineering has been slow to gain popularity. However, with more recent advances in both the speed of computer processors, as well as discoveries made in the field of stochastic processes, these techniques have become significantly more practical to use on increasingly affordable hardware. Despite these advances, MCMs typically often remain only accessible in the realm of more advanced or academic modellers, rather than a tool common to the wider hydrology community.

Since the Monte Carlo simulation technique (MCST) better mimics the random processes observed in nature, it is an excellent tool to understand and study the uncertainty that is inherent to all hydrologic models. This paper demonstrates how the Laurenson's method based XPRAFTS can be used to study impacts on catchment behaviour with uncertainty in the input parameters via the MCM, as well the traditional "design-storms" approach.

Using a previously established XPRAFTS hydrologic model that was calibrated at a location downstream of our area of interest, we check and validate some of the main hydrologic parameters, including (but not limited to) loss rates, Manning's "n" values and stream lag times, in order to test the suitability of the existing hydrologic model for the upper and mid catchment areas. We inspect the variations in catchment response due to these uncertainties and demonstrate that the MCST can be a simple-to-use tool with minimal technical knowledge required of probability theory or advanced statistics.

A hydrochemical survey of the groundwater resources of South Canterbury, New Zealand

Lee Burbery[1], Phil Abraham[1], David Wood[1], Nicola Kaelin[2]
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Water hosted in strata of the Kowai Formation – the name given to greywacke-derived alluvial sediments deposited between 2 and 13 million years ago – is an important freshwater resource in the South Canterbury region, New Zealand. Upper layers of the geological formation comprise gravel, clay and sand of wholly terrestrial origin, whereas in lower layers similar sediments are inter-bedded with beach gravels, shells and occasional lignite. Relatively little is known about the hydrogeological characteristics of the Kowai Formation, in particular the routes by which groundwater in the Kowai aquifers is recharged. In an attempt to accrue knowledge about groundwater flow paths (including identification of routes for aquifer recharge and discharge), the groundwater chemistry of the Kowai Formation aquifers underlying the 1,547km² South Canterbury coastal zone (SCCZ) has been surveyed.

Based on evaluation of its major ion compositions, we have classified groundwater of the SCCZ into 12 hydro-facies. Eight facies relate to natural geochemical phenomena; the other four signal anthropogenic impacts (i.e. evidence of modern water). Natural recharge waters include rainfall recharge and river water, which are characterised by Na-Cl and Ca-HCO_3major ion water-type, respectively. Weathering of feldspar minerals in the ubiquitous greywacke sediments, ion exchange and calcite dissolution from fossilised shells in the lower Kowai have been identified as the main processes affecting chemical evolution of groundwater in the SCCZ.

Conceptualised groundwater flow models are presented on the basis of mapped hydro-facies. Hypotheses are to be tested when stable isotope and radioisotope age data become available.

Uncertainty in future rainfall and river flows in New Zealand under changes in climate

Chris Cameron[1], Jared Lewis[1], Greg Bodeker[1], Andreas Jobst[2], Daniel Kingston[2], Nicolas Cullen[2]
[1]Bodeker Scientific, [2]Otago University

The high temporal and spatial variability of precipitation, coupled with New Zealand's mountainous terrain and prevailing moist westerly air-stream, makes it challenging to make robust projections of both precipitation and subsequent river flow. On the other hand, demand for robust information regarding likely changes in precipitation and its level of uncertainty is very high – particularly from primary industries, hydro-power generation, tourism, land use planners, and in hazards management (particularly for floods).

Here we present initial results from a new method for assessing the uncertainty in precipitation scenarios, based on the use of statistics from precipitation projections that encapsulate model structural uncertainties associated with 19 different climate models and 10 different carbon cycle models. These precipitation projections are then linked to a fully distributed physically based hydrological model to generate a similar function for river flows, thereby providing improved simulations of both mean and extreme precipitation and river flow. This approach is demonstrated for the Clutha/Mata-Au catchment in Otago.

Output from such modelling can be used to provide important new insights for land use and water management strategies, identify likely areas of future flooding or drought and implement appropriate mitigation strategies, and better understand and accommodate the effects of different levels of climate change.

The rejected hypothesis – its contribution to science success

Stewart Cameron[1]
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Hydrological conferences are typically overflowing with success stories – for example, how a scientific hypothesis or research question was supported or answered by experimentation, or how well a model represented reality. What are often not presented (for obvious reasons you may say) are the scientific hypotheses that were refuted, research questions that were not able to be answered, or models that were found to be a poor representation of reality. However, these "non-success" stories can also inform science knowledge, and influence future scientific hypotheses, research questions, and methodologies. Airing the hydrogeological dirty laundry may well stop the next researcher from repeating the same flawed approach. Furthermore, the crooked pathway of arriving at the supported hypothesis may have involved some kind of error/oversight/learning experience along the way, which helped to achieve the success, but was not presented. This presentation provides examples of hydrogeological-related research for which the scientific hypothesis was rejected, and/or the error or oversight made helped to inform future research direction and made a positive contribution to the body of scientific knowledge.

Understanding mean transit times of river water in Australian headwater catchments using tritium

Prof Ian Cartwright[1], Uwe Morgenstern[2], Dylan Irvine[2]
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Headwater streams contribute a significant proportion of the total discharge of many river systems. However, despite their importance, the transit time in headwater catchments is largely unknown as are the catchment characteristics (such as drainage density, topography, land use, or geology) that determine variations in transit times. Here we use tritium measurements to understand transit times of water contributing to perennial streams in the adjacent upper catchments of several streams in Victoria, Australia. Mean transit times at summer baseflow conditions calculated using an exponential-piston flow lumped parameter model are generally between 3 and 60 years. Mean transit times during the recession periods following winter high flows are shorter, which may reflect either the dilution of a baseflow component with recent surface runoff or mobilisation of different stores of water with different residence times (e.g. from the soils or the regolith) from within the catchment. The difference in mean transit times appear to be controlled by a variety of factors, including drainage density, runoff coefficients, and catchment slopes.

Numerical model simulations were performed to assess the reliability of lumped parameter models when there are variations in recharge, aquifer dimensions, heterogeneity. These simulations show that while mean transit time estimates differ from those made using the lumped parameter models, the overall conclusion that the mean transit times are in the range of years to decades remains.

Monitoring and measuring river flows using image analysis: From concept to operational applications

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[1]*Edytem (cnrs – Université de Savoie Mont Blanc),* [2]*TENEVIA*

Aims

Traditional discharge measurements rely on the continuous monitoring of the water level using pressure or radar sensors and frequent field campaigns to remote sites in order to establish and update the state–discharge relationship (rating curve). Estimation of a reliable rating curve requires manual discharge measurements over many years, which represents a significant cost and effort for hydrological services. The advent of powerful and cost-effective imaging devices opens news trends for the development of intuitive and verifiable measurement systems. The patented TENEVIA RiverBoard solution aims at providing operational video-based hydrometry. It can be seen as alternative or complementary sensors for the monitoring and measuring of river flows.

Method

Using computer vision and image processing techniques, an operational solution was developed. Water level and surface velocity measurements are operated on sequences of images. Surface velocities and water level are automatically detected and converted from pixel units to metrics values using topographic and bathymetric data gathering of the river section. Hydraulic calculations help then in calculating discharges.

Results

Given the accuracy, robustness and frequency of surface velocity measurements, numerous discharge estimates can be carried out during a single flood of 2–3 days only. This enables the rapid establishment and/or updating of rating curves. Moreover, substantial modifications of the river bathymetry can be detected using the monitoring of surface velocities (e.g. for a given water level, larger surface velocities due the riverbed erosion after a significant flood).

Operational flood forecasting with a bias-corrected high-resolution weather forecast

Celine Cattoen[1], Trevor Carey-Smith[1]
[1]*NIWA*

In the last decades, flooding and other related natural disasters have led to an increased interest in hydrologic forecasting systems. Operational flood forecasting can mitigate the losses of human life and infrastructure by providing accurate and timely indication of the occurrence of major flooding events. These systems are highly dependent on the quality of the weather forecast.

We investigate the impact of coupling the hydrological model TopNet with the bias-corrected high-resolution New Zealand Convective Scale Model (NZCSM). The high spatial resolution of the weather forecast leads to an overall realistic rainfall spatial distribution. However, the precipitation has known biases, with persistent over-forecasting of light drizzle and under-estimation of rainfall magnitudes in high elevation regions worsened during flood events. We account for these biases using an observed gridded product (Virtual Climate Station Network) assumed to be the "truth" and used for the hydrological model calibration. We compare the NZCSM-TopNet coupled model when using the raw and bias-corrected weather forecast. The numerical weather prediction model is a local implementation of the UK Met Office Unified Model System (UM) for New Zealand, with a grid resolution of 1.5km for NZCSM. The distributed hydrological model TopNet is based on TOPMODEL concepts of runoff generation controlled by sub-surface water storage.

We evaluate the model performance during two major rain events: a 20-year and a 2-year returned period flow event. The case study catchment is located upstream of the Hutt River catchment in the Wellington region in New Zealand.

Application of daily SedNet for modelling catchment-scale sediment generation and transport: New Zealand case study

Lydia Cetin[1], Andrew Freebairn[2], Stuart Easton[1], Michelle Sands[1], Philip Pedruco[1]
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In catchments that have experienced long-term land clearance and agricultural intensification, sedimentation can have a significant impact on the health of receiving water environments. Since the early 2000s, the "Sediment River Network Model" (SedNet) has been used as a regional-scale tool for estimating long-term annual sediment budgets that identify patterns in erosion processes and transport of sediment in surface waters. SedNet has been applied in many catchments in Australia and New Zealand to assess management actions and prioritise soil conservation investments to improve water quality.

Although SedNet provides comprehensive spatial resolution, there are instances where a finer temporal resolution than an annual sediment budget is required to simulate event-based sediment export (e.g. impact of high flows) at different times within a year and to investigate within-year variations.

Dynamic SedNet (dSedNet), a time-stepping spatially distributed sediment budget model for predicting daily sediment loads, was developed to fit such catchment modelling requirements. The dSedNet sheet and gully erosion rates are simulated based on disaggregation of mean annual rates by daily rainfall and runoff. The sediment generation models are assigned to hydrological units representing land use and soil types. Fine and coarse sediments are transported through the river node-link network, where in-stream deposition occurs.

This paper discusses the development and calibration of a dSedNet model coupled to an integrated catchment hydrological model for simulation of sheet and gully erosion processes in the Onepoto and Hutt River catchments, New Zealand.

Development Of Hydro-Economic Water Allocation Model

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It has been important issue to secure the enough water for the water supply due to the unstable water supply environment caused by the long-term climate change, increased population and water demand. New index has been developed for the economic water value evaluation through virtual water, water footprint and so on. In general, the socio-economic damage caused by water shortage is more severe than it appears. Therefore, in many countries, water allocation model was developed to cope with water demand and typical characteristics in the country for the best utilization of the available water. However, the conventional water allocation model cannot simulate water dispute, considerable change of environment, various alternatives to solve water related problems. In this study, a new water allocation model was developed based on K-WEAP which is the most popularly used to simulate water policies. The water allocation strategy was optimized using the newly developed model. Particularly, the optimization module in K-WEAP was substantially improved for the best water allocation and user interface was also improved for the better understanding about the water distribution networks, algorithm and results. The developed model could be applied in the various watersheds. The model could be revised according to the applied results. The developed model would contribute to secure water resources and distribution.

Utilisation of non-contact velocity radar and velocity index techniques to validate rating extrapolations

Mic Clayton[1]
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Theoretically derived discharge curve extensions are often the only “information” available to engineers and hydrologists for design and modelling purposes. Obtaining high-flow stream discharge measurements to improve confidence in these derived curve extensions is a common challenge for field hydrologists. High-flow events challenge equipment and safety to obtain accurate measurements, let alone being able to access the measurement location in the short windows of time that these events often occur. An extreme flow event in the Geehi River raised questions around the representativeness of the extension of the rating. Mass balance analysis of a downstream reservoir, even with ungauged contributing catchment uncertainties, provided a strong indication that the rating may have been overestimating flows in extreme flow conditions.

Post-event site inspections indicated potential downstream controlling features as well as significant bank vegetation effects that may not have been considered/known when traditional rating extrapolation techniques were applied previously.

Non-contact velocity radar systems and velocity indexing techniques are being utilised to analyse high-flow behaviour at this site to assist with validating the “new” rating extrapolation.

Utilising surface velocities can provide an indication on roughness variability through the cross-section as well as identifying potential impacts of downstream features, improving the information available for rating extrapolation.

Unfortunately “extreme” peak flows did not occur during the 2015 spring runoff as hoped, and data acquisition will be continuing through the winter/spring of 2016 to extend the data set available for further analysis and assessment of the rating.

Modelling the impact of denitrification on nitrogen removal in the Reporoa catchment

Murray Close[1], Bronwyn Humphries[1], Catherine Moore[1,2], David Scott[1], Greg Barkle[3], Channa Rajanayaka[3]
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Nitrate is a key contaminant of concern in the management of New Zealand's water resources. Although there is a degree of uncertainty, it has been reported that in the Lake Taupō catchment between 15% and 50% of nitrate leaching from the root zone can potentially be removed via groundwater denitrification, before the remaining nitrogen discharges into the surface water. The Reporoa Basin, which is adjacent to the Lake Taupō catchment, has variable subsurface redox conditions which have the potential to remove nitrate within the subsurface environment.

A numerical groundwater flow and transport model (ModFlow with MT3D) has been developed to simulate and understand the nitrate fluxes and removal processes in the Reporoa groundwater system. The model has been calibrated to groundwater levels, surface water–groundwater fluxes and groundwater nitrate concentrations. The predicted locations of subsurface reducing conditions have been used to determine the likely impact of denitrification on the export of nitrogen to the Waikato River. The aim of the study is to provide information that can assist the management of land and water resources within the Reporoa Basin.

Modelling heat as a groundwater tracer in heterogeneous aquifers

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Heat can be used as a tracer in at least two ways – injection of heat into a well or using the seasonal variability of temperature in rivers to gain insight into recharge of surface waters into groundwater. We describe two studies which use temperature in these two different ways. In the first study we injected warm water (37°C) combined with rhodamine dye as groundwater tracers for 16 days at our Burnham experimental well array. The aim was to gain insight into groundwater flow and mass transport in an alluvial gravel aquifer, in particular to understand the proportion of mass transported through fast and slow zones and interchange between these zones. In the second study we monitored temperature continuously for a year in wells near the Wairau River to determine where most of the recharge from the river was occurring and how far from the river we could observe the variations in temperature.

Groundwater modelling using ModFlow with MT3D was carried out at both sites and the relevant aquifer parameters were determined. This information can assist in the development of more realistic groundwater contaminant transport models.

Flood frequency models of New Zealand: Past, present and future

Daniel Collins[1], Roddy Henderson[1], Daan Kling[2], George Griffiths[1], Alistair McKerchar[1], Charles Pearson[1]
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Flood frequency estimation in ungauged catchments is an important element of flood hazard management and engineering design. With over 25 years having passed since the previous flood frequency model of New Zealand was developed, we revisit the problem with new data and new methods, reassessing the old approach, developing a new one, and identifying future research directions. The accuracy of the previous model is reassessed using new data and shown to be less certain than originally stated; its use of error-correcting contours in particular clouds the model's accuracy in ungauged catchments. A new empirical model is developed using an updated data set, split by island, and employing a larger suite of catchment and climatic characteristics than previously. Catchment area and mean annual precipitation are fundamental variables, as are those describing the geology and physiography, although the best selected variables depend on the island. In keeping with the previous model's methods, the residual error surface of the composite model is then interpolated with a method akin to that used to develop the Virtual Climate Station Network, with the resulting correction applied to the empirical model. This is contrasted with a process-based simulation approach using the catchment hydrology model TopNet at the national scale. Shortcomings of both the empirically and physically based frequency estimates highlight our incomplete understanding of flood frequencies and indicate a need to advance our process-based knowledge of floods occurrence if we are to appreciably reduce existing model uncertainties.

Estimation of plotting position for flood frequency analysis

Rob Connell[1], Magdy Mohssen[2]
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The probably distribution of flood peaks for a given river is unknown and many have been developed for analysis.
Analyses in New Zealand presently use the Gringorten plotting position. The plotting position of the largest flood in 100 years is 178 years, which matches the figure for the largest expected flood for the EV1 distribution of Gumbel as stated in his 1958 book *Frequency of Extremes*.
This is different to the Weibull plotting position, which for the largest event in 100 years is 101 years.
This will make a huge difference to the calculated design floods and economic analysis.
If the definition of a 100-year event (i.e. it has one chance in 100 of being exceeded in one year) is used, this shows that within any given 100-year period there is a 33% chance that the 100-year event will not be exceeded. Similarly, for a 200-year event in 100 years is 61%.
If the probabilities are calculated for the full range of flood events, i.e. the 1-year event up to the probable maximum flood and integrated from 0 (PMP) to 1 (the 1-year event), the largest flood's expected probability is 1/(n+1). Others have obtained this result, including Gumbel.
It is hypothesised that a distribution should be found to match this result.
It is therefore proposed that this be examined in detail to review the work on plotting positions to collaborate with other researchers overseas who are currently working on this problem.

Testing models for simulating urban hydrology

Robin Connolly[1]
[1]*Hydrologia*

Part of the testing associated with the Australian Rainfall and Runoff revision process involves evaluating parameterisation techniques for hydrology models in an urban context.

This paper presents the results of testing for sites in Queensland (Burpengary Creek), the Northern Territory (Karama) and Victoria (Kinkora).

The following models were tested:

- Rational Method, using the 1987 ARR method
- DHI Mike 11 – single catchment and reach
- DHI Mike 11 – multiple catchments and reaches
- RORB
- DHI Mike SHE – rain on grid.

The testing involved simulating peak discharge with and without calibration of model parameter values. Models were calibrated against observed streamflow data for a gauge in the catchment. Differences in predictions between the models were then compared.

Before calibration, the simpler models generally did not reproduce the flood frequency data or trend reliably. The more complex models were more likely to represent the catchment behaviour more accurately in the absence of direct calibration.

All of the models could be calibrated to the available data and used to estimate flows for design events larger that covered by the data record, but the ease of calibration and application of the models varied.

The more detailed models, though, were more able to represent variable catchment conditions and complexity than the simple models and provide more detailed output.

The testing highlighted that the selection of a hydrology model for an urban application should depend on the available data, catchment characteristics and required outcomes.

Atmospheric controls on snow and ice melt on Brewster Glacier, South Westland

Jonathan P Conway[1], Nicolas J Cullen[2]
[1]*Bodeker Scientific,* [2]*University of Otago*

Snow and ice are an important part of the hydrological cycle in New Zealand, altering the timing of runoff and storage dynamics. These effects are especially prominent in the Southern Alps where a major fraction of precipitation falls as snow; the release of this stored water is delayed until melt occurs in spring and summer. In this way, snow and ice contribute to the New Zealand economy by providing water for hydroelectricity and irrigation. With climate change, the snow and ice resources of New Zealand face an uncertain future. The evolution of these resources in the future will depend on how anthropogenic and internal forcing of local and regional climates are transferred to changes in accumulation and melt. A decade of glaciological and meteorological investigation on Brewster Glacier, South Westland, has provided a robust platform to model the physical processes that control the accumulation and melt of snow and ice in the Southern Alps. In particular, high quality datasets of meteorology and surface radiation fluxes have allowed the effect of clouds on incoming radiation to be parameterised and time-series of cloud metrics to be constructed. These cloud products have provided a basis to explore the effect of clouds on the sensitivity of snow and ice melt to changes in atmospheric temperature, through simulations with a surface energy and mass balance model. These simulations suggest that the future evolution of melt will depend on future states of both atmospheric moisture (as water vapour, clouds, and precipitation) and temperature.

A modern perspective on hydrology processes of two catchments in regional Victoria

Prof Peter Coombes[1], Mark Colegate[2], Luke Barber[2], Mark Babister[3]
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Armstrong Creek rises from a flat catchment that discharges into an internationally recognised Ramsar wetland adjacent to the outlet of the Barwon River near Geelong. The Canadian Creek catchment also contains flat terrain, urban development, and conveyance infrastructure, and discharges through the centre of Ballarat into the Yarrawee River.

Both catchments are characterised by historical flooding and environmental challenges; location within emerging urban growth corridors; debate about proposals for water-sensitive urban design solutions, including restoration of the waterways; critical impacts on downstream catchments; and disagreement about hydrological parameters.

The catchments do not contain hydrological gauges to define flow parameters or regimes. Analysis of hydrology and hydraulics has been based on assumed rational method peak flow parameters and validation against other reports with similar assumptions. Detailed investigations of both catchments by the authors have established that the behaviour of the catchments are highly sensitive to assumptions and driven by the volumes of storm events, which are not included in peak event assumptions. The hydrological and environmental impacts on the urban planning decisions in each catchment are uncertain.

The historical and future performance of the catchments was analysed using the best practice approaches recommended by recent revision of Australian Rainfall and Runoff, flood frequency analysis using surrounding hydrological and rainfall stations, big data analysis, and high definition hydrological and ecological analysis. This study provides recommended parameters for hydrological analysis in both regions, future flood and ecological risks and opportunities for mitigation.

Stormwater, waterway and water resource benefits of water conservation measures in Australian cities

Prof Peter Coombes[1], Michael Smit[2], Josh Byrne[3], Christopher J Walsh[4]
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There has been considerable debate about the value of alternative water sources and stormwater management measures (green infrastructure), which largely resulted in the dismissal of these strategies in favour of sole reliance on large-scale grey infrastructure, such as desalination and water grids. However, during recent drought, actions of the community in changing water use behaviours, installing rainwater and stormwater harvesting, and water-efficient appliances halved the water use in our cities, which contributed to avoiding a water resources disaster. In spite of this helpful outcome, there are many theoretical studies that these green infrastructure strategies do not provide water resource benefits and are not economically viable.

This study investigates audited records and data from the last 20 years as an evidence-based approach to establishing water resources and economic value of green infrastructure interventions. This forensic analysis of all available big data reveals that green infrastructure interventions (such as rainwater harvesting and water-efficient appliances) are providing substantial value in each Australian capital city. A fully calibrated systems analysis was used to extend this audited data to reveal the stormwater, waterways and water resource benefits from the last 20 years and a reliable prediction of the future value of water-sensitive urban design measures.

This investigation reports on the historical and future impacts of rainwater harvesting, water-efficient appliances, bio-retention and stormwater harvesting on household budgets, operating costs of water utilities, stormwater managers and the environment.

Impact of spatial and temporal averages on prediction of water security using systems analysis

Peter Coombes[1], Michael E Barry[2]
[1]*Urban Water Cycle Solutions,* [2]*2BMT WBM*

The author has completed over a decade of applied research into systems approaches of the impacts of distributed solutions and behaviours on security of regional water resources. Methods have emerged that combine linked demand, hydrology and water balances at distributed scales within a systems framework.

Analysis of water resources for Sydney and Melbourne reveal that use of global averages to replace the natural spatial and temporal variation of urban areas generates dramatic reductions in certainty about system behaviour. The use of averages cannot capture the substantial spatial and temporal variation of parameters, including climate, demographics, urban form and socio-economics that drive the behaviour of urban settlements – local-scale strategies such as rainwater harvesting increase this variability. The use of global averages or engineering judgement in simulation of regional water systems is unlikely to describe the spatial and temporal characteristics of local approaches that generate water resources or reductions in water demands within cities.

Separate analysis of water demands with or without local solutions to determine yields for water resources produces significant uncertainty in assessment of water security and impacts on rivers. Integration of distributed local and regional scales in systems analysis is recommended as the most reliable method for determination of security of water supplies that include solutions at multiple scales. This paper compares traditional "top down" demand and yield analysis techniques to systems analysis that incorporates "bottom up" spatial detail for determining water security.

Water balance of the Upper to Middle Niger Basin and the impact of climate change

P Hazelton[1], J Ball[1], W Milne-Home[1], **Boubacar Seydou Coulibaly**[1]
[1]*University of Technology Sydney*

The River Niger is 4,200km long and its catchment area is 2.6 million km^2. It has an annual peak average discharge rate of 20,000m^3/s. It is the third longest river in Africa, after the Nile and the Congo. From the early 1970s to the 1990s, the Niger Basin experienced a prolonged drought that reduced the annual rainfall by 15% to 30% compared to the records of the 1950s and 1960s. The river flow at many stations was reduced by more than 40%. The inflow data to the Internal Delta in Mali also showed a sharp decline during the same period. Understanding the surface and groundwater balance of the River Niger is paramount to the management of its water resources and adaptation to climate change for the people living within its basin. The present study uses MIKE SHE of the Danish Institute of Hydraulics to model integrated surface, groundwater and evapotranspiration of the Upper to Middle Niger Basin (over 600,000km^2) in order to analyse the long-term water balance of the area continuously for the period 1950 to 2007. This will encompass the Iullemeden/Taoudeni/Tanezrouft Aquifer System. Data from over 250 rainfall stations, more than 20,000 bore wells and 50 river gauge stations is used for this study across four countries: Guinee, Cote d'Ivoire, Mali and Burkina Faso. The MIKE SHE model is used to simulate the previous water balance and estimate future conditions based on the meteorological and hydrological trends, and climate change predictions.

Investigating the challenges of water governance in Oceania

Katherine Daniell[1], Sévèrine Bouard[2], Anne Poelina[3], Nils Ferrand[4], Prof Ian White[1], Jason Alexandra[5,6], Leila Apithy[2], Marion Bois[7], Michael Spencer[8,9], Kate Andrews[1], Jean-Emmanuel Rougier[10], Ehsan Nabavi[1], Emeline Hassenforder[1,4]

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The Pacific Islands, Australia and New Zealand are surrounded by water, but not the kind that is required for drinking and sanitation, agriculture, industry and a range of other land-based economic, social and cultural purposes. Freshwater in Oceania is variably distributed and not always accessible in the places and volumes required for human and ecological needs and desires. Moreover, there are management issues in many areas, due to conflicting values and understandings about how water should be used and managed, and whose rights it should be to do so – for example, the government, landholders (indigenous or non-indigenous), private businesses or even a river itself, as is the case for the Whanganui River in New Zealand. These issues have led to a range of water conflicts and present part of the reason why deciding on water policies and management plans, as well as implementing them, is such a challenge in some parts of Oceania. This paper reports on the preliminary findings of an international cooperation "Fonds Pacifique" funded project on water governance in Oceania that seeks to understand water and land management conflicts and develop some learning exchanges and participatory tools to start to transform them. Examples including those from New Caledonia, the Kimberley region of Australia and the Republic of Kiribati will be presented. The conflict transformation tools include the development of a culturally adapted "water stewardship" approach and use of the "Wat-a-Game" modular modelling and game development toolkit.

Modelling groundwater: Surface water interactions with the double-averaged Navier–Stokes equations

Andrew Dark[1], Prof Roger Nokes[2], John Bright[1]

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A finite-volume numerical model based on the double-averaged Navier–Stokes (DANS) equations has been developed and used to simulate interacting groundwater and surface-water flows without the need to numerically couple two systems of equations for the surface and subsurface domains. This approach helps to address a number of the shortcomings of existing methodologies for modelling coupled surface/subsurface flow systems.

The new model conserves momentum across the surface/subsurface interface, which is typically neglected in existing modelling approaches. It is not necessary to specify the location of the interface explicitly: this is determined by the spatial distribution of hydraulic properties (permeability and porosity).

A novel modification of the turbulence model used in the DANS numerical model allows the model to handle the transition between turbulent flow in the surface layer and Darcian laminar flow at some depth below the interface. This allows the model to determine whether flows in the hyporheic zone are in a turbulent, non-linear laminar or Darcian regime, rather than specifying *a priori* that subsurface flows are laminar throughout.

For configurations that include only surface flows or only subsurface flows, the DANS model agrees with results from the Saint-Venant equations and Darcy's Law respectively.

For interacting surface and subsurface flows, the numerical model has been compared with results from laboratory experiments that used a combination of particle tracking velocimetry and a refractive-index-matched transparent soil to measure two-dimensional velocity fields in a coupled surface/subsurface flow system.

This work is part of the Ministry of Business, Innovation and Employment (MBIE) funded "Waterscape" programme.

Methods for mapping uncertainty in modelled groundwater age

Chris Daughney[1]
[1]*GNS Science*

The outputs from environmental models should be communicated to communities to support decision-making under the National Policy Statement for Freshwater Management (NPS-FM). Maps may be well suited to this purpose because they allow the output from an environmental model, and its associated uncertainty, to be displayed using a spatial and/or temporal context. This study presents four different mapping methods for displaying the uncertainty from a spatially distributed environmental model, for the specific example of groundwater age in the Middle Wairarapa Valley. The strengths and weaknesses of each method were evaluated in a workshop that involved 30 participants from regional authorities, research organisations and consultancies. The preferences of the workshop participants indicated that the ideal mapping method would depend on the context, the purpose and the audience, and in all cases the maps would need to be carefully constructed for clarity and style. The workshop participants also noted that the mapping methods should be used to complement other numeric, verbal and graphical approaches for communication of uncertainty, and that background, context and explanation need to be provided to the audience to support the interpretation and use of uncertainty information, including in community decision-making under the NPS-FM.

Multi-objective optimisation and trade-off analysis for distributed stormwater harvesting systems

Michael Di Matteo[1], Emeritus Prof Graeme Dandy[1], Prof Holger Maier[1]
[1]*University of Adelaide*

In this presentation a modelling framework is introduced that handles the optimal placement of stormwater harvesting (SWH) infrastructure within an urban development. The framework produces preliminary SWH system designs representing optimal trade-offs between cost, water conservation, and water quality improvement measures. These trade-offs are dependent on a large number of design decisions for the type, size, and spatial distribution of stormwater harvesting components. To evaluate and identify optimal designs, the framework includes an integrated urban stormwater model (eWater MUSIC) linked with a multi-objective genetic algorithm (NSGA-II).

The framework was applied to a case study for a greenfields housing development in the northern suburbs of Adelaide, South Australia. Results illustrated the potential benefits of distributing stormwater best management practices (BMPs) in an integrated SWH system where space at the catchment outlet is limited. Trade-offs between lifecycle cost, supply reliability and total suspended solids (TSS) reduction were influenced by the proportion of investment in storage size to maximise yield and BMP surface area to capture and treat runoff. Bioretention basins were preferred in locations that received the highest inflows in order to achieve cost-effective, reliable systems with high TSS reduction performance.

The framework can be used to identify preliminary designs for efficient stormwater harvesting systems at catchment or sub-catchment scale for any new development.

Nutrient variability over short time scales in pristine alpine catchments

Emily Diack[1], Sarah Mager[1]
[1]*University of Otago*

Temporal monitoring of low impact rivers provide insight into the natural variability of constituents that are vital for sustaining and maintaining aquatic communities. Temporal variations in water quality were monitored for two years in a low disturbance alpine stream, including flow, electrical conductance, pH, temperature and turbidity. Additionally, grab samples, collected every 3 days, have been analysed for silica, nitrate, major and minor ion chemistry, suspended sediment and stable isotopes (2H and 18O). This paper reports on the seasonal variations in dissolved nutrients and the response of silica and nitrogen to flow events. Silica concentrations were usually consistent throughout the year, although during an algal bloom in December 2014 both the silica and nitrogen levels decreased to below detection limits, a trend that was not observed in December 2015 when algal mats were largely absent. Nitrogen concentrations in the river were strongly cyclical, ranging from less than 30 µg/L in summer to over 100 µg/L in winter. The seasonal variations in nitrogen likely reflect a decrease in biotic uptake during winter, and increased uptake during late spring and summer. Suspended sediment rates were low year-round, despite the study catchment being in a high-rainfall, steep alpine catchment with snow and ice cover, possibly suggesting that fine material is supply-limited.

CHES for the Grey River catchment

Jan Dietrich[1], Stefan Beaumont[2], Jo Armstrong[3], Jing Yang[1]
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CHES (Cumulative Hydrological Effects Simulator) is a NIWA-developed ArcGIS add-in that simulates stream flows across a catchment resulting from consented abstractions under given abstraction rules. CHES is then able to model instream and out-of-stream attributes, such as fish habitat availability and reliability of water supply.

CHES has been applied to the Grey River Catchment (South Island), with a modified version of the TopNet hydrological model that includes a conceptual ground water to surface water module (referred to as TopNet-GW2SW) used to provide hydrograph data for each river reach. TopNet-GW2SW allows for a better simulation of surface water flow for gaining and losing reaches. Spot gaugings carried out by the West Coast Regional Council were used to calibrate the TopNet-GW2SW model in conjunction with flow data at Grey at Dobson and Grey at New Waipuna.

Several different water use and management scenarios were executed within CHES: i) maximum consented abstraction, ii) proposed National Environmental Standard (NES) rules, iii) an imaginary new off-line storage abstraction, and iv) a climate change scenario. Results of instream fish habitat change and reliability of supply will be presented, and compared.

Example results show that the amount of water supply decreases for existing abstractors under scenario ii) when compared with scenario i). However, the imaginary scenario iii) has no impact on any existing abstractor and causes minimal habitat change.

Identifying groundwater flow and transport pathways beneath the Canterbury Plains: 3D probabilistic geology modelling using multiple point statistics (MPS) of the HINDS catchment

Henry Dillon[1], Mark McCulloch[1]
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The depositional system of the Canterbury Plains has produced local geological complexities that exasperate traditional modelling efforts. The complex system of large interbedded glacial outwash fans and the reworking by interglacial migrating braided river systems has made the Canterbury Plains difficult to model. To date, no lithological model of the Canterbury Plains has satisfactorily incorporated the vertical and lateral complexities to support the detailed assessment of groundwater flow and water quality effects. This is, however, crucial for assessing the groundwater quality and quantity benefits of a full-scale groundwater replenishment scheme on the Hinds Plains.

Utilising traditional geostatistical and pattern based Multiple Point Statistical (MPS) modelling algorithms, Golder has produced a probabilistic model of the geology of the entire Hinds-Valletta catchment in Canterbury to support groundwater flow and contaminant transport modelling.

MPS employs a statistically correct conceptual model of the system of interest, called a Training Image (TI), in place of the semi-variogram. This TI is used to estimate model nodes by pattern-matching the image to the source data in 3 dimensions. The MPS simulation algorithms have been used to generate a model of 5 categorisations of lithology where categories were delineated by the materials propensity to transmit water.

In this paper we provide a case study of how modern geological modelling techniques can provide detailed inputs to catchment-scale groundwater models to assist with our understanding of groundwater movements and the size and locations of aquifers.

Relationship between meteorological and hydrological drought characteristics

Chandi Shakila Dissanayake[1], Niranjali Jayasuriya[1], Muhammed Bhuiyan[1]
[1]*RMIT University*

Drought forecasting plays an important role in planning and managing water resources as well as developing associated mitigation measures. A meteorological drought is defined by low rainfall and is the most commonly studied drought type locally and globally. However, the extent of meteorological drought doesn't necessarily explain the impact of the drought on hydrology and the water availability. The aim of this study is to explore the relationship between the commonly studied meteorological drought and the hydrological drought in order to use the latter in drought preparedness plans. In this study, the rainfall-based Standardised Precipitation Index (SPI) and the streamflow-based Standardised Hydrological Drought Index (SHDI) were used to assess the relationships between meteorological and hydrological drought characteristics. SPI and SHDI were applied to 31 catchments in the Murray Darling Basin in Australia. Both indices identified landmark historical drought events over the 1970–2010 period, with significant perturbation in the drought characteristics defining the two drought types. However, SHDI identified fewer drought events compared to SPI, confirming the fact that a low rainfall condition doesn't necessarily lead to a low stream flow condition or vice versa. The correlations between SPI and SHDI are poor when the entire 31 stations are considered, although reasonably good correlations exist for individual catchments. This shows that there are regional or in some cases catchment-based differences between the two indices. Relationship between two drought types can be explained by catchment and climatic conditions.

Mine pit lake water level recovery

James Dommisse[1]
[1]*MWH*

The recovery of pit lake water levels post mine dewatering has important environmental implications on groundwater flow and quality. On cessation of dewatering, groundwater levels begin to recover (rebound), gradually filling the residual void to form a lake. The final water level is determined by the eventual balance between inflows and evaporation. Analytical and numerical groundwater modelling predicted that water levels will recover to much lower levels than those pre-mining. This was shown to be largely the result of high rates of evaporation compared to low rates of rainfall and groundwater inflow. With long-term water levels lower than the regional groundwater level, the pit lakes will act as a steady-state sink for groundwater. As a result, eventual pit lake salinities of up to 400,000mg/L are predicted in many of the pits. This is a product of the high natural salinity in the groundwater (150,000mg/L compared to 35,000mg/L in sea water) and high rates of evaporation. The analytical modelling was based on a transient solution called CRYPITIC and generally compared well to the numerical model results. The advantage of using CRYPTIC was the ability to model a large number of pits without the significant time and cost involved with more detailed numerical techniques whilst still achieving realistic predictions.

