NZ Battery Project

Technical Reference Group Meeting

5 August 2021 – KPMG, Wellington

MAHI TAHI
BETTER TOGETHER

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

Today's programme

No	Time	Item	Lead
	8.45am	**Arrival Tea and Coffee**	
1.	9.00am – 9.05am	Welcome / Karakia	Adrian Macey and Hoani Langsbury
2.	9.05am – 9.30am	Project news • Overall update	Andrew Millar and Adrian Tweeddale
3.	9.30am – 10.00am	Stakeholder update • Industry meetings / Otago visit update	Maria Hernandez -Curry and Carl Walrond
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12.	4.00pm – 4.30pm	Q&A Summary	Adrian Macey

NZ Battery Project update

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

For this session:

Purpose of this session

- Give you an overall project status update and cover off the current workstreams underway
- What have we completed over the past 6 weeks
- What is coming up over the next 6 weeks

What we want from you

- This is for your information but please provide feedback or observations

Project news update - Last 6 weeks' milestones

- Shortlisting and evaluation of the respondents for Lake Onslow environmental, engineering and geotechnical investigation. Intention to select a preferred supplier by the first week of August
- Procurement process underway for consultant to assist in the development of a scope of work for the technical investigations into comparator technologies (Work Stream 3)
- Finalised our list of alternative hydro sites for further investigation – **Malcolm will update you on this later today**
- Developed internally first-draft operational models – **Conrad will update you on this later today**
- Visited Central Otago and meet with landowners in the Teviot Valley community, and the Central Otago District Council, among others last week – **Carl and Maria will update you on this trip later today**
- Working on revising the project plan and timeline, scope and milestones
- Finalised procurement (in conjunction with Ngāi Tahu) for a Ngāi Tahu values assessment, a historic values assessment and an archaeological assessment of the Lake Onslow area

Next 6 weeks' milestones

- Kick off supplier for the Lake Onslow environmental, engineering and geotechnical investigation. Aim to commence by mid-August (subject to contract negotiations)
- Other pumped hydro: Peer review of current progress/process and initiate procurement in parallel for a desktop level engineering assessment of alternative sites (as well as modification of existing hydro assets)
- Further economic modelling of the different dry-year risk management options
- Kick off procurement for main Work Stream 3 investigations, focusing on identifying the most feasible options related to bioenergy, green chemicals (including hydrogen), large scale planned load reduction
- Further development of operational governance models
- Issue updated project plan and schedule

Stakeholder update

Purpose

Purpose

Provide you with an update on engagement to date & show progress on engagement so far

What we want from you

Hear your feedback on our approach and stakeholders we're engaging at a project level and for the Lake Onslow option

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Phase 1 – Lake Onslow option

Landowners around Lake Onslow

Landowners along proposed tunnel route – TBC

Ōtākou Rūnanga (with Hokonui Rūnanga & Kati Huirapa ki Puketeraki)

Teviot Valley community

Roxburgh/Teviot business community

Central Otago District Council

Otago Regional Council

Pioneer Generation

Who are the Phase 1 key stakeholders?

Government & political
- Minister of Energy & Resources
- Other members of cabinet
- Climate Change Commission
- DOC & MfE
- Electricity Authority & Security & Reliability Council

Mana Whenua & Iwi
- Mana Whenua for Lake Onslow area
- Murihiku Regeneration
- Iwi Chairs Forum
- Iwi in other study areas

Investors & financial institutions
- When's the right time to start engaging? Phase 2?
- What do we want from these conversations?

Gentailers
- Contact
- Meridian
- Trustpower
- Genesis
- Mercury

Other energy generators
- Independent Energy Generators Assoc
- NZ Wind Energy Assoc
- Sustainable Energy Assoc NZ
- Solar Assoc NN

Electricity network providers
- **Electricity Network Assoc**
- **Transpower**

Electricity Retailers
Electricity Retailers Assoc
- Independent Electricity Retailers Assoc

Electricity Users
- MEUG
- Community Energy Network
- Domestic Energy Users Group

ENGOs
- Environmental Defence Society
- Greenpeace
- Forest & Bird
- Fish & Game
- NZ Climate Action Network

Academia and Crown Research Institutes
- NIWA
- Cawthron
- Scion etc

General public
- Youth
- E-news
- NZBattery@ inbox
- Media releases

Media
- Local, national & international

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Next steps

- Work on procuring information to reduce uncertainty for landowners
- Procure services from Aukaha
- Continue industry engagement
- Continue ENGO engagement – inc at project-wide scale
- Ōtākou rūnanga et al – continued engagement & introduction to providers
- Build Teviot/Roxburgh business database
- Introduce Teviot/Rox landowners and community to providers
- Stakeholder engagement for other hydro sites – TBC