Is there still room for large stormwater infrastructure in the Super City?

Lisa Dowson[1], Amelia Cunningham[1], Andrew Chin[1], Krpo Yasenko[1]
[1]*Auckland Council*

While the management of stormwater and flooding is trending away from large-scale infrastructure towards avoidance and onsite treatment and management, there is still occasion to implement large, integrated stormwater solutions. Auckland's population is expected to grow by between 700,000 and 1 million people in the next 30 years. The region's growth pressure combined with constraints around geography, transport corridors and other infrastructure has resulted in some Greenfield Growth areas being located in areas of extensive floodplain.

Funding of the $20 million Artillery Drive stormwater tunnel and associated conveyance channels to reduce flood extents and release land for growth in Takanini South was not possible under the legacy Papakura District Council, despite the clear cost benefit. By leveraging off the Auckland Super City, this project is now under construction. However, the delays in this project, combined with the marching progress of live zoning and development in the area, have increased the project cost, particularly around land acquisition.

Lessons learned from the Artillery project are being applied to a sister scheme in Takanini North. Working alongside the Transport for Future Urban Growth and Future Urban Land Supply projects allows for a better understanding of land costs and consideration of new funding models for large, integrated stormwater solutions.

This paper will discuss the ongoing need for large-scale infrastructure projects in the Auckland Region and how such infrastructure is constructed to provide amenity and biodiversity benefits. The paper will also explore the advantages of alternative funding mechanisms to facilitate such projects.

Real-time flood forecasting: You probably already have what you need

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[1]*WorleyParsons,* [2]*Ipswich City Council,* [3]*Toowoomba Regional Council*

Large-scale flooding in recent years has led to the requirement, and indeed expectation, that government authorities be better prepared for impending flooding. Part of this is the need to understand the implications of impending rainfall, in real time.

Traditionally, flood forecasting has focused on hydrologic modelling using telemetted rainfall information combined with a broad-based forecast rainfall distribution. The outputs are usually likely flood levels at specific locations in the catchment (often stream gauges).

In recent times, various weather forecasting agencies, in both the government and private sectors, have made available gridded rainfall forecasts, in real-time. With lead-times of up to 7 days, these datasets can provide an effective means of "buying time" in preparation for impending flooding and provide temporal and spatial detail on forecast rainfall.

When combined with information available from formal flood studies and GIS datasets, an effective flood forecasting system can be readily built using data that most government agencies and local authorities have available.

Importantly, such systems are capable of providing real-time flood intelligence on what the implications of flooding may be, such as who and what will be affected by the coming flood, by how much and when.

The creation of real-time flood intelligence has continued to evolve over the past few years and is demonstrated in a number of Australian case studies covering both mainstream and flash flooding, including evaluation against actual events.

An integrated modelling approach to the design of the Hinds catchment proposed groundwater replenishment scheme

Patrick Durney[1]
[1]*Canterbury Regional Council*

The Hinds/Hekeao catchment is home to a large groundwater resource as well as several hill-fed streams and more than 36 spring-fed coastal streams. Across the catchment, groundwater levels and stream flows are declining, reducing the biodiversity in spring-fed streams and the reliability of supply for abstractors. Declines are attributed to changing irrigation practices, increased groundwater abstraction, and piping of irrigation and stockwater distribution. As part of a strategy to address these declines, a large-scale groundwater replenishment scheme (GRS) is proposed.

To aid development of the GRS programme, I used an integrated catchment model I had previously developed in support of the Hinds/Hekeao plan. I modelled GRS scenarios with a primary focus on the placement, timing and total volume of water required to meet the outcomes of the Hinds/Hekeao plan.

My modelling showed that optimal placement of the recharge sites and GRS operational design is essential to the programme. Initial modelling used an operating window of nine out of twelve months, with GRS ceasing when the source water is prioritised for irrigation and during the wettest period of winter. Results indicated that the initially proposed site placement of large basins in the upper catchment, operating in irrigation shoulder seasons, would be insufficient to mitigate seasonal low flows caused by groundwater irrigation abstraction. Revision to the scheme design has demonstrated that careful placement of the large recharge basins, and some targeted stream augmentation during the irrigation season, would enable the GRS to meet stream flow requirements.

The journey to a water sensitive city: A case study of Ballarat, Victoria, Australia

David Ebbs[1], Assoc Prof Peter Dahlhaus[1], Harpreet Kandra[1]
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Objective

Water security is a vital part of ensuring a sustainable future. This is particularly true for many cities in Australia where relatively low rainfall, population growth and climate change places communities under water stress.

The water sensitive city has been proposed as an idea where the city uses a range of water supplies and sustainably interacts with the surrounding environment. Each city has a unique water history, where the economic, environmental and social history impact the development of water management. Tracking the water management of a city from its initial stages can provide information regarding what drives this development.

Results

The water management in Ballarat has been tracked from the establishment of the first water supply to the city in 1862 until now using historical records from the water authority. This includes the quantity of water supplied, reservoirs, sewerage and alternative water sources, along with population and water connections.

As expected, the water use increased dramatically from the 1940s until 1980. Surprisingly, the water use has since declined, despite continued population growth. Commercial water use has decreased as a percentage of total use and external water use has declined.

Conclusions

Ballarat follows a classical water development model with the introduction of water supply, sewerage and water treatment. The dramatic increase in water use in line with the increased standard of living up until 1980 is as expected. The decline in water use since that time may contain lessons for establishing a sustainable water supply for a city.

The role of an integrated continental hydrological model (AWRA modelling system) to inform water resources assessment

Amgad Elmahdi[1], Mohsin Hafeez[1], **Adam Smith**[1], Andrew Frost[1]
[1]*Bureau of Meteorology*

Globally, water data and information are needed for sustainable planning and management for water resources, taking into account climate changes. Assessing water resources and accounting for their availability and use at a regional, national and continental scale require comprehensive and consistent information on water distribution, storage, availability, and use. This information needs to be accurate, up-to-date and take account of local climatic and hydrological conditions. It also needs to be produced in a robust, transparent and repeatable manner. The Australian Water Resource Assessment (AWRA) modelling system is a new integrated continental hydrological simulation system. It is being developed to enable the Bureau of Meteorology to meet its legislated role (as per the Water Act 2007) in providing an annual National Water Account (NWA) and regular Australian Water Resource Assessment reports. The AWRA Modelling System (AWRAMS) provides nationally consistent and robust water balance estimates at a national to regional and catchment scale for the past and present using observations where available, and modelling otherwise. The AWRAMS has two modelling components: a landscape water balance (AWRA-L) and a river balance (AWRA-R). It is flexible enough to use all available data sources, whether modelling data-rich or data-sparse regions, to provide nationally consistent and robust estimates of water balance terms.

This paper provides a description of how AWRAMS is being conceptualised and used in producing water balance fluxes for the NWA and Water in Australia (WIA, formerly AWRA report) since 2010. Finally, it provides pathways for potential use of AWRAMS by other agencies.

River load calculator: A novel, web-based tool for annual river load estimation

Ahmed Elwan[1], Ranvir Singh[1], Assoc Prof Dave Horne[1], Jon Roygard[2], Brent Clothier[3]
[1]*Massey University,* [2]*Horizons Regional Council,* [3]*Plant and Food Research*

Water quality management requires accurate estimates of river contaminant loads. In most catchments, there are fewer measurements of water quality parameters compared to flow data because of the high cost of sampling and analysis. Thus, several load estimation methods have been developed to make use of these measurements with different temporal resolution. However, these load estimation methods have not been translated into readily available tools. These tools are essential to reduce the time and effort required by the water quality managers to analyse and map spatial and temporal distribution of river loads.

We developed a web-based tool to calculate river contaminant loads. The main feature of this tool is its ease of use. An example spreadsheet is provided as a template to enable the user to format their data accordingly. This file can be uploaded into the tool to generate a selection of interactive tables and graphs displaying the user's data. Another unique feature of the tool is its ability to estimate the annual loads of water quality parameters at several sites and plot the results on an interactive map. Currently, the tool estimates the annual river loads using the flow stratified load estimation method. In addition, the tool provides interactive spatial distribution of the loads, statistical analysis of flow and water quality parameters and trends over time. The tool is promising in its speed of calculation and enabling the user to compare the spatial distribution of loads at several sites at the same time.

Investigation of nitrogen loads and transport pathways in the Kaiapoi River catchment

Zeb Etheridge
[1]*Environment Canterbury*

Flows in the Kaiapoi River are sustained by groundwater discharges from the lower Waimakariri plains. Nitrate-N concentrations in Silverstream, one of the four main tributaries of the Kaiapoi River, exceeded 10mg/L in 2015, and they have consistently exceeded the National Policy Statement for Freshwater National Bottom Line of 6.9mg/L since 2012.

Environment Canterbury is working with the Waimakariri Zone Committee and the local community to set nutrient load and flow limits for the Waimakariri zone, including the Silverstream catchment. Questions were raised about the cause of the high nitrate concentrations in Silverstream during a series of community and Zone Committee meetings held in late 2015.

Environment Canterbury consents data show that irrigated land area in the inferred groundwater recharge zone for the upper Silverstream reaches increased from around 20% in 2006 to over 70% in 2015. A large part of this increase relates to a major land conversion from forestry to irrigated dairy farming in 2012/2013. Any impacts from this development are unlikely to have been fully reflected in stream water quality measured to date.

This paper provides a summary of the work we have undertaken to investigate nitrogen discharges from land within the Kaiapoi River catchment; transport pathways through the groundwater system; time lags between land use change and stream water quality effects; and the potential for denitrification between the soil root zone and the point of discharge to the surface water system.

An evaluation of analytical stream to groundwater exchange models based on spatial flow assumptions

Michael Exner-Kittridge[1], Jose Salinas[2], Prof Matthias Zessner[2]
[1]Environment Canterbury, [2]Vienna University of Technology

In this paper, a new method for estimating gross gains and losses between streams and groundwater is developed and evaluated against two existing approaches. These three stream to groundwater exchange (SGE) estimation methods are distinct in their assumptions on the spatial distribution of the inflowing and outflowing fluxes along the stream. The two existing methods assume that the fluxes are independent and in a specific sequence, while the third and newly derived method assumes that both fluxes occur simultaneously and uniformly throughout the stream. The results show that the three methods produce significantly different results and that the mean absolute normalised error can have up to an order of magnitude difference between the methods. These differences between the SGE methods are entirely due to the assumptions of the SGE spatial dynamics of the methods, and the performance for a particular approach strongly decreases if its assumptions are not fulfilled. The assessment of the three methods through numerical simulations, representing a variety of SGE dynamics, shows that the method introduced, considering simultaneous stream gains and losses, presents overall the highest performance according to the simulations. As the existing methods provide the minimum and maximum realistic values of SGE within a stream reach, all three methods could be used in conjunction for a full range of estimates. These SGE methods can also be used in conjunction with other end-member mixing models to acquire even more hydrologic information as both require the same type of input data.

The seasonal dynamics of the stream source waters and flowpaths in an Austrian headwater catchment

Michael Exner-Kittridge[1], Prof Peter Strauss[3], Prof Günter Blöschl[2], Alexander Eder[3], Ernis Saracevic[2], Prof Matthias Zessner[2]
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Our study examines the source aquifers and stream inputs of the seasonal water and nitrogen dynamics of a headwater agricultural catchment to determine the dominant driving forces for the seasonal dynamics in the surface water nitrogen loads and concentrations. We found that the alternating aquifer contributions throughout the year of the deep and shallow aquifers were the main cause for the seasonality of the nitrate concentration. The deep aquifer water typically contributed 75% of the total outlet discharge in the summer and 50% in the winter when the shallow aquifer recharges due to low crop evapotranspiration. The shallow aquifer supplied the vast majority of the nitrogen load to the stream due to the significantly higher total nitrogen concentration (11mg-N/l) compared to the deep aquifer (0.50mg-N/l). The main stream input pathway for the shallow aquifer nitrogen load was from the perennial tile drainages providing 60% of the total load to the stream outlet, while only providing 26% of the total flow volume. The diffuse groundwater input to the stream was the largest input to the stream (39%), but only supplied 27% to the total nitrogen load as the diffuse water was mostly composed of deep aquifer water.

Back to basics: Water inventories to implement water sharing in páramo catchments of Colombia and Ecuador

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[1]Landcare Research, [2]NIWA, [3]CorpoPalo, Santander de Quillichao, [4]CESA

We discuss the methodology and inter-cultural learnings from a New Zealand-funded 4-year water management project in the Rio Palo catchment (1,655km^2; population 200,000) of Cauca, Colombia, and the Rio Cutuchi catchment (1,999km^2; population 244,000) of Cotopaxi, Ecuador.

With local partners, the project is implementing (1) land and water inventories with upland indigenous communities, (2) mechanisms for collective water management within indigenous and local legal frameworks, and (3) specific water-related livelihoods projects including dam water storage feasibility, water sharing among trout farmers, and mechanisms for protecting páramo tussocklands from loss of water yield.

Observations of relevance to water management in both Australasian and developing world contexts include:

- When designing a hydrometric monitoring network, being clear about the types of hydrological assessment that the data will allow (e.g. specific discharges, drought return period flows, cumulative water usage).
- Despite low labour costs, the use of inexpensive locally sourced rainfall and water level monitoring equipment requires assessment of its reliability and precision, and local capability for monitoring and repair.
- The importance of socialising with local communities the uses of the data, to reduce risks of vandalism or assumptions that the data may be to facilitate water charges or theft by more powerful downstream interests.
- Legitimising informal catchment groups within national and provincial legal frameworks (e.g. Ecuador's new Ley de Aguas formalises catchment committees but at very large catchment scale).
- Surprising similarities between the holistic cosmovisions of indigenous Andean communities with those of Māori tribes in New Zealand, which provide opportunity to develop shared indigenous catchment management approaches.
- Surprising receptiveness to partnerships between indigenous communities and the private sector, to achieve whole catchment outcomes (e.g. through payments for protecting páramo water sources).
- The opportunity to test anecdotal information with hydrological data and modelling (e.g. assertions that climate change has already reduced water yield, and that planting pines and eucalypts in páramo tussocklands will increase water yield).

A multiproxy 1,000-year hydroclimate reconstruction for eastern Australia, and implications for water management and infrastructure

Anna Flack[1], Anthony Kiem[1], Carly Tozer[2], Tessa Vance[2], Jason Roberts[3]
[1]University of Newcastle, [2]Antarctic Climate & Ecosystems Cooperative Research Centre, University of Tasmania, [3]Australian Antarctic Division

Knowledge of Australia's drought and flood history is of great importance for water resource management and infrastructure. However, as Australia's instrumental record generally only covers the period post-1900 (at best), recent research has focused on developing longer hydroclimate records based on paleoclimate information from a variety of different sources. This study uses a multiproxy approach to compile, compare and analyse 14 paleoclimate records developed from sources including ice cores, tree rings, and cave and sediment deposits.

Wet and dry epochs of the pre-instrumental period were identified if there was agreement across the majority of paleoclimate records analysed. The occurrence, frequency, duration and spatial extent of pre-instrumental wet and dry epochs were then compared to wet and dry epochs since 1900. The results show that pre-instrumental wet and dry epochs were longer and more frequent than those in the instrumental period. Even more disturbing is that over 70% of the pre-instrumental period had no identified instrumental equivalent, implying that the majority of the past 1,000 years was unlike anything that has been encountered in the period on which all water infrastructure, planning and policy is based. We demonstrate the implications of these findings via a case study in eastern Australia. This case study clearly shows that current water resource infrastructure and management strategies would not cope under the range of pre-instrumental wet and dry events that have occurred. When coupled with projected impacts of climate change and growing demands, these results highlight some major challenges for water resource management and infrastructure.

Machine-learning based assistance for groundwater model calibration

Michael Friedel[1], Chris Daughney[1], Lawrence Kees[2]
[1]*GNS Science,* [2]*Environment Southland*

Numerical models provide a way to evaluate groundwater systems, but determining the hydrostratigraphy used in their construction is often challenged by spatially limited field data. We propose a machine-learning approach to obtain optimal starting values and geostatistical constraints to better inform the numerical groundwater model calibration process under these conditions. First, a type of unsupervised neural network, called the self-organising map (SOM), is trained to recognise non-linear relations among hydrogeologic variables. The values of these variables are then estimated at random locations across the model domain by iterative minimisation of SOM quantisation and topographic error vectors. Cross-validation is used to ensure unbiasedness and compute prediction uncertainty for select subsets of the data. Second, analytical functions are fit to experimental variograms derived from original plus resampled SOM estimates producing model variograms. Efficacy of the proposed approach is demonstrated in using mutual information to estimate spatial continuity of hydraulic properties field parameters, major ions, and lithology in Southland, New Zealand.

Incorporating photography to educate future hydraulic engineers

Heide Friedrich[1]
[1]*University of Auckland*

Traditionally, our water resources are overseen, controlled and managed by hydraulic engineers. In the 20th century, hydraulic engineering was one of the pillars of large-scale construction projects, not only in New Zealand, but worldwide. The success of those projects is essentially allowing us now to enjoy the water resources infrastructure we take for granted. During their education, future hydraulic engineers were exposed to, and understood the need to collaborate with, other engineers, such as geotechnical and structural engineers.

In this century, however, we become crucially aware that in order to engineer sustainable water resources infrastructure, economic, social and environmental aspects need to be understood and incorporated in future projects, as well as a much wider variety of engineering skills. All those fields are in a state of flux. How can we align our hydraulic engineering education to prepare future engineers for such a complex and ever-changing landscape?

In this paper I will present how photography fundamentals are used in the engineering curriculum to better prepare the new generation of hydraulic engineers to comprehend, and thus solve, the present water resource challenges our society is facing. What can photography teach us about the flow, storage and usage of our water resources?

Extending flood series using river sedimentary archives

Ian Fuller[1], Prof Mark Macklin[1,2], Willem Toonen[2], Kat Holt[1], Kevin Norton[3], Erica Malloy[1], James Veitch[1]
[1]Massey University, [2]Aberystwyth University, [3]Victoria University of Wellington

Current assessment of flood risk in New Zealand is compromised by short instrumental flow records (generally less than 50 yr) in most large river catchments, which do not typically include the largest floods that cause the most damage to life, property and infrastructure. This paper addresses the need to better understand the magnitude and frequency of floods which occurred prior to the instrumental record by investigating the sedimentary archive of flooding in four New Zealand catchments: Whanganui, Manawatū, Ruamāhanga, and Hutt rivers. One primary objective is to compare fluvial sedimentary archives in bedrock and a range of alluvial river types. In the Whanganui, two sedimentary archives have been investigated: 1) overbank deposits on an alluvial bench c.20m above river level within a bedrock reach of the Whanganui Gorge; 2) palaeochannel fills on terraces 6m and 8m above river level within a mixed alluvial-bedrock reach located in the piedmont zone downstream. In contrast, study reaches in the Manawatū and Ruamāhanga catchments are fully alluvial, with infilled palaeochannels well-developed on a series of low elevation terraces. Holocene floods are recorded as a series of minerogenic sand and silt units in finer-grained organic rich channel fills. Finally, the palaeoflood record of shallow palaeochannel fills was investigated in the formerly wandering/semi-braided gravel-bed reaches of the Hutt River. Flood chronologies are constrained using a combination of radiocarbon dating, OSL, documentary sources, palynology, and an innovative application of cosmogenic isotopes. Flood sedimentology was recorded using high-resolution ITRAX XRF core scanning.

Development and calibration of the HEC-RAS model for the Juqueriquerê River basin in São Paulo, Brazil

Vassiliki Terezinha Galvão Boulomytis[1], Monzur Alam Imteaz[1], Antonio Carlos Zuffo[2], José Gilberto Dalfré Filho[2]
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In order to understand the hydrodynamics of a river basin, it is essential to evaluate its discharge capacity. It is a challenge though, particularly for an ungauged basin, as the discharge frequently changes due to geometric and climate features. Hydraulic models, calibrated with reliable measured data, are efficient tools to assess river basin flow characteristics. Aiming a sustainable river basin management strategy for the Juqueriquerê River basin, located in the northeastern coastline of São Paulo State, Brazil, the widely used HEC-RAS model was developed for the river-basin system. It was calibrated against measured stage data at three locations within the river-basin system. For this purpose, Camburu, Claro and Areeiro gauging stations were selected. The Manning's roughness coefficients for these locations were adjusted to fit with the measured data. The Manning's n-values corresponded to the left bank, bed and right bank of each selected gauged cross-section. These n-values were compared with an earlier estimation of n-values, which was done based on a theoretical approach and field campaigns. The absolute deviation and Mean Absolute Deviation (MAD) values between the estimated and calibrated Manning's n-values were calculated for each cross-section. It is found that, for some cases, calibrated n-values do not match with the theoretical estimations. In this paper, the reasons for these discrepancies are approached.

The value of consumer grade drones (UAVs) for river engineers

Matthew Gardner[1]
[1]*Land River Sea Consulting Ltd*

Over the past 18 months, Matthew Gardner has been using consumer grade drones to assist with river engineering jobs. One of the techniques he has been using is a relatively new process called Structure from Motion, which is an exciting technique that is able to convert a series of photographs taken from different angles and positions with a standard digital camera into a detailed 3D scale model. When combined with accurate ground control points this technique can be used to develop accurate digital elevation models (as accurate as LiDAR), generate georeferenced, orthorectified photos for use within GIS, and the generation of detailed 3D computer models and flyover videos. The process is cost effective, fast and reliable.

This presentation will run over a little bit of background information about how the process works as well as examples of recent jobs and discuss its potential for making detailed 2D modelling possible in areas with little available topo data. The presentation will also look at other examples of the use of consumer grade drones within a river engineering context.

Accounting for water at a national level

Janice Green[1], Penny Fiddes[1], Aaron Wassing[1]
[1]*Bureau of Meteorology*

In Australia, as in other countries, individual states and regions have a good understanding of the sources, availability, and usage of water in their own jurisdictions. However, questions such as who is entitled to use water, when and under what conditions; how the availability of water in rivers and aquifers is changing; what the reliability of urban water supply is; and how much water is being allocated to the environment are often not able to be answered at a national level. This was certainly the case in Australia during the Millennium Drought, in the early 2000s, when rainfall and storage levels were at historic lows and the outlook for urban, rural and environmental water supplies looked dire.

In response to this, the Australian Bureau of Meteorology was tasked with developing a suite of products that report annually, in a standardised approach, on the national status of water availability, water allocations, water trades and water used. These products, which include the National Water Account, ensure that Australia is now in a position to answer, on a national level, previously unanswerable questions. Further, it enables comparisons to be made across states and regions on issues including the proportion of recycled water as a source of urban water for each city; irrigator entitlements and water availability across regions; and the balance between environmental and non-environmental water across Australia.

Although these products were developed for Australia, they are also applicable to other countries and regions in providing a standardised approach for managing water resources.

New design rainfalls for Australia: Lessons learned…

Janice Green[1], Catherine Beesley[1], Cynthia The[1]
[1]*Bureau of Meteorology*

The Australian Bureau of Meteorology recently released new design rainfalls for Australia. The new design rainfalls are based on a large rainfall database which was analysed using "state of the science" techniques. They are available for probabilities from 1 month Average Recurrence Interval (ARI) to 2,000-year ARI and for durations from 1 minute to 7 days.

The derivation of the new design rainfalls was undertaken over 8 years, involving 50 person years, at a cost of over $5 million. The process of estimating the new design rainfalls involved the trialling of numerous approaches at each step. This included the quality controlling of rainfall data from numerous organisations; the selection of the most appropriate distribution and fitting method for the extreme value series; the identification of an optimal approach for regionalising the data; the assessment of methods to be used to extract short duration rainfall statistics from daily read rainfall stations; and the trialling of gridding techniques in order select the most suitable one.

The outcome of the considerable amount of time spent testing at each step was an overall method for deriving design rainfalls that was scientifically rigorous, defensible, and that could be applied across the whole of Australia and not just in data-rich areas. The resultant method not only enabled new design rainfalls to be produced for Australia but also provides a tried and tested approach that can be applied by other countries, such as New Zealand, who are looking to estimate design rainfalls.

Evaluation of a model for disaggregating daily rainfall into hourly rainfields: The Logan-Albert case study

Prof Yeboah Gyasi-Agyei[1]
[1]*Central Queensland University*

The Logan-Albert catchment (3,839km^2) is located in South East Queensland, Australia. Only 5 automatic weather stations (AWSs) that record rainfall at a temporal resolution of 1 minute are located within the catchment, but there are 32 AWSs located within a square region (150 × 150km) encompassing the catchment. For daily rain gauges, 66 are located within the catchment and 283 within the square region. These datasets were used to generate hourly rainfields over the catchment at a grid resolution of 1km^2. The spatial rainfall model is based on Kriging interpolation with the parameters estimated using daily radar rainfields and observed gauged data. In order to test the model, the full hourly radar rainfields for the region were used as input into a GIS rainfall-runoff model, and the generated discharges were considered as the "TRUTH". Then, the daily radar rainfall values at the daily gauge locations (co-located) were selected to run the spatial rainfall model to generate the daily rainfields. The daily rainfields were then disaggregated into hourly rainfields using the limited AWS data, and also used as input into a GIS rainfall-runoff model. Discharges at 11 sub-catchments' outlets were compared, assuming the same parameters and topographic, soil and initial conditions. It was observed that the discharges at all 11 sub-catchments compared very well with the "TRUTH", attesting to the robustness of the spatial disaggregation rainfall model. The over 100 years observed point daily rainfall data can, therefore, be confidently used to generate corresponding hourly rainfields.

Groundwater–surface water interaction in the vicinity of the Blue Spring

John Hadfield[1], Ralph Ostertag[2], Doug Stewart[1], Katie Noakes[3]
[1]*Waikato Regional Council,* [2]*WildImpact Ltd,* [3]*University of Waikato*

Groundwater–surface water interaction in the vicinity of the Blue Spring on the Waihou River, Waikato, was investigated to improve understanding for management of this resource. The Blue Spring supplies the township of Putaruru and a number of water bottling companies, as well as having tourism value. A simultaneous survey of flow and water quality, notably including radon, was undertaken in late February 2016 during a period of low flow.

The distribution of radon and gaugings along the 13km section of the river investigated showed the majority of flow gained (about 4.5 cumecs) was from 800m below the Blue Spring to 1,200m above it. The spring itself was calculated to be flowing at a rate of about 0.46 cumecs. Radon analyses from 22 Waihou River main stem sample locations varied substantially from 0.2Bq L-1 to 16.0Bq L-1, with the highest concentration measured in the Blue Spring. Due to this signal contrast, radon was found to be a very useful indicator of groundwater inflow and substantiated understanding of the flow regime near the Blue Spring.

Deriving discharge with quantified uncertainty using index velocity observations: A probabilistic machine learning approach

Stuart Hamilton[1], Touraj Farahmand
[1]*Aquatic Informatics*

Application of the index velocity method for computing continuous records of discharge has become increasingly common. The method is especially appropriate when more than one specific discharge can be measured for a specific stage. Discharge is derived as the product of the outputs from two models (ratings), a stage-area model and an index velocity model. The stage-area model is generally derived by calculating the area of a surveyed channel cross-section in suitable increments of level. The index velocity model is often determined by a multivariate regression parametric method, such as linear regression, relating surveyed mean channel velocities (Vm) to observed index velocities (Vi). The main challenges with the existing techniques are:

- preprocessing and synchronising continuous Vi data with Vm data
- poorly understood, often non-linear, relationship between Vm and Vi
- model exploration and analysis in order to find the optimal regression model predictor(s) and model type (linear vs non-linear and if non-linear number of the parameters)
- dynamic changes in the environment over time (e.g. geomorphic, biological)
- deployment of the final model into a Data Management System (DMS) for continuous discharge derivation
- objective estimation of uncertainties caused by:
  - field measurement uncertainties
  - structural uncertainties
  - parameter uncertainties
  - continuous sensor data uncertainties.

A novel machine-learning technique has been developed to address these problems. Index velocity data from ADVM, field observations from ADCP, uncertainties and human inference are combined to build a non-parametric/ non-linear self-adaptive Bayesian model.

Blockage is random! A probabilistic framework to estimate blockage factors for design flood modelling

Rhys Hardwick Jones[1], Mark Babister[1]
[1]*WMA Water*

Debris blockage is a significant source of uncertainty in floodplain management and design flood estimation. Blockage is generally either ignored in modelling, or an estimate of blockage potential made from qualitative assessment of likely contributing factors. This presentation will present a probabilistic modelling framework for determining AEP neutral blockage factors for design flood estimation. Application of the methodology to an aggregated spatial dataset of photographic historical blockage records in the Wollongong region is presented. Statistical distributions were fitted to the available data to form a blockage likelihood function. This distribution was used as an input to a Monte Carlo modelling framework to assess the influence of blockage on design flood levels. At 20 sites, a stratified sampling approach with 1,000 samples was used to determine the AEP neutral blockage for a range of culvert sizes. This framework provides a step forward for interpreting limited observed data into a robust and transparent parameter assumption for design flood modelling.

Blockage assumptions are a significant factor for design decisions such as sizing of bridges and culverts. It is also directly relevant to the classification, development and use of flood-prone land. The methodology developed facilitates management and development of the floodplain through an improved estimate of the true flood risk near culverts and bridges. Limitations of the existing understanding of blockage processes and the availability of measured data for hydraulic blockage is also discussed, with recommendations for future data collection processes using currently available remote sensing technology.

The Australian Government's role in reducing community flood risk: The National Flood Risk Information Project

Martyn Hazelwood[1]
[1]*Geoscience Australia*

In the summer of 2010–11, south-eastern Australia experienced a significant number of major flood events, culminating in the flooding of Brisbane in January 2011. The losses experienced by these events initiated the National Disaster Insurance Review to assess whether appropriate national measures were in place to foster more complete sharing of risk. The review highlighted the need for consumers to be more aware of the risk they may face to enable informed decisions to be made on where to live. In response, the Australian Government determined that a 4-year programme to improve the quality, availability and accessibility of flood information across Australia should be undertaken. In July 2012, Geoscience Australia initiated the National Flood Risk Information Project (NFRIP) to meet this objective. NFRIP was composed of three core activities:

- Australian Rainfall and Runoff – improving the quality of future flood information by completing the revision of the Australian Rainfall and Runoff guidelines.
- Australian Flood Risk Information Portal – working towards making legacy flood information and associated mapping freely available from a central location through an online portal.
- Water Observations from Space – analysis of Geoscience Australia's historical archive of satellite imagery to derive water observations to help understand where flooding may have occurred in the past in areas of Australia.

The presentation will outline the NFRIP outputs, discuss some of the challenges encountered in making hazard and risk information available to the community, and the use of the Creative Common Attribution 4.0 Licence in overcoming them.

A methodology for optimisation of mine water management infrastructure

Amir Hedjripour[1]
[1]*WSP | Parsons Brinckerhoff*

A case study including the required dewatering configuration for a mine water dam is discussed to meet no-spill criteria for a defined Average Recurrence Interval (ARI). There is an option for the sediment dam to pump the water to another storage facility before its capacity is exceeded. An optimised dam/pump configuration is proposed by detailed assessment of storm temporal patterns and recording critical points for various storm events and storage-dewatering envelopes to meet the design criteria. A simplified economic analysis is also presented to assist with financial assessment of each configuration and selection of the best alternative.

An integrated catchment modelling approach to set and review New Zealand water and nutrient policies

Andrew Herron[1], Lydia Cetin[1], Richard Cresswell[2], Nic Conland[3]
[1]*Jacobs,* [2]*Eco Logical,* [3]*AWA Environmental*

Regional councils and private industry groups across New Zealand are in various stages of natural resource planning to achieve a balance between sustainable land use intensification, reliable water security and maintaining healthy water-dependent ecosystems. This planning is guided by the National Policy Statement for Freshwater Management.

The Sustainable Land and Water Group engaged Jacobs to provide advice on the effects of the proposed changes to the Land and Water Regional Plan on water quantity and water quality in the Selwyn-Waihora catchment. The key information that policy and management decisions would be based on were the reliability of supply to irrigators and mitigation of nitrogen loads to Lake Ellesmere/Te Waihora.

To provide this advice, Jacobs developed an integrated surface water and groundwater model in eWater Source using inbuilt catchment modelling and a networked groundwater model. The groundwater model was used to represent the flow and water quality transport through the multiple groundwater aquifers beneath the Selwyn-Waihora catchment that are a crucial component of the water and nutrient balance within the system.

This paper discusses the integrated surface water and groundwater modelling approach that facilitated the water resource and nutrient limit assessments at a catchment scale, its application in exploring scenarios for assessing changes to flow regime and nitrate-nitrogen loads under physical and management conditions and the effect on the reliability of supply and nitrogen loads.

Assessing flooding potential in the vicinity of the Myponga Reservoir area

D Ratnayake[1], **Guna Hewa[1]**, J Frizenschaf[2]
[1]University of South Australia, [2]South Australia Water Corporation

Rural properties, located in the fertile floodplain of the Myponga catchment (South Australia) have experienced periodic flooding over the past decades, resulting in the loss of livestock and crops. New landowners, unaware of the flood-prone nature of the landscape when purchasing properties in these topographically low-lying drainage areas during the recent Millennium Drought, have been particularly affected. In order to assist landholders and planners in their efforts to minimise future damage, a study was devised to explore the flooding potential caused by the runoff from the Tiers catchment, which drains into the Myponga reservoir. The flooding potential of the Tiers ungauged stream and its tributaries was assessed using the 1-D floodplain model HEC-RAS. The Australian Water Balance Model (AWBM) is used with parameters estimated for a hydraulically similar catchment to estimate streamflow series of the Tiers ungauged catchment. Annual Maximum (AM) series analyses using Extreme Value Type 1 (EV1) was adopted to estimate the design flow rates at eight selected ARIs (ARI = 2, 5, 10, 15, 20, 25, 50 and 100). The estimated flow quantiles were then used as the input flow rates for the 1-D floodplain model developed using HEC-RAS for an 820m channel stretch of Tiers stream. The results confirmed the extent of flooding in the vicinity of the Tiers stream and allowed a better understanding of the causes of flooding, which ultimately assisted with the identification of a suite of mitigation measures.

Application of AWRA-L gridded soil moisture data for flood estimation

Peter Hill[1], Rory Nathan[2], Jing Zhang[2]
[1] Hydrology and Risk Consulting (HARC), [2]University of Melbourne

Although it is relatively easy to estimate loss parameters for a single recorded event, it is often difficult to characterise how loss varies between events on a given catchment. Likewise, the relationship between typical loss values and catchment characteristics has been elusive.

The Australian Bureau of Meteorology has recently developed the Australian Water Resource Assessment – Landscape (AWRA-L) model which is a daily water balance model at a 5km grid over the whole of Australia. The inputs and outputs from AWRA-L were investigated to see if they were helpful in explaining the observed variability in loss values for a particular catchment and also between catchments.

The soil moisture from AWRA-L was shown to reduce the uncertainty in the prediction of initial loss for a given catchment. For the majority of catchments the soil moisture outperformed the Antecedent Precipitation Index (API) and thus has potential to be a useful tool for flood forecasting.

The AWRA-L soil moisture was also used to define regions across Australia for developing prediction equations for estimating median loss values. AWRA-L inputs and outputs were then used to develop and apply prediction equations for loss values for the whole of Australia. This will form the basis of the guidance for losses in Australian Rainfall and Runoff (ARR).

Mangorei Power Station flood harvesting of the Waiwhakaiho River

Michelle Hitchcock[1]
[1]*Trustpower*

The Mangorei Power Station has recently been granted a change in consent conditions to increase the water take from 7m³/s to 10m³/s in high flow conditions from the Waiwhakaiho River. Hydraulic investigations were undertaken to establish what flow and levels were needed in the river, and behind the river weir, to capture the higher flows. Flow is taken from the river through a gate-controlled tunnel and deposited into a lake before entering the power station. To establish the sedimentation effects on the lake, sediment loadings were also investigated.

The Waiwhakaiho River runs from Mt Taranaki and frequently has quick, peaky flows. Median flow is 3.93m³/s but high flows regularly exceed 150m³/s with a mean annual flood flow of 329.6m³/s. These quick floods mobilise sediment, which, if deposited into the storage lake between the tunnel and the power station, can reduce the storage capabilities of the lake.

Investigation results will be discussed.

The future of flood hazard mapping

Mark Hooker[1], **Ben Fountain**[2]
[1]*Greater Wellington Regional Council,* [2]*Wellington Water*

Over the last 15 years hydraulic modelling of flood hazards has evolved enormously. This has been driven by a combination of widespread collection of LiDAR, modelling software and technique advances, and ready access to vast computer processing power. However, the way we map and communicate the flood hazard modelling information has not kept step.

This is changing, and changing fast. There are four main drivers behind this change:

- The leaky building disaster of the late 20th century led to a tightening of all building consent processes and standards, culminating in the 2004 Building Act. Flood hazards are now a major influence in what, where and how you can build on your flood-prone property. This has greatly increased the demand for detailed and accurate flood hazard information.
- There is a trend in the New Zealand insurance market towards insurance premiums and policies that reflect the specific hazards at the site. Insurance companies are requesting flood hazard information and property owners/buyers are more aware of it.
- The need to adapt to climate change is driving a greater emphasis on sustainable development and appropriate use of flood-prone land.
- Increased public awareness of council processes and challenges to hazard mapping or planning.

Ben and Mark have identified a range of ways to respond. They will draw on their experience from the Wellington Region and across the country on how we can adapt our techniques, terminology and community engagement to achieve better flood risk management.

Attenuation of nutrients through a ferruginous cemented sand layer in sandy soils

Marino Evangelisti[1], **Rosemary Edwards[1]**, **Owen Hoar**[1]
[1]*PDC*

Extensive groundwater quality monitoring has occurred on a rezoned priority 3 Public Drinking Water Source Area (PDWSA) for new urban development in Perth, Western Australia. Nutrient and physico-chemo samples have been observed over a seven-year period in dozens of bore locations throughout pre- and post-development stages. A range of geotechnical and geophysical methods were used in the pre-development phase to clarify the hydrogeology of the site, which was widely believed to be Bassendean sand to depth. PDCs investigations showed a layer of ferruginous cemented sand existed, colloquially known as "coffee rock", acting as a lower permeability aquitard within the study site.

Pre-development work by PDC (then Emerson Stewart) theorised that the layer would act to remove dissolved nutrients from the groundwater, thus substantially reducing the risk of contamination from the development impacting on the drinking water source. The coffee rock layer was considered to be one barrier in the multiple barrier design to protect the groundwater, and was one of the contributing factors to the site being permitted to develop as a test case for the area.

This paper presents data from the monitoring programme which demonstrates that stratification of nutrients with depth is occurring, validating the proposed theory.

Technical learnings from 36th Hydrology and Water Resources Symposium Workshop on Australian Rainfall and Runoff

Graeme Horrell[1]
[1]*Graeme Horrell Consultancy Limited*

I attended the 36th Hydrology and Water Resources Symposium in Hobart from 6–10 December 2015 with support from HydroSoc.

The purpose for attending was to listen to and meet scientists and engineers responsible for the intensity frequency duration (IFD) updates for the Australian Rainfall and Runoff (ARR) (same as NIWA's High Intensity Rainfall Design System, HIRDS) with my specific interest in their methodology (and software) for temporal design storm and areal reduction factors, as these will be attempted for the first time in New Zealand by NIWA, in the planned HIRDS upgrade.

The Bureau of Meteorology has split their rainfall frequency analysis into three: frequently occurring storms, 1-month to 2-year events, 2-year to 100-year, and 100-year to 2,000-year, all covering 20 durations from 1 minute to 7 days.

Areal reduction and temporal design rainfall analysis has advanced considerably in this 4th version of ARR.

Two take-home messages were:

- A huge emphasis on data: "Recorded flood events demonstrate how a catchment responds to rainfall. Recorded data is used in the development of tools and approaches for design flood estimation."
- The age demographics of those attending and presenting on rainfall, runoff and design research is very healthy in Australia.

Managed Aquifer Recharge using a pilot to develop a groundwater replenishment scheme, Poverty Bay

Clare Houlbrooke[1], Brett Sinclair[1], Robert Bower[1], Dennis Crone[2]
[1]*Golder Associates (NZ) Limited,* [2]*Gisborne District Council*

The Poverty Bay community in New Zealand has identified long-term water availability in the area as being a potentially limiting factor in future regional development. A substantial proportion of the water used for irrigation of the intensive horticultural area of the Poverty Bay Flats is derived from groundwater, with most of the abstraction being from the confined Makauri Aquifer. Reviews of groundwater levels have identified declining groundwater pressure trends in this aquifer as an environmental and water supply reliability issue. The Gisborne District Council (GDC) together with interested community partners are investigating water management options to stabilise and restore groundwater trends and improve future water supply reliability, including Managed Aquifer Recharge (MAR). GDC with support from Golder Associates (NZ) Limited are applying in May 2016 for a resource consent for a pilot injection trial at the Kaiaponi site. This is a new proposed recharge site from that presented in past papers. By December 2016 the pilot trial bore should be constructed and initial results from the injection trial can be presented.

Quantifying the effects of macrophyte growth on stage–discharge relationships in New Zealand lowland streams

Jo Hoyle[1], David Plew[1]
[1]*NIWA*

Demand for water resources in New Zealand has increased pressure on river managers to monitor and set limits on water quality and quantity to maintain in-stream environmental values. This requires both continuous monitoring of stream flow, which is typically done using continuous stage records and a stage–discharge relationship, and the need to predict hydraulic variables for quantification of physical habitat. However, this is problematic in lowland streams due to the effect that macrophytes (aquatic plants) have on hydraulics and their highly variable coverage, both spatially and temporally. This paper establishes a relationship between macrophyte blockage and flow resistance for two common but different macrophyte communities (sprawling emergent macrophytes and submerged macrophytes) to quantify the effect of these two types of macrophyte growth on the stage–discharge relationship.

TUFLOW GPU: Best practice advice for hydrologic and hydraulic model simulations

Bill Syme[1], **Chris Huxley[1]**
[1]BMT WBM

Modelling is a useful tool for supporting evidence-based floodplain management decision making. It has been the industry standard assessment approach to estimating flood behaviour for over 20 years. However, data limitations, computation overhead and hardware constraints have historically limited either the spatial coverage or resolution of modelling efforts. A range of factors have combined over the past five years to fuel major advances in 2D flood modelling that largely remove these limitations. The factors are primarily:

- Computer Graphics Processor Unit (GPU) hardware improvement
- GPU flood modelling software development
- significant increases in data availability and accuracy.

GPU computer hardware has advanced exponentially in the last decade for the purpose of computer gaming. Many software companies, such as TUFLOW, are now benefiting from these hardware advances using their new generation of GPU flood modelling software. Testing has shown the 2D GPU models are between 20 and 100 times faster than traditional Computer Processor Unit (CPU) flood models. This equates to university standard super computing power within a desktop computer!

Similar parallel advances have been made in remote sensing technology. Accurate topography information with full coverage over entire catchments, states and in some cases countries is now a reality. These data can now be used to their full potential for hydrologic and hydraulic applications using 2D GPU flood modelling technology.

GPU computing represents a significant advancement in the evolution of flood modelling. BMT WBM, the developers of TUFLOW, are continually undertaking research work focused on how best to use the software. This paper presents real world validation results to a flood event in Far North Queensland, Australia, using a catchment-wide direct rainfall GPU model. Key learnings from the work are discussed:

- What model resolution is required to achieve result convergence (accuracy)?
- Infiltration loss parameterisation, why standard hydrology loss parameters should not be applied to hydraulic models that use an infiltration loss approach (as opposed to a lumped rainfall loss approach).
- How to optimise execution to achieve fastest model simulation. Brute force computing is not always the answer!

Combined regression modelling of winter rainfall in Western Australia using potential climate indices

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Rainfall forecasting using climate indices has become one of the best ways to predict rainfall variability in many parts of the world. Such strategy has also been proved as an effective tool to determine such variability. As Australia is affected by many different weather systems, several studies have been conducted to identify potential climate indices like Indian Ocean Dipole (IOD), El Niño Southern Oscillation (ENSO), Southern Annular Mode (SAM), Blocking highs, MODOKI etc. and their interactions with rainfalls in different parts of Australia. As different regions of Australia have been exposed to different climate indices, it is often recommended to study different regions separately to understand the effects of climate indices and their effectiveness to predict long-term rainfall. This study explores the seasonal variability of rainfall in the Northwest division of Western Australia (NWWA) considering the effects of dominant climate indices responsible for this region. Very few studies have ever been found which had a primary concentration in determining rainfall variability in NWWA. Moreover, none of these studies has considered the relationship between winter rainfall and lagged individual climate indices in NWWA.

Three stations (Mingenew, Northampton and Nabawa) of NWWA were chosen to conduct the study. These stations were selected considering availability of 100 years of continuous rainfall data with minimum number of missing values. Statistical correlations between rainfall and several climate indices (IOD, ENSO-MODOKI, and SOI) were explored using a combined regression model. Models that satisfied the desired statistical significance with high correlation were suggested to predict long-term rainfall for this region.

How big was the January 2016 Geelong storm really? A novel use of radar data

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On 27 January 2016 a severe storm affected the Geelong area causing flash flooding, hail and millions of dollars in damage. Media reports indicated this to be a 1 in 100 event, but how big was this event really?

The significance of an event can be characterised by comparing the recorded rainfall totals to design rainfall estimates. Based on this assessment the rarity of an event (or parts of an event) can be assessed in terms of Annual Exceedance Probability (AEP).

Traditionally such an assessment would have been performed on the basis of rain gauges. In our paper we will be comparing the results from the traditional rain gauge-based approach to a novel approach using radar and gauge data.

The big advantage in using gauge data is that one can obtain a quick estimate of the significance of a rainfall event. However, under-sampling might lead to under-estimating the true significance of the rainfall event. Radar data can overcome this limitation because it provides a much better spatial coverage than the gauge network.

"Rainfields" is a product that the Bureau of Meteorology has developed to combine the higher spatial resolution of radar data with the accuracy of gauge data at the gauge location. By using Rainfields together with gauge data, one can construct maps of event AEP. This novel technique is applied to the January 2016 Geelong storm. The technique and results are validated using data from a dense station network provided by the City of Greater Geelong Council.

Water use efficiency and infrastructure

Dennis Jamieson[1]
[1]*Ecan*

Water use efficiency is emerging as a key factor in achieving both economic and environmental targets of the Canterbury Water Management Strategy. The lack of direct pricing of both water and the effect of pollutants challenges conventional economic approaches. The combination of fostering industry leadership in conjunction with regulatory ("Planning") and non-regulatory processes in Canterbury is leading to insights about the transformation of water use in irrigation already underway – and where it is expected to go in the future.

This paper will draw on local and international examples to illustrate how significant progress in being made in New Zealand. It will stress the necessity of applying existing hydrology/climatology based technology to provide a basis for future advances in water management to ensure New Zealand remains competitive internationally in terms of both economic and environmental goals.

SUMMA time in the Waikato: Rainfall-runoff modelling in ungauged catchments

Bevan Jenkins[1]
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Ungauged catchment or basin is the term applied to catchments with no streamflow time series. Despite recent efforts such as the decade of Predictions in Ungauged Basins (PUB) and subsequent advances, significant challenges remain in modelling flow in ungauged catchments. The development of hydrodynamic models for the Coromandel, Te Kouma, and Manaia harbours require river inflow time series as boundary conditions. There are no currently operated flow recorders in any of the inflowing rivers. Short-term flow time series are available for one stream and a series of spot flow measurements. The approach taken uses a range of techniques of increasing complexity to estimate streamflow time series. The methods used include specific discharge and the use of existing flow recorders from other parts of the Coromandel, development of a parsimonious rainfall-runoff model (GR4J), and use of the process-based hydrological modelling approach of SUMMA (Structure for Unifying Multiple Modeling Alternatives). SUMMA is a recently developed modelling framework which has the ability to alter the modelling approach based on observed data and theoretical considerations. This paper attempts to show the use of SUMMA in relativity data deficient catchments. In addition, it shows the systematic testing of different model structures to improve understanding of streamflow generation processes within the Coromandel catchments. The results from the different approaches will be compared, with a discussion of limitations and thoughts on future model development. The value of a framework that allows the flexibility in model complexity is highlighted.

Assessing the potential impacts of climate change on the Clutha catchment

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The water resources of the Clutha/Mata-Au catchment have a great economic value for the Otago region with the main types of use being hydropower and irrigation. Climate change is expected to alter both temperature and precipitation patterns, which will have an impact on seasonal streamflow, water storages and water management. In this study a model chain is developed in which a fully distributed hydrological model is forced with an ensemble of Regional Climate Model (RCM) simulations. Two model versions of the fully distributed and process-oriented hydrological model WaSiM are implemented (first time in New Zealand), differing only in their snowmelt routines. The ensemble of RCM simulations consists of two emission scenarios and four General Circulation Models (GCM). The meteorological variables were bias-corrected using two different approaches (quantile mapping and delta change) and downscaled to the resolution of the hydrological model (1km^2). With multiple members available in the individual steps of the model chain, their contribution to the overall uncertainty in the projected climate change impacts could be investigated. The whole model chain was run continuously for 110 hydrological years beginning with the reference period (1992–2012), covering both the near future (2040–2060) and the far future period (2080–2100). The transient runs allowed for a continuous simulation of the natural storages (i.e. lakes, groundwater, seasonal snow and glaciers) and the dominant hydrological processes. Finally, the results of the impact study are presented encompassing substantial changes in the historic runoff regime and natural storages.

Serious fun for tomorrow's catchment managers

Carl Johnson[1]
[1]*DHI*

Aqua Republica is a globally benchmarked, engaging online strategy game about water resources, in which each player is a catchment manager, balancing the needs of human populations with those of the environment. The New Zealand Aqua Republica Eco Challenge is an extra-curricular learning event for 11–17-year-old New Zealand youth, using a version of Aqua Republica customised to the New Zealand environment, in which school pupils throughout New Zealand compete for regional and national honours. Aqua Republica has strong relevance to the practical implementation of recent legislation such as the New Zealand Coastal Policy Statement (NZCPS) and the National Policy Statement for Freshwater Management 2014 (NPS-FM), particularly where there are competing demands on water resources. We believe this initiative is filling a current gap in New Zealand education, particularly by combining knowledge from multiple fields of study. Aqua Republica looks, on the screen, like a typical strategy game, but uses DHI's MIKE Hydro Basin behind the scenes to account for water routing and water budgets. Aqua Republica is based on a catchment within New Zealand, with names and features well-disguised. Aspects of iwi co-governance and environmental pollution have been included in simplified forms, with great scope for extension in the future. The game is expected to have more serious applications: Councils that have made significant contributions to the New Zealand Aqua Republica Eco Challenge will benefit from having extended access to the game for internal training and workshops.

Novel methods for improved filtering of rain on grid results for flood mapping

Elliot Jones[2], **Daniel Copelin**[1]
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Rain on Grid (ROG) flood modelling is a relatively new technique in flood modelling. It is gaining popularity due its ability to apply rainfall over an entire catchment area and reduce assumptions based on catchment delineation and flow paths. The post-processing filtering of ROG results in modelling software is necessary to distinguish between overland flow and mainstream flooding. Put simply, a ROG model is "wet" in every cell, so results must be filtered to be sensible. Existing methods are based on a combination of depth, velocity, and catchment size. While these are useful they have certain fall-backs. Specifically, they contain an inherent trade-off between continuity along main flow paths and control over the "order" or magnitude of flow paths. This trade-off has been identified as a hindrance to the presentation of results, and there are currently no readily implementable or automated solutions to this problem (refer to AR&R Project 15, Chapter 11).

Having identified this shortcoming in the filtering of ROG results, two additional post-processing tools have been developed and assessed, with the aim of improving the quality of ROG flood extents and maps. The first is to apply a catchment area threshold, which is used to filter out less-contributing upstream flow. The second method applies flow tracing between disconnected areas of flooding. Both methods involve a novel application of DEM-based flow accumulation algorithms to velocity vector outputs from 2D hydraulic models. These new methods, developed in Python, are compared with the existing methods and provide useful results.

Building wider engagement through creative interfaces to water quality models developed in Source

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The New Zealand National Policy Statement for Freshwater Management directs regional councils to set objectives for the state their communities want for their water bodies in the future and to set limits to meet these objectives. In most catchments, the limit setting process includes the development of integrated water quantity and quality models. However, models have often required access to, and expert knowledge of, sophisticated modelling software, constraining access by other stakeholders.

Models have been developed in the eWater Source software for many New Zealand and Australian catchments. The Veneer interface was developed to create custom front ends for models. Veneer uses web browsers to provide access to a Source model that may have been run on another computer. The results are pulled directly from Source and displayed in the browser and the browser can be used to make certain changes to the Source model and to trigger new runs. Since results are on the web, public access may be provided or the results limited to a more limited set of stakeholders via password protection on the web page.

An example will be presented in the Upper Waikato catchment, demonstrating the web browser interface to provide access to flows, nutrient and sediment loads computed by a Source model.

Estimation of qualifying rainfall events for stream classification

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Under Auckland's proposed resource management plan (the Auckland Unitary Plan) water courses will be classified as either permanent, intermittent or ephemeral. Controls on activities such as reclamation will apply to both permanent and intermittent stream reaches. A major challenge is the distinction between ephemeral and intermittent stream reaches, particularly during the summer season, when groundwater levels are low and intermittent stream features are less distinguishable from ephemeral characteristics. Therefore, a practice note is currently being developed for the classification of water courses in the field, providing guidance on six criteria that need to be considered in stream classification. One of the criteria requires assessment of whether or not a stream reach contains surface water more than 48 hours after a rain event which results in stream flow. This study aimed at estimating the magnitude of a rain event required to cause elevated stream flow that lasts for more than 48 hours, so that the above assessment is meaningful. Rainfall data and flow data from 22 permanent streams across the Auckland region were analysed to infer rainfall-flow-relations that can be applied to intermittent stream reaches. Influencing factors such as underlying geology, catchment size and land cover were investigated. Results indicate that during summer, field assessments may be undertaken after rain events of no less than around 10mm in 6 hours across a range of influencing factors. Further field investigations in intermittent stream reaches are required to test the assumptions and validate the results.

Stuck in the 1960s: The need for fundamental change in flood hydrology in Australia

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Most of the flood hydrology modelling undertaken in Australia uses a derivative of the runoff routing model developed by Laurenson in the 1960s, the Laurenson Runoff Routing Model (LRRM). These include models such as RAFTS, RORB, WBNM and URBS. All these LRRM-based models have two fundamental limitations: there is only one runoff process modelled, and the modelled result depends on the number of sub-catchments within the model. This dependence on sub-catchment numbers leads to the models not being internally consistent – in other words, predicted flows within the model are incorrect because of the model structure. The recent and ongoing update of Australian Rainfall and Runoff has been based on the use of these models, but has failed to provide a procedure for flood estimates by continuous simulation, has not found any consistent means of determining initial loss for an ungauged catchment, and only uses an empirical means of estimating baseflow for design purposes. This paper will examine these issues, and will propose a fundamental change in flood hydrology methodology to a runoff routing model that is internally consistent and can model several runoff processes, including baseflow within the model. Using this more complete and reasonable modelling approach can be expected to substantially increase the chance of a viable continuous simulation flood model, and negate the need for separate baseflow hydrograph estimation.

Estimating the change in stream flow resulting from groundwater takes

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Scoping tools have been developed to investigate how surface water takes from rivers affect the flow regime, and how surface water take rules (e.g. minimum flows and maximum rates) affect the reliability of the surface water takes. These tools are useful to assist with deciding how surface water takes might affect the stream environment and how different rules affect the value of the surface water takes.

Groundwater takes also affect the stream flow regime, but have not previously been considered in these tools. A new method of considering groundwater takes has been developed based on the concept that the baseflow of a stream is derived from groundwater. Through consideration of aquifer locations and the relative contribution of aquifer groundwater to a stream reach's baseflow, the effect of a groundwater take from an aquifer on the reach's flow regime is estimated. This extends the applicability of the scoping tools to regions where both surface water and ground water takes need to be considered.

Disparity between observed rainfall trends in Canterbury and climate change guidelines

Tim Kerr[1], Peter Brown[1], John Bright[1]
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New Zealand temperature has increased over the last 100 years. Analysis of rainfall statistics in the Canterbury Region shows no trend discernible from the high noise of inter-annual variation. Guidelines for estimating future rainfall are based on theoretical relationships between rainfall and temperature whereby 1 degree Celcius leads to an 8% increase of rainfall. Using the historical record as an analogue of future trends, application of the theoretical relationship between temperature and rainfall as a means of estimating future rainfall appears to overestimate rainfall.

Possible reasons for the lack of discernible temperature–rainfall relationship in the historic record are explored.

1,000-year rainfall reconstructions for eastern Australia: Implications for water resources infrastructure and management

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Recent palaeoclimate research indicates that Australia's instrumental climate records (available for ~50–100 years depending on location) do not cover the full range of hydroclimatic variability that is possible. To better understand the implications of this on water resources management, a 1,013-year (1000–2012 common era (CE)) annual rainfall reconstruction was produced for the Williams River catchment in coastal eastern Australia. The Williams River catchment is the main source of water for Newcastle, the sixth largest residential region in Australia. The catchment-scale rainfall reconstruction was based on a teleconnection between summer sea salt deposition recorded in ice cores from East Antarctica and rainfall variability in eastern Australia. The rainfall reconstruction shows that significantly longer and more frequent wet and dry periods were experienced in the preinstrumental period (i.e. before ~1900) compared to the instrumental period. This means existing drought and flood risk assessments are underestimates due to reliance on data and statistics obtained only from instrumental records. The implications of this for water resources management are demonstrated when the rainfall reconstruction is converted to streamflow, reservoir inflows, reservoir levels, time spent in restrictions and other metrics commonly used to assess the reliability of water supply systems. The results clearly demonstrate the inadequacy of the existing system if dry/wet epochs that occurred pre-1900 were to reoccur, and raise serious questions about water security and the robustness of existing water resources management, infrastructure design and catchment planning – not only for the Williams River catchment but also for the wider eastern Australian region.

Assessing flood risk and how it changes over time

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Floods are a recurrent and natural part of the Australian hydroclimate, with evidence of flooding dating back thousands of years. The cost and impact of flooding is high, yet current flood risk is poorly understood and fundamental questions exist as to how flood risk changes over time (and why, where, when and by how much). Climate variability (and change) is known to influence flood risk but its role is not yet properly understood, quantified or managed. Here we tackle this problem by implementing new palaeoclimate information which provides insights into how Australian rainfall, streamflow and influential climate mechanisms (e.g. El Niño Southern Oscillation (ENSO), Interdecadal Pacific Oscillation (IPO)) have varied over the past 2,000 years. This new palaeoclimate information is then used in conjunction with a novel combination of hydrological, climate and stochastic modelling to provide significantly more realistic and useful estimates of existing and future flood risk. These improved estimates of existing flood risk, and how flood risk changes over time, will enable development of adaptation strategies (e.g. infrastructure, planning policy) that reduce the costs of floods and are optimal and robust under a range of plausible futures.

Development of a groundwater model for a tropical eogenetic karst aquifer in Rote Island, Indonesia

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Groundwater is a prime source of drinking water for inhabitants living in the remote tropical karst island of Rote in Indonesia. In this island, karst spring is the only dependable source of water throughout the year because of the intermittent river flow and porous nature of carbonate rocks in the catchment. Rapid regional development resulting in increased population and land use changes are likely to cause reduction of recharge to the groundwater source, which may ultimately threaten the ability of the current springs to continuously provide water for the community in Rote Island. In order to assess the effect of these anthropogenic stresses on future groundwater availability in the catchment, a calibrated and validated groundwater model is necessary. In this study a single-continuum model using MODLFOW was developed using spatial discretisation of 50 × 50m grid cell size. For the model calibration and validation, groundwater level data from seven observation wells were collected for a period of 16 months. Recession curves in the observation wells were established, which suggests that the studied aquifer is eogenetic in nature, having a lower degree of karstification and absence of preferential flow path/conduits. Using Parameter Estimation (PEST) and geospatial Pilot Point methods, hydraulic conductivity and specific yield values were estimated. The results of the simulations show good model performances both in calibration and validation steps.

Automated Geosynthesis: A framework concept for immediate spatial-temporal decision support from environmental data

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Going beyond the technical developments of geoportals Klug and Kmoch (2015) demonstrate that environmental information can be immediately made available and post-processed towards indicators for decision making. This refers back to the Leitbild approach after Potschin and Klug (2010) where stakeholders and decision makers are the key recipients for spatial-temporal information. The scientific and technical achievements in standardised workflows provide a heuristic conceptual basis for driving the next generation of real-time multi-purpose data assembling, evaluating, modelling, and visualisation towards the operationalisation of decisions. This process overcomes the previously hampered transfers of approaches due to incompatible data formats, data availability limitations, and/or unavailable modelling routines. Developing approaches towards operational spatio-temporal solutions, the previously mentioned scientific and technical achievements converge in an "Automated Geosynthesis" approach. Geosynthesis is committed to the combination of spatio-temporal components or elements on the earth to form an interconnected whole. Considering the sum as an entity greater as the amount of its single elements, the geosynthesis should provide spatio-temporal improvements in the understanding of the processes and functions operating in landscapes. Thus, the "Geosynthesis" provides a basis for dialectical reasoning as a discourse between two or more parties holding different interdisciplinary viewpoints. Parties establish a common ground guided by reasoned arguments from environmental, social, economic and political spheres. "Automated Geosynthesis" should deliver operational (web-)services and products that assemble geospatial information from distributed Spatial Data Infrastructures (SDI) for complex analysis to enhance and support the qualified decision-making process in a more efficient and effective way than manual assessments.

Real-time measuring and modelling phosphorus runoff using SWAT and AGNPS

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Lake Mondsee, located in the Long-Term Ecosystem Research (LTER, http://www.lter-europe.net/lter-europe/infrastructure/networks/austria) site "Mondsee", suffers from excess nutrient loads. Phosphorus runoff from the catchment is critical, causing the lake's poor ecological status in past years. Continuing with the setup of a wireless sensor network and an automated assessment of phosphorus runoff and streamflow discharge as described in Klug et al. (2015) , this work extends towards real-time automated phosphorus runoff modelling with the "Soil and Water Assessment Tool" (SWAT) and a desktop analysis based on "Agricultural Non-Point Source Pollution" (AGNPS). We compare stream nutrient and discharge measurements with the SWAT modelling deployed as an OGC Web Processing Service (WPS) and with the manually operated AGNPS modelling. While the static input data (soil, land use, relief data) have been pre-modelled on a desktop GIS, the dynamic environmental conditions (precipitation, soil moisture) are fed into the web process from live data. A Jenkins instance is scheduling and monitoring the model runs. The model output is stored in an OGC-compliant format in a Sensor Observation Service (SOS) and displayed in a WebGIS.

Automated detection of (missing) buffer stripes surrounding rivers in the Mondsee catchment

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Nutrients replaced on intensively used grassland areas impact the ecological quality of surface waters and lakes. As a consequence Lake Mondsee at the pre-alpine/alpine border close to the city of Salzburg in Austria continuously failed reaching its good ecological status as required by the European Water Framework Directive. In collaborative efforts with the Federals State Agencies Salzburg and Upper Austria the farm advisory services, chambers for agriculture, department of hydrology, the waste water sewage treatment plant driver, and many local farmers, we identified missing buffer stripes between intensively used grassland and surface water bodies as one potential emission pathway. In this oral presentation we report on the use of GIS and Object Based Image Analysis (OBIA) techniques to enable an automated quantification of (missing) buffer stripes within the 248km^2 catchment. From the literature we identified parameters such as relief, land use, flow accumulation, and soil properties to determine place-dependent breadths of buffer stripes. A locally adapted structure and type of buffer stripe should ensure the retention of nutrients and the uptake of especially the limited nutrient phosphorus through locally adapted plants before reaching the water body. We conclude that altogether 80.400 metres of buffer strips alongside rivers bordering intensive grassland use are missing. Some of the existing buffers need to be broadened to ensure proper nutrient retention function. Based on local prices the calculated implementation costs for new or to be extended buffers for the 340 hectares require €836.500. We expect this approach to be transferable to New Zealand's landscapes.

Can recharge be reliably estimated through regional-scale groundwater model calibration?

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The estimation of recharge through groundwater model calibration is hampered by the non-uniqueness of recharge and aquifer parameter values. It has been shown recently that the estimability of spatially distributed recharge through calibration of steady-state models for practical situations (i.e. real-world aquifer settings) is limited by the need for unrealistic amounts of hydraulic-parameter and groundwater-level data. However, the extent to which temporal recharge variability can be informed through transient model calibration, which requires the additional consideration of storage parameters, is presently unknown for practical situations. In this study, time-varying recharge estimates, inferred through calibration of a field-scale highly parameterised groundwater model, are systematically investigated using numerical experiments. The analysis involves the use of a synthetic reality, i.e. a reference model, based on a groundwater model of Uley South Basin, South Australia. Recharge estimability is examined subject to changes in (1) the degree to which hydraulic parameters including hydraulic conductivity (K) and specific yield (Sy) are constrained, (2) the number of water-level calibration targets, and (3) the time-varying recharge parameterisation scheme adopted. The identifiability of calibrated recharge and hydraulic parameter values is quantified. Results show that, where a considerable amount of transient water-level targets are available, time-varying recharge values can be accurately determined (<20% average error) through joint recharge-and-Sy estimation, providing that the spatial distribution of K is known. Joint estimation of recharge, Sy and K, however, does not yield accurate recharge values. This study suggests that the estimation of temporal recharge variability through calibration may be impractical for real-world settings.

Geochemical modelling of electron donors involved in denitrification in the Lake Taupō catchment

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Determining the mechanisms of denitrification in groundwater in the Lake Taupō catchment is important for the management and protection of the lake water quality. To identify the electron donors involved, a long-term tracer test was undertaken using a stainless steel chamber installed below the water table that partially isolated a portion of Ōruanui Ignimbrite. The site is located on a dairy farm in the northern Tutaeuaua sub-catchment. The tracers introduced were KNO_3 and KBr.

Based on the evolution of water quality data as denitrification progressed, geochemical modelling was used to estimate the electron donors contributing to the denitrification. The results suggested that, on average, denitrification was caused by organic carbon (~30%) and ferrous iron [Fe(II)] consisting of Fe(II) in a hypothetical pyroxene (~42%) and "free" Fe(II) (~28%), perhaps residing in an amorphous phase like volcanic glass. Measured increases in Na were best modelled by incorporating it into the hypothetical pyroxene ($Na_{0.11}Fe^{2}Fe^{3}_{0.63}Si_2O_6$) used as a source of Fe(II). Measured decreases in K could not be explained by dilution or ion exchange; it was possibly taken up in halloysite or other clay minerals. Denitrification was best modelled as being first-order (R^2 = 0.98) with a rate of 0.0058/day. Findings indicate that groundwater denitrification is not limited to formations with organic carbon as the electron donor. This has important implications for assessing where denitrification may occur within the lake catchment.

Case study: How hydrological modelling identified dam gate operational issues and mitigated potential dam failure risks

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Lenthalls Dam is the main water supply for Hervey Bay in Queensland. The height of the dam was raised in 2007 to secure Fraser Coast's water supply for its growing population. The project and dam upgrade won a High Commendation award from Engineers Australia in 2008.

The Lenthalls Dam catchment has been subject to a number of flood events subsequent to the raising of the dam, including a 1% AEP event. In all cases, the dam operated safely with no hidden risks evident.

An anomaly in the flow behaviour at the dam was first observed when calibrating the hydrology model to historical flood data. Essentially, higher than expected flood levels were observed. While this was readily dismissed as due to modelling inaccuracies, the modelling also disputed the automatic and manual field data logs of how the dam gates were operated during the floods.

Nevertheless, extensive efforts were made in investigating and reconciling the unexpected discrepancies, including reviews of rainfall data, hydrological assumptions, field observations, event data logs, and new underwater field inspections.

It was finally resolved and accepted that the hydrological modelling was correct, and that the operational behaviour of the dam gates had somehow behaved anomalously under the peak flow conditions. The results validated the robustness of the hydrology model and exposed the hidden operational risks at the dam. It led to urgent efforts in rectifying and upgrading of the dam gates in order to minimise any potential risks of dam failure.

The state of hydrologic practice in Victoria, Australia

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This paper provides a summary of current hydrologic practice in Victoria based on a review of 33 recent flood studies in rural areas. Information is provided on the approaches that have been used, the hydrologic models selected, and the consistency of analysis with recommendations in Australian Rainfall and Runoff (1987 edition, the revision projects and the 2015 edition).

Most flood studies use a combination of hydrologic and hydraulic modelling. A runoff routing model, generally RORB, is used to estimate design flood hydrographs that are then used as inputs to a 2D hydraulic model that is used to provide depths and flood extents for mapping. The RORB routing parameter, kc, was chosen based on fitting the model to historical floods. The routing exponent, m, was universally fixed at 0.8. The selection of values of impervious fraction varied widely. Some consultants set these to zero while others based them on information from local planning schemes so used various non-zero values for the different sub-areas. Design losses were generally based on recommendations from ARR 1987 with little use of more recent guides. Design losses are sometimes based on matching RORB results to flood frequency estimates. Temporal patterns were based on the Average Variability Method as documented in ARR1987. Even though temporal patterns can be extracted from local pluviographs using a tool provided in RORB, no examples were found where this was used.

Modelling to support water resource management of the Hakataramea catchment in South Canterbury

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The Hakataramea River drains an 890km² rural and upland catchment in South Canterbury, and is a north (true left) bank tributary of the Waitaki River. The confluence of the two rivers is at Kurow. Water from the river is used for irrigation, stock water and community uses.

With a view to an update of sections of the Waitaki Catchment Water Allocation Regional Plan (Plan) relating to the management of water in the Hakataramea catchment, Environment Canterbury (ECan) sought to improve, through modelling, their understanding of the hydrology of the catchment, and the effect of abstraction on the flow regime of the river.

This paper considers the water resource modelling undertaken; particularly determination of naturalised river flows, flow gains and losses along the river, modelling of historic and current consents to abstract, and assessment of abstraction reliability for consent holders.

While the modelling was being undertaken, a consent application for additional abstraction from the river was being processed by ECan, and subsequently was subject to an Environment Court Hearing in March 2016. The model described in this paper was modified to assess the impacts of the proposed additional take on the river's flow regime and the reliability of existing abstractions. The results of the modelling were presented in evidence and assisted other experts to assess economic and ecological implications of the proposed take.

The model is being calibrated using recorded abstraction data for current consents, and will be migrated to a new software platform to reduce model complexity.

Dambreak analysis to evaluate downstream hazard potential: Several case studies

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Dams are a class of water infrastructure that can pose a potential hazard to communities, the environment and property well beyond their as-built location from an uncontrolled release of their reservoirs' contents. Furthermore, dams typically have expected life spans well in excess of other engineered works and need to demonstrate resilience over time.

Current international best practice is to relate the design standards, such as safe spillway capacity and earthquake resistance of a dam, to the severity of the hazard from a hypothetical dam failure. The key point is to ensure that the probability of failure is extremely small related to the degree to which the potential impact is high. Modelling of sunny day and flood failure scenarios allow the potential consequences of failure, specifically the downstream damages and hazard to life, to be determined.

In this paper, we present several dam break studies that illustrate the process, and which encompass a large variation in the scale of dams assessed. The dam break studies presented range from a modest 20m high flood detention dam in Greater Wellington, to a much more substantial hydropower dam but of a similar height on the River Nile, and to a complex of dams up to 114m high retaining over 1,000 million m^3 of water for irrigation and hydropower in the Philippines.