Operational Governance

For this session:

Purpose of this session

- Electricity wholesale market primer
- NZ Battery operating models – first draft

What we want from you

- Feedback on operating models

Next steps from here

- Refine and further develop operating models
- Progress the revenue and operator parts of operational governance

Operating model

At last TRG meeting:
- Intro to operational governance
- Operator models
- History of SOS in NZ

Operational governance

Operating

Operating model

Operating mandate w.r.t.:
- Purpose
- Bid/offer strategy
- Market power mitigation?
- Offering of hedges?

X

Revenue

Cost/revenue could be highly variable across years:
- Recovery of costs
- Allocation of revenues
- Inter-year smoothing?
- Upstream/downstream river-chain issues?

X

Operator

Entity

Degree of Government control

Checks and balances

NZ Battery operating model: assumptions reminder

- The current focus of this analysis is on long-term storage
- The NZ Battery operator will determine its operating strategy in accordance with:
  - Its operating mandate
  - Any Government directions if not independent
  - The Code
- NZ Battery operation will commence from the point of commissioning, and so include the initial fill

- The wholesale electricity market and its governance will remain structurally as now:
  - Generation and retail competition
  - Market-driven investment (only exception being NZ Battery itself)
  - Independent regulator with responsibilities that include Code evolution, security of supply and preventing market power abuse
  - Electricity Industry Participation Code (Code) developed by the regulator and mandatory for all participants including NZ Battery
  - Neutral system operator

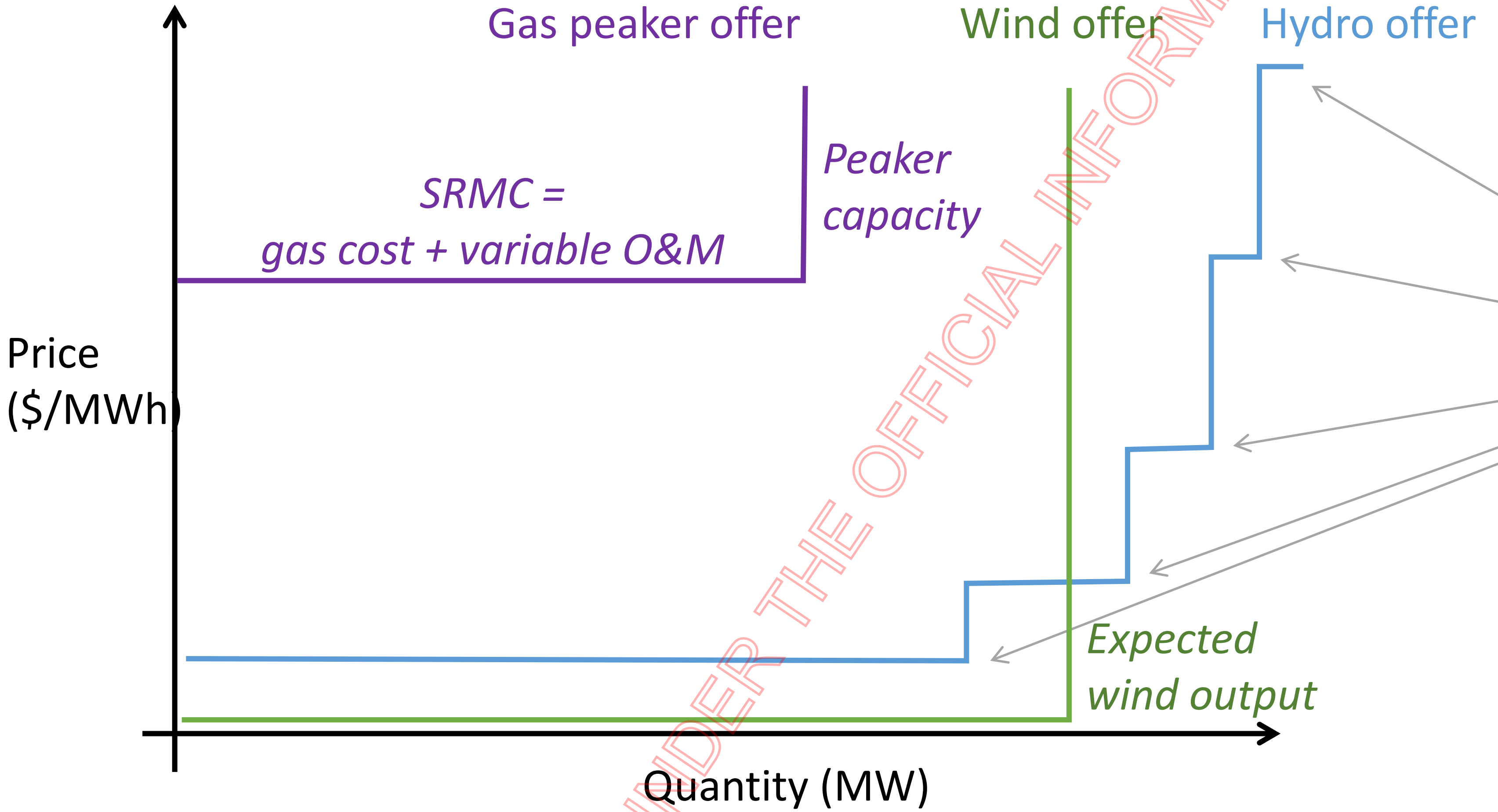
Wholesale electricity market primer (1) – Why?