Long-term variability of proglacial groundwater-fed hydrological systems in an area of rapid glacier retreat

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Proglacial groundwater-fed features, such as seeps, substantially impact proglacial hydrology, ecology, and geomorphology. However, there is a paucity of research with regard to the impacts of climate change and glacier retreat on the spatial extent of these features. This paper investigates the impact of glacier retreat on the spatial extent of proglacial groundwater-fed seeps and groundwater levels. Research took place in western Skeiðarársandur, the large proglacial outwash plain of Skeiðarárjökull, a retreating temperate glacier in SE Iceland. Changes in the extent of proglacial groundwater seeps were mapped using historical aerial photographs from 1986, 1997, and 2012. Proglacial groundwater levels were monitored in shallow boreholes between 2000 and 2012. The western margin of Skeiðarárjökull has retreated approximately 1km beyond its position in 1986. However, this retreat was punctuated by short periods of re-advance. The surface areas of groundwater seeps and lakes in the study area have declined by ~97% between 1986 and 2012. Most of the decline took place after 1997, when the mean annual rate of retreat increased threefold. Groundwater levels declined substantially between 2000 and 2012, although this trend varies spatially. Direct impacts of glacier retreat are suggested as the main cause for these declines, which are projected to adversely impact sandur ecology. The paper also provides a conceptual model of the controls and impacts of proglacial shallow groundwater systems.

That bloody pipe does leak: Understanding the nuances of waded gaugings

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Upstream and downstream concurrent waded gaugings were used to assess losses from, and the efficiency of, numerous existing open race irrigation distribution networks throughout the Manuherikia catchment, Central Otago.

A gushing discharge from a rocky slope approximately 20m below a piped section of distribution race was measured at >50L/s. It was suspected that the discharge was being fed by leakage from the approximately 100m long piped section of race. Waded gaugings in the race (which was flowing at approximately 450L/s) immediately upstream and downstream of the piped section using the 0.6 depth method indicated very limited flow losses through the piped section but indicated the losses occurred in an approximately 150m section of race immediately downstream of the piped section. Subsequent investigation involving upstream-downstream gauging using a velocity profiler, physical isolation and draining of sections of the race and inspection of the drained pipeline confirmed that the leakage was from the piped section, and the leak was subsequently fixed.

The exercise highlighted the need to understand the parameters associated with undertaking wading gauging using the 0.6 depth method and the need to appropriately select both the gauging method and the gauging location.

Standardising hydrological modelling for the Wellington region (Wellington's own TP108)

Charlotte Lockyer[1]
[1]*Cardno*

Councils throughout New Zealand face a similar dilemma with regard to flood protection. As our stormwater infrastructure ages, development and infill housing is increasing, the effects of climate change are driving more extreme flood events, and there is pressure to keep our rates to a minimum, councils are needing to effectively manage flood risk. Wellington Water (the three waters governing body for Wellington City Council, Hutt City Council, Upper Hutt City Council and Porirua City Council) are pushing for all new developments to be built hydraulically neutral to help limit the demand on existing stormwater infrastructure. For this to be effective there needs to be a consistent approach to how the hydrology of ungauged catchments is calculated.

Cardno have developed a standardised hydrological modelling methodology for Wellington Water to improve how flood hydrology is calculated for small ungauged urban catchment across the region based on a methodology and parameters calibrated to local data. The drivers for this study have been to develop a methodology that will be robust, defendable and useable, while balancing conservatism (minimising the likelihood of underpredicting large floods without placing undue onus on developers to over-design stormwater infrastructure).

Following analysis of regional rainfall and flow records, three catchments were selected for calibration. There was a good match between calibrated model results and observed flow data when using the SCS unit hydrograph. Catchment parameters were refined for design storms and will form part of a user guide for stakeholders to estimate flood hydrology across the Wellington region.

Interdependence of design losses and temporal patterns in design flood estimation

Melanie Loveridge[1], **Mark Babister**[1]
[1]*WMA Water*

Design flood estimation in Australia has more recently shifted towards a joint probability assessment of flood-producing characteristics. This can lead to irregularities in flood frequency estimates due to the interplay of stochastic variables. The current study highlights the interdependence between design losses and temporal patterns in the estimation of flood frequency curves. Historical temporal patterns are adopted along with an Australia-wide initial loss probability distribution, as derived in the Australian Rainfall and Runoff revision projects. Design flood estimates are then derived within a Monte Carlo framework for a number of catchments around Australia. Results show particular sensitivities when using high losses with a sample of temporal patterns that are reasonably uniform (in time).

Efficacy of a storm-based Monte Carlo approach in modelling flood volumes

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Monte Carlo simulation allows for more realistic estimates of true flood characteristics to be derived. To date, the efficacy of these models has been assessed against a single flood characteristic, being the peak flow. Another key flood characteristic, however, is the runoff volume (over a given duration), which is crucial when designing flood mitigation structures (such as flood control dams and detention basins). When considering the peak flow, it is reasonable to adopt a model based on the most extreme burst of an event. However, to model flood volumes accurately, a complete storm approach needs to be adopted, which encapsulates the pre- and post-burst periods. This paper develops a Monte Carlo framework for the estimation of design floods and compares the results to at-site flood frequency analysis of the runoff volume. A storm-based approach is adopted where the limitations of critical duration theory (as previously adopted) are overcome using a synthetic time series of differing duration rainfall events. The key flood-producing characteristics are treated as stochastic variables, including the AEP, depth, duration, temporal patterns, initial loss and inter-event arrival time. Results are presented for eight small rural catchments along the east coast of New South Wales, Australia.

Hawke's Bay Lysimeter Project: Installation to data collection – What have we learnt so far?

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Five rainfall recharge lysimeter sites have been operating on the Heretaunga Plains and Ruataniwha Plains, Hawke's Bay, since installation in 2011–2013. The primary aim of these sites is to quantify rainfall recharge, and to improve rainfall recharge and flow models that enable informed water management policy. The lysimeter sites include three non-weighing, cylindrical soil monolith lysimeters that measure 500mm in diameter by 700mm deep. Drainage from each lysimeter flows to an underground concrete enclosure and is measured by tipping bucket rain gauges. Each site includes a ground-level rain gauge and a standard rain gauge for comparison. A number of modifications were made to the enclosure design to prevent flooding of instruments, and is now being used in other regions of New Zealand.

Up to five years of data has been collected at some sites. Results indicate rainfall recharge at the dryland sites ranges from an average of 22% at Bridge Pā to an average of 47% at Substation. Data collection QA/QC procedures been developed for these sites, and may be subsequently included in the New Zealand National Environment Monitoring Standards programme for data collection from lysimeter sites. In addition, these datasets will be compared with recharge assessments to support the groundwater modelling projects for the Heretaunga Plains and Ruataniwha Plains aquifer systems.

Gravel transport and aggradation in the Kauaeranga River

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The Kauaeranga River is a steep mountain stream draining the Kaimai Ranges and meets the Waihou River near the sea. Rainfall is high, with short, intense events, resulting in a "flashy" temporal flow pattern and a high gravel bedload. The risks of flooding, channel erosion, and channel avulsion are also high, and in flatter reaches downstream will be exacerbated by an expected high aggradation rate.

Gravel transport was calculated from output from hydraulic modelling of flood events. These calculations demonstrate that the long-term bedload is dominated by extreme events such as the 1% AEP event, and also show a change in bedload regime at a gradient change 2.2km upstream of the Waihou confluence:

- Upstream, bedload transport is high and probably erratic.
- Downstream, bedload transport is lower (about 18,000m^3/year) and more uniform.

The river's lowest reaches have a bed of silts and muds, but gravel is said to lie underneath. Calculations confirm that in flood events gravel is carried through to the Waihou River confluence.

Long-term aggradation at the change in gradient may be only partly mitigated by gravel abrasion, but could be controlled by gravel extraction. This would require calculations to determine the best location and extraction rate, and a bed level monitoring programme. Calculations indicate creating a reach of wider channel may be a practicable long-term way of trapping gravel.

A gravel management plan endorsed by Waikato Regional Council is needed, to specify the approach most suited to the Kauaeranga River's particular geomorphic characteristics.

Why do suspended sediment–turbidity relationships fail?

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Rivers route significant volumes of suspended material to coastal areas, estuaries, wetlands and lakes. However, when landscapes are disturbed, the volume of exported material greatly increases and has potentially adverse effects on river form and function. It is widely recognised that activities like forest clearance increase the delivery of suspended sediment to waterways. Deforestation is a closely monitored activity to ensure that clearance activities mitigate against the effects of sediment loss. In 2015 a study was conducted at Glendhu Forest in the Lammerlaw Ranges in Otago, utilising the existing paired catchment infrastructure. The objective of this study was to assess the preliminary effects of partial forest clearance on stream flow and water quality. Suspended sediment was measured in a control catchment covered in indigenous snow tussock (*Chionochloa rigida*) and the *Pinus radiata* catchment. As expected, this preliminary study concluded that the suspended sediment concentration was higher during forest clearance, relative to the tussock catchment. However, in both catchments, no relationship between suspended sediment concentration and turbidity could be determined. Thus, turbidity records could not be used as an effective predictor of suspended material.

Robust supply planning for a metropolitan city: Portfolio optimisation and real options

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This paper shares the experiences gained in the application of multi-objective optimisation in the context of bulk water planning for the greater Sydney region. It involved development of a hydro-economic model of the bulk water system that was coupled with an evolutionary genetic algorithm to identify the set of non-dominated optimal solutions. The optimisation identified the minimum expected cost portfolio (comprising a mix of operating and infrastructure options) for a given demand. By varying the level of demand (from current demand to demands that could occur decades into the future) and finding the minimum cost portfolios, it is possible to develop an understanding of how the system should evolve into the future. This approach has considerably reduced the time spent by modellers developing portfolios and provided decision makers with a richer set of choices.

One major issue confronting decision makers is the considerable uncertainty about the future trajectory of demand and climate change. This makes the selection of the "optimal" schedule of portfolios difficult because it can be sensitive to the choice of future trajectories. In response to this challenge, strategic water planning has embraced the "real options" approach. The core idea is to select portfolios that may not be "optimal" for a given scenario but perform acceptably over the range of scenarios considered to be plausible. Such portfolios retain flexibility to be able to adapt to changing circumstances. This paper describes the application of these principles to ensure the planning for Sydney's future robustly delivers a secure yet cost-effective supply.

Understanding the value of reconstructing environmental history of reservoirs for improved water supply management

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This study emphasises the importance of understanding the environmental history of water supply reservoirs to improve the management practices of reservoirs. A deep reservoir (Lake Bellfield, which is 36m) and a shallow reservoir (Lake Wartook, which is 8m) in the eastern Grampians Ranges, near Halls Gap in Western Victoria, Australia, have been chosen to understand historical water quality transitions.

Lake Bellfield and Lake Wartook are good case studies as they have both experienced recent floods and fires which caused water quality issues that impacted the water supply for the Wimmera Mallee community. Moreover, while there are concerns about the water quality, particularly after the floods and fires, only irregular detailed monitoring has occurred to date. Thus, there is currently little or no coherent understanding of the historical water quality transitions of these lakes.

Key questions now focus on the extent of the recovery of these reservoirs – whether a complete recovery to original water quality can be achieved or whether climate change and geochemical processes will lead to water quality conditions that remain different from the past. Answers to these questions require understanding of historical water quality transitions over the life history of the reservoirs.

This study will measure a range of water quality parameters as well as hydrodynamic characteristics of both lakes. Monitoring to date has focused on water quality parameters which have the most potential to impact on water supply operations. Additional monitoring and paleolimnological assessments will be undertaken to better understand the environmental history and mixing characteristics of the lakes, to help inform the future operations of the reservoirs following the influx of sediments and inflows after floods or fires.

Role of consistent and transparent water accounting modelling for sustainable water resources management

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Increasing competition for often scarce water resources and water management reforms triggered by the recent Millennium Drought have required individual user water accounting in hydrological modelling for development and implementation of sustainable water resource policies to meet wider water user needs. Seasonal determinations undertaken throughout the season specify water availability in regulated river systems. Victoria introduced a carryover rule in 2007, allowing unused allocation to be carried over to following seasons, as a contingency measure for individuals to manage risks. Subsequent reviews resulted in six types of carryover accounts, each defined by nine different features. Although these carryover types with nine features provide flexibility to entitlement holders for sustainably managing water, the complexity of the rules has presented challenges to modelling these in a consistent, transparent and defensible manner. Models of water accounts in river basins, agreed and trusted by stakeholders, underpin effective water sharing dialogues and negotiations. Therefore, a generalised module based on a complex algorithm simulating all aspects of the rules has been developed to model the complex carryover rules. It includes a set of parameters/flags to define the carryover account type and features, thus providing users a simple, easy and flexible tool to choose the carryover account type to be modelled. It has been tested in two complex Victorian river systems by incorporating generalised modules for entitlement holders in hydrological models of these systems. The model results illustrated robustness of the module for simulating carryover and accounting rules. The module can be easily modified and incorporated in other systems.

Surface water and groundwater dynamics in the Ōhau and Waikawa catchments, Horowhenua

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Regional councils are required to meet both national and regional policies and objectives regarding the maintenance and enhancement of freshwater quality. In catchments such as the Ōhau and Waikawa to the south of Horizons Region, strong connectivity between surface water and groundwater requires an in-depth understanding of hydrogeological processes and the interaction between these systems.

To better understand the cumulative effects of groundwater abstraction and effects of land use on water quality and in-stream values, and to inform the implementation of Horizons Regional Council's rules for nutrient management, an investigation of the Ōhau and Waikawa catchments is being carried out by Horizons Regional Council and GNS Science to characterise areas of recharge and discharge, water flow paths, and hydrochemical processes, and to identify sources of nitrate in both groundwater and surface water.

A concurrent flow gauging and water quality survey was carried out across the catchments during low flow conditions in March 2016, followed by groundwater level and quality surveys to quantify groundwater flow and identify hydrochemical processes. Radon, dissolved gases, age tracers and stable isotopes were employed to delineate water flow pathways, interactions and catchment lag times. Nitrate isotopes were also included to identify sources of nitrate within the catchments.

This investigation complements an intensive bio-monitoring programme to establish the current state of periphyton, macroinvertebrate, and fish communities, and identify drivers that influence changes in these communities. Baseline coastal and estuary water quality sites have also been established.

Constraining the Ensemble Kalman Filter for improved streamflow forecasting

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The Ensemble Kalman Filter is often applied to hydrological models with minimal volume/capacity constraint. Flux constraints are rarely, if ever, applied. Consequently, model states can be adjusted beyond physically reasonable limits, compromising the integrity of model output. We investigate the effect of constraining the Ensemble Kalman Filter (EnKF) on forecast performance. A "free run" in which no assimilation is applied is compared to a completely unconstrained EnKF implementation, a "typical" hydrological mass constrained implementation and then to a more tightly constrained implementation where flux as well as mass constraints are imposed to force the rate of water movement to/from ensemble states to be within physically consistent boundaries. Eight events over 2008–2010 were selected for analysis. Mass constraints alone did little to improve forecast performance; in fact, several were significantly degraded compared to the free run. In contrast, the combined use of mass and flux constraints significantly improved forecast performance in six events relative to all other implementations, while the remaining two events showed no significant difference in performance. Placing flux as well as mass constraints on the data assimilation framework encourages physically consistent state estimation and results in more accurate and reliable forward predictions of streamflow for robust decision-making. We also experiment with the observation error, which has a profound effect on filter performance. We note an interesting tension exists between specifying an error which reflects known uncertainties and errors in the measurement versus an error that allows "optimal" filter updating.

The irrigation efficiency dilemma

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The pressure is on New Zealand's water managers and users to demonstrate that water for irrigation is allocated and used efficiently. Adding additional pressure is the universal introduction of water quality targets and the need to minimise leaching of nutrients to groundwater.

While regional councils include policies and rules in plans and conditions on resource consents that aim to achieve efficient water use, assessing the effectiveness of these rules and conditions is very difficult. The dilemma is that overall performance results from the collective effect of individual irrigation events where application efficiency and drainage below crop root zones is highly variable and difficult to measure. While water use and water quality can be measured, quantitatively linking individual irrigation events to changes in water quality is challenging.

Farm environment plans are now mandatory on many irrigated farms. However, while these plans include actions that are likely to improve irrigation efficiency and minimise nutrient leaching, specific benchmarks around irrigation performance are scarce. Measurements of rainfall, water use and soil moisture are made and regularly used to efficiently manage irrigation events, but use of that information to quantify performance, such as on an annual basis, is not routinely done.

This paper reviews current performance measures and discusses ways of using benchmarks derived from measured data to quantify irrigation performance and assess it against efficiency targets. Use of benchmarks will help both water users and water managers to assess ongoing irrigation performance annually, and demonstrate whether improvements are being achieved.

Strategic water resource planning using eWater Source in Port Macquarie, Australia

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The eWater Source model was used to assess secure yield, compare future headworks options and ultimately support long-term water supply planning in Port Macquarie, NSW.

In this rapidly developing region, Port Macquarie-Hastings Council (PMHC) is responsible for undertaking a Secure Yield Study to ensure sufficient water supply headworks capacity under current and future climate conditions.

To support the study, PMHC sought a modelling platform appropriate for planning as well as future operational, optimisation and catchment modelling applications, along with a user-friendly interface to foster internal capacity building. The eWater Source model was selected to facilitate this.

The project involved the development of calibrated Source Rivers models to calculate the secure yield under existing and future infrastructure and climate scenarios. This was combined with economic analysis to inform decisions on water restrictions and infrastructure development.

The complexity of the existing supply system presented a modelling challenge. It incorporates multiple storages, backflow arrangements, and complex operating rules that are used to overcome water quality challenges inherent in this unfiltered system. Modelling of future scenarios incorporated treatment and innovative measures such as direct potable reuse. Source provided a platform to model these complexities and use automation to optimise system yield.

This is the first application of eWater Source on an NSW Secure Yield project. Although increasingly used for river system modelling, there are few examples nationally of its use in yield modelling, particularly for complex headworks systems. This project has provided greater insight into the functionality of Source in supporting strategic water resource planning.

Defensive engineering or engineering a defence

Greg McMahon[1]
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A panel discussion was organised at HWRS 2016 on "Liability and Hydrology – How is the threat of class actions affecting engineering decision making?" The event featured a paper by Professor Hayes defending the operators of the Wivenhoe Dam during the January 2011 Flood, and expressing concerns that criticism of the operators could lead to adverse professional circumstances for the engineering profession. There was only time for four questions to the panel, two from the facilitator.

This paper expands that discussion by providing some support and some criticisms of points made by Professor Hayes. The paper identifies certain assumptions and assertions included in the paper for which there may be counter-indications. Expertise and its nature, independence and the perception of independence, and compliance with the scientific method are aspects considered by the paper in this context.

Some sound points made in Hayes (2015) are acknowledged, concerning the importance of outcomes, understanding of technical issues by the law, the exercise of discretion by an expert, and the responsibilities of the operator and regulatory agencies. This paper sets out how some of these points, however, may have been misapplied in Hayes (2015) to the matters at issue during that January 2011 flood on the Brisbane River.

While Hayes (2015) and the short discussion voiced the threat of future perversions to water engineering and to engineering expertise, this paper points to possibilities that certain perversions may have already occurred, about which the panel discussion and the paper presented thereat may be unknowing.

Major floods: Random or irregular

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Flood frequency analysis as a methodology assumes that flood events are randomly distributed. As the understanding of weather has developed into ocean-scale and world systems, the notion of regularity of systems has come into evidence. Most discussions of this genre have been with respect to drought, but some interesting observations have also been made with respect to flood events.

This paper examines the data on flooding within the 10 major catchments comprising more than 63,000km^2 bounded by three mountain ranges in South East Queensland. The purpose was to test the existence and the strength of any such regularity to flooding in this well-populated region of Australia.

The basic approach was to identify the flooding that occurred during predetermined 5-year periods that were 35 years apart – the 40-year cycle – and the flooding that occurred outside of these nominated 5-year periods. The basic statistics were weighted for the length of flood record, catchment area, ranking of flood, and a combination of these factors. The results indicate that 75% to 91% of major floods in South East Queensland have occurred within a set of 5-year periods exactly 35 years apart.

The University of Newcastle has reported 40-year and 20-year flood cycles for coastal New South Wales. The research unit was asked to provide an explanation, or confirm the lack of an explanation, for this apparent phenomenon.

An alternative or supplementary approach to describing the frequency of flooding is described.

KiwiRail Main South Line: Bridge 190 Shag River hydraulic assessment

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Bridge 190 over the Shag River is a part of the KiwiRail Main South Line (MSL). It is a 130m long bridge supported by timber piers. KiwiRail is currently considering options to upgrade the bridge due to deterioration of the timber piers, frequent debris raft formation and the scour risk on the north abutment.

The Shag River is a part of an extensive floodplain, which also includes Muddy Creek, approximately 450m to the north.

This paper describes a computational hydraulic modelling study of the Shag River/Muddy Creek system to investigate flood patterns across the floodplain and establish design flood levels for the upgrade. Topographic data from an unmanned aerial vehicle survey was combined with LiDAR data to construct a digital terrain model of the floodplain. The model was qualitatively calibrated against observed flood inundation patterns and observed flood levels from historical flood events.

The hydraulic modelling investigations demonstrated that both watercourses and the floodplain must be considered as a single hydraulic system. Muddy Creek functions as a major overflow facility for flood events in the Shag River. As the magnitude of a flood in the Shag River increases, the proportion of the total flood volume conveyed by Muddy Creek increases to almost 50 percent.

The calibrated model provided suitable design flood level predictions to enable options for upgrading the bridge to be developed. It also demonstrated that there is potential to reduce the overall span length of the bridge without upsetting the balance of the hydraulic system.

Flood forecasting by scenario lookup

M Antoine Chiaverini[1], Graeme Smart[1], **Richard Measures**[1]
[1]*NIWA*

Flood losses are increasing worldwide. Accurate flood forecasts permit short-term countermeasures and evacuations – reducing economic losses and saving lives. Forecasting inundation has 3 stages: weather forecasting, runoff forecasting and floodplain modelling. Weather forecasts are routinely produced worldwide, rainfall-runoff models are being used to forecast river flows, and 1D hydrodynamic models are sometimes used to forecast overbank inundation. However, hydrodynamic modelling in real time has drawbacks: 1D hydrodynamic models or simplified 2D hydrodynamic models have limited accuracy and are not suitable for complex flow path configurations or urban situations; 2D models (which solve the full shallow water equations) may not run fast enough (even with GPU acceleration) to give sufficient warning time, and the inundation warning system will fail if the hydrodynamic model fails. These drawbacks have been overcome by a system which uses look-up of potential inundation extent from a library of pre-computed scenarios. The paper describes the methodology to characterise rising floods and use these characteristics to select approximate inundation scenarios from a library. The approximate, pre-computed scenarios are interpolated in real time to give a representative inundation forecast. Implementation demonstrated the system to be accurate and robust with very fast computation time (minutes or seconds). The low computational requirements allow low cost forecasting installations and suggest that the system could also be used with ensemble weather/flow forecasts to predict uncertainty.

Measuring success: Horizons Regional Council's water allocation framework in the rear-view mirror

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For the last 6 years, the Manawatū's surface water resources have been managed and monitored under the policies and rules of Horizons Regional Council's combined Regional Plan and Policy Statement (the One Plan). This is a "second generation", "science led" policy document aimed at allocating from the region's rivers and streams to agricultural, industrial, and public uses whilst maintaining and supporting identified instream values, hydrological variability, and ecosystem health. Implementation of the framework is principally via the resource consent process. With the framework well-embedded into the resource management matrix, the time has come to assess, review and report on the effectiveness of the policy framework in achieving its stated objectives for each river, stream or catchment – a process that appears relatively simple on the surface, but requires a considered, systematic and detailed approach, to our knowledge yet to be attempted in depth by any other agency in New Zealand.

Using Envirolink funding, Horizons Regional Council engaged Cawthron Institute scientists specialising in instream habitat requirements, flow limit setting and ecosystem function to help delve into the world of policy effectiveness monitoring and reporting.

The learnings from this process to date are relevant and applicable to all regional councils in New Zealand who may be attempting to manage freshwater resources using allocation limits and minimum flows in a similar fashion to Horizons Regional Council, and this paper aims to share where we are at, and what we have learnt in this realm of water allocation and river health management.

eWater Source as an integrated modelling tool supporting policy and management in Southeast Asia

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Source is a whole of river system modelling framework designed to support the needs of Integrated Water Resources Management (IWRM). Key innovations of Source are that it incorporates sophisticated algorithms for representing water policy and operations, and that it is designed to be modular and extensible. This paper presents two Source projects underway in the Mekong River Basin that demonstrate contrasting approaches to modelling for IWRM. Both projects seek to address complex, trans-boundary issues in water resources management. One uses Source's built-in algorithms to create a truly integrated model, the other uses Source as an integrative framework to combine results of other models. The first project, Procedures for Water Use Monitoring (PWUM), aims to ensure that the use of water resources is reasonable and equitable throughout the Mekong Basin. Three Source pilot project models have been developed, integrating rainfall-runoff modelling with irrigation, reservoir and hydropower modelling to evaluate the impacts of water use scenarios. The second project, the Mekong River Commission (MRC) Council Study, aims to assess the positive and negative impacts of water resources developments on people, economies and the environment. A Source model of the Upper and Lower Mekong Basin has been developed to assess the impacts of the development scenarios on flows, sediments and water quality. Rather than relying solely on built-in algorithms, the Source model uses "plugins" to integrate outputs from other models and tools. A common theme of both projects is the importance of integrating water policy and operations with hydrological modelling.

Using transition probabilities in combination with a smoke tracer test

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Representing heterogeneous alluvial gravel aquifers presents challenges when assessing groundwater impacts to support decision making. Because small-scale structures, which may impact groundwater responses, cannot be characterised uniquely, stochastic or probabilistic approaches are typically adopted to identify worst-case outcomes. These approaches rely on generating multiple equally-likely aquifer property realisations, and running the model with each realisation to provide probabilistic predictions.

Markov-chain geostatistical methods (transition probabilities) are one stochastic approach used in this context. The transitional-probability models characterise the juxtapostional tendencies of stratigraphic units (e.g. open-framework-gravels, sand, sandy gravels and claybound gravels). However, estimation of the transition-probability model parameters often result in very non-unique solutions, resulting in a wide range of equally plausible transitional probability models: therefore the stochastic model itself cannot be characterised uniquely. Nevertheless, the range of equally plausible transition probability models are seldom explored in a stochastic sense; instead, a single stochastic description of the hydrostratigraphy is usually selected.

Using an additional data set, the dominant flow directions from a smoke tracer test, we were able to further evaluate the plausibility of the candidate Markov-chain geostatistical parameters and identify the statistical characteristics of the hydrostratigraphy more precisely than based on lithological observations alone. The basis for this was a clear relationship between the mean facies lengths in the X and Y dimensions and the number of successful model-to-measured matches with observed dominant flow directions from the smoke tracer test. This provides a method for determining the stochastic nature of our heterogeneous aquifers that is easily transferable to another site.

SAM and decision crash testing models

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Increasingly the question is asked "Can models that aren't optimised to make a specific type of prediction make predictions which reliably inform model based decisions?" Nowak et al (2012) apply statistical methods to test the decision fit-for-purpose capability of models and the worth of decision-critical data used to inform these models, with type I and II error analyses. Similarly Tolsen and Craig (2016) developed a decision-oriented surface water model testing framework called "Decision Crash Tests". Kitanidis (2016) suggests a paradigm shift from models as simulators to models as receptors for data important to the decision-making process. He defines a good model as one which quantifies uncertainty and supports a comprehensive risk-based evaluation of design or policy alternatives.

We support these conclusions. The "Smart Models for Aquifer Management Project" (SAM) aims to provide a practical implementation of this philosophy. Using linear and subspace analysis tools we gain insights into appropriate simplification strategies for a particular data and decision context. The analyses use the premise that models require simplification to support numerical processing of data. Furthermore, simplification must optimise model receptacles for existing data (so that predictive uncertainty can be reduced) at the same time as it optimises receptacles for data that are lacking (so that predictive uncertainty can be assessed). It must do this in ways that orthoganalise these receptacles (to prevent predictive bias). We present a synthetic model study that illustrates "fit-for-decision/purpose" model design and construction, with applications to the limit-setting context in New Zealand.

Using leading-edge research to inform freshwater management policies: Example of the Southland region, New Zealand

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The 2014 New Zealand National Policy Statement for Freshwater Management requires regional authorities to set objectives, policies and methods balancing national objectives and community values for water quality. In response, the Southland region has developed a 6-year science programme articulated around four collaborative projects following the source, pathway, receptor model. This paper focuses on the Fluxes and Flows project, co-funded by the region and central government (contestable research fund), which provides a framework for understanding water flux to inform freshwater management policy. Both project updates and reflections on the challenges inherent in working at the science–policy interface will be presented.

The objective of the project is the development of a 3D regional, steady-state groundwater flow model, loosely coupled to a surface water flow model, as the foundation for a series of downscaled transient groundwater-surface water flow and transport models (TN, TP and sediments). The outputs are designed to facilitate community engagement and explore options for managing freshwater through catchment limit setting. A biophysical conceptual framework, nutrient inputs and ecological sensitivity of receptors, required to inform and be informed by the flow and transport models, are outputs from the other three collaborative projects.

At the end of June 2016, project outputs included a 3D regional geological model, a comprehensive hydrochemical review of surface water and groundwater, and a loosely coupled regional flow model. With catchment limit setting for Southland scheduled to begin in late 2016, there is increasing emphasis on successful science communication.

Updating a national groundwater sampling protocol

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Environmental monitoring standards are currently being prepared for New Zealand at the initiative of regional authorities and the Ministry for the Environment. Ten standards have already been published and are in use by the industry. This paper focuses on the development of the Groundwater Domain section of the Discrete Water Quality Standard for the purpose of state of the environment monitoring.

The objective of the standard is to ensure that representative water samples are collected from an identified source, accompanied with the relevant metadata and field measurements necessary to interpret the sample chemical analysis, and handled appropriately. It also provides guidance on quality check on chemical analyses, quality coding and record preservation, in accordance with the Environmental Reporting Bill (2015).

The current groundwater sampling protocol (2006) was used as a basis to develop the NEMS standards. Existing content was checked against standard publications published after 2006; new content was developed through workshops and review of groundwater experts and presentation to relevant scientific groups. Each of the four freshwater domains (rivers, coastal, lakes and groundwater) were first developed through a domain-specific panel, and then harmonised, with considerations for the need of cross-domain consistency for both data collection and record management.

The Groundwater Domain NEMS standard clarifies the water quality data cycle and provides context information to equip samplers and data managers with sufficient knowledge to undertake sampling using a defensible protocol. Currently open for review, this standard will supersede the 2006 protocol as a best practice tool rather than a mandatory requirement.

Stratification of groundwater age and quality at Lake Taupō from push-drill tests

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To understand detailed nutrient flow pathways from the catchment into Lake Taupō, we have performed four push-drill tests near the lake shore to depths of 20–27m. Groundwater was sampled with 2–3m depth resolution for hydrochemistry, age tracers, and isotopes. Results clearly show stratified and confined flow conditions. This knowledge is crucial for understanding nutrient fluxes from the land to the lake, and potential for nitrate attenuation in the groundwater system.

Vertical stratification of groundwater age and geochemistry in the Wairau Aquifer

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Due to a clear declining trend of water levels in the Wairau Aquifer since the early 1980s, Marlborough District Council require a better understanding of how the groundwater dynamics vary in the vertical direction. Knowledge of vertical differences in aquifer processes will help understand the Wairau River–Wairau Aquifer recharge mechanism, which potentially accounts for much of the long-term water level decline. This information is required for setting new limits for managing land surface contaminants and refining the existing allocation limits for the Wairau Aquifer. Marlborough District Council has a reasonably good understanding of how Wairau Aquifer hydraulic properties and flow processes vary spatially near the land surface, but little is known about how these aquifer properties or processes vary vertically within the aquifer.

Age tracer and chemistry samples from paired shallow and deep wells have been collected to obtain a more complex 3D understanding of recharge mechanism and flow dynamics of the Wairau Aquifer.

Optimisation of Greater Wellington Regional Council's groundwater monitoring networks using multi-correlational and Kriging-based methods

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Long-term groundwater monitoring networks can provide essential information for the planning and management of water resources. Greater Wellington Regional Council is in the process of rationalising its groundwater network in line with the allocation of resources in the Long Term Plan. A multi-correlation analysis was undertaken to determine which wells to exclude (or commit lesser monitoring resources) from the current network because they add little or no beneficial information (redundant). A set of key (index) wells were identified and used to generate multi-regression equations to reproduce data for the redundant wells.

Kriging-based spatially balanced and density sampling algorithms were used to optimise the monitoring network and also identify where new well locations are required. The algorithms were used to find the set of wells whose removal leads to the smallest increase in the weighted sum of the:

- mean standard error at all nodes in the Kriging grid where the piezometric surface is estimated (the Kriging grid was modified to include index wells identified from the multi-correlation method)
- root-mean-squared error between the measured and estimated water-level elevation at the removed sites
- mean standard deviation of measurements across time at the removed sites
- mean measurement error of wells in the reduced network.

The network design methods were applied to optimise groundwater level observation well networks in the Kāpiti Coast, Wairarapa and Hutt groundwater zones. Each network was optimised 10 times by removing wells in sets of tens in both shallow and confined wells.

Improving aquatic community health with the help of big data bedload transport studies

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Infrastructure development and the associated impacts to water and the environment have seen growing media coverage in New Zealand. Development of water storage infrastructure is a major issue around the world. The alteration of hydrological and sediment regimes as a result of impoundment leads to modified stream habitats with a corresponding detrimental effect on instream biota. This may increase periphyton biomass downstream of dams, a major concern for in-stream biota. Flushing flows to maintain substrate turnover below dams may be a key tool in managing periphyton biomass. However, this requires an accurate understanding of initiation of motion thresholds to release flushing flows capable of moving the surface layer of the bed. The initiation of particle motion is the product of a complex set of hydraulic and geomorphic interactions operating at high spatio-temporal resolutions. This creates significant issues for river managers, stewards, and scientists to calculate initiation thresholds. Advancements in remote sensing technologies may hold the key to calculating initiation thresholds in natural channels, provided we can process the "big data" produced by these methods. This paper looks at the potential role of some of these remote sensing technologies and big data in river health management using case study examples from the Pohangina River, New Zealand, and the Rio Cordon, Italy.

ARR blockage: Numerical implementation and three case studies

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Comprehensive guidance on the blockage of hydraulic structures, especially culvert entrances, has always been sparse. The long-awaited guidance on the blockage of hydraulic structures has now been provided to the industry through the ARR review research Project 11 (Stage 1 and Stage 2 reports). The ARR blockage methodology differs significantly in its approach to "hydraulics" from conventional industry practice and is yet to be widely adopted by the industry; therefore the effect on flood and stormwater studies is largely unknown. The approach also produces blockage factors that are both AEP and location dependant within a catchment, and are therefore difficult to implement in flood modelling packages.

In this paper the ARR blockage method is implemented in the TUFLOW software, whereby blockage scenarios based on differing AEPs and catchment land uses may be easily managed via TUFLOW's Event Management functionality. The ARR blockage method is compared with conventional industry blockage calculations to examine how the methods differ in theory. Finally, the ARR blockage method is compared with conventional practice using three flood models. Two of the models are large creek models from the Brisbane local government area. The third model is of a recent large subdivision application where the impacts on development pads and lot yield are important. The findings show that where the kinetic energy (V2/2g) is high and large blockage factors are required, the ARR blockage approach can produce significantly higher upstream water levels.

Lake Coleridge power scheme: Enhancement initiatives

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The Lake Coleridge power scheme is nestled in the Canterbury high-country and has been utilised for hydro-generation for over 100 years. Initially the scheme had three units and an installed capacity of 4.5MW, with additional turbines installed in 1917, 1922 and 1925. To augment the natural catchment inflow, the Harper River and the Acheron River were diverted to the lake. In 1977 the Wilberforce River was also diverted. More recently, most of the generating units have been replaced or upgraded with a maximum station output of 39MW, generating on average 270GWh pa.

The hydro scheme is managed within station, lake, and diversion consents. At high lake levels, diversions cease. Likewise, diversions cease at high Harper and Wilberforce flows.

To better manage and to increase inflows to the lake, several enhancement initiatives were investigated. These initiatives involved a review of consents requirements, a review of scheme instrumentation, and options to improve spill and diversion management. Several projects have resulted and include:

- in 2015, Acheron weir upgrade
- in 2015, improved Lake Coleridge level measurement
- in 2015/16, improved instrumentation and monitoring on the Harper, Wilberforce and Acheron.

Also being progressed are the Wilberforce-Oakden canal gate optimisation and spill control project and outcomes from the review of consent limits.

This presentation will discuss the review, investigation and outcomes of these enhancement initiatives.

Generalised equations for rainwater tank savings under different climatic conditions: A case study for Sydney

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Rainwater harvesting is an established effective alternative water source besides the main water supply around the world. However, optimised harvesting of rainwater is always a challenge as the reliability of this water supply depends on many factors, e.g. rainfall, size of the water tank, catchment etc. Various studies have been done in this context considering water usages and rainfall and roof area, and different methods are proposed to maximise the water supply reliability for an optimum rainwater tank. Among the analysis methods, a daily water balance method is the most acceptable and reasonably accurate. However, general end-users hardly can interpret outcomes of these types of analyses. This paper presents the relationships of expected water savings under different climatic conditions for selected tank sizes with two major contributing factors – demand and roof area – for an Australian city, Sydney. Expected annual water savings were calculated for different combinations of tank size, roof area and demand using an earlier developed daily water balance model, eTank. For a given tank size under different climate conditions, expected water savings for different roof areas and demands are presented in the form of a chart that end users can easily understand. Also, produced charts for particular conditions (climate and tank size) were formularised in a generalised equation; one equation for each tank size and each climatic condition to facilitate computer-aided programs. Eventually, results from these developed equations were compared with the model-simulated results, where it is found that the generalised equations are reasonably accurate.

Development of generalised equations of water savings from rainwater tanks for North Adelaide, Australia

Upendra Paudel[1], Monzur Imteaz[1]
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Rainwater harvesting systems are a popular alternative water source because it needs less treatment and easy to collect. Rainwater's popularity would be increased further if end users knew how much water can be harvested with different tank sizes for particular locations. Different models and software are available to quantify the harvested rainwater. Most of the models use long-term average annual rainfall data for the analysis. With the climate change effect, these long-term average data may not provide reliable rainwater tank outcomes. So, this research used a daily water balance model, "eTank", which can calculate rainwater savings in three different climatic conditions: dry, average and wet year. Further, all these models need appropriate rainfall data for the analysis, which might be cumbersome and may not be used correctly by end users. Therefore, this research is focused on the development of generalised equations for rainwater tank savings for Edinburgh, a northern suburb of Adelaide, South Australia. Through analysis on eTank-generated outcomes, 12 different equations were developed for different tank sizes having roof area and water demand as independent variables for different climatic conditions. Furthermore, utilising the parametric trend, these 12 equations were reduced to only three water savings equations, one for each climatic condition.

Application of ARR FLIKE for at-site flood frequency analysis in New South Wales, Australia

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Design flood estimation is needed to size hydraulic structures and for many other water resource management tasks. Flood frequency analysis is the preferred method for design flood estimation when a longer period of streamflow data is available. In the new Australian Rainfall and Runoff (ARR), for at-site flood frequency analysis, no particular probability distribution has been recommended; however, a greater emphasis has been provided on the log Pearson Type 3 (LP3) and Generalised Extreme Value (GEV) distributions. In this paper, 20 catchment sites (with high quality recorded streamflow data) have been selected from New South Wales (NSW) State in Australia and flood frequency analyses have been undertaken using ARR FLIKE software. A number of goodness-of-fit tests are applied to compare among five most commonly adopted probability distributions: LP3, GEV, log-normal (LN), Extreme Value Type 1 and Generalised Pareto (GPA). A boot-strapping is conducted to compare flood quantile estimates by different distributions and assess the level of uncertainty. It has been found that two-parameter distributions do not perform well in New South Wales. Among the three-parameter distributions, GEV and LP3 perform equally well; however, GEV is found to introduce a relatively higher degree of error to some cases compared with the LP3 distribution.

Trends in rainfall data in New South Wales, Australia

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Rainfall varies widely from year to year in the Australian continent. These changes have a significant impact on the Australian environment. Therefore, analysis of rainfall trends is essential in assessing the impacts of climate change in the designing, planning and management of various water resource projects. This paper examines the trends of sub-hourly, sub-daily and daily extreme rainfall events, and the number of rainy days and annual total rainfalls in 30 rainfall stations located in New South Wales, Australia. A non-parametric Mann–Kendall test was applied to test statistical trends at 1%, 5% and 10% significance levels during the study period 1978–2010. It is found that the statistically significant positive (upward) trends are more prominent than a statistically significant negative (downward) trend, especially for short duration events. Furthermore, there is an overall decreasing trend in annual rainfall total and number of rainy days.

Hydrogeological study of a fossilised geothermal environment: Case study for a gold-silver prospect at Puhipuhi

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Puhipuhi, Northland, represents a well-preserved hydrothermal system that has been historically mined for mercury during the early 20th century, and explored since the 1980s for deeper economic reserves of gold and silver. It is a geologically complex setting consisting of a faulted basement overlain by recent sedimentary rocks and basalt, with relict geothermal activity manifesting as silicification, vent breccias and extrusive sinter deposits, and enriched with gold, silver, arsenic, antimony and mercury.

A conceptual model has been developed from a number of sources, including deep CSAMT/AMT geophysical surveys, historic exploration drill holes, and NRC water bore logs, as well as existing literature. A 3D geological and structural model has been developed by ENZ using Leapfrog. A baseline groundwater and surface water monitoring project has been completed for the region to aide with planning for potential deep exploration drilling. Additional to standard water quality monitoring, the study included stygofauna sampling and taxa identification, and surface water fauna tissue analysis for trace mercury.

The environmental and cultural value of the groundwater and surface water resources within and surrounding the tenement is high. The shallow groundwater quality is good, with private springs and wells harnessing the resource. The high quality of the groundwater is interesting given the recent geothermal influence the area has experienced, which would typically produce acidic, non-potable groundwater conditions. Planned exploration drilling requires sound environmental management and public consultation to mitigate risks and concern over the mobilisation of heavy-metal enriched groundwater. Drilling is planned mid-2016, and further information is hoped to be included in the long abstract.

Non-traditional stabilisation of a reach of Brookvale Creek in Brookvale, New South Wales

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Warringah Mall is a major regional shopping centre located within the Brookvale Creek catchment in Sydney's northern suburbs. Extensive drainage augmentation works are being constructed within Warringah Mall to reduce the flood risk within the shopping complex.

An upstream reach of Brookvale Creek between Old Pittwater Road and Warringah Mall has been experiencing bank erosion periodically over many years.

It was estimated that the drainage augmentation scheme in Warringah Mall would generate a small increase in the channel flood velocities in Brookvale Creek upstream of Warringah Mall. It was concluded that there is a need to stabilise the creek banks for a minimum distance of 90m upstream of Warringah Mall in order to eliminate an increase in erosion risk. The creek bank conditions also led to the need to secure the structural stability of any erosion control works to be included in the creek.

The proposed stabilisation works were developed through an exhaustive process of hydraulic and geo-technical investigations and detailed discussions with stakeholders. They comprise a concrete-lined channel with a flat bed and vertical walls to a height equal to 2/3 of the current bank height. The upper bank has been re-graded, stabilised and revegetated with herbaceous and small woody plants. These investigations and the resulting works are described. It is concluded that the non-traditional works will improve bank stability and improve stream water quality due to reduced bank erosion, and do not impact on the flood risk to adjoining lands.

Comparing design storm burst and embedded design storm approaches in the Narellan Creek catchment, New South Wales

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In 2013 a new Draft Flood Study addressing both mainstream and overland flow flooding in the Narellan Creek catchment in south-western Sydney was prepared. However, an earlier 2000 flood study is still being used by Camden Council to issue flood information along Narellan Creek. Flood levels determined in the 2013 study for some areas along Narellan Creek are significantly higher than the flood levels documented in the 2000 study.

The 2013 study was prepared using a TUFLOW floodplain model with a 5m grid. Runoff was estimated using the Direct Rainfall Method (DRM) and an Embedded Design Storm with the 2-hour burst embedded in a 24-hour storm. Based on the recommendations of two independent peer reviews, Camden Council commissioned further hydrological assessments comprising:

- review of the hydrology documented in the 2013 study
- RAFTS hydrologic modelling of the 1% AEP storm
- validation of the 1% AEP flows determined in the 2013 study with those derived using the RAFTS model.

The objective of these investigations was to ascertain whether the hydrology in the 2013 study can be adopted or whether additional assessments should be undertaken. The hydrological assessments which were undertaken are described. To overcome the issue of "losses" in the 2D terrain in the 2013 study, it was recommended that a hydrological model be used to generate runoff rather than the DRM approach.

These recommendations were implemented, and the impact on the flood levels along Narellan Creek is overviewed.

Estimating the incremental increase in inflows due to cloud seeding over the Australian Snowy Mountains

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Snowy Hydro have implemented a wintertime, ground-based, glaciogenic cloud seeding programme in the Snowy Mountains region of New South Wales, Australia. The experimental period started in 2004 and was expanded to a larger area in 2010. A series of reviews showed that during suitable conditions, cloud seeding increased precipitation by an average of 14%, with no adverse environmental impacts. In 2013, legislation was passed to operationalise the experimental programme. Cloud seeding is intended to enhance precipitation, increasing inflows to the Snowy Mountains Hydro-Electric Scheme, which in turn increases water storages for the generation of hydroelectricity.

Cloud seeding occurs between May and September, and snowmelt influence on inflows typically recedes by the end of November. A robust statistical relationship has been developed to estimate the incremental increase in inflow from May to November, due to the contribution of the calculated annual increase in precipitation created by cloud seeding. Precipitation enhancement was determined through rigorous analysis of data from a network of representative precipitation gauges across the region. The analysis encompasses four sub-catchments of the scheme within the cloud seeding target area. Inflow data for these catchments are prepared independently to the precipitation data. A range of other environmental variables have also been considered.

To maximise the value of the additional water captured in storage, Snowy Hydro is seeking to unlock more operational flexibility from the regulatory processes that govern their operation. This is a crucial part of the process to manage stakeholder expectations and ensure the ongoing commercial viability of the programme.

Deriving temporal patterns for areal rainfall bursts

Scott Podger[1], Mark Babister[1], Peter Brady[1]
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Areal temporal patterns have been derived for the update of Australian Rainfall and Runoff (ARR) 2016 as part of Project 3: Temporal Patterns of Rainfall. These patterns have been developed for a range of Annual Exceedance Probabilities (AEP), durations and catchment areas. This paper outlines the method of extracting these patterns, including shapes and rotations of the catchment area to achieve the rarest areal pattern. The selection of areal patterns for recommended use is also discussed, including limitations and issues encountered. The testing of the patterns has been undertaken on the Hawkesbury-Nepean catchment. The areal temporal patterns are compared with the traditional simple design event method and the new regional point temporal patterns.

UTSA decision support system for Burrinjuck Dam flood operations and airspace management

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The management of Burrinjuck Dam reservoir in the Murrumbidgee Valley balances the objectives of maximising the water resource available for irrigation and the environment, and minimising the potential flood risk downstream. The dam has historically been managed using a set of operational nomographs that require the user to manually obtain dam level and gauging station data, estimate inflows during a forecast window period, and work through a formulated process to calculate recommended gate settings. In 2015 WaterNSW initiated the development of a Storage Operations system to automate the input and output data exchange processes for dam operations, provide rainfall runoff model-based inflow forecasts to the dam, embed the existing gate-setting nomograph procedures, estimate downstream tributary inflows, and provide hydrodynamic routing of dam outflows to determine resulting downstream peak discharges and water levels. The system was implemented in a user-configurable decision support system framework with a map-based user interface. This allows flood operators to review real-time hydrometric data throughout the catchment, to set up and execute catchment and dam inflow forecasting models, to visualise and review model and nomograph process outputs, and to send automated alerts to users via email. The system has recently completed operational testing, and is currently being adopted into flood management procedures in the Murrumbidgee Valley.

Spring depletion potential in the Heretaunga Plains semi-confined aquifer zone: Implications for water permit consenting

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This study considers the conceptual setting of a new deep well located in the Heretaunga Plains semi-confined aquifer zone, Hawke's Bay. The new well is deeper and larger in diameter than other surrounding wells in the area. It is situated adjacent to an excavated drainage channel and is flowing artesian with a positive head pressure of +4m. The aquifer is brown gravel alluvium with evidence of thick overlying blue clay aquitard. The Ngaruroro River flows across the plains approximately 1.5km to the north and east. There is some heterogeneity with the aquitard material, and areas of weak seal are apparent, particularly towards the west. A high rate (120L/s) and three-day duration free-flow test was carried out. Monitoring was undertaken within a number of surrounding wells. Analytical modelling techniques were used to determine aquifer parameter estimates. The modelling included quantitative assessment of the potential to deplete nearby known spring locations.

The property holds an existing irrigation water permit. This permit has low flow cut-off conditions. The outcome of the modelling was reviewed against the management approaches currently used within the region. The appropriateness of the existing low flow cut-off conditions, if the water permit is transferred to the new well, was considered along with options to increase the overall volume of abstraction for the property.

Regional flood modelling in Tasmania: Comparison of ARR RFFE Model and Kriging

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Regional flood estimation is widely used in hydrologic practice for estimation of design floods in ungauged catchments and also to compare design flood estimates obtained by other methods (such as rainfall-runoff modelling) in both the gauged and ungauged catchments. In Australia, a new regional flood frequency estimation (RFFE) model, known as "RFFE Model 2015", has been developed recently and included in Australian Rainfall and Runoff (ARR), the national guide for flow estimation. This paper compares ordinary Kriging and the RFFE Model 2015 in estimating design floods for Tasmania State in Australia. The RFFE Model 2015 is based on a regional LP3 distribution and region-of-influence approach, while Kriging uses spatial interpolation technique to estimate LP3 parameters. Based on a leave-one-out validation, it has been found that the relative error in flood quantile estimates is relatively smaller for Kriging, but bias is higher for Kriging compared with the RFFE Model 2015 and at-site flood frequency analysis estimates. The findings of this research will be useful to enhance regional flood estimates in Tasmania.

Regionalisation of the parameters of a rainfall-runoff model: A case study adopting the Australian Water Balance Model

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A rainfall-runoff model is an integral tool in estimating climate change impacts on future runoff. In order to use a rainfall-runoff model in a runoff estimation process, it needs to be calibrated and validated beforehand adopting the observed data (e.g. rainfall, runoff and evaporation). But one of the major limitations in calibration and validation of a rainfall-runoff model is the unavailability of the data for many catchments due to lack of gauging stations and poor quality data. In these conditions, regionalisation of the parameters of a rainfall-runoff model can play an important role in estimating runoff for the ungauged and data-poor catchments. This study has applied three different techniques in regionalising the parameters of a rainfall-runoff model, namely the Australian Water Balance Model (AWBM), to produce the best possible runoff estimates for the catchments. A total of 20 catchments from Eastern New South Wales, Australia, have been adopted as study catchments. The three regionalisation techniques adopted in this study are: (i) transposing calibrated parameter values of the AWBM model from the gauged catchments to the other catchments, (ii) producing a single set of parameter values by averaging the calibrated parameter values from all the catchments, and (iii) linking AWBM model parameters to physical catchment characteristics. The results indicate that all three techniques have been able to simulate runoff with minimum error.

Rainwater harvesting potential in Sydney: Are we harvesting enough?

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Rainwater harvesting has become popular in Australian urban areas due to water restrictions, greater environmental awareness, government regulations and incentives for installation of rainwater harvesting systems. It can provide non-potable water to meet various needs such as toilet flushing, laundry, gardening and car washing. In peri-urban and rural areas of Australia, rainwater is also used for drinking. In the urban areas, rainwater tanks are connected with water mains and hence users have no idea how much water he/she is saving due to having a rainwater tank. In this paper, rainwater harvesting potential in Sydney is investigated by developing a continuous simulation model that accounts for daily rainfall and water demands. The water savings and reliabilities for 3kL, 5kL and 10kL tanks are investigated and compared with BASIX requirements in New South Wales (NSW). It has been found that the currently recommended 3kL tank size in NSW is unlikely to provide optimum water savings from a rainwater harvesting system. The findings of this study will be useful to recommend an appropriate tank size for Sydney, Australia.

Evaluation of hydrological drought severity

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Hydrological drought is characterised as a substantial reduction in the availability of water in the land phase of the hydrological cycle. This study evaluates hydrological drought thresholds, which are easy to use in real-time conditions . The applicability of the Standardised Hydrological Drought Index (SHDI) across time and space make it a useful index for monitoring, assessing and predicting hydrological drought events. Two stations in the Yarra catchment in Victoria, Australia, were used to evaluate hydrological drought events at various time scales spanning 3-, 6-, 9-, and 12-month scales. The severity of drought classes (SHDI=0, −1, −1.5, −2) were assessed based on the selected time scale. The calculated SHDI threshold values were transformed into the mean monthly streamflow threshold values. The study showed that the mean monthly streamflow threshold value decreased with an increase in drought severity class. The decreasing trend is more significant in the shorter time scale than that of longer time scales. However, the differences in mean monthly threshold values at different time scales at SHDI=0 is not significant, although the values changed considerably with the increase in drought severity class. Monthly threshold streamflow values from the 12-month time scale were 1.2, 2, 3, and 4 times larger than the value for the 3-month scale considering SHDI=0, −1, −1.5, −2 respectively for Alderman Creek, in Victoria. In Walsesh Creek, the values were 1.2, 2.5, 4, and 7 times larger than that of the 3-month scale for the drought classes listed before. Moreover, the average durations of drought events changed noticeably as a function of the time scale for both test catchments.

Strategies to overcome unavailability of land use and nitrogen-loading inputs in groundwater modelling

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Waikato Regional Council, through the "Healthy Rivers: Plan for Change" project, is implementing plans to restore and protect the currently degraded health of the Waikato River. It was identified that recent land use intensification in the Upper Waikato catchment, with conversions from forestry to dairy, is a major factor for reducing water quality in the catchment. To better understand the effect of land uses and travel time of nutrients (i.e. groundwater lag times), Waikato Regional Council and Aqualinc have developed a flow and transport coupled groundwater–surface water model for the Upper Waikato catchment. The primary objective of the model is to help understand the response from potential land use scenarios that would, over time, reduce nitrogen (N) entering water bodies. However, there are two main challenges associated with modelling N: (1) there are no accurate current and historical land use data and associated N leaching loads; and (2) the amount and distribution of subsurface attenuation potential is not properly understood. Obtaining these crucial data over a large spatial area requires significant investment. In lieu of sufficient information, inverse modelling techniques via the PEST parameter estimation suite are being used to estimate the N loading from different land areas and potential attenuation, and uncertainty associated with these estimates. This will be achieved by utilising the best available data and knowledge of the system (e.g. land use information using AgriBase). The transient contaminant model simulation is then calibrated against measured N concentrations in both groundwater and surface water allowing, as possible, for attenuation.

Calibration of a complex groundwater model using modern computation techniques: Example of the Heretaunga Plains model

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Heretaunga Aquifer is a deep sedimentary basing in Hawke's Bay and is a major source of water in the region. A groundwater model was developed by Hawke's Bay Regional Council as a tool to assess abstraction impacts, manage water allocation and assess nutrient contamination risk.

Extensive input data were available for model calibration, including numerous measured spring discharges and river losses, water level responses in the aquifer due to flooding, long-term water level monitoring, several piezometric surveys, and measured spring flow reductions due to pumping.

Despite these data, significant uncertainty was still present, including aquifer depth and properties, connection to deeper aquifer layers, and abstraction volumes from irrigation.

In an attempt to simulate this complex system, a detailed groundwater model has been set up using MODFLOW code.

Model calibration was undertaken using the parameter estimation software PEST, which allows for automatic parameter estimation and uncertainty analysis.

The presentation will describe how the original model setup had to be simplified to allow for automatic calibration, and how the calibration was undertaken using modern techniques, such as pilot points, regularisation and parallel processing in the cloud server. The outcome of the calibration will be presented, including assessment of the uncertainty. Depending on the outcome of the project (which is ongoing), the presentation may include uncertainty impact assessment on model predictions.

Long-term rainfall prediction using large-scale climate variables through linear and non-linear methods

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El Niño Southern Oscillation, Southern Annular Mode and Indian Ocean Dipole have enormous influences on occurring rainfalls across the world. The variability of Australian rainfalls is also greatly influenced by the potential phases of the climate variables. When rainfall forecasting skills in Australia are compared, South Australia (SA) is showing very low predictability and variability in seasonal rainfall. In reality, environmental variability is full of uncertainties where changes occur non-linearly. So far, no study has been conducted to establish a rainfall-predicting model for SA with a non-linear multivariate Artificial Neural Network (ANN) technique considering the combinations of multiple climate variables with maximum lagged-time influences in a single complex matrix. Therefore, to the best of the author's knowledge, this study will be the first research contribution using non-linear ANN in conjunction with large-scale climate variables to forecast seasonal rainfall in SA. From this viewpoint, SA was chosen as a case study, and it is highly expected that this lack of research investigation will be eradicated through the current research framework. Traditional linear regression models were developed as a benchmark to compare the forecasting capability of ANN models. The study revealed that rainfall prediction using ANN can provide higher correlations and lower error. Results also demonstrated high rainfall variability and predictability from ANN models compared to linear methods. The study concluded that the ANN technique would be an appropriate tool for predicting SA's seasonal rainfall. This technique is applicable for other parts of the world with similar relationships in rainfall–climate variables, which would not be otherwise possible.

Comparison of two modelling approaches for a pilot catchment flood study in Qatar

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A country-wide flood study is being undertaken to estimate and map flood risk across the State of Qatar. An extensive data collection and literature review activity were initially undertaken to gather rainfall, topographical and environmental records from Qatar and neighbouring countries to allow selection of appropriate flood modelling approaches and calibration parameters. It was realised during this early phase that there was a lack of good quality flood calibration data and that detailed two-dimensional hydraulic modelling has not been widely undertaken in the Gulf region.

Due to the lack of model calibration data, compounded by the relatively flat nature of the study area, two alternate flood-modelling approaches were tested on a pilot catchment, and a preferred modelling approach was identified for application across the rest of Qatar. The first method was a traditional two-stage hydrologic/hydraulic modelling approach and the second method was a two-dimensional (2D) "rain on grid" hydraulic model based approach. An assessment of results from both approaches determined that the 2D "rain on grid" hydraulic modelling approach was the most appropriate methodology for implementation in the Qatar flood study. This was primarily because the rain-on-grid approach provided a more realistic simulation of the rainfall-runoff process, higher resolution model outputs, and greater efficiency and potential for automation in model setup times.

Real-time groundwater monitoring of managed recharge dispersion of groundwater at Hinds, Canterbury

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The Hinds Plains is underlain by a glacial outwash aquifer that has been subject to nitrate-nitrogen accumulation under intensive agriculture for at least the last 40 years. Canterbury Water and a number of associated parties are in the process of undertaking a pilot trial of managed aquifer recharge by applying up to 500 litres per second of very low nitrate content race water to an infiltration basin. The author intends to provide characterisation of the displacement and dispersion of native, high nitrate groundwater in the shallow water bearing layers down-gradient of the infiltration basin. The means of characterisation utilises locally developed optical nitrate sensors suspended in the slotted interval of a series of monitoring bores immediately beneath the pre-trial water table. The initial time-series of high frequency nitrate measurements is capable of batch telemetry to the investigation base offices, allowing superior data-validation and capture.

Having a network of continuous and periodically sampled bores, the investigation was able to assess the effect on down-gradient groundwater nitrate concentration in the lateral and vertical planes. The influence of open framework gravels will be examined as they affect differential passage of the low nitrate concentration peak following the onset of injection. Continuous nitrate monitoring also serves to support the assessments of environmental impacts of the pilot project in the wider Hinds Plains, including domestic water bores and spring-fed creeks or drains.

Experiences exploring the feasibility of constructing a very large scale 2D flood model of Tasmania

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This paper discusses the various problems encountered in constructing and running a single, rainfall on the grid, flood model for the State of Tasmania. It also discusses the solutions developed and adopted in response to these problems. Tasmania is a very rugged island, some 91,000km^2 in area, with a very high drainage density and spatially variable rainfall. The State Department of Primary Industries, Parks, Water and the Environment wished to explore the feasibility of using a single statewide flood model to control and manage flood planning levels throughout the State. Problems were initially encountered with the quality of inputs and lack of information on workable procedures for the development of appropriate well-formed meshes. These and scaling issues with the adopted software were eventually overcome and a variable resolution (10–500m) triangular mesh "Proof of Concept" model, with appropriate rainfall, roughness and boundary conditions, was constructed and run. This 7.5 million unstructured grid model ran in 4.5 hours and was able to replicate flood extents and levels in a previously studied flood prone area at an acceptable level. It was concluded that constructing and using a statewide flood model to establish flood planning levels for Tasmania is therefore feasible. Further work would, however, be needed to calibrate and validate it more widely, across the state, before putting it to use.

Physiographic controls over Southland's groundwater and surface water chemistry: Lessons learnt

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The Southland physiographic work is a novel approach, which maps the spatial controls or "drivers" of spatial variation in regional hydrochemistry (including water quality) of surface water and shallow, soil-influenced groundwater. The approach was based on an extensive dataset of c. 28,000 ground, surface, precipitation, soil, soil water and soil chemical analyses, of which c. 7,000 samples were analysed for up to 50 hydrochemical parameters including the stable isotopes of boron (11B), carbon (13C-DIC), water (18O and 2H) and nitrate (15N and 18O).

Hydro-biogeochemical data enabled identification of the critical characteristics of existing spatial frameworks (i.e. Soil (TopoClimate and S-Map), hydrology (REC), hydrogeology, geomorphology and geology (Qmap)) that drive spatial variation in hydrochemical signatures. The key characteristics or "drivers" of hydrochemical variation were then resolved as four key spatial (GIS based) layers, namely: (i) precipitation source; (ii) recharge mechanism and water source; (iii) combined soil and geological redox, and; (iv) geomorphic setting and substrate (rock and biological sediments) composition. When each driver layer is combined with surface water and shallow, soil-influenced groundwater capture zones, it is possible to estimate with reasonable accuracy the spatial variation in median hydrochemical (and water quality) signatures across Southland. The lessons derived from the hydro-biogeochemical calibration of nationally available spatial frameworks (GIS frameworks of soil, geology, hydrology and hydrogeology) may now be applied elsewhere, using existing regional water quality or hydrochemical data sets and/or through augmentation of these data sets without the need for the same degree of exhaustive sampling.

No rain recorded – Why did it flood?

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On Christmas Eve 2015, a high-intensity short-duration storm occurred at the Ōmaha catchment on the east coast of north Auckland. The storm event resulted in significant flooding in the catchment. The closest rain gauge recorded approximately a 2-year ARI event over the period while private and golf course rain gauge records recorded rainfall depths greater than a 100-year ARI. Following the flooding observations from the storm, the rain radar was interrogated and it confirmed the local rainfall observations.

Flooding has been a major point of contention for the Ōmaha community over recent years. The extent of predicted flooding is criticised by the community for being too extensive. The distances between the rain gauge stations are 8–11km. In a region where the spatial variability of rainfall is significant, this is a considerable distance apart.

In order to replicate the flooding experienced on Christmas Eve, an assessment of whether rain radar can be used for the validation of a stormwater model has been carried out. Use of Rain radar should minimise the uncertainty normally experienced with regard to spatial variability of rainfall for observed events.

This paper outlines the methodology and findings from the assessment regarding the appropriateness of applying rain radar in catchment validation of observed storm events. The paper also demonstrates how applying this technique can reduce one of the major uncertainties of the inputs used in model validation.

Fundamentals for on-site stormwater detention design: Optimising design outcomes and reducing risk of regional effect

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A widespread approach in flood management is the attenuation of peak discharges through on-site detention. In this study, fundamental empirical formulas for on-site detention dimensioning are developed to improve outcomes for a given subject site. The system developed can be summarised by three interrelated modules: (i) graphical extrapolation of the Rational Method for hydrograph approximation; (ii) depth-storage-discharge programming; and (iii) numerical runoff routing using an alternative solution to the continuity equation given by the Queensland Urban Drainage Manual 2013 (QUDM). The QUDM recommends one of four computing models or an explicit solution to the continuity equation to perform runoff-routing and dimensioning of on-site detention. As an alternative, some Queensland local councils provide deemed-to-comply solutions that involve basic inputs of site area and land usage to calculate on-site detention. Via observation, the volumes produced by deemed-to-comply solutions greatly exceed those calculated by runoff-routing methods. The improved outcomes presented by this study refute deemed-to-comply solutions and provide a simplistic system that is compliant with the QUDM fundamentals. On-site detention is one sustainable method to mitigate flooding due to development. However, inappropriate detention location in a regional catchment is a well-known factor that can result in increased flood levels and adverse hydraulic impacts, a phenomena known as regional effect. A return to fundamentals and critical review of deemed-to-comply solutions is expected to result in reduced superfluous volumes of on-site detention within development sites. This in turn would reduce the potential for regional effect whilst optimising construction and land use efficiency.

Scenario planning as a tool for integrated, collaborative, freshwater management decision making

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Implementing the National Policy Statement for Freshwater Management 2014, with the additional option for local government to consider collaborative approaches, brings many challenges. For freshwater scientists a key challenge is how to help integrate multi-disciplinary technical work streams into a clearly communicated, risk-based framework that will help communities to make decisions.
Our paper outlines the role that scenarios can play in addressing this challenge. In our day-to-day lives we all use scenarios to help us weigh the pros and cons of different choices, asking ourselves "What if…?" This conceptually simple approach can help even for the wicked problems faced in water management. Scientists and other experts can develop models to predict what outcomes may arise in certain alternative future scenarios, such as under different policy futures (e.g. water quantity and/or quality limits) or under different physical futures (e.g. future effects of climate change). These predictions can then be compared to desired environmental outcomes (freshwater objectives), as well as social, economic and cultural outcomes, that together make up a community's long-term vision for a catchment or freshwater management unit. These different futures can be compared and refined to help communities understand the relative importance of certain decisions, and develop solutions that meet their desired outcomes to the greatest extent. We will outline a case-study of how scenarios, together with information management techniques, have helped water managers and communities make the hard decisions required for freshwater management for the benefit of the community and future generations.

Increase in vertical permeability after the Mw7.1 Canterbury earthquake

Helen Rutter[1], Simon Cox[2], Tim Kerr[1]
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Horizontal changes in permeability following earthquakes have been suggested by numerous authors. Changes in vertical permeability have been less well researched, though Wang et al (2004) inferred this from increases in streamflow. More recently, Wang et al (in press) describe an increase in permeability and disruption of aquifer confinement after the 1999 M7.6 Chi-Chi earthquake in Taiwan. We consider whether a similar increase in vertical permeability could have occurred following the Mw7.1 Darfield earthquake in September 2010.
Consistently, piezometric levels in ECan's multi-level piezometers converged after the earthquake, irrespective of whether there was an upward or downward hydraulic gradient. In one case, there was a co-seismic increase in water level in one piezometer, correlated with a decrease in a shallower one. We present the hypothesis that vertical permeability increased, allowing greater vertical connection between aquifer layers. This hypothesis was tested using numerical modelling. This confirmed that the convergence in piezometric levels would happen if there was an increase in vertical permeability ("leakage"). The sequence is heterogeneous and described as a semi-confined rather than confined system: there are no distinct confining layers across most of the Plains' aquifer system. However, flow is likely to be predominantly sub-horizontal, through high permeability open framework gravels. Disruption of the sedimentary sequence during the earthquake could have increased vertical connection between layers. Wang et al (in press) suggested that the "fractures" healed within 6 months of the earthquake. Further analysis will assess whether this occurred in Canterbury.

Variables controlling the sustained groundwater level change after the Darfield Mw7.1 earthquake

Helen Rutter[1], Caroline Fraser[1], Simon Cox[2], Charles Williams[2], Caroline Holden[2]
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The Darfield Mw7.1 earthquake in September 2010 resulted in a wide range of hydrological and hydrogeological responses. Of particular interest was the sustained change in groundwater levels in the deeper wells of the inland Canterbury Plains, where modelling suggests water levels are now up to 12m higher than they should be, based on pre-earthquake hydrogeological conditions.

We presented preliminary results previously, but now have a larger range of explanatory variables related to the earthquake. We used stepwise regression to explore relationships between the observed change in water table level and a range of variables.

Individually, the variables most strongly correlated with the change in water table level were depth to water, and "distance"; the greater the depth to water and greater distance to a discharge point, the greater the water level rise. Preliminary results show that the variables that explained the largest amount of the observed variability in the water level rise were dynamic shaking (ARIAS intensity and PGA_max) and position in the catchment (elevation and distance). The new shaking variables did not add significantly to the regression. It appears that the greater accuracy of much more complex shaking models is not required in this type of analysis, which is possibly due to the variability caused by the heterogeneous nature of the aquifer system.

The role of tyre crumbs as a substitute for coarse aggregates in stormwater management features

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In Australia, it has been estimated that over 48,000,000 waste passenger car tyres are being generated annually, with less than 20% of these tyres being properly managed or recycled. Literature has indicated that there are a few methods for tyre recycling at the end of their life, such as the use of crumbed tyre rubber as an adsorbent surface for pollutants in aqueous solutions. The present study aims to determine the function of tyre crumbs as an alternative for coarse aggregates in Water Sensitive Urban Design and its applicability in the removal of pollutants from urban runoff. Column tests are conducted to investigate the potential for tyre rubber to be utilised in the filter media of Water Sensitive Urban Design features, such as raingardens. These tests compare the removal of pollutants from synthetic stormwater runoff between different columns. Columns contain either no crumb rubber substitutions; 10% or 20% crumb rubber substitutions; or 10% or 20% crumb rubber substitutions with the addition of perlite, an adsorbent surface. Water quality analysis is completed on a combination of key metals found in urban stormwater runoff: zinc, copper and lead. Other experimental studies focus on the hydraulic conductivity of raingarden filters, also using crumb rubber as a substitute for coarse aggregates in the same percentages as previously mentioned, on both saturated and unsaturated filters. Results from infiltration and column tests will be presented. A statistical analysis will be attempted based on the results collected from these experiments.

Hydrogeology and groundwater analysis for the Kaituna-Maketū-Pongakawa Water Management Area, Bay of Plenty, New Zealand

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The Bay of Plenty Regional Council (BOPRC) commissioned Jacobs to develop a groundwater flow model of the Kaituna-Maketū-Pongakawa Water Management Area (WMA). The purpose of the model is to provide the BOPRC with a tool to simulate the impact groundwater takes will have on the groundwater system in the long run. This will enable the council to better understand the connectivity of the groundwater systems and groundwater–surface water interactions, which helps determine how much can be allocated from the aquifer system without having any significant detrimental effect on the environment.

The model development process involved the use of the Australian Groundwater Modelling Guidelines as a framework, and included the key project stages: planning; conceptualisation; numerical model design and construction; model calibration and sensitivity analysis; predictive scenarios; predictive uncertainty analysis; and model reporting.

The MODFLOW model was calibrated, both in steady state and transient modes, using a number of criteria such as the ability of the model to replicate estimated baseflows in the major rivers that drain the catchment, and seasonal fluctuations in groundwater levels. When the model was shown to simulate the hydrogeological environment within an acceptable accuracy, the model was then used for testing various groundwater management scenarios and to establish sustainable abstraction limits on an annual basis and also considering seasonal peak abstraction. With this tool, the council can improve the management of groundwater and surface water resources as population and economic growth in the area leads to greater stress on the hydrological system.

Addressing embedded bursts in design storms for flood hydrology

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In design flood hydrology, storm depths for rare events are characterised using methods such as Intensity Frequency Duration curves. These approaches are concerned with the main part of a storm, referred to as the "burst". The burst represents the period within the storm that has the smallest probability of occurrence.

When input into runoff-routing models, burst depths are disaggregated using temporal patterns. However, this process can result in "embedded bursts" occurring in the hyetograph. This is where a sub-period of rainfall within a burst has a smaller Annual Exceedance Probability (AEP) than that of the burst being considered. For instance, a 48-hour, 2% AEP burst may have a 12-hour window that exceeds the 12-hour 2% AEP depth from the IFD curves. Unaddressed, this can lead to overestimates of peak flows for a given AEP and duration.

The temporal pattern database presented in Australian Rainfall and Runoff (ARR) has been tested for embedded bursts at the source location of each event. However, the patterns are intended to be transposed across meteorologically similar regions. The occurrence of embedded bursts is driven predominantly by the gradients of the design rainfall curves at the catchment of interest; subsequently, correcting embedded bursts is the modeller's responsibility.

This paper demonstrates the impact of embedded bursts on peak flows for several case study catchments. This involves understanding the change in magnitude of embedded bursts for different burst durations and AEPs. Finally, approaches and considerations regarding the smoothing of hyetographs with embedded bursts are discussed.