- Why did we introduce wholesale markets?
  - We wanted a level playing field for generation and demand response irrespective of ownership
  - All generation plant gets recompensed by market prices in a way that reflected their value to the system
  - Consumers, if they choose to consume, pay electricity prices that reflect the fair value of the electricity they consume
  - Disaggregation of decision making
  - Private rather than public capital at risk

Wholesale electricity market primer (2) – How?

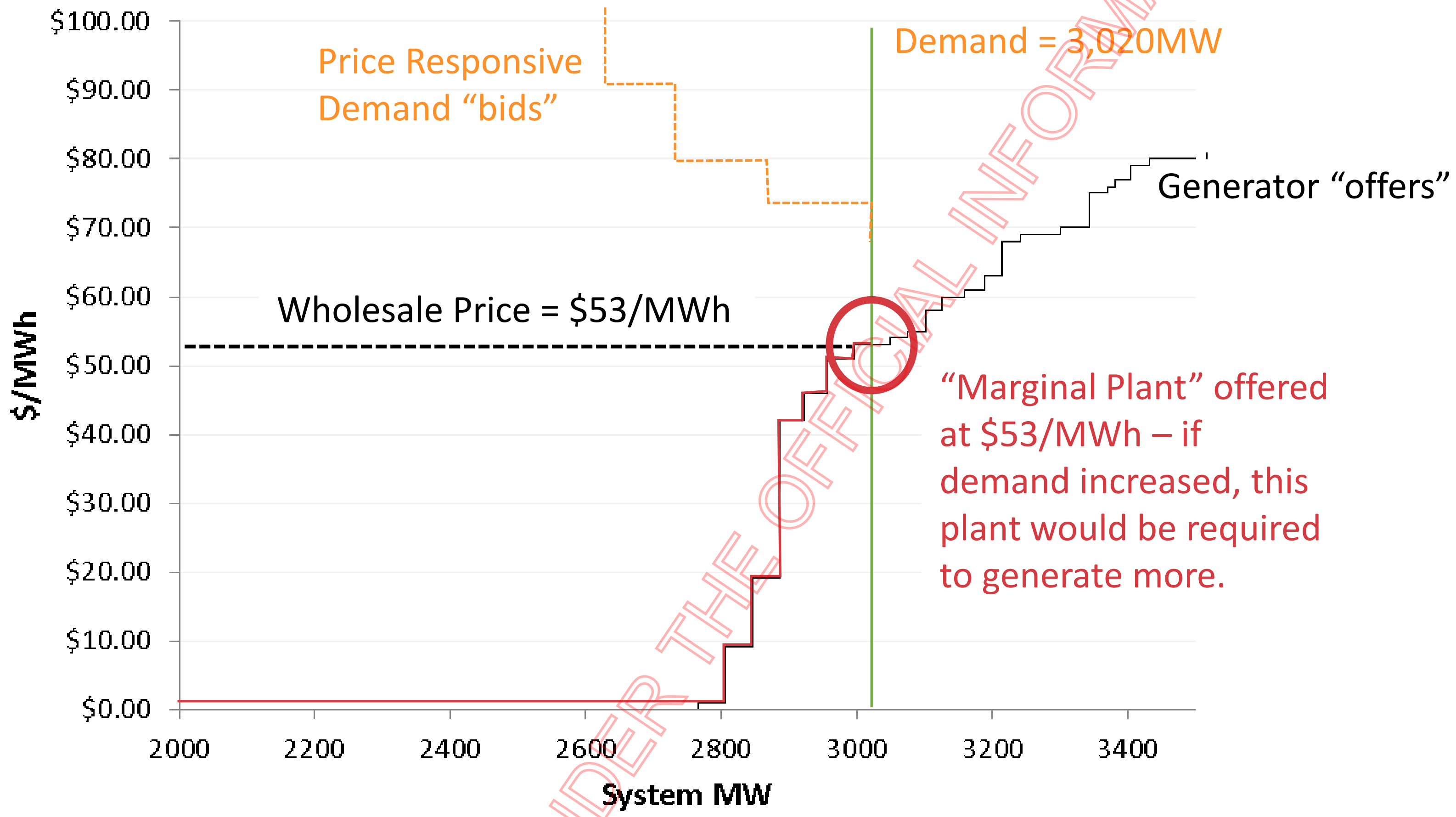
		Criteria	How?
Make sure the right stuff is turned on and off at all times	1	Generators need to be assured that, in the short run, they will at least recover the cost of the fuel they burn (+ variable O&M)	*We achieve this by asking generators to "offer" their capability into the market at a price that recovers their costs*
	2	Demand-responsive consumers need to be assured they will only consume if the price is below the value of consumption	*We achieve this by asking DR consumers to "bid" their willingness to consume into the market at a price that reflects their valuation*
	3	In aggregate, the lowest cost combination of generation and consumption occurs each time period (short-run efficiency)	*We achieve this by imposing a least cost dispatch algorithm*
Make sure the right stuff is built	4	Generators need confidence that, over the long run, they will earn enough revenue to cover their fixed costs in addition to their variable costs	*We achieve this by adopting marginal pricing in an energy-only market, which allows generators to earn more than their variable costs in some periods*
	5	New plant is built (and old plant decommissioned) at the right time, for the lowest cost	*We achieve this through confidence in the above mechanisms*

Wholesale electricity market primer (3) – Offers



SRMC
Short Run Marginal Cost

Wholesale Primer (4) – Market clearing and marginal pricing



SPD
Scheduling
Pricing
Dispatch

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Other Pumped Hydro

Another automated scan for elevated basins – by NIWA GIS hydrologists

For this session:

Purpose of this session

- Review of NIWA’s search for elevated basins using straight dams
- Results of latest search from NIWA, using a new approach allowing multiple dams
- Development of a screening methodology

What we want from you

Have we missed anything? Comments on appropriateness of;

- Input parameters; dam height/length, distance to source, fill time
- Search approach; any alternatives/refinements to NIWA’s approach
- Screening criteria; input parameters plus exclusions – conservation areas, inundation of infrastructure

How big does pumped hydro need to be?

Depends on which Island, Concept/John Culy examined a range of alternatives;

South Island options

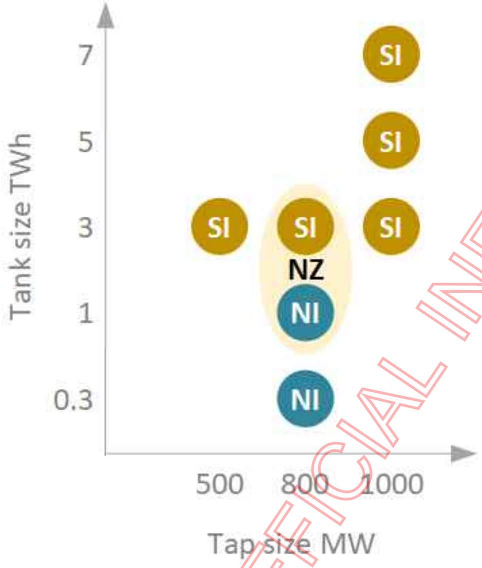
- 3TWh at 1.0GW, 0.8GW & 0.5GW
- 5TWh/1.0GW
- 7TWh/1.0-GW