Investigating nutrient pathways in groundwater to meet community expectations

Marta Scott[1]
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As part of a collaborative community process to set nutrient limits in the Lower Waitaki catchment, the community have asked Environment Canterbury to investigate nitrate transport and fate in groundwater near Elephant Hill Stream, located on the north side of the Waitaki River. High nitrate concentrations were detected in nearby springs, and the community asked if recent intensification in the Elephant Hill catchment contributed to these high nutrient levels.

Our investigation is ongoing. We have sampled groundwater wells and surface water sites and carried out river stage and groundwater level measurements. We are planning to install eight additional wells near the Elephant Hill fan and repeat our sampling and water level monitoring. The data will help us investigate groundwater flow and nutrient pathways and the likelihood of extensive denitrification.

Testing the limits: Methods for setting stormwater contaminant limits for urban streams

Annette Semadeni-Davies[1], Jenni Gadd[1], Jonathan Moores[1], Sharleen Yalden[1]
[1]*NIWA*

Councils around the country are dealing with the implementation of the National Policy Statement for Freshwater Management (NPS-FM). The main focus for water quality management has been on setting limits on contaminant loads from agricultural runoff. While the water quality of urban streams has received less attention, these streams likewise need to be managed in accordance with the NPS-FM. Urban streams have faster response times and higher peak flows compared to their rural counterparts; moreover, the contaminant sources and range of contaminants borne in stormwater differ from those in agricultural runoff. This means that methods for limit setting in rural catchments may not be transferable to urban catchments. In anticipation that councils are likely to set limits for zinc and copper, this paper compares the robustness and practicality of two pilot methods for limit setting to manage concentrations of these contaminants in urban streams according to target median and 95th percentile values. Both methods have the Catchment Contaminant Annual Loads Model (C-CALM) developed by NIWA at their centre. The first is a deterministic method that couples hydrological and contaminant load modelling to predict in-stream concentrations of zinc and copper from stormwater loads, while the second is a statistical method that relates catchment-based contaminant yields to long-term in-stream concentrations. It was found that the first method could be useful in monitored catchments but has high data requirements, making it less practical for widespread application. The second method appears to be promising in the absence of catchment-specific information on load–concentration relationships.

Integrated monitoring – Can it be done?

Helen Shaw[1]
[1]*Environment Canterbury*

Data about a catchment are often collected by a number of different disciplines and agencies, to inform separate processes or answer particular questions. Often we don't know what else is out there, or who has it.

The majority of the science data analysis for the collaborative Waitaki sub-regional planning process was undertaken by Environment Canterbury, primarily using our network of state of the environment or investigative monitoring sites.

However, there is a significant amount of information collected in the Waitaki catchment by other groups, and the zone committees in the sub-region recommended that an integrated monitoring framework be established to make the best use of all data collected in the future. The purpose of the framework is twofold:

1. To coordinate data collection
    a. Provide guidance for sampling and analysis protocols
    b. Coordinate lake, surface water and groundwater monitoring
    c. Coordinate consent, Ecan and voluntary sites for best coverage of catchment
15. To make the best use of data collected
    a. Facilitate data collation
    d. Provide analysis of all data
    e. Make results available to all

The development of the framework is being undertaken in three phases, looking at monitoring locations, protocols, data-sharing platforms, and implementation.

1. Gap analysis, where we assess what data are needed to measure progress against a variety of statutory and non-statutory outcomes.
16. Pilot project, where we look at platforms for sharing data and information, with sample catchments in the sub-region.
17. Implementation, where the framework is rolled out across the sub-region.

How does uncertainty in land use change influence flow and sediment projections?

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Quantitative understanding of potential changes of flow and sediment is complicated by uncertainty in land use change projections. This study assessed the implications of uncertainty in land use change on flow and sediment projections. We use the Sesan, Srepok, and Sekong rivers (3S), the most important tributaries of the lower Mekong River, as case study. The uncertainty in land use change was represented using an ensemble forecasting approach consisting of land demand scenarios, transition potential modelling approaches, and inclusion of specific constraints (i.e. retaining or not retaining current protected areas), which generated various land use change scenarios in 2060. Results indicate that land demand leads to the greatest uncertainty in land use change projections. Transition potential modelling approaches do not make much difference in the total change, but can result in spatial variations of change. Constraining the land use allocation can contribute significantly to uncertainty in land use change projections. All scenarios showed decreases (−3% to −21%) in annual flow compared to current conditions from the basin. In contrast, the changes in annual sediment outflux from the basin ranged from −8% to 249%, depending on the particular land use change scenario. In general, the results indicate high uncertainties in magnitude of changes of flows and sediment loads due to uncertainty in land change projection. In addition to the assessment of uncertainty in land use projections, uncertainties due to climate models, emissions scenarios and hydrological modelling should be considered when modelling water and sediment in watersheds around the world.

Streamflow forecasting based on an ensemble streamflow prediction technique: A case study in New Zealand

Shailesh Kumar Singh[1]
[1]*NIWA*

Streamflow forecasts are essential for optimal management of water resources for various demands, including irrigation, fisheries management, hydropower production and flood warning. The objective of the present paper is to explore ESP-based forecasts in New Zealand catchments, highlighting its capability for seasonal flow forecasting. In this paper, a probabilistic forecast framework based on ESP technique is presented, with the basic assumption that future weather patterns will reflect those experienced historically. Hence, past forcing data (input to hydrological model) can be used with the current initial condition of a catchment to generate an ensemble of flow predictions. The present study employs the ESP-based approach using the TopNet hydrological model with a range of past forcing data and current initial conditions. Ensemble stream flow predictions which provide probabilistic hydrological forecasts, reflecting the intrinsic uncertainty in climate, with lead-time up to three months are presented for the 14 catchments across New Zealand . Verification of the forecast over the period 2000–2010 indicates a Ranked Probability Skill Score of 23% to 69% (over climatology) across the four catchments . In general, improvement in ESP forecasting skill over climatology is greatest in summer for all catchments studied. The ESP-based forecast exhibited higher skill for a greater percentage of the forecasting period than climatology. As a result, the ESP forecast can provide better overall information for integrated water resource management. ESP-based forecasts using the TopNet hydrological model have potential as tools for water resource management in New Zealand catchments.

Water resource opportunities from near real time national soil moisture assessment

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Soil moisture assessment and forecasting has emerged in recent years, with increasing operational capabilities over different scales. The Australian Bureau of Meteorology has a 5km gridded national landscape water balance assessment model (AWRA) that includes soil moisture, and numerical weather prediction systems that forecast it. The water balance model is conceptualised as a small, unimpaired catchment and with flow paths including rainfall, evapotranspiration, runoff and deep drainage to the groundwater. The model has three soil layers (0–10cm, 10–100cm, 1–6m) and provides daily estimates of these stores. The operational global NWP system employed by the Bureau – ACCESS-G – incorporates a physically based land surface model (LSM) with a horizontal resolution of about 40km. Soil moisture is one of the prognostic variables simulated by the LSM. The LSM surface exchange scheme soil is 3m thick and is discretised into four layers of 0.1, 0.25, 0.65 and 2m thickness, from top to bottom. ACCESS Global NWP does not assimilate precipitation and adjusts the model soil moisture to minimise the errors in six-hour forecasts of daytime screen temperature and humidity. Investigation of NWP soil moisture accuracy has included fire-focused applications, such as testing soil dryness indices. Both AWRA and ACCESS soil moisture outputs have implications for water resources, such as in crop growth, runoff prediction and improved precipitation forecasts. This paper will discuss the system capabilities and data sets that are available now, likely future developments and example applications of these in water resources.

Hydrological applications of Australian and New Zealand atmospheric reanalysis

Robert Argent[1], Peter Steinle[1], **Adam Smith[1]**
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Atmospheric reanalysis produces consistent data sets for environmental analysis, assessment and forecasting. Reanalysis takes a fixed atmospheric modelling suite and data assimilation scheme, and runs these at a sub-daily temporal resolution with all available observations over a long past period. The value of reanalyses has been well established. However, reanalyses are generally based on global systems, with resolutions generally too coarse for many hydrological applications. Output variables, such as soil moisture, precipitation and evaporation, contain many biases and errors. The Bureau of Meteorology is undertaking a higher resolution reanalysis over the Australian region in order to address some of these problems. This involves using a 4D variational combination of observations and short model forecasts to provide a 12km reanalysis over the Australian and New Zealand region. This then directly drives higher resolution, convective-scale (~1.5km) models. This combination of models has been shown in Numerical Weather Prediction to provide significantly improved estimates of sub-daily rainfall, both in terms of amounts and the distribution in time and space. The reanalysis project will be providing 1.5km downscaled reanalyses over selected areas within Australia, with the capability to support this anywhere in the Australian-New Zealand domain. The temporal resolution for both the regional and higher resolution domains will generally be one hour, with some fields such as 10m winds and 2m temperatures and dew points available every 10 minutes. This paper will report details of the reanalysis, the outputs, and will discuss the application of these to water resource analyses.

We've got how many of these things? Rediscovery of lost river protection

Hamish Smith[1]
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Between Christchurch and Greymouth the Midland Line runs adjacent to some of New Zealand's most powerful and dynamic rivers, carrying passengers, coal, milk products and bulk freight. These rivers include the Waimakariri, Bealey, Rolleston, Ōtira, Taramakau, and Grey rivers. Along the 55km stretch from the Mount White Bridge to Jacksons (excluding the 8.5km long Ōtira Tunnel), the line runs adjacent to one of the largest collections of river protection works in New Zealand, which protect the route from flood and scour.

Over the last three decades, institutional knowledge and asset information has been lost with the railways transition between public and private ownership, and the turnover of many staff, and very few records of the assets remained, making management difficult. Recent investigation has used tablet computers and unmanned aerial vehicle photography, as well as more traditional techniques, to catalogue and assess hazard and risk. This information will be used as the basis of assessing the reliability of the line and forecasting what investment is needed.

Water use efficiency – What's working and what's not: An update from a field study

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NIWA has been leading a pilot study to improve irrigation water use efficiency in a river-based irrigation scheme north of Christchurch, New Zealand. Eight farms from the irrigation scheme are supplied with real-time measured data on farm-specific irrigation, rainfall, soil moisture and evaporation, and 2-, 6- and 15-day forecast data, via a secure website. Over the past four irrigation seasons, through a series of formal and informal interactions and semi-formal workshops with stakeholders (researchers, water resource managers, regulators, irrigation schemes and farmers), we have been learning the drivers and challenges to adopting improved water management practices in a scheme that is impaired with poor supply reliability. This pilot study highlights that education of stakeholders is the first and foremost step to improving water use efficiency.

Managed Aquifer Recharge: A multi-criteria feasibility assessment tool

Dave Stafford[1], Aslan Perwick[1], Alan Pattle[1]
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Many surface water and groundwater bodies in high-demand areas are already close to their allocation limit. Managed Aquifer Recharge (MAR) is a method to increase allocation in aquifers by increasing stored volumes for later use. As such, there is growing interest in such schemes around New Zealand.

A high-level Multi-Criteria Assessment (MCA) tool has been developed to objectively select sites where MAR is best suited. The tool is best used at a preliminary stage in a MAR investigation.

The MCA uses a series of 10 criteria, weighted according to their importance. Greatest weightings are applied to aquifer properties, with high transmissivity and storage being essential to allow successful injection or soakage of significant volumes. Sites with low storage and/or transmissivity are considered to be fatally flawed and are not considered further. Medium weightings are applied to aquifer water quality and the potential benefit of MAR to existing users. This benefit is considered by using aquifer properties to analytically calculate a radius of benefit of a MAR scheme. Engineering feasibility is also considered, but given the lowest weighting.

This MCA tool has been successfully applied to three areas in the North Island to identify the feasibility of MAR for wastewater reuse. A desktop conceptualisation of aquifer properties, water quality and groundwater usage within each area was undertaken. This information was then fed into the MCA tool and the top-ranking sites were selected for further study.

Modelling of bio-morphodynamics in braided rivers: Applications to the Waitaki River

Guglielmo Stecca[1,2], Murray Hicks[1], Richard Measures[1], Prof Guido Zolezzi[2], Walter Bertoldi[2]
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The planform shape of rivers results from the complex interaction between flow, sediment transport and vegetation processes, and can evolve in time following a change in these controls. The braided planform of the lower Waitaki, for instance, is endangered by the action of artificially introduced alien vegetation, which spread after the reduction in magnitude of floods following hydropower dam construction. These processes, by favouring the flow concentration into the main channel, would likely promote a shift towards single thread morphology if vegetation was not artificially removed within a central fairway.
The purpose of this work is to address the future evolution of these river systems under different management scenarios through two-dimensional numerical modelling. The construction of a suitable model represents a task in itself, since a modelling framework coupling all the relevant processes is not straightforwardly available at present. Our starting point is the GIAMT2D numerical model, solving two-dimensional flow and bedload transport in wet/dry domains, and recently modified by the inclusion of a rule-based bank erosion model. We further develop this model by adding a vegetation module, which accounts in a simplified manner for time-evolving biomass density, and tweaks the local flow roughness, critical shear stress for sediment transport and bank erodibility accordingly.
We plan to apply the model to address the decadal-scale evolution of one reach in the Waitaki River, comparing different management scenarios for vegetation control.

Incorporation of snowmelt into joint probability event-based rainfall-runoff modelling

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There are a small number of catchments in Australia where it is important to explicitly consider the contribution of snowmelt to design floods, though this a common problem in many overseas locations. Such analyses must incorporate the effects of snowpack melting during a rainfall event and contributing to the peak flow and volume of runoff leaving the catchment. This paper describes the incorporation of an event-based snowpack melting module sourced from the United States Bureau of Reclamation into the hydrologic model RORB, and its subsequent use in a joint probability framework for the estimation of design floods. The paper describes the conceptual hydrologic processes at play in melting snowpack, and discusses how these processes are represented numerically in the USBR module. The various model parameter values are identified and discussed, and guidance is provided on how to use recorded snowpack and meteorological data to estimate the historic or design values of these parameters. The incorporation of the USBR module in RORB's native "rain-only" joint probability framework is also discussed. An example application of the model is provided for a catchment in south-east New South Wales. The process of model calibration to historical events is discussed, as well as verification of the model results to complete gauge flood frequency curves. Finally, the seasonal impact of the snowmelt contribution to the design flood estimates for this catchment is presented and discussed.

Application of rainfall-runoff modelling to large catchments: Flood estimates for the Swan-Avon River

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The Swan River is Perth's major waterway. It has a long history of flooding, with significant events being recorded from the late 19th century through to the early 1970s. With a total catchment area of close to 125,000km², the Swan River catchment is larger than the North Island of New Zealand. As part of the ongoing floodplain management process, design flow estimates for the catchment were recently updated. The method for deriving updated flow estimates involved the use of historic gauged data and event-based rainfall-runoff modelling implemented within a joint probability framework. A RORB model was developed for the entire catchment, and calibrated and verified to gauged data. Model simulations were undertaken in a stochastic manner that gave explicit consideration to the different ways in which losses, rainfall patterns, and natural lake levels combine to yield peak flow estimates and hydrographs for a range of AEPs. The design inputs to the model (rainfall IFD, areal reduction factors, temporal and spatial patterns) were sourced from a variety of methods. In some cases, new techniques and approaches were required to adapt the design information to fit such a large catchment. This included the use of gridded rainfall data to derive IFD values for very long durations, and the comparison of these estimates with recently updated Australia-wide datasets from the Bureau of Meteorology. The results of the design modelling demonstrated the large spatial variability exhibited by this catchment, and the different mechanisms involved in the generation of floods at Perth.

A review of the capabilities of RORBwin: An enabling tool for application of ARR 2016

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The event-based rainfall-runoff model RORB is one of the most widely used hydrological modelling packages in Australia. The original program was developed in the late 1970s by Eric Laurenson and Russell Mein, and since then has been continually enhanced and developed to ensure that it remains relevant and applicable to modern flood estimation. With the recent release of the revision of Australian Rainfall and Runoff, some of the capabilities of the freely available program RORBwin deserve consideration. In particular, RORBwin has a mature, tested and widely applied joint probability Monte Carlo framework fully integrated within the software. The Monte Carlo framework allows for variations in initial loss and temporal pattern to be sampled, and provides probabilistic peak flood estimates using the total probability theorem. RORBwin's user interface provides a clean and easy means of incorporating joint probability estimation into design flood estimation. Other relevant capabilities of the model include the option to include user-defined IFD data, allowing for any range of durations and AEPs to be simulated. The recently updated Bureau of Meteorology IFD data can also be easily used. Developing and editing of catchment files is fully graphical, and the existing GIS plug-in for MapInfo has recently been supplemented with a plug-in for ArcGIS. This enables catchment files to be developed within a GIS and then seamlessly exported to RORBwin.

Tritium-based transit times in hydrological systems

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Disappearance of bomb tritium from the atmospheres of both hemispheres in recent years means that tritium is becoming more effective for determining transit times in hydrological systems. In particular, increasing use of tritium is being made to determine transit times of water through catchments from rainfall to rivers in order to derive vital information for the protection and management of river systems. Tritium reveals the transit times of the older water in streamflow, transit times which are too long to be seen by stable isotope or major chemical variation methods (this has been characterised as "hidden streamflow"). Documenting these longer timescales is vital for understanding the flow and water quality responses of rivers to changes in land use, diffuse or point-source chemical pollution, ecological degradation, and climate change, responses which have proven to be considerably longer than previously expected. Including the longer timescales in the models allows more realistic approaches to management of catchments and emphasises interdisciplinary differences between surface water and groundwater hydrologists' views of river basins.

Kopeopeo canal remediation: Community engagement and dredging trial

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The Kopeopeo Canal Contamination Remediation Project will remove approximately 40,000m^3 of dioxin-contaminated sediments from 5.1km of canal and place them in secure storage cells for later dioxin bioremediation. This high priority remediation (3rd on the Ministry for the Environment Contaminated Sites Remediation Fund priority list) is described, focusing on key aspects of recent work, including dredging trials, community engagement and progress on initial physical remediation works.

The Kopeopeo Canal, on the outskirts of Whakatāne, was contaminated with stormwater discharge that contained dioxin from a former sawmill between the 1950s and late 1980s. Remediation will address the long-term health risk to the community associated with dioxin exposure, improve the quality of the aquatic habitat within the canal and wider drainage network, and facilitate future drainage and flood relief within the Rangitāiki Drainage Scheme.

Consent for remediation was granted in early 2014; however, community positions on the consented remediation were polarised with emotions and concerns were high around dioxin contamination. The consent required establishment of a Community Liaison Group, which has proved invaluable in sharing project information with the community and providing suggestions and feedback to the project team.

The contamination extraction methodology involved excavation and extensive trucking. Despite rigorous safety control measures to avoid potential exposure, the community remained concerned. These concerns, together with developments in technology, led to the trial of dredging as an alternative extraction and transfer method.

The dredging trial, lessons in working with the community and recent remediation progress will be presented.

Hydrologists and hydrographers holding hands

Ben Tate[1], Jessica Littlejohn[2], Rebekah Webb [2],
[1] *Water Technology*
[2] *Ventia*

This paper outlines work undertaken to upgrade a number of rating curves in Victoria with unreliable extrapolated sections beyond the highest rating curve gauging. The work follows on from a paper presented at the Hydrology and Water Resources Symposium in Perth in 2014. The previous paper identified significant issues with a number of streamflow records for high flow events as a result of unreliable rating curves. This has further been demonstrated through a number of flood studies in Victoria, some of which are used as case studies in this paper. The paper demonstrates the importance of a reliable rating curve and how Victoria is moving to deliver this. It makes a strong case for why hydrologists and hydrographers need to work closely together to achieve improved rating curves and improved streamflow records.

Regional temporal patterns for Australian Rainfall and Runoff

Isabelle Testoni[1], Mark Babister[1,2], Monique Rettalick[1], Melanie Loveridge[1]
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As part of Australian Rainfall and Runoff (ARR) 2016, updated regional patterns for Australia have been developed. ARR Research Project 3: Temporal Patterns of Rainfall investigated a number of different methods of temporal patterns selection and created an Australia-wide storm database.

The final recommended regional temporal patterns for ARR have been through a rigorous testing process. These temporal patterns have been sourced from pluviographs within the region and/or adjoining regions. The patterns were then sorted into three Annual Exceedance Probability (AEP) "bins". Temporal patterns were then selected based on a criteria set. The evolution of this criteria and the lessons learnt from this project are discussed in this paper. Final testing and quality control of the patterns has also been undertaken and is presented herein.

A conceptual model of groundwater movement through the Ōhau and Waikawa groundwater catchments

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Horizons Regional Council (HRC) manages groundwater resources across 11 Groundwater Management Zones within their jurisdiction. The Horowhenua Groundwater Management Zone (GMZ) is located at the south-western extent of HRC's jurisdiction. The Horowhenua GMZ includes a number of surface catchments which are defined by major surface water drainages within each catchment. The Ōhau and Waikawa are two sub-catchments which border each other at the southern extent of the Horowhenua GMZ and cover areas of 54km² and 38km² respectively.

At present, there is relatively limited information regarding the conceptual hydrogeology of the Ōhau and Waikawa catchments. The purpose of this study was to collate information available within the catchment to provide an overall picture of the hydrogeology in the catchments. The information has been used to define a conceptual picture of groundwater movement and help identify areas where further data collection may be beneficial. Initial information indicates that despite their spatial proximity, the two catchments behave differently, due in part to the seepage effects of the Ōhau River.

This presentation will help to set the scene for other talks on the catchments at this conference, including age tracer data results and how that information will feed into policy implementation and strategies for the catchments.

How low will they go? Diminishing summer flows in the Wairarapa

Mike Thompson[1]
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The Ruamāhanga River is the main artery of the Wairarapa Valley. It is a high-value river in all senses of the word. Since the mid-1990s there has been an apparent tendency towards lower and lower annual flow minima in both the main stem Ruamāhanga River and its main tributaries. Is the pattern a real trend? What is causing it? How important is it from a resource management point of view? And where might things head in the future? These questions are especially important to the catchment committee tasked with agreeing on sustainable allocation limits in the Wairarapa. This paper explores the above questions and looks in particular to identify the respective roles of background climate drivers and other possible influences such as increasing abstraction. Along with examination of annual flow and rainfall minima time series, a comparison of baseflow recession curves from the 1980s and more recent times is undertaken. Results of these analyses and conclusions formed from them will be presented.

Modelling groundwater–surface water balance dynamics for water allocation

Blair Thornburrow[1], Edmund Brown[2]
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Groundwater in the Pukekawa Aquifer, Lower Waikato, is extracted primarily for horticulture irrigation. Water is extracted from a surficial basalt and an underling sand unit. Discharge from the basalt aquifer supports a number of springs at its margins which contribute to surface water flows in local streams and the Waikato River.

Waikato Regional Council has undertaken modelling to characterise the groundwater system and support the setting of allocation limits for the aquifers in the Waikato Regional Plan. The main focus of the study was to characterise the relationships between aquifer recharge, extraction and discharge, both in a spatial and temporal sense. Key questions included:

- To what degree do seasonally variable groundwater takes impact surface water low flows, such as the Q5?
- How spatially localised or widespread are the surface water impacts?

Modelling of the aquifer was undertaken in three parts. A 3D geological model of the area was developed from borehole and spatial data using Leapfrog. A catchment water balance model was developed and calibrated to continuous spring flow data collected at two locations, producing a time series of rainfall recharge. The geological model was then used to define the structure of a 3D porous flow model in FEFLOW, calibrated to spring discharge and groundwater level time series data.

Various abstraction scenarios were developed to assess the impacts of current and consented abstraction and to investigate the temporal and spatial relationships between abstraction and surface water flow impacts.

Policy responses to the identification by Māori of flows necessary to maintain their cultural values

Gail Tipa[1], Kyle Nelson[1]
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Many Māori are concerned at the modification of rivers and what they perceive to be inappropriate flow regimes. Māori want to see instream flows that are not limited solely to a consideration of ecological values. Rather, they want it to be explicit how management decisions and policy/plan provisions with respect to river flows recognise and provide for their cultural association with freshwater.

We have presented on the Cultural Flow Preference methodology at previous conferences. This presentation goes a step further and describes the outcomes in statutory plans/policies/resource consents that have been achieved by Māori who have completed a Cultural Flow Preference Study, which enabled Māori and freshwater managers to discuss flows that tangata whenua believe would be sufficient to protect their cultural values. We have completed flow studies in more than 40 streams across New Zealand. Our presentation examines the results of some of these studies.

This presentation focuses on:

1. the range of analyses that were undertaken that result in increased understanding of the attributes of flow that are important to whānau and how we identify the flows necessary to protect valued attributes.
18. examples from flow preference studies that have been undertaken in a variety of catchments across New Zealand
19. how the results of cultural assessments compare to the results and recommendations of other flow assessments undertaken in the case study catchments.

We conclude by summarising how resource managers have responded to the cultural recommendations in statutory planning processes.

Bias of the Big Fella Flood: Influence of anecdotal floods on Mary River FFA

Luke Toombes[1]
[1]*Aurecon*

Recent improvements in the implementation of Bayesian fitting methods to Flood Frequency Analysis (FFA), such as the FLIKE software package advocated by ARR, allow contiguous data records to be augmented with isolated historical events, leading to improved confidence. Historical stream level data for the Mary River at Gympie dates back to the flood of record in 1893, which peaked in excess of 3m higher than any subsequent event and caused significant damage to the township. However, anecdotal evidence suggests that this event was preceded and exceeded by an event locally referred to as the "Big Fella" flood. Details of this event, other than its status in legend, are sketchy.

Although the city of Brisbane lies 140km to the south, the Brisbane and Mary river catchments are adjacent. Like Gympie, Brisbane also experienced a major flood in 1893, equalled only by a similar sized event back in 1841. Could this correspond to the "Big Fella" flood? Could the Brisbane River flood records be used to estimate flood magnitudes in the Mary? If so, what would this mean for the Gympie FFA?

This paper presents results of a case study investigating the development and uncertainties associated with a correlation between Brisbane River and Mary River flooding, as well as the influence that inclusion of a single major historical flood event of questionable magnitude and veracity can have on a stream gauge FFA.

Smart Aquifer Characterisation of the Hutt Valley aquifer using novel age tracers

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The Hutt Valley aquifer system requires a high certainty of characterising groundwater travel times and capture zones to the groundwater supply bores to ensure an effective management of groundwater resources. Aquifers, like the Hutt Valley, can be characterised using a wide range of methods, many which are time consuming and expensive. The Smart Aquifer Characterisation (SAC) research programme aims to provide a suite of innovative methods to save money and reduce time (SMART). A suite of novel tracers are used to assess their ability to reduce the uncertainty in the characterisation of the aquifer by simplifying a MODFLOW/MT3DMS model for the Hutt Valley. Age tracers considered in this investigation include Halon-1301, SF6, CFCs and tritium. A data worth technique was used to assess the value of each novel age tracer in different spatial and temporal frequencies for a range of predictive contexts related to groundwater travel times and capture zone extents. Each tracer was simulated in a numerical groundwater transport model, and the "worth" of each theoretical measurement was assessed in its ability to reduce the model's uncertainty for the predictive contexts. Outputs from this assessment can be used to help build cost-effective monitoring programmes.

Groundwater chemistry and residence time in the Lower Hutt Aquifer: The relationship to iron bacteria

Rob van der Raaij[1], Uwe Morgenstern[1]
[1]*GNS Science*

Several wells from the Lower Hutt well field have recently been affected by iron bacteria biofilm. Hydrochemistry data were analysed to identify conditions under which biofouling is occurring, and to assess the potential for biofilm development in other parts of the aquifer system. General chemistry of the system is closely related to the chemistry of the recharge source and further evolves due to mineral dissolution and redox processes. Concentrations of CFC12 and nutrients show that significant recharge occurs via rain recharge alongside recharge from the Hutt River. At the wellfield, groundwater mean residence times are between 1.5 to 4 years and increase further downstream. Recent trends of the water chemistry are towards a more evolved state, as indicated by trends of increasing concentrations of calcium, chloride, sodium, and silica, increasing pH, and decreasing trends in dissolved oxygen and nitrate. A survey of other wells in the aquifer system has identified several other wells where iron bacteria are also present. Comparison of the well field chemistry to these other wells shows that the other wells have more suitable conditions for iron bacteria colonisation. Presence of oxic and anoxic conditions in the well can provide the oxygen and dissolved iron required for biofouling. Water at the Waterloo well field is oxic, and dissolved iron concentrations are below the detection limit. The source of dissolved iron, which is required by iron bacteria, is not apparent and could involve either a change in flow patterns in the aquifer, or corrosion of the well casing.

Hydrological modelling to assist community decision making: The Manuherikia Catchment Water Strategy optimisation process

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The Manuherikia Catchment Water Strategy Group (MCWSG) was established with the aim of developing and implementing cost-effective, efficient and sustainable options for water users within the Manuherikia River catchment while achieving wider community and environmental goals.

To assist the MCWS with their decisions, a simplistic hydrological model for the catchment was developed and used to stress test and compare various potential water development options.

This paper briefly describes the model and how it was used. More importantly it discusses the usefulness of such models in supporting community decision making and the role water scientists/engineers/managers could/should play in facilitating community discussions regarding water.

The Manuherikia Catchment model was constructed using the GoldSim modelling platform and is based on a simple daily water balance that uses 40 years of historical climatic and flow data. The model includes multiple sub-catchments, storages, run of river takes and irrigated areas, and the three key variables predicted by the model are: storage volume, residual flow and water supply reliability. Model flexibility allows rapid adjustment of storage volume, minimum flows, area irrigated, water supply rate and water source. This flexibility, coupled with the model's ease of use and rapid run time (in the order of 10–20 seconds for the daily timestep over 40 years), allowed workshop type modelling sessions where the community were able to run numerous "what if" scenarios. This greatly improved overall understanding and increased community confidence in the option assessment and evaluation process.

Hinds MAR pilot: Site characterisation using infiltration test pits

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Presentation intended as part of MAR and IWMS session

The Hinds Managed Aquifer Recharge (MAR) pilot trial is aimed at assessing if a full-scale groundwater replenishment scheme can help in addressing long-term groundwater level declines and nitrate concentration increases in shallow aquifers.

Investigations were undertaken at the preferred pilot trial site to assess the effectiveness of an infiltration basin to recharge shallow aquifers, which included two percolation tests in pits. Monitoring data from these tests were interpreted conceptually to understand seepage flows from the pits. SEEP/W numerical models were then developed to simulate the tests, with calibration against water level records from the pits and nearby shallow monitoring wells.

Modelling the first test suggested rapid preferential lateral flow of infiltrated water from the pits as opposed to downward seepage. Information from local quarries indicated an iron pan may exist at shallow depth, influencing the test outcomes. A second test was therefore undertaken in a deeper pit, with a similar outcome. Sensitivity analyses performed on the models indicated the residual pore water content in the unsaturated aquifer zone at the start of the test contributed significantly to a perceived high lateral seepage rate. No iron pan or other low permeability layer was encountered at shallow depth in holes subsequently drilled on site.

The test and model outcomes indicated that the planned infiltration basin would function effectively at the site. The infiltration basin design includes “recharge shafts” to enhance downward percolation to groundwater and reduce the risk of infiltration water becoming “perched”.

Extremes in rainfall and runoff in the Monsoonal North West of Australia from paleoclimate archives

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The Monsoonal North West (MNW) comprises natural resource management regions in Western Australia and the Northern Territory. This region experiences a pronounced wet and dry season with moderate to strong year-to-year variability relative to other parts of Australia. A range of climate change impacts and adaptation challenges have been identified by the NRM organisations for this region. However, future changes to rainfall regimes remain unclear due to the inability of Global Climate Models to capture the weather/climate processes that are known to be important. Therefore, this paper investigates an alternative method to produce a plausible long-term rainfall record for the MNW utilising paleoclimate records. In the absence of local rainfall reconstructions (at a suitable temporal resolution), various remote paleoclimate records are identified that resolve 25% of the annual variability observed in the instrumental record. Importantly, when the model is applied over the last 500 years, events that are greater than observed in the historical record are simulated (both wet and dry). For example, the maximum number of consecutive years of below-average rainfall is 19 in the reconstruction, which is almost twice as long as observed in the instrumental record. The maximum consecutive number of above-average rainfall was 11, compared to eight years in the instrumental record. Further, implications for flood risk are studied via a simple Budyko framework to convert the rainfall into runoff. The findings of this study have relevance to water management and supply, cropping, mining and tourism in the MNW.

Finding spatial climate-oceanic precursors of hydro-lake inflows: Waitaki catchment, New Zealand

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Seasonal and monthly forecasts of hydro-lake inflows are of significant value for the management of hydro-power companies. However, seasonal and monthly forecasting poses a challenge in catchments with minimal groundwater reservoir influence and relatively small basins. Additional climatological information could be utilised in forecasting models when there is a lack of correlation between adjacent months and seasons. Using large-scale climate information in predictive models has a potential to improve forecasting skill and also provide new insights into physical mechanisms regulating streamflow.

This study presents results of seasonal streamflow forecasting in the Waitaki catchment. The predictive models are based on using high-dimensional climatological data as predictors. The usefulness of regularised regression methods is highlighted as an exploration tool in identifying relationships between large-scale climate events and streamflows.

Assessing groundwater–surface water interactions in the Sukhuma District, Champasak Province, Southern Laos

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[1]*University of Technology Sydney*

Southern Laos is undergoing economic and agricultural development, resulting in a large increase in groundwater and surface water use. However, these water resources are not known in detail. This study aims to investigate groundwater–surface water interactions in the Sukhuma District of Champasak Province using a network of 16 rain gauges and groundwater level measurement points. Groundwater levels are measured weekly in 11 domestic wells, which are pumped irregularly, and also in five observation bores. Aquifer recharge occurs from direct infiltration of rainfall and also is derived using baseflow calculated from daily streamflow measurements at the re-established gauging station on the Khamouan River in the Sukhuma District. The Khamouan River is connected to the groundwater in its lower reaches in both dry and wet seasons. Baseflow proportion to the total streamflow in the wet season 2015 has been estimated at 46%. The distribution of direct recharge has been mapped with ArcGIS and is spatially variable. Preliminary estimates of rainfall recharge have been calculated by the water table fluctuation method for 2015 but show a high degree of uncertainty related to the specific yield estimates. Time series analysis has confirmed the observed lag of some three to four weeks between the wet season start and rise in groundwater levels. These preliminary results indicate that there is close interaction between groundwater and surface water in the Sukhuma District. Further analysis will refine these results and extend them through remote sensing across southern Laos for application to integrated water resources management.

Stochastic updating for ensemble hydrological forecasting

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Ensemble streamflow forecasts are invaluable for flood and water resource management. Ensemble forecasting models aim to provide forecasts that are as accurate as possible, and represent the remaining uncertainty reliably. Availability of high quality observations and forecasts of precipitation and high performing hydrological models is critical to achieving good accuracy. Updating based on real-time observations of streamflow can also be highly effective in improving accuracy. To reliably quantify forecast uncertainty, it is necessary to represent two major sources of uncertainty. One is input uncertainty in future boundary conditions, such as precipitation and evapotranspiration. Another is hydrological uncertainty due to imperfection of hydrological models and in initial catchment condition.

Past research on hydrological certainty has mostly been on uncertainty of hydrological simulations either without updating or with only one-step-ahead updating. For forecasting streamflow multiple steps ahead, it is necessary to represent temporal evolution of uncertainty over the forecast target period. In this study, we develop a stochastic updating method for generating ensemble traces, each of which represents a possible future outcome. Here we present an error model for one-step-ahead updating, a method for applying this to multiple steps ahead, and model calibration strategy. We present a case study to demonstrate the effectiveness of the stochastic updating method.

How effective is quantile mapping for post-processing GCM ensemble forecasts?

Tongtiegang Zhao[1], **QJ Wang**[1], James Bennett[1], David Robertson[1], Andrew Schepen[1]
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Seasonal global climate model (GCM) ensemble forecasts provide useful information for hydrologic modelling and water resource management. However, the raw forecasts are usually biased and unreliable in ensemble spread (too narrow or too wide). In some situations, the forecasts can be so erroneous that climatology forecasts would have been better. Therefore, post-processing is a necessary step before using GCM forecasts for hydrological applications. Ideally, post-processing should be able to remove bias from forecasts, make forecasts reliable in ensemble spread, and return forecasts to climatology where there is no evidence of skill in raw GCM forecasts.