North Island options

- 1TWh/0.8GW, 0.3TWh/0.8GW

New Zealand options

- 4TWh/1.6GW, 3.3TWh/0.8GW

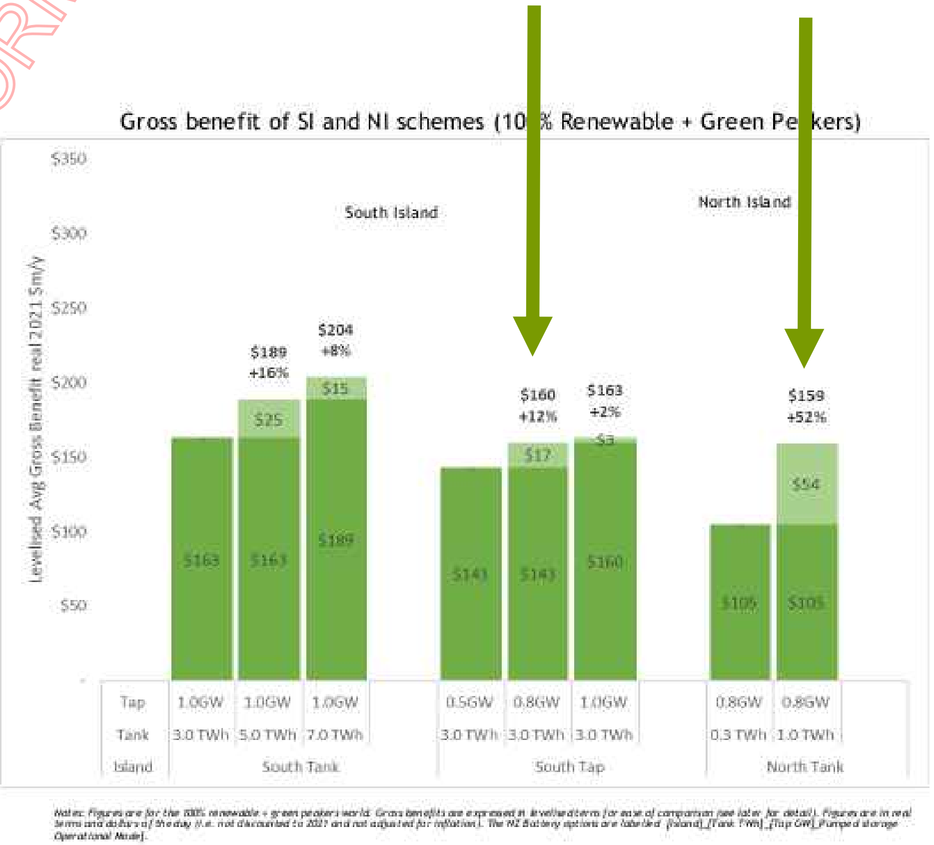


And estimated gross benefits

- Bigger options have greater value
- But value increase declines with size
- 3TWh/0.8GW SI option has same gross benefit as 1TWh/0.8GW North Island option

Suggests 3 to 5TWh in South Island and 1TWh in North Island

- So we look for South Island solutions greater than 3TWh (but keep in mind this may be made up of more than one option) and
- North Island options of 1TWh or more (again, might be more than one)



Tank = big, high, fill-able, dam-able....

What we asked NIWA for; find elevated basins suitable for use in a pumped hydro energy storage scheme, with the basins to be;

BIG

- must be **1 TWh** or larger
- **~5TWh =** the difference between average and driest year (on record)
- needs to impound a lot of water **= 'big tank'**

HIGH

- elevated (volume x height = gives you the energy)
- head > 300m **= 'big, high tank'**

FILL-ABLE

- Access to large water source to fill the 'big tank'
- Distance between water source and 'big tank' ≤ 30km **= 'big, high fill-able tank'**
- Fill time less than 2 years

DAM-ABLE

- Dam length ≤ 3km total
- Dam height ≤ 120 m max = **= 'big, high fill-able, dam-able tank'**

NIWA's approaches

1. Find a big enough water source

- A 1TWh storage with a head of 300+m requires at least $1Bm^3$ of water
- Filling this volume from a river within two years requires a flow rate of $20m^3/s$, or $40m^3/s$ if only take half of river's flow. Only 2% of NZ's rivers have median flow greater than $40m^3/s$.
- If using lake as source, only 0.8% of lakes have volumes greater than $1Bm^3$

2. Find nearby basins

- Match river reaches in basin with water source, within 30km

3. Dam basins with straight dam

- At each river reach in the basin, dam up to 120m high and **3km long** – does it impound 1+TWhs of potential energy?

3'. Dam basins with contour dam

- For each basin catchment trace out edge damming where necessary to see if it encloses enough water, dams up to 120m high but now allowed to be **6km long**.

NIWA's approaches

Now have two methods for finding large elevated basins capable of providing TWh scale storage.

- Straight dams – don't allow plugging basins at saddles, but could dam adjacent catchments
- Contour dams – plug saddles – allow multiple dams, but restricted to single catchment

Combining results from the two methods;

- Most straight/contour dams coincide, at or near same location
- Some straight dams not found by contour dams, some contour dams not found by straight dams

The two approaches are complementary providing additional options

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How are we thinking about shortlisting options?

Cabinet requires that any proposal or group of proposals will be assessed against its ability to:

- provide at least [5,000 GWh]* of energy storage or equivalent energy supply flexibility
- provide significant levels of employment as part of post COVID-19 recovery
- reduce emissions either directly or indirectly through facilitating decarbonisation
- maximise renewable electricity in order to provide a pathway to achieve the goal of 100 per cent renewable electricity
- lower wholesale electricity prices
- be practical and feasible
- take into account wider social, cultural and environmental factors

** magnitude to be investigated as part of the project*

Security of supply
Social, cultural, environmental
Renewable
Job creating
Affordable
Practical

Criteria	An ideal solution will…
Security of supply	Be large and reliable enough to guarantee economic security of supply (storage amount could be made up of multiple smaller schemes): capacity, storage duration, resilience and location are all important
Renewable	Meet climate change objectives; minimise emissions; provide a pathway to achieving the goal of 100 per cent renewable electricity
Social, cultural, environmental	Avoids, remedies, mitigates, or offsets localised environmental effects; furthers the aspiration of Māori; serves the needs of the local community
Job creating	Creates a significant number of NZ jobs in construction then ongoing operation; skilled vs unskilled; cities vs regions
Affordable	Reduce wholesale electricity price (consistent with declining costs of new renewable generation); maximise value; incentivise private investment; retain options for the future
Practical	Cost effective; use dependable technology; be constructible and operable; safe and resilient; aligns with wider Government objectives (energy, resource management, conservation and climate)

Screening criteria

- Initial screening criteria based on a subset of Cabinet paper assessment criteria
- Security of Supply – economic security of supply – "Problem 1" results suggest size of solution; SI around 3-5TWh, NI around 1TWh
- Renewable
- Social/Cultural/Environmental – restricted to excluding options in National Parks or Conservation Areas
- Job creating – not assessed without design concept (next steps)
- Affordable – not assessed without design concept (next steps)
- Practical
  - Constructable –dam length, fill time
  - Operable – (re-)fill time

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NIWA GIS latest scan, comments

The NIWA scan provides optimistic options:

- Builds each dam to maximum height, dam length relaxed somewhat too.
- Energy stored in lake is calculated from bottom to top of lake – i.e. to get the energy you have to drain it to empty – unlikely.
- Tunnel route extended downstream as far as possible to a source point– so usually 30km long. This maximises head – and so stored energy – and quantity of water available to be pumped up – minimising time to fill.

Any options align with Concept/J Culy "Problem 1"?

- Lake Onslow for the South Island
- Probably none for the North Island – but this needs testing

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Freshwater work streams

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For this session:

Purpose of this session

- update TRG on findings to date and seek input into plans

What we want from you

- How do we ingrate existing providers with new Provider?
- Do we need DOC to look at a translocation for Teviot flatheads?
- What are we missing?

Next steps from here

- NIWA workshop late September
- Plan fieldwork

Structure

Context: where the freshwater work streams sit

- What is the history of the lake and catchment?
- What lives in it?
- What happens if you raise the lake?