One of the most popular methods of post-processing is quantile mapping (QM). In QM, forecast values are mapped to new values by matching the quantile function of all forecast values to the quantile function of all observations according to non-exceedance frequency. We evaluate the effectiveness of QM for post-processing seasonal precipitation forecasts from the Predictive Ocean Atmosphere Model for Australia (POAMA). Forecasts for all of the 122 POAMA grids covering Australia, from January to December, from 1981 to 2011, and at lead times from 0 to 8 months are analysed.

Overall, QM improves forecast skill and reliability. It effectively removes bias in raw forecasts. However, the post-processed forecasts can still be unreliable in ensemble spread. In general, the spread is still too narrow. Most significantly, QM does not solve the issue of seriously erroneous forecasts. In many situations, the post-processed forecasts can still be much worse than climatology forecasts.

Design flood estimation in a warmer climate

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The changing nature of precipitation in a future warmer climate has significant implications for flooding and the design of infrastructure. It is generally accepted that intensity of precipitation extremes is set to increase. However, what is less well known, but just as important, is how precipitation patterns will change.

Design flood estimation relies not just on precipitation intensity, but also the temporal pattern, spatial pattern and the design flood losses. Here we link changes in temperature to intensifying temporal and spatial patterns of precipitation, as well as reductions in soil moisture and hence increases in the loss parameters in design flood estimation. The results are shown to be consistent with predictions for a future climate using regional climate simulations as well as historical trends. The results suggest a greater potential for flooding in a future warmer climate, particularly for short durations and the rarest of events.

As the number of changes occurring to precipitation is far reaching, we argue that continuous simulation offers a flexible method for incorporating all these changes into design flood estimation. By conditioning model parameters in stochastic precipitation generators, we are able to replicate the expected changes due to a warmer climate, including the simulation of precipitation extremes which are required for flood design. We argue that continuous simulation offers a natural flexibility to incorporate the many correlated changes in precipitation that may occur in a future climate.

Thresholds for earthquake-induced hydrological changes in New Zealand aquifers

Konrad Weaver[1], Simon Cox[2], Caroline Holden[2], Assoc Prof John Townend[1]
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Earthquakes generate stress changes and shaking intensities that induce both transient (15 min to 2 hr) and persistent (15 min to day[s]) groundwater changes. The furthest distance from the epicentre exhibiting a specific type of response requires optimal site conditions. Thus bedrock and soil type are important at these locations and the study of earthquake-induced hydrogeological thresholds may elucidate the wider governing processes.

We use 12 years of hydrogeological and seismic data from instruments in Southland, Canterbury, Marlborough, Wellington, Gisborne, Waikato and Auckland. Several shaking parameters are calculated at each borehole location: peak ground acceleration and velocity, Arias intensity, spectral amplitudes, and ground motion prediction equations. Induced static stress estimates are made using an elastic-half space model. Temporal transmissivities are computed from oceanic tidal responses.

We observe a range of hydrogeological responses to earthquakes, including signals of different polarities (rises and falls), varying amplitudes, and time-scales. We attempt to classify aquifer compliance by assigning boreholes a predicted site shear-wave velocity. Coupled shaking-bedrock thresholds are determined for 637+ bores screened in schists, volcanics, shelly marine sandstones, limestones and gravels.

Preliminary results in gravel aquifers show a transient and persistent change threshold of~0.001 and~0.0016m/s peak ground velocity, respectively. The Seddon and Grassmere earthquakes together induced transmissivity increases in four wells of Central New Zealand.

Ongoing work utilises data mining to assess the contribution of seismic, hydrological, and geological parameters to earthquake-induced hydrogeological processes.

Groundwater microbial community assessment – Can shifts in composition predict contamination?

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As part of ESR's Core Funding, the Microbial Early Warning Systems Project (MEWS) aims to provide a method of determining contamination occurring in groundwater systems using shifts in natural populations present in groundwater. Detailed analysis of the microbial diversity and their associated biogeochemical cycling potential will provide a method for determining long-term impacts of anthropogenic activities. The project identifies how groundwater biota responds to known contaminants. The project's science impact will be delivered through the new approach to *in situ* groundwater remediation that the project is developing.

Until recently, gaining a clear picture of microbial community composition and function in aquifers has been hindered by a lack of methods able to detect the entire population; traditional microbial culture techniques permitted only a small fraction (<1%) of the complex community present in groundwater to be detected and thereby identified and their function speculated. Compounding microbial culture-dependence limitations, the subsurface environment is studied less than above-ground freshwater ecosystems, mainly due to sampling issues, and has resulted in this environment being significantly under-represented in the literature. Next generation sequencing (NGS) offers an alternative approach for biota detection that provides a culture-independent method which overcomes traditional shortcomings.

An overview of the project results so far will be presented, including preliminary findings on the shifts that occur in response to different contaminants. The project will demonstrate the potential for a novel tool for measuring groundwater drinking water contamination and potentially offer a method for remediation of groundwater sources.

Changing flow regimes in the springs of Christchurch

Emma Barr[1], **Prof Jenny Webster-Brown**[1]
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A preliminary investigation of the summer flow and water quality of artesian springs around Christchurch City in 2014/2015 turned into a longer-term monitoring commitment when spring flows that had disappeared over summer failed to resume after winter recharge of the aquifer, as had been expected. The flow and quality of these springs affects the lowland streams flowing through the city of Christchurch, and the low (or lack of) flow in urban streams over the 2015/16 summer has been a source of much consternation to the city's residents.

From 2 December 2014 until the 13 February 2015, flow and water quality measurements were taken weekly from six springs at Redwoods in Belfast, Ngaio Marsh in Papanui, Jellie Park and Ilam Gardens in Ilam, and Knights Reserve in Halswell. Mean summer flows ranged from 14.5L/sec at Redwoods to 0.03L/sec at Jellie Park, and only the northernmost springs (Redwoods and Ngaio Marsh) continued to flow throughout this period. Ongoing weekly monitoring through to late August 2015 showed that none of the remaining springs resumed flow in this time frame. Further fortnightly monitoring of the two Ilam Garden springs through to April 2016 showed that they remained dry, and did not resume flowing in late August/early September, as had been observed in the 3 years prior. The relationships between spring flow and recent rainfall, local groundwater levels, river flows and urban (re)development have been analysed to assess the relative importance of these factors in reducing recent spring flows.

Using best-available data for robust groundwater model development: An example

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As discussed in Weir et al (2014) , defensible groundwater models are data hungry. They must be constructed with real information, which can require considerable investment. Such data sets are vast and seemingly endless, but two sets are important for representing long-term transient response: land use and associated land surface recharge.

Recently, Aqualinc has re-engineered the Canterbury groundwater model with the assistance of funding provided by the Ministry of Business, Innovation and Employment (MBIE) through the Wheel of Water programme and the Marsden Fund. As part of this process, we have developed updated estimates of time-varying land use derived primarily from a consents database with additional verification from site surveys and satellite imagery. In addition, we have developed corresponding daily time series of land surface recharge using Aqualinc's soil–water balance model, IRRICALC. The resulting recharge has been compared to measured recharge under four dryland lysimeters and five irrigated lysimeters located on the Canterbury Plains, with favourable results.

These methods present some of the most up-to-date techniques currently available to estimate these important model inputs, which at a regional scale are typically unmeasured. The methods are relatively economical to use to generate data sets for large model domains. Uncertainty in the prediction of these inputs will be accommodated through model calibration that will allow variation in the magnitude of the recharge (through scaling factors) with associated post-calibration uncertainty analyses.

This paper will present the results of both the time-varying land use estimates and the land surface recharge calculations that will be used to support model redevelopment.

Sensitivity of groundwater recharge estimates to distribution of intensities in satellite and reanalysis precipitation products

Micha Werner[1,2], **Rogier Westerhoff**[2,3], Catherine Moore[3]
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Simple water balance models are widely applied in establishing estimates of recharge due to precipitation. Typically, precipitation is divided into canopy interception, runoff and infiltration, with infiltrated water adding to the root zone soil moisture storage. On saturation of the root zone, excess water is considered to contribute to groundwater recharge. The partitioning between different processes in these models often depends on (variable) intensity thresholds. As a consequence, the results of these models are sensitive to the precipitation product used as forcing. In this paper we compare recharge rates using a simple water balance model using several precipitation datasets. These datasets have been assembled through the Earth2Observe, a European research initiative, and the SMART aquifers project, and include both satellite and meteorological reanalysis products. We compare the distribution of rainfall intensities of these different precipitation products against benchmark precipitation datasets based on observed data, and explore how these differences in rainfall intensity distribution impact recharge. Results of the comparison for selected sites across New Zealand show recharge estimates to be sensitive to the frequency distribution. That sensitivity is highest in dryer locations, where there is a pronounced shift in the distribution of the recharge response. For more humid locations, this shift is not as marked, and the sensitivity is quite a bit lower. Our results underline the importance of using precipitation products that not only represent the total amount of rainfall, but also the intensities.

Classification of the New Zealand geological map into hydrogeological and aquifer properties

Rogier Westerhoff[1,2], Zara Rawlinson[1], Conny Tschritter[1], Paul White[1]
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New Zealand's national geological map, QMAP, is an important GIS-based resource that is often utilised within hydrogeological studies. To place the mapped geological units into a hydrogeological context, however, significant research and data manipulation is often required. Hydro-lithology mapping refers to the mapping of geological units in terms of their hydrogeological properties (such as permeability, effective infiltration, hydro-capacity). Here, a methodological approach is described that utilises the geological information from the original cartography of QMAP and builds a GIS-based multi-criteria hydro-lithological database of New Zealand (GWMAP). GWMAP creates a valuable new data set for New Zealand and will provide the basis for other interpretive mapping products to be produced, e.g. "aquifer potential" and national aquifer delineation.

GWMAP is further enhanced by combining the hydro-lithological information with information from national digital soil maps (S-map and FSL soil properties), international literature values of hydraulic conductivity (K), and locally measured K values. This allows for the preliminary mapping of K nationwide.

Presented are the first national maps of hydro-lithology, K, and aquifer potential. These maps will continue to be refined through the collation of all measured hydraulic property information in New Zealand, along with other localised hydrogeological information. One intended outcome of this work will be the establishment of "literature values" for hydraulic properties of New Zealand-specific materials, which will improve the efficiency of developing numerical models with reduced uncertainty nationwide. The extension of this database and associated mapping products to 3D will be ongoing research.

Developing a consistent floodplain risk assessment process for Tasmania

Chris White[1], **Chris Irvine**[2], **Craig Ludlow**[3], **Jane Mullett**[4], Timothy Ramm[1], **Fiona Ling**[3], **Prof Darryn McEvoy**[4]
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Floods are the most damaging natural hazard both in terms of fatalities and economic impacts. Climate change offers the prospect of increased frequency or severity of flood events; it is therefore important that flood risk management decisions are based upon the appraisal of risk that is both accurate and consistent, accompanied by a well-informed appraisal of the associated uncertainties and their potential impact on decision-making.

In this study, we develop a methodology for the assessment of floodplain risk across Tasmania that has been developed to be consistent with the Australian Emergency Handbook 7 (AEM7) and the revised 2015 National Emergency Risk Assessment Guidelines (NERAG).

Here, we demonstrate a) the development of the risk assessment process, and b) its application through a case study of the Huon River at Huonville to produce an assessment of existing, future, and residual risks.

A key emphasis of the methodology is an explicit focus on uncertainties throughout the floodplain risk assessment process that provide advice regarding appropriate methodologies for the identification, analysis, and evaluation of risks, including the empirical quantification of the consequences and likelihoods of risks.

The key outputs from the project are:

- assessment of current, future and residual risks, with quantitative likelihood assessment and consequence metrics that can be integrated into municipal level "all hazards" risk assessments
- practical guidelines for the conduct of municipal-level flood risk assessments using best practice methods, flood studies and other quantitative data.

Water budget of the Heretaunga Plains

Paul White[1], Abigail Lovett[1], Pawel Rakowski[2], Jing Yang[3], Dougall Gordon[2]
[1]GNS Science, [2]Hawke's Bay Regional Council, [3]NIWA

Water budgets were developed using a water budget zone approach for the Heretaunga Plains aquifer system where groundwater is the key water source for agricultural and urban supplies. These budgets aim to assist with the Hawke's Bay Regional Council's groundwater investigations and with water management policy development for the "TANK" catchments (i.e. Tūtaekurī, Ahuriri, Ngaruroro and Karamu), which include the Heretaunga Plains. Water budget components were calculated in each of these zones with a 100 × 100m grid at a daily time step in the period 1972 to 2015.

Water inflows to the study area were from rivers and groundwater. The TOPNET model was used to provide daily flow estimates in the 227 rivers and streams that cross the study area boundary. Groundwater inflows to the study area were calculated with water budgets of the TANK catchments. Groundwater inflows from rivers were from the Ngaruroro River (major and minor recharge zones), the Tūtaekurī River and the Tukituki River. In addition, distributed temperature sensing measurements in the Ngaruroro River and the Tūtaekurī-Waimate Stream contributed to the understanding of groundwater–surface water interaction. Rainfall recharge to groundwater was calculated with the SOILMOD model, including corrections for runoff and ponding, using VCSN data that were calibrated at the local scale to observed rainfall recharge at three lysimeter sites and at the zone scale to modelled quickflow. Water outflows included spring-fed streams, groundwater use and estimated groundwater outflows to balance the water budgets.

Forecasting the Hutt

Mike Harkness[2], **Greg Whyte**[1]
[1]DHI Water & Environment, [2]Greater Wellington Regional Council

A flood forecasting system has been developed for the Hutt River that uses forecast rainfall along with real-time measured rainfall and river flows to predict flood magnitude at chosen locations.

Around 130,000 people live in the Upper Hutt and Lower Hutt cities with many of them residing on the floodplain. This urban community forms a major component of the Wellington regional economy, and flooding from the Hutt River is one of the biggest environmental and emergency management issues facing the area.

Greater Wellington Regional Council (GWRC) has adopted a joint initiative approach which includes our regional Civil Defence Emergency Management Group and DHI Water & Environment (DHI) to develop the flood forecasting system and to investigate methods of disseminating the forecast information.

Rainfall-runoff modelling of GWRC's network of rainfall and river gauges has been completed using the NAM rainfall-runoff module within the MIKE by DHI software suite. Existing GWRC hydraulic models (MIKE11) have been coupled with the NAM rainfall-runoff models and implemented in a real-time environment within MIKE Operations.

The rainfall-runoff models are calibrated against long-term rainfall and flow records, focusing on flood peaks, accumulated runoff volume, and the correlation coefficient between observed flows and modelled flows. The hydraulic model calibration has been focused on replicating a number of discrete historical events. A crucial part of the system is data assimilation and error forecasting on discharge and water level in the hydraulic model.

The flood forecasting system will run 24/7 and produces a new forecast every 1–3 hours.

Low-gradient streams need more flow for oxygen

Thomas Wilding[1]
[1]*Hawke's Bay Regional Council*

Water is taken from streams and aquifers for irrigation, industry and town supply. Deciding how much water should be allocated, and when takes should be subject to restrictions, requires information on flows required to sustain stream ecosystems. This investigation focused on how flow requirements for dissolved molecular oxygen vary spatially across the riverscape. A Generalised Oxygen Model was successfully developed for single-thread streams of the Heretaunga Plains. The model uses Froude number to predict oxygen, with oxygen measured as daily minimum oxygen saturation at multiple sites on 21 January 2015.

Froude number increases with velocity and decreases with depth; so is smaller for slow, deep pools.

The model predictions were tested against a second set of dawn oxygen measurements (total 50 sites across 5 occasions). The validation data produced a similar rate of decline in oxygen saturation with Froude number, and indicated that the Generalised Oxygen Model was predicting a worst-case-scenario (i.e. annual minima), rather than typical summer conditions.

In terms of flow management, the use of Froude number demonstrates that the flow requirements for oxygen saturation decrease with channel slope and increase with channel size. Potential applications of the model include selecting representative monitoring sites, and classifying streams where lower oxygen standards are applicable.

Parameterisation and simulation of the SMWBM within the Source catchment model

Jon Williamson[1], Emily Diack[1]
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The Soil Moisture Water Balance Model (SMWBM) is a semi-deterministic lumped parameter model for simulating the components of the catchment water balance including streamflow and baseflow. The SMWBM is based on the algorithms of Pitman (1976) for simulating river flows using daily rainfall data, and has been continuously developed by Jon Williamson between 1998 and the current time to incorporate many features of the environment important for catchment water balance, irrigation scheduling and water quality simulation in New Zealand and other places. Implementation of the SMWBM as a Source plugin enables the model to behave in a more distributed manner enabling regional-scale catchment simulation within a single framework. However, this introduces the requirement to parameterise the SMWBM over a wide area where climatic and geomorphological variables may be significantly different. This presentation will describe the structure and parameters of the SMWBM, procedures adapted to parametrise the model for calibration in two regional-scale water quality simulation projects in the North Island, and some of the model calibration results.

New approaches to water management in Otago

Peter Wilson[1]
[1]*Otago Fish and Game Council*

Water management in Otago is facing a watershed – on 1 October 2021, long-standing rights dating back to the 1860s gold rush to abstract water from many rivers end. There are over 400 of these rights. These rights, known as mining privileges, or deemed permits, were originally issued in perpetuity, and usually with no regard to water availability or instream environmental needs. A direct consequence is the drying up of many Central Otago rivers and streams in summer months. However, the introduction of the Resource Management Act in 1991 resulted in these rights being grandfathered forward for 30 years, and this time is up.

The challenge facing water managers in Otago is replacing these rights with modern water permits, and this is not an easy challenge, given the many competing demands for this water – either instream, to sustain or restore aquatic life, or for irrigation, where there are strong equity and fairness considerations between the multiple irrigators reliant on surface water. There is often an absence of baseline surface and groundwater hydrological information to inform decision-making.

However, this challenge is resulting in innovation in water management. Higher residual flows with a trade-off of water harvesting at times of high flow for storage has emerged as a viable option. Group management structures, including single all-of-catchment consents, are emerging, and there is a substantial degree of collaboration between irrigators, stakeholders, and statutory agencies. Some catchments, for example the Sowburn River, have already been successfully transitioned to RMA permits.

Spatial prediction of groundwater redox status

Scott Wilson[1], Murray Close[2], Phil Abraham[2]
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Aims

Groundwater denitrification is a powerful ecosystem service that could be considered in land use planning if its distribution is known. Our aim is to develop a regional-scale spatial prediction method using publicly available national and regional council datasets. We have tested our approach using data for Southland and Hawke's Bay aquifers.

Methods

Water quality data from regional council databases were assigned a redox status following an approach modified from McMahon and Chapelle (2008) . Three redox states were applied: reduced, oxidised and mixed. These data were used to develop a model for relating redox status to spatially varying predictive variables using linear discriminant analysis. A range of predictive variables thought to have a bearing on nitrate concentrations were included in the analysis. These included soil type, carbon content, land use, lithology and age, elevation, slope, depth to water table, representative hydraulic conductivity, and land surface recharge rate. The discriminant models were tested by re-calibrating to a randomly selected portion of the full dataset. The re-calibrated models were then tested on the full dataset and validated using the remaining independent portion of the dataset.

Results

Linear discriminant analysis has enabled us to produce maps of predicted redox status. The average agreement using predicted and measured redox status was X and Y percent for Southland and Hawke's Bay aquifers, respectively. Data validation indicated that the models are robust with less than X percent change in the data correctly predicted.

NB: Model revision is currently underway to inform the extended abstract.

Wairau Aquifer recharge pathways

Scott Wilson[1], Peter Davidson[2], Thomas Wöhling[1,3]
[1]*Lincoln Agritech Limited,* [2]*Marlborough District Council,* [3]*Technische Universität Dresden*

Aims

The Wairau Aquifer is almost entirely river-recharged, although the distribution of recharge groundwater flow paths is poorly constrained. To improve conceptualisation and inform numerical flow modelling, the stratigraphy of the Holocene alluvial fan was reviewed. Previous authors have noted subtle variability within the gravel assemblage. Our aim was to identify spatial patterns of deposition informed by climate-mediated changes in the energy of the river environment.

Methods

We used a three-stage process: an initial scan of deep well logs, 3D visualisation using GMS software, and a final refinement by plotting intercepts of distinctive facies in GIS. Drillers' well logs were referred to throughout this approach. The lithologies were lumped into four depositional environments, from high-energy (proximal channel gravels) to low-energy (distal overbank flow). Lithological information was supplemented by qualitative comments made by the drillers on the water-bearing nature of the sediments encountered.

Results

The alluvial fan consists of upper and lower members which are separated by low-permeability matrix-supported gravel. The upper member shows lateral facies changes which have distinct hydraulics properties. Three areas for preferential recharge can be recognised:

- 35% via a 3km reach in the fan apex where lower member is in contact with the active river channel gravels
- 20% via a shallow historical overbank flow channel
- 45% via a 3–4km reach in the fan toe where the river traverses a thickening high-permeability upper member gravels. Recharge from this reach provides a shallow groundwater pathway to downgradient springs.

Changes in the hydrological regime of the Wairau Plains Aquifer

Thomas Wöhling[1,2], Moritz Gosses[1], Scott Wilson[2], Val Wadsworth[3], Peter Davidson[3]
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The Wairau Aquifer covers a small proportion of the Wairau catchment in the Marlborough District of New Zealand just prior to the river discharging into the sea. The aquifer is almost exclusively recharged by surface water from the Wairau River and serves as the major resource for drinking water and irrigation in the region. A constantly declining trend in aquifer levels and spring flows have been observed over the past decades, which triggered a range of investigations on the Wairau Plains but also for the entire Wairau catchment (3430km²). The current state of knowledge shows a strong relation between declining trends in aquifer levels and similar trends in Wairau river flows. Experimental evidence and numerical modelling of the interacting river–groundwater exchange flows suggest that the river is perched in the upstream regions and that aquifer recharge is particularly sensitive to an increase of days with extreme low river flows. Since the Wairau River flows and therefore also the fate of the Wairau Plains aquifer are strongly linked to the hydrological processes in the entire catchment, investigations are under way to analyse the hydrological regime and potential trends or changes thereof on the catchment scale. The analysis of a 50-year period of precipitation from NIWA's Virtual Climate station network already revealed that there is potentially also a declining trend in annual mean catchment precipitation. However, questions remain due to uncertainties in the hydrological data and concurrent land use changes in some parts of the catchment.

Bayesian calibration of a lumped model to estimate catchment nitrate fluxes from monthly monitoring data

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Nutrient exports from headwater catchments are commonly monitored by monthly water quality sampling at the catchment outlet. Comparison with high-resolution stream flow data, however, highlights how poorly these monthly samples capture storm flow conditions, which may represent a significant component of annual load for many nutrients. We used a daily time step lumped-parameter model to estimate water and nutrient contributions arriving at the catchment outlet via near-surface, shallow seasonal groundwater, and deeper older groundwater flow paths in three mesoscale catchments in the Waikato region of New Zealand. Markov chain Monte Carlo calibration of the model in each catchment, to monthly nitrate-nitrogen and daily stream flow data simultaneously, allowed estimation of annual average fluxes along the different flow paths, as well as the uncertainty in these estimates due to data accuracy and coverage. Results confirmed the relatively high uncertainty in near-surface flux predictions estimated from this type of data. Shallow and deeper groundwater contributions, on the other hand, were able to be estimated relatively accurately. Some suggestions for improved water quality monitoring strategies will be discussed.

Modelling surface water–groundwater interaction using a newly developed conceptual surface water–groundwater model

Jing Yang[1], Christian Zammit[1], Hilary McMillan[1]
[1]*NIWA*

Most lowland rivers in New Zealand are characterised by a strong interaction with groundwater systems. This is usually characterised through losing and gaining reaches, which is of significant importance to assess impact of human activity (e.g. agriculture, industry, etc.) on water resources as well as for the development of water resources driven policies (e.g. NPS for Freshwater Management). This characteristic is usually modelled using a physically based groundwater model requiring significant amounts of geological and river information. As an alternative, we developed a conceptual surface water–groundwater interaction module implemented as part of NIWA's national hydrologic model (TopNet) to simulate surface water–groundwater interaction from catchment to national scale in New Zealand.

In addition to conventional surface hydrologic components (i.e. evaporation, surface water generation, river routing, soil process), the newly developed model (named TopNet-GW) is able to simulate cross-subcatchment-boundary groundwater flow, surface water–groundwater interaction, and inter-catchment groundwater flow based on limited hydro-geological information.

The developed model was applied to two New Zealand catchments under different geological settings: the Pareora in Canterbury, and the Grey on the West Coast. Both catchments have concurrent spot-gauged flow information allowing the verification of the internal structure and model parametrisation. Results show that model simulations not only fit quite well to flow measurement but also to concurrent spot-gauged flows. Compared to the original TopNet simulation, significant improvement in the reproduction of low flow conditions was achieved. This indicates that the proposed conceptual approach is promising for nationwide modelling without requiring large amounts of geology and aquifer information.

Selecting Representative GCMs to Preserve Uncertainties

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Climate change studies usually face the use of many scenarios, and selecting an essential number of scenarios among the many scenarios available is very important, because using all scenarios is impossible in practice. Furthermore, climate change impact assessment and adaptation strategy are often sensitive to the choice of GCM scenarios. This study warns that selecting the best-performing scenarios based on a past period should be avoided in nonstationary cases like climate change, and then proposes a new approach that can preserve uncertainty, as much as all scenarios contain. The new approach groups all scenarios into several clusters, and then selects a single representative scenario among member scenarios of each cluster, based on their skill scores. The proposed approach is termed 'selecting the principal scenarios', and applied to select 5 principal GCM scenarios for the South Korean Peninsula, among 17 GCM scenarios of the 20C3M emission case. The uncertainty preservation is measured with maximum entropy theory. The case study presents that the principal scenarios preserve the full range of total uncertainty, while the best scenarios do so only less than 65 %, confirming that preserving uncertainty with the principal scenarios is more adequate, than selecting the best-performed scenarios in climate change studies.

Towards collaborative groundwater: Surface water interaction models from catchment to regional and national scales

Christian Zammit[1], Rogier Westerhoff[2], Jing Yang[1], Lawrence Kees[3]
[1]NIWA, [2]GNS Science, [3]Environment Southland

The development and implementation of environmental policies across New Zealand (such as the NPS for Freshwater Management or water allocation limits) requires assessment of annual and seasonal river flow. One of the least known parts of river flow in New Zealand is the location and associated flow volumes of losing and gaining streams and rivers.

Research on losing and gaining streams in New Zealand is currently carried out under three different threads: surface water–groundwater model, statistical model, and water chemical model. Surface water–groundwater methods represent surface water–groundwater interaction either conceptually (e.g. TopNet-gw model) or physically (MODFLOW) with observed flow data or groundwater data for verification, at a catchment scale or regional or national scale. Statistical models usually integrate different knowledge (e.g. flow measurement, geophysical information, and expert opinions) into a modelling system, such as the statistical classification system for gaining and losing streams. Water chemical models use chemical (e.g. hydrogen and oxygen isotopes and radon) measurements in river and groundwater to derive the groundwater age and groundwater recharge and discharge.

To stimulate the collaboration between these threads, we evaluated and compared gaining/losing stream classifications in Southland, through i) descriptions of stream gauging results and other observations by regional council hydrologists, ii) regional surface water and groundwater models, and iii) groundwater age radon field techniques. Results show this collaboration improves understanding of losing/gaining rivers significantly. We therefore recommend further collaboration to improve estimates of groundwater recharge from rivers or baseflow estimates from groundwater, at watershed, regional and national scales.

Climate change impacts on hourly precipitation across New Zealand: Potential downstream impacts

Scott Graham[1], Bruce Dudley[1], Abha Sood[1], Johanna Springer[1], **Christian Zammit[1]**
[1]NIWA

Climate change is projected to have a significant but spatially variable impact on New Zealand's water cycle. Municipalities within New Zealand generally assess climate change impacts on precipitation using the High Intensity Rainfall Design Tool (HIRDS), based on IPCC3 projected climate change. IPCC3-based intensity–duration–frequency (IDF) curves of precipitation assume that weather patterns remain constant. In the fifth assessment reports of IPCC (IPCC5), the use of Regional Climate Models (RCMs) in the Coupled Model Intercomparison Project Phase 5 (CMIP5) indicate that in addition to temperature, weather patterns will also change. As a result, IPCC5 includes more severe climate scenarios than those in IPCC3. Risk of design storms may exceed that predicted from existing IDF curves within the lifespan of municipal infrastructure, which could incur major property damage, loss of economy, and even human life. This study looks at potential climate change impacts on sub-daily precipitation under IPCC5 scenarios using hourly RCMs. Climate change fields (precipitation and temperatures) were generated using RCMs for four Representative Concentration Pathways (RCPs) under six CMIP5 models. We examined precipitation characteristics (i.e. duration, frequency and intensity) over the period 1990–2110 for different precipitation event thresholds. Our results across the range of RCMs and RCPs indicate that substantial changes to sub-daily precipitation intensity, and duration of large events should be expected. These results have important implications for flood design of infrastructure across New Zealand.

Assessment of the AWAP large-scale hydrological model to detect the influence of climate drivers on runoff variability

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Multi-decadal variability is of particular interest because the security of urban water supply is sensitive to runoff variations over such time scales and there is opportunity to adaptively manage and plan bulk water supply systems. To study multi-decadal variability in the context of water supply, it is necessary to have long streamflow records. However, streamflow observations before the 1950s are sparse in Australia. The AWAP (Australian Water Availability Project) product provides Australia-wide monthly streamflow estimates from 1900 onward. An assessment of AWAP streamflow against streamflow in the Hydrological Reference Stations (HRS) dataset showed that AWAP predictions of streamflow had poor to very poor Nash–Sutcliffe efficiency statistics. However, it was found that the correlation coefficients were reasonably high, suggesting AWAP streamflow is subject to considerable bias. This suggested that AWAP streamflow may be useful in studying the effect of climate drivers on runoff variability if non-dimensional statistics are constructed. We stratified streamflow by ENSO and IOD positive and negative states and non-dimensionalised the difference in stratified means using the overall mean. Further analysis showed that AWAP streamflow products captured both spatial and temporal differences induced by ENSO and IOD, with uncertainty decreasing in regions where there is a strong ENSO or IOD signal. This assessment suggests there is considerable benefit in using non-dimensionalisation to mitigate the possible bias in large-scale hydrological models and suggests such products may produce useful indicative estimates of the strength of climate drivers on runoff variability in locations not served by long streamflow records.

POSTER ABSTRACTS

Community owned micro-hydropower in developing countries: Success, challenges, and added benefits

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Isolated communities in developing countries struggle to meet their energy demands partly due to the difficulty in connecting to national electricity grids. Basic energy demands are often met with the use of expensive and polluting fossil fuels. An alternative way of meeting energy demands can be through the use of micro-hydropower (MHP) systems, if the right conditions exist. To evaluate the feasibility of an MHP scheme at a particular location, economic, physical, environmental, social and political factors need to be considered. Evaluating some of these factors often requires engineering skills and complex calculations, which prevents isolated communities from assessing the feasibility of a potential MHP scheme. Research is needed to understand how the various factors contribute to the success or failure of MHP schemes in developing communities. Numerous communities from Nepal, Bolivia, Cambodia and the Philippines have been visited to acquire the necessary field experience. New Zealand's existing MHP schemes have also been studied to provide perspective on the socio-economic linkages to further understand the hindrances affecting undeveloped countries. The research done has identified the key intervenient factors of MHP success and is developing a pre-feasibility analysis tool that considers and correlates affecting factors. A multi-criteria decision-making algorithm has been chosen to analyse the qualitative and quantitative multidisciplinary variables affecting MHP schemes. This research will create a tool to facilitate remote villages with limited economic and educational possibilities to perform pre-feasibility assessments for MHP generation. This study will help advance the knowledge of MHP management and design.

Solute mixing in hierarchical sedimentary deposits

Jeremy Bennett[1], Claus Haslauer[1], Martin Ross[2], Olaf Cirpka[1]
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Solute mixing and spreading are important processes in understanding many contamination problems. These processes are determined by the spatial distribution of hydraulic conductivity. Many approaches to characterising hydraulic conductivity fields reduce complex sedimentary architectures to relatively simple geometries. The assumptions implicit in these methods are often violated and therefore sedimentary architecture may not be realistically represented in hydrogeological modelling efforts.

Hierarchical sedimentary deposits are typically unconsolidated sediments composed of assemblages of facies at multiple scales and are formed by cyclical depositional processes (e.g. glacial advance and retreat). Such deposits often form important aquifer systems, from which groundwater is extracted. The properties that make these aquifer systems productive, such as high hydraulic conductivity, also make them vulnerable to over-extraction, as well as contamination from diffuse and point sources.

In this PhD project, realistic spatially distributed hydraulic conductivity fields will be generated using various sediment generation tools, constrained by quantitative and qualitative information. Groundwater flow and solute transport modelling will be performed using the hydraulic conductivity fields, and the model outputs will be assessed using relevant metrics. A framework for including geological information in hydrogeological modelling studies will be developed, including a workflow suitable for practice. This poster presentation will include preliminary results and a project outlook.

Field-saturated hydraulic conductivity testing: Groundwater testing in geotechnical boreholes

Sean Berry[1], Zeljko Viljevac[1]
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The need for groundwater impact and dewatering assessments may not be identified until late in the overall investigation phase. The collection of meaningful groundwater information within a geotechnical investigation is achievable, provided the correct methods are used in the field, suitable numerical solutions are applied to the data, and the reliability of the results is appropriately reported.

Various field methods are available; the practicality of each must be individually assessed for any given project. Where the need for groundwater data may not yet be fully realised or understood by stakeholders, wanting to proactively undertake onsite testing early on in an investigation may require ways of fitting the groundwater agenda in to the geotechnical programme. Factors such as limits on field-time, borehole drilling methods and stratigraphy can all impose constraints on the validity of groundwater testing data.

Aims

This assessment has aimed to:

1. Identify potential limitations and issues with onsite testing methods
2. Assess reliability of field-testing techniques, and provide meaningful discussion of reliance on results
3. Find ways in which protocols can be revised to provide a higher degree of confidence.

Regional high resolution mapping of irrigated areas

Peter Brown[1]
[1]*Aqualinc Research Ltd*

Accurate maps of irrigated area and type are important for both water quality and quantity management. We present a method for mapping in detail both the irrigated area and irrigation type. We have applied the method in Canterbury, where about 500,000ha is irrigated. We discuss data accuracy, including a comparison with the Normalized Difference Vegetation Index and consents databases. We discuss potential applications of this dataset, including catchment nutrient accounting, irrigation efficiency mapping, and water infrastructure planning. The method also provides a means for tracking changes over time in greater detail than is possible with Statistics New Zealand five-yearly estimates.

Soil moisture infiltration rates and groundwater residence time in Central Otago tussock grasslands

Josephine Cairns[1], Sarah Mager[1], Peter Wilson[2]
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Tussock grasslands of Central Otago have high water yields as a result of their low evapotranspiration rates and ability to intercept precipitation from fog. This study builds on current research into water yields and tussock grasslands, using a soil moisture budget approach combined with direct measurements of soil moisture to determine if the incidence of fog contributes meaningful amounts of water to soil moisture. Time domain reflectometry probes were installed in a tussock grassland catchment site to complement an existing two-year record of precipitation, runoff and meteorological observations. These data were used to develop a soil moisture model for the study site, and the model output compared to in field observations of soil moisture. The objective of the study is to validate a soil moisture model suitable for grassland high country in Otago, as well as quantify the seasonal trends and the response of soil moisture to precipitation in a variety of forms (rain, fog and snow) and across differently scaled events. These observations will aid in developing a better hydrological model that accounts for the distinctively high water yields that occur under tussock grasslands and contribute to the development of a framework for valuing and preserving the hydrological function of high country tussock in water allocation in the region.

Validation of TAPM's meteorological data generator on Australia's east coast

Elliot Dacre[1]
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As predictive modelling become increasingly prominent in engineering, it also becomes important to ensure that the data being utilised for these models are accurately portraying the reality.

The Air Pollution Model (TAPM) is software developed by the CSIRO as a prognostic modelling system which has been utilised for meteorological generation. The purpose of this study is to determine the effectiveness and accuracy in which TAPM is able to generate meteorological data for three different sites on the east coast of Australia.

Historical data collected from the Bureau of Meteorology (BOM) monitoring stations at northern (Weipa), central (Archerfield) and southern (Newcastle) sites on the east coast of Australia have been compared using statistical methods to the data generated in TAPM.

Two key indicators have been looked at when comparing generated to observed data: consistency and accuracy. Consistency was tested using correlation to compare how well the annual pattern is being followed. Accuracy was tested with forecasting skill comparing the values at each point.