- Next steps for Lake Onslow freshwater investigations

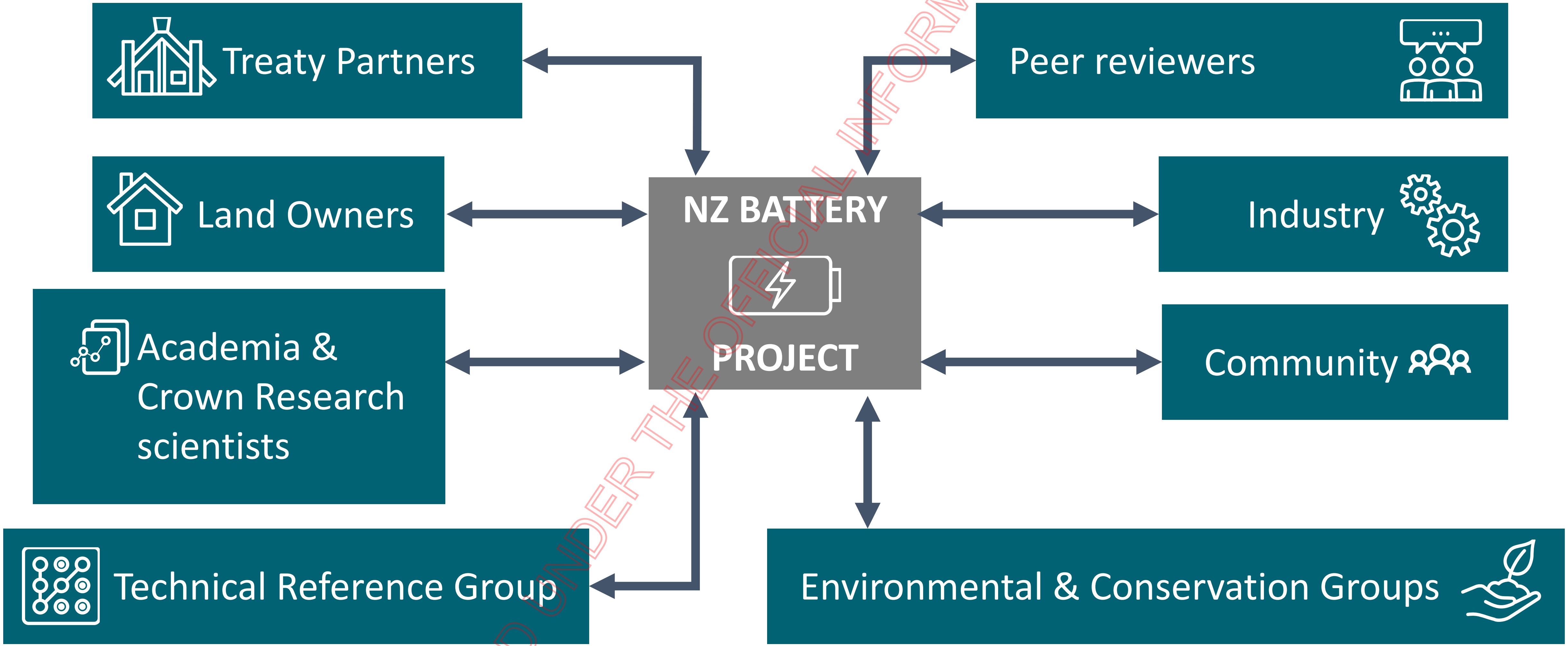
Our strategy

- Thinking of what we would need for an AEE
- Contract early to build environmental baseline (Feb/March)
- Use DOC (and contractors) and CRIs and independent science (OU, Cawthron, NIWA)
- Integrate and share information between work streams
- Establish relationships with landowners
- Negotiate access agreements for environmental fieldwork (ongoing)
- Keep stakeholders informed
- Integrate the Provider into environmental work streams (Aug/Sept)

Big picture environmental Qs....

- What is the hydrology of the catchment?
- What lives in these waters?
- What is the lake ecology?
- What will happen to the lake ecology and species as the climate changes?
- What happens to the lake ecology if you build a big lake that goes up and down more?
- Can you move any rare plants or animals?
- What are the methane emissions of a larger lake?
- What about sediment and biosecurity?

Engagement


Treaty Partners
Peer reviewers
Land Owners
NZ BATTERY
PROJECT
Industry
Academia &
Crown Research
scientists
Community
Technical Reference Group
Environmental & Conservation Groups

Phase 1 key workstreams: Work underway

Lake Onslow pumped hydro

Environmental assessment: desktop work **underway**, fieldwork **planned**

Hydrological and ecological modelling: **underway**

Engineering and geotechnical investigation: desktop and field work **planned**

- Is a pumped hydro scheme at Lake Onslow technically, economically, commercially, and environmentally feasible?
- Can any adverse impacts or risks be effectively managed or mitigated?

→ Environmental assessment (**DOC and subcontractors**)

→ Lake ecology assessment (**NIWA /Cawthron Institute/Otago Uni**)

→ Hydrology (**NIWA**)

→ Generation implications (**Contact**)

→ Transmission implications (**Transpower**)

→ Social impact (if it passes feasibility)

→ Engineering and geotechnical study (Aiming to appoint consultant August)

Catchment

Catchment history – how did we get a lake?

1904.
NEW ZEALAND.

NEW ZEALAND WATER-POWER

REPORT ON) BY MR. P. S. HAY, M.A., M.INST.C.E., SUPERINTENDING ENG
PUBLIC WORKS DEPARTMENT.

Presented to both Houses of the General Assembly by Command of His E

Public Works Department, Wellington, 16th Sept

Memorandum for the Hon. the Minister for Public Works.