The results indicate that TAPM is able to generate data for temperature and evaporation with high accuracy (skill_V; 1.27 to 1.09 and skill_R; less than 1) and consistency (correlations 0.80–0.93). The least accurate was rain (skill_V; 0.03 and skill_R; greater than 1) (correlations; 0.14).

From this study, it was found that the general annual weather patterns were being followed; however, there were often large discrepancies in value.

Hydrological modifications in the Mekong floodplains from development and climate change

Thanh Duc Dang[1], Thomas A Cochrane[1]
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The Mekong floodplains play an important role in poverty and hunger alleviation in Vietnam and Cambodia. Their high agricultural productivity is partially due to the natural hydrological regime of the Mekong River; however, regional demand for electricity is leading to the development of over 120 upstream hydropower dams, which may alter the hydrology of the floodplains forever. Within the floodplains, an extensive system of delta-based flood protection is being constructed to increase agricultural production, but which can have negative effects on other parts of the delta. Rising sea levels due to climate change and the observed land subsidence will exasperate the problem of flooding in unprotected regions. The main aim of this study was thus to investigate the effect of potential changes in floodplains' hydrological regimes by modelling development and climate change scenarios. Full development of hydropower dams will increase dry season water levels by 23%, but wet season water levels will only change by slightly over 1% in the upper floodplain. Flood protection systems will significantly change water storage capacity and water allocation in the floodplains, causing significant regional changes in flood patterns. Sea level rise will result in the inundation of a vast region of the Vietnamese coast, while land subsidence could cause localised changes in flooding patterns, but to a lesser impact than water infrastructure development. Region-wide transboundary water resource use policies are needed to address future changes in the balance between agricultural productivity, energy generation, and the natural environment.

Uncertainty in climate change impacts on Southern Alps catchments: The role of hydrological model complexity

Ryan Jones[1], Daniel Kingston[1], Sarah Mager[1]
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Climate change scenario modelling for New Zealand indicates a series of hydrological changes can be expected. Hydrological modelling is a critical tool to assess the likely impacts of future climate change on river runoff. The most comprehensive (i.e. distributed) hydrological models are generally complex and require large amounts of input data, computer power and time. The use of semi-distributed models to perform essentially the same function can yield a relatively efficient method of scenario hydrological modelling. Thus, this research tests whether a relatively simple model can be effectively used for scenario modelling in the context of the Southern Alps of New Zealand, specifically the Shotover River. This research will provide useful insight into appropriate hydrological modelling methodology in the Southern Alps, as well as the likely implications climate change may have on future availability of New Zealand's freshwater resources.

The power of radioactive isotopes in hydrology

Johannes Kaiser[1]
[1]*GNS Science*

This presentation gives an overview of the production, sample analysing (including sample preparation) and application of tritium, radon and radiocarbon in the water dating laboratory at GNS Science.
These radioactive isotopes have half-lives of 12.3 years, 3.8 days, and 5,730 years, respectively.
Applications are groundwater dating, drinking water security and groundwater–river water interaction in New Zealand rivers.

How much carbon is transported in pristine river systems?

Alexandra L King[1], Sarah M Mager[1], Emily E Diack[2]
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Mountainous rivers are important conveyors of organic carbon to the marine environment. Estimates of carbon flux vary greatly between different river systems, and relatively few studies have investigated the carbon flux of New Zealand rivers. This study investigates the sources and transfer of carbon within a pristine alpine catchment in New Zealand, based on data collected in the Haast River. The study reports on the different portions of carbon being transferred through the Haast River, derived from observations collected at different times of year (e.g. seasons) as well as a consideration for downstream changes in carbon. Chemical and isotopic tracers were used to determine where carbon is derived within the landscape to quantify the flux of atmospheric carbon that is drawn down via rock weathering, and what influence weathering and thin alpine soils have on sources of inorganic carbon. Water samples were collected and analysed for particulate and dissolved organic carbon, as well as inorganic carbon, in conjunction with major and minor solute chemistry. Preliminary data analysis suggests that under baseflow conditions particulate organic content is not a significant contributor to overall suspended material concentrations, accounting for <2% of suspended load (0.5mg C/L). By comparison, dissolved organic and dissolved inorganic carbon occur in significantly higher concentrations (1.2–1.9mg C/L and 3.5–5.5mg C/L) in the Haast River and under baseflow conditions are the dominant forms of carbon flux.

Water scarcity and drought in the Lindis catchment, Central Otago

Jessie Loft[1], **Daniel Kingston[1]**, Sarah Mager[1]
[1]*University of Otago*

Water-scarce situations (i.e. where demand is greater than supply) are a critical issue in water resource management. Water scarcity can be exacerbated by drier than usual conditions, but separation of the effects of water scarcity versus drought can be difficult. This study investigates the relative importance of water scarcity and drought for the availability of water in the Lindis River, Central Otago. The Lindis River frequently runs dry in the summer, becoming disconnected from the larger Clutha River. To determine the extent that extreme low flows are driven by abstractions versus the naturally low rainfall conditions that occur in summer, a two-step hydrological modelling procedure was employed. First, a model was developed for the upper Lindis River, where flows are not altered from allocated abstraction. This model is then applied to the lower Lindis flow records, to reconstruct what "natural" flow would likely be in the lower catchment. Comparison of the modelled "natural" river flow record with the observed (impacted) river flow record suggests that summer river flow in the Lindis is substantially lower than it would be in the absence of human abstraction. Results indicate that the Lindis River would never disconnect from the Clutha during January–March, and would only have rare disconnection events in December and April, in comparison to their frequent actual occurrence. As such, the results of this study provide a useful tool for reconstructing river flows to account for the effects of human abstraction and provide vital information for ongoing management of this catchment.

Engaging with Groundwater Resources of New Zealand: An interactive poster presentation

Abigail Lovett[1], Uwe Morgenstern[1]
[1]*GNS Science*

The Groundwater Resources of New Zealand (GWR) Programme is GNS Science's core funded hydrogeology research programme (2011–2021). The programme is funded by the Ministry for Business, Innovation and Employment and includes collaborations with regional and national authorities, and other research and industry organisations. The primary aim of the GWR Programme is to inform ways to improve the sustainable management of, and economic returns from, groundwater resources in New Zealand. The current programme is structured through six hydrogeological research projects: hydrogeology, water fluxes, bio-geochemical tracers, National Groundwater Monitoring Programme, resource pressures, and stakeholder engagement. One of the objectives of the programme is to increase collaboration and relevance of research by engaging and working with end-users. The aim of this interactive poster presentation is to increase stakeholder awareness of the GWR programme research topics and aims, present recent science outputs, and to promote engagement and collaboration with stakeholders.

Quantifying groundwater discharge using radon-222

Heather Martindale[1], Uwe Morgenstern[1], Rob Van der Raaij
[1]*GNS Science*

Radon-222 is a hydrological tool useful for identifying the locations of where groundwater is discharging into rivers or streams. However, radon has not yet been used to quantify groundwater discharge into rivers in the New Zealand environment. To quantify groundwater discharge using a box model approach, the rate at which radon degasses from the river needs to be calculated. In this study radon samples are collected in areas of nil groundwater discharge. Over a relatively small stretch of river this will provide the degassing rate of radon. These results are then compared to modelled values with the purpose of providing a range of expected radon degassing rates under different flow and geological conditions. From this, groundwater discharge can then be quantified with an associated uncertainty.

Construction of an impact plate geophone to record sediment movement in New Zealand gravel-bed rivers

Andrew Neverman[1], Ian Fuller[1], Prof Russell Death[1], Jon Procter[1], Ranvir Singh[1]
[1]*Massey University*

Gravel-bed rivers are a significant feature in the New Zealand landscape and a focal point for many issues surrounding water, infrastructure and the environment. Bedload transport is a key process in gravel-bed rivers as a driver of erosion which has implications for infrastructure development in and around rivers. Bedload transport is also significant for many other instream processes, in particular as a control on habitat structure and aquatic community composition. Understanding bedload transport should therefore be a high priority for effective management of New Zealand rivers, both for maintaining ecological health and reducing impact on infrastructure.

Despite decades of research, the accurate predication of bedload transport still eludes scientists. The inability to record bedload transport in natural channels at suitable spatio-temporal resolutions has been a significant limiting factor in this pursuit. Geophone-based impact plates are seeing increasing use in bedload transport studies and as monitoring tools. However, many of the impact sensors in the literature either require permanent support structures for installation, or are installed in paving slabs in relatively low-energy systems, limiting their application in New Zealand rivers. This paper demonstrates the development of a novel installation method for impact plate geophones in New Zealand's relatively high-energy, dynamic gravel-bed rivers which anchors the impact plate without permanent support structures.

Application of ANNs for regional flood estimation: A case study for New South Wales, Australia

Prof Ataur Rahman[1], Sasan Kordrostami[1]
[1]*Western Sydney University*

Flood estimation in ungauged catchments is often needed in hydrology. Regional flood frequency estimation (RFFE) methods can be used for this purpose. The RFFE models in Australia are mainly based on linear models, such as Index Flood Method, Quantile Regression Technique, Parameter Regression Technique and Probabilistic Rational Method. The application of non-linear RFFE techniques such as Artificial Neural Networks (ANNs) is quite limited in Australia. In this paper, an ANNs-based RFFE model is presented for New South Wales (NSW) State in Australia. It uses data from 88 gauged catchments in NSW which are smaller than 1,000km^2. A total of eight predictor variables are considered and five different model forms are tested. It has been found that an ANNs-based RFFE model can provide more accurate flood quantiles than the Australian Rainfall and Runoff (ARR) RFFE Model. The relative error values for the ANN models are in the range of 35% to 55%, which are generally smaller than the ARR RFFE Model. It has also been found that use of a greater number of predictors does not necessarily enhance the prediction accuracy of an RFFE model.

Physiographic controls over Southland's groundwater and surface water chemistry: Methods

Ewen Rodway[1], Clint Rissmann[1], Monique Beyer[1], Rachael Millar[1], Lisa Pearson[1], Michael Killick[1], Janet Hodgetts[1], Tapuwa Marapara[1], Roger Hodson[1], Abbas Akbaripasand[1], James Dare[1], Tim Ellis[1], Maggie Lawton[1], Nick Ward[1], Jane McMecking[1], Darren May[1], Lawrence Kees[1]
[1]*Environment Southland*

The Physiographic Project is a component of Environment Southland's Water and Land 2020 and Beyond programme, and their response to the National Policy Statement for Freshwater Management. The physiographic work is a novel approach, which characterises the landscape based on water source, recharge mechanism, combined soil and geological reduction potential, geomorphic and substrate (soil, rock and biological sediments) composition to provide a better understanding of the relationships between key characteristics of these spatial frameworks and both hydrochemical and water quality variation. Simplification of the hydrochemical framework to account for only water quality outcomes results in nine Physiographic Units that respond differently to land use pressures in terms of water quality outcomes.

This talk details the methodology applied to develop physiographic units for Southland. Specifically: (i) the underlying theory of by which spatial gradients in hydrochemical signatures were understood – our "bottom up" data-driven approach, followed by (ii) a "top down" approach to spatially map areas with similar inherent properties (driver assemblages) that influence regional water quality (2) . Development of a "top down" mapping process involved development of objective mapping rules for classification of key driver assemblages (recharge mechanism and combined redox) that respond distinctly to land use pressures. Specifically, nine unique water quality driver assemblages produced nine distinct physiographic units. The mapped units are intended to help facilitate and inform land use management for the protection of human and ecological health of regional waterbodies.

Evaluation of the predictive reliability of flow and transport models of heterogeneous alluvial aquifers

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Alluvial deposits are known to be highly heterogeneous, yet standard methods for interpreting and predicting alluvial aquifer behaviour are often based on methods that assume relatively homogeneous and isotropic conditions. Furthermore, while this heterogeneity can impact aquifer responses, predictive model simulations of aquifer impacts are typically undertaken using a model discretisation that is much coarser than many of the heterogeneous aquifer structures. We have generated a "virtual" braided aquifer model and used it to simulate the response to pumping and tracer tests. These test results have then been interpreted using model-calibration based methods to infer alternative descriptions of the hydraulic conductivity distribution of the "virtual" aquifer. These model calibrations have been undertaken using a coarser model grid than that of the "virtual" aquifer. The utility of these alternative "upscaled" hydraulic conductivity descriptions has been evaluated by considering how well they are able to predict the "virtual" aquifer's response to pumping or tracer injection at other locations. Comparisons of predictive performance of these calibration-based upscaled fields are made with alternative upscaled fields based on a numerical permeameter method. This comparison demonstrates that predictive reliability is influenced by many factors, including the way in which the model-calibration problem has been formulated, the nature of the test under evaluation, and the type and location of a particular prediction.

Dynamics of nitrogen compounds in Haytons urban drainage stream, Christchurch

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[1]*Hydrological and Ecological Engineering Research Group, Department of Civil and Natural Resources Engineering, University of Canterbury*

Concentrations of nitrogen compounds in Haytons Stream, an urban waterway in Christchurch, New Zealand, have been reported to be above local guidelines. High levels of ammonia and/or related nitrogen compounds can be toxic to aquatic organisms and can have a significant effect on the stream's ecological health. Numerous environmental and physical factors such as organic matter content, hydrology/hydraulics, temperature, sediment characteristics and interactions with other contaminants can cause transformation or dilution of nitrogen compounds along the stream. The aim of this project was thus to assess the sources, types, and transformation of nitrogen compounds in Haytons Stream through water quality monitoring at various locations along the stream, over time and in stormflow and baseflow conditions. Initial results have confirmed previous reports. Levels of oxidised nitrogen were found to exceed the local guidelines in 90% of samples while ammoniacal nitrogen in some of the samples was up to 8 times higher than local guidelines. Results also show that the predominant nitrogen form changes with flow conditions. During baseflow, nitrogen is mostly in its inorganic form at the upper and middle parts of Haytons and in organic form at the lower part. During stormflow, the majority of the nitrogen is in its organic form. Nevertheless, the total nitrogen at each site is of about the same magnitude in both conditions. Analysis suggests that point discharges, sediments in the stream bed and street runoff water are contributing to the nitrogen load in Haytons Stream. Results of this study have implications for stormwater management.

Effect of observational uncertainty on hydrological modelling

Shailesh Kumar Singh[1], Subhajit Dutta[2]
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Hydrological models account for the storage, flow of water and water balance in a watershed, which includes exchanges of water and energy within earth, atmosphere and oceans. These models use metrological data to generate flow. There are several sources of error in meteorological data; namely, through measurement at point level, on interpolation etc. When erroneous input is pass to model, one cannot expect error-free output from our prediction. Every prediction is associated with a certain uncertainty. Quantification of these uncertainties is of prime importance in real-world forecasting. In this study, an attempt has been made to study uncertainty associated with hydrological modelling, using data depth function. To see the effect of uncertainty in rainfall on flow generation through the model, the input to this model was altered by adding error, and a different realisation was made. A Monte Carlo simulation was done to generate a huge number of hydrological model parameter sets from uniform distribution. The model was run using these parameters for each realisation of the rainfall. The parameters which are good for different realisation are more likely to be good parameters sets. For each parameter set, data depth was calculated and a likelihood was assigned to each parameter set based on the depth values. Based on this, frequency distribution of the likelihood was analysed. This methodology was demonstrated using the TopNet model on Waipara catchments located in the South Island of New Zealand. It has been found that the likelihood assigned is reasonable in quantifying uncertainty in the model prediction.

Building a stable isotope map of New Zealand groundwaters

Vanessa Trompetter[1]
[1]*GNS Science*

Stable isotopes are valuable tracers for groundwater, allowing for recharge source determination.
The two main sources of recharge into groundwater are seepage from rivers or infiltration from rainfall. Variations in δO18 and δ2H can be used to study transport times of water through a catchment, into a stream or through a soil to an underlying aquifer.
During the analysis of tritium, stable isotopes are measured on the distilled water sample, before and after enrichment, as part of the tritium calibration procedure. The Water Dating Lab at GNS Science has quantified the isotope shifts during the distillation process to allow for correction of the altered isotope data for hundreds of New Zealand groundwater samples.
This corrected stable isotope data can be mapped, enabling us to refine the current precipitation model and provide a spatiotemporal distribution of isotopes for identification of regional flow processes and a source of estimated isotopic values at unmonitored sites. This stable isotope data from groundwaters will be added to the database for rain to obtain a higher spatial resolution of stable isotope signature in New Zealand catchments.

Groundwater residence times and chemistry of the Pukekohe and Bombay basalt aquifers

Rob van der Raaij[1]
[1]*GNS Science*

A study of groundwater Mean Residence Time (MRT) and the relationship to groundwater chemistry has been carried out in the Bombay and Pukekohe volcanic aquifer systems in response to high nitrate concentrations observed in groundwater from these systems. MRT of groundwater from the sites tested in the Bombay and Pukekohe aquifer systems ranges between 16 years and 99 years with fractions of exponential mixed flow ranging from 30% to 90%. Groundwater in Bombay aquifers shows an increase in MRT both in the direction of groundwater flow and with depth. In comparison, groundwater from Pukekohe in the upper aquifer generally has MRT younger than 50 years; meanwhile, the oldest ages are seen in the lower volcanic aquifer system. Statistically significant positive relationships with MRT are observed for pH, bicarbonate, dissolved reactive phosphorus, potassium, and to a lesser extent, silica. Nitrate shows an inverse relationship with groundwater MRT. This is common for analytes associated with land use changes and intensification. The chemistry of younger waters reflects the impacts of recent land use, while older water retains the chemical signature of less-impacted recharge sources. Changes in chemistry observed at SOE monitoring wells Rifle Range Shallow and BP Bombay indicate that pumping-induced changes to the aquifer flow regimes may be occurring. This may have consequences on the groundwater age structure of the aquifer systems.

The effect of windbreaks on spray irrigation evaporation

Erik Kilaka[1], Tom Cochrane[2], Tonny de Vries[2], **Prof Jenny Webster-Brown**[1]
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Conversion to modern sprinkler irrigation methods, namely centre pivot and lateral spray irrigation technology, has led to the removal of many windbreaks in Canterbury. Although originally installed largely to reduce the soil losses during high winds in summer, well-established shelterbelts also reduce water evaporation by reducing wind speeds across the pasture. The loss of spray irrigation water to evaporation is a waste of water and energy, but before such losses can be effectively reduced, we need to better understand the relationship between farm and climate conditions. We have determined a relationship between windbreak height and permeability, and sprinkler irrigation efficiency by measuring spray evaporation from an experimental “irrigator” fitted with Nelson Rotator R3000 and Spinner S3000 nozzles, under various climatic conditions, as well as wind speed reduction across pastures with multiple windbreaks of variable height and permeability. This showed that the increased wind speed due to windbreak removal could lead to significantly increased evapotranspiration and spray evaporation losses of up to 64% in the dry northwesterly Canterbury winds. However, irrigation water could be made to go further using irrigation systems that can operate in conjunction with lower but still effective windbreaks. With climate change projections indicating that the Canterbury region will become windier and hotter in the future, the role of effective windbreaks in reducing water losses will become increasingly important.

ATTENDEE LIST

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Greening	Simon	Watercare Services Ltd
Hadfield	John	Waikato Regional Council
Hanna	Arsini	Auckland Council
Hannah	Paul	Otago Regional Council
Hansford	John	Tonkin + Taylor
Hardwick Jones	Rhys	Wmawater
Harkness	Mike	Greater Wellington Regional Council
Hausler	Greg	Hausler Hydrology
Hazelwood	Martyn	Geoscience Australia
Hedjripour	Amir	Wsp | Parsons Brinckerhoff
Heiler	Michael	Riley Consultants Ltd
Hemmings	Brioch	GNS Science
Henderson	Roddy	NIWA Christchurch
Henderson	Vicki	Barnett And Macmurray Ltd
Herring	Allan William	Brisbane City Council
Herron	Andrew	Eco Logical Australia
Hewa	Guna	University Of South Australia
Hill	Peter	Hydrology and Risk Consulting (HARC)
Holwerda	Nick	Auckland Council
Hooker	Mark	Greater Wellington Regional Council
Horrell	Graeme	Graeme Horrell Consultancy Limited
Hoyle	Jo	NIWA
Hughey	John	Waikato Regional Council
Huxley	Chris	BMT WBM TuFlow
Iezzi	Brany	Brisbane City Council
Islam	Jahangir	AECOM New Zealand Limited
Jackson	Henrietta	University Of Otago
Jackson	Kenzie	University Of Otago
Jamieson	Dennis	Environment Canterbury

Jempson	Mark	Venant Solutions Pty Ltd
Jenkins	Bevan	Waikato Regional Council
Jenkins	Chris	Environment Southland
Jobst	Andreas	Department Of Geography Otago University
Johnson	Carl	DHI Water & Environment Ltd
Jones	Elliot	GHD
Jordan	Phillip	Hydrology And Risk Consulting Pty Ltd
Jowsey	Rose	DHI
Kaiser	Johannes	GNS Science
Kang	Boosik	Dankook University
Keane	Alasdair	Keane Associates Ltd
Keenan	Laura	Jacobs NZ Ltd
Kees	Lawrence	Environment Southland
Kelly	Robert	Aurecon NZ Ltd
Kelsey	Philip	Earthtech Consulting Limited
Kemp	David	University Of South Australia
Kerr	Tim	Aqualinc Research Ltd.
Khadka	Denjam	Bay of Plenty Regional Council
Kim	Young-Oh	Seoul National University
King	John	Geotechnics Ltd
King	James	Ministry For The Environment
King	Alexandra	University Of Otago
Kingston	Daniel	University of Otago
Klaas	Dua	Swinburne University of Technology
Klug	Hermann	Interfaculty Department Of Geoinformatics - Z_GIS, University Of Salzburg
Knowling	Matthew	GNS Science
Korom	Scott	Barr Engineering Company
Kouvelis	Brian	Sustainable Futures NZ Ltd
Kozarovski	Pavel	K&P
Krestan	Matthew	Brisbane City Council
Kuta	Laddie	E2 Environmental Ltd
Ladson	Anthony	Moroka Pty Ltd
Law	Mike	Beca Ltd
Le Gars	Sandrine	Northland Regional Council
Leong	David	Tonkin & Taylor Ltd
Lester	Andrew	Watercare Services Ltd
Levy	Amir	Lattey Civil and Precast
Ling	Fiona	Wmawater
Lochhead	Sally	Tonkin & Taylor Ltd
Lockyer	Charlotte	Cardno NZ Ltd
Lough	Hilary	Pattle Delamore Partners Ltd
Loveridge	Melanie	Water NSW
Lovett	Abigail	GNS Science
Macky	Graham	DHI Water & Environment Ltd
Mager	Sarah	University Of Otago
Mahadeva	Kandiah	Department Of Primary Industries - Water
Male	John	Aecom

Mall	Neeraj	Federation University
Malloy	Erica	Massey University
Mamoon	Abdullah	Ministry Of Municiplaity & Environment
Manandhar	Uttam	Department of Environment, Land, Water and Planning
Marr	Toni	Anderson Lloyd
Martin	Adam	Environment Canterbury
Martindale	Heather	Gns Science
Matthews	Abby	Horizons Regional Council
Mcbeth	Kurt	ESR
McCartney	Phil	Environment Southland
Mccowan	Andrew	Water Technology Pty Ltd
Mcdonald	Michael	Environment Southland
McGill-brown	Matt	Gisborne District Council
McGrath	Toby	Water Solutions
McLindin	Mahala	Jacobs
Mcmahon	Greg	G M Mcmahon Consultants
McMecking	Jane	Environment Southland
Mcmullan	Daniel	Opus International Consultants Ltd
Mealey	Glenn	Jordan Mealey & Partners
Measures	Richard	NIWA
Miller	Blair	Lincoln Agritech Limited
Mills	Florence	University Of Otago
Milne	Juliet	NIWA
Moolman	Juanita	Ewater
Moore	Catherine	GNS Science
Moreau	Magali	GNS Science
Morgan	Paul	Riley Consultants Ltd
Morgan	Leanne	Waterways Centre For Freshwater Management, University Of Canterbury
Morgenstern	Uwe	Gns Science
Moriarty	Elaine	ESR
Morris	Tim	Tonkin & Taylor
Mourot	Frederika	Otago Regional Council
Mullane	Kevin	Waikato Regional Council
Mzila	Doug	Greater Wellington Regional Council
Nally	Nicole	Aquatic Informatics
Nathan	Rory	University of Melbourne
Neverman	Andrew	Massey University
Niall	Asha	Department Of Economic Development, Jobs, Transport And Resources
Novis	Sarah	Cardno NZ Ltd
Ogilvie	Hamish	Environment Southland
Ollett	Paul	Hydralinc Pty Ltd
O'Rourke	Graeme	Bay Of Plenty Regional Council
Osbaldiston	Susie	Northland Regional Council
Pahlow	Markus	University Of Canterbury
Pak	Ingrid	Bay of Plenty Regional Council
Palmer	Kelly	Ministry or the Environment
Palmer	Lennie	Trustpower Ltd

Parker	Glen	Marlborough District Council
Parsons	Tom	Innovate Consulting
Paudel	Upendra	Swinburne University of Technology
Paul	Himadri	Western Sydney University
Payne	David	Mighty River Power
Payne	Gareth	GHD Global Pty Ltd
Pearson	Charles	NIWA
Pedraza	Aaron	Waikato Regional Council
Pedruco	Phil	Jacobs Group (australia) Pty Ltd
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Perwick	Aslan	Pattle Delamore Partners Ltd
Pham	Hoa	Northland Regional Council
Phillips	Brett	Cardno (NSW/ACT) Pty Ltd
Phipps	Regan	Taranaki Regional Council
Pinkert	Andre	ESR
Pinto	Maria	Camden Council, NSW, Australia
Podger	Scott	Wmawater
Pugh	Ann	Innovyze
Rabbitte	Susan	Lattey Group
Rahman	Ataur	Western Sydney University
Rahman	Sadia	RMIT University
Rajanayaka	Channa	Aqualinc Research Ltd
Rakowski	Pawel	HBRC
Regan	Ben	GHD
Reichel	Steffen	University Of Salzburg - IFFB Geoinformatics
Rekker	Jens	Lincoln Agritech Limited
Retallick	Monique	WMAwater
Reynolds	Dexter	Venant Solutions Pty Ltd
Rigby	Ted	Rienco Consulting
Rissmann	Clint	Waterways Centre for Freshwater Management - Canterbury/Lincoln Univeristy
Rix	Jon	Tonkin + Taylor
Rodgers	Mark	Hilltop Software Ltd
Rodway	Ewen	Environment Southland
Ronalds	Rodney	Griffith University
Rouse	Helen	NIWA
Rutter	Helen	Aqualinc Research
Sands	Michelle	Jacobs
Sarpi	Mitchell	Rmit University
Sarris	Theo	ESR
Schmidt	Jochen	NIWA
Scorah	Matt	HARC
Scott	Marta	Environment Canterbury
Scott	David	Institute of Environmental Science and Research Ltd
Senarath-Angus	Nadeesha	Riley Consultants
Shaw	Helen	Environment Canterbury
Sheppard	Greg	Jacobs
Shipton	Suzana	DHI Water & Environment Ltd

Shrestha	Bikesh	University Of Canterbury
Silveira	Fabio	University of Canterbury
Simon	Marta	Aalborg University
Simpson	David	Brisbane City Council
Singh	Shailesh Kumar	NIWA
Smart	Graeme	NIWA
Smith	Grace	Environment Southland
Smith	Adam	Bureau Of Meteorology
Smith	Mitchell	Bmt Wbm Pty Ltd
Soo	Sun	Waikato Regional Council
Srinivasan	M.S.	NIWA
Stafford	Dave	Pattle Delamore Partners Ltd
Stead	Eddie	Meridian Energy Ltd
Stecca	Guglielmo	University Of Trento
Steel	Kate	Environment Canterbury
Stephens	David	HARC
Stewart	Michael	Aquifer Dynamics & Gns Science
Stinton	Brett	BG&E Pty Limited
Tarboton	Ken	Aqueus Consulting
Tate	Ben	Water Technology Pty Ltd
Taylor	Alicia	Victoria University of Wellington
Taylor	Antoinette	DHI
Testoni	Isabelle	WMAwater
Thomas	Joseph	Tasman District Council
Thomas	Chris	Advisian (worleyparsons Group)
Thomas	Neil	Pattle Delamore Partners Ltd
Thompson	Mike	Greater Wellington Regional Council
Thorley	Mike	Beca
Thornburrow	Blair	Pattle Delamore Partners Ltd
Tipa	Gail	Tipa & Associates
Toews	Mike	GNS Science
Trevelyan	Alice	Gisborne District Council
Trompetter	Vanessa	Gns Science
Tuck	Elliot	Beca Ltd
Tutulic	Dragan	DHI Water & Environment Ltd
Van Alst	Nikki	Aalborg University
Van Der Raaij	Rob	GNS Science
Van Nieuwkerk	Eric	Golder Associates (NZ) Ltd
Velluppillai	Damian	Tonkin Taylor
Verdon-Kidd	Danielle	University of Newcastle
Verhagen	Floris	Royal Haskoningdhv
Vetrova	Varvara	University Of Waikato
Viljevac	Zeljko	Soil And Rock Consultants
Vincevicius	Ainis	BG&E Pty Limited
Vodjansky	Eugene	Bloxam Burnett & Olliver
Voss	David	Voss Infrastructure Consulting Limited
Wadsworth	Val	Marlborough District Council

Wallace	Phil	DHI Water & Environment Ltd
Walsh	Jeremy	NIWA
Walter	John	CCC
Walton	Richard	
Wang	QJ	CSIRO Land and Water
Ward	Mikayla	WMA Water
Wasko	Conrad	University of New South Wales
Watson	Jeff	Horizons Regional Council
Watson	Marianne	Hydronet Limited
Weaver	Louise	ESR Ltd
Weaver	Konrad	Victoria University Of Wellington
Webster-Brown	Jenny	Waterways Centre For Freshwater Management
Weeks	William	Consultant
Weir	Ian	Waikato Regional Council
Weir	Julian	Aqualinc
Westerhoff	Rogier	GNS Science, Deltares
White	Chris	University Of Tasmania
White	Paul	Gns Science
Whyte	Greg	DHI Water & Environment Ltd
Wilding	Thomas	Hawke's Bay Regional Council
Williams	Daniel	Gisborne District Council
Williamson	Jon	Williamson Water Advisory
Wilson	Peter	Wellington Fish And Game Council
Wilson	Scott	Lincoln Agritech Limited
Wilson	Karen	Landpro Limited
Wöhling	Thomas	Technische Universität Dresden, Lincoln Agritech Ltd.
Woodward	Simon	Lincoln Agritech Ltd
Yoon	Byung-Man	Myongji University
Young	Colin	Environment Southland
Zammit	Christian	NIWA
Zarour	Hisham	Environment Canterbury
Zhang	Jin Rong	GNS Science
Zhang	Lanying	The University Of Newcastle
Zolfaghari	Hanieh	Brisbane City Council

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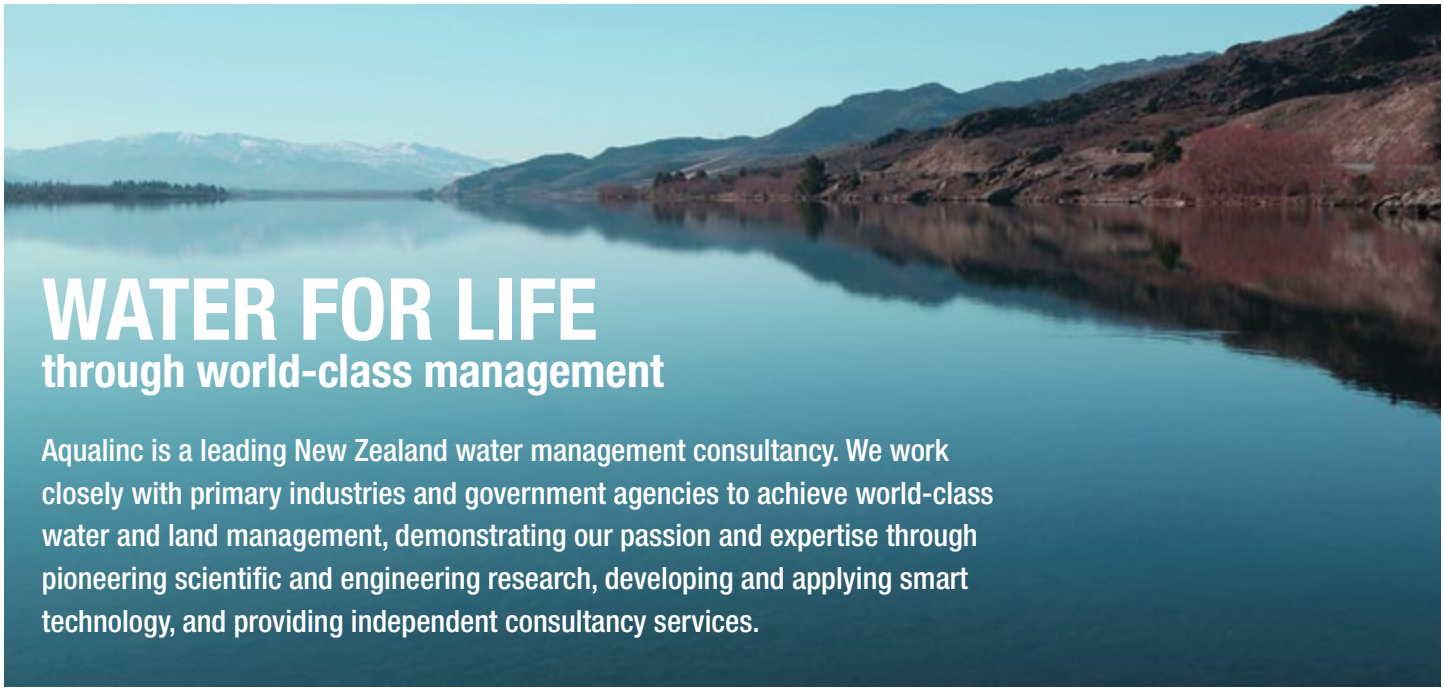


WATER FOR LIFE
through world-class management

Aqualinc is a leading New Zealand water management consultancy. We work closely with primary industries and government agencies to achieve world-class water and land management, demonstrating our passion and expertise through pioneering scientific and engineering research, developing and applying smart technology, and providing independent consultancy services.

WATER & LAND MANAGEMENT

The catchments, rivers and groundwater systems of New Zealand have a wide range of stakeholders. Changes made to benefit one water or land user may often have a negative impact on another. At Aqualinc, we use measured data and, through sophisticated modelling, help our clients predict the impacts of proposed changes so they can explore, and select, options that best manage water quality and quantity in their region.

SURFACE & GROUNDWATER

Our team is one of New Zealand's leading providers of specialist services in groundwater and surface water, providing solutions to improve the management of land and water. We provide expert services in groundwater and surface water modelling, allocation management, aquifer testing and well development, source protection, groundwater level and quality monitoring, and surface water monitoring.

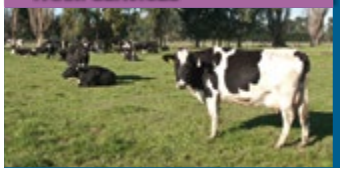
CLIMATE

New Zealand has a variable climate, due to short-term weather systems, medium-term climate cycles and longer-term trends. This variability affects water resource and asset management, and consequently the socio-economic benefits derived from their use. Aqualinc interprets and models data from a point scale to a national scale, to enable councils and other stakeholders to assess the effects of climate variability and trends on resources and assets.

IRRIGATION

As irrigation water demand increases, historical approaches, and the use of arbitrary daily and/or annual demands, are not efficient. Through science and proven modelling approaches, Aqualinc develops more appropriate irrigation allocation guidelines for regions. These guidelines provide for more efficient water and land use, decreased nutrient leaching, and maximisation of irrigated area.

FARM SERVICES



The modern farm environment requires a high level of monitoring and data handling, together with the assessment of compliance with consent conditions and liaison with regional councils. Aqualinc develops and audits farm environment management plans, provides advice and prepares consent applications, monitors soil moisture, undertakes flow meter verification, and uses telemetry data transfer and web-based data feedback reports for compliance monitoring.

If you need help or advice in any of these areas, please call

Aqualinc Research Ltd / Christchurch 03 964 6521 / Ashburton 03 307 6680 / Hamilton 07 858 4851

www.aqualinc.com