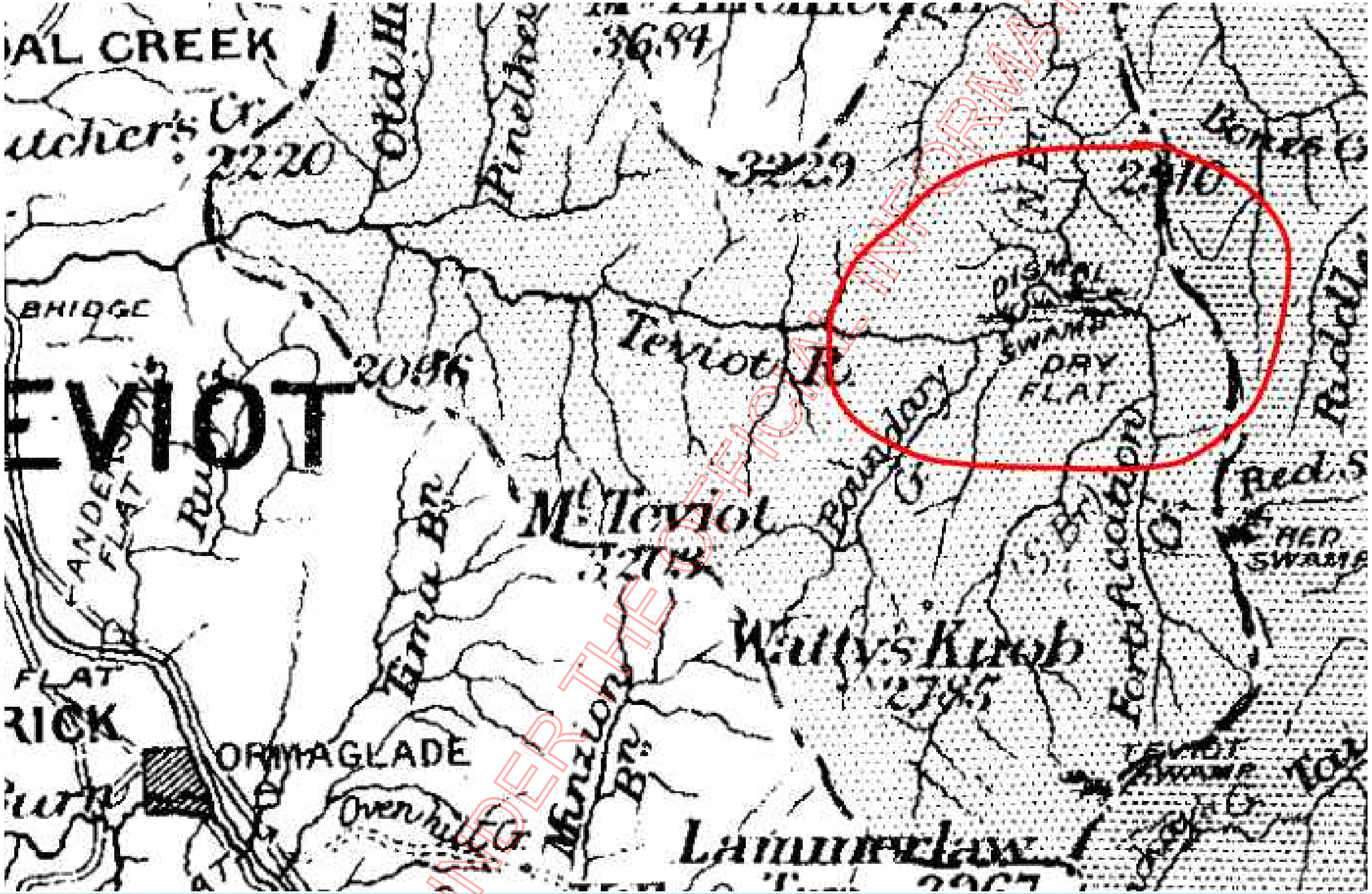
I HAVE the honor to submit the following report embodying all the information co garding the water-power available in the colony.

Some of the larger schemes outlined may at present appear to be of speculativ industries of magnitude sufficient to utilise the power available in these schemes ma to be develope deven in the near future; but I think it is worth while to make th

TEVIOT RIVER.

This river joins the Clutha just opposite Roxburgh. The level of the Clutha here is 257 ft. above sea-level, and the flood-level of 1878 is 291 ft. above sea-level, as ascertained by levelling down from a trig. station. At a distance of about three miles and a quarter from the Clutha the Teviot attains a level of 1,203 ft. Above this point the drainage-area is 115 square miles, and the minimum flow is put at about 140 cubic feet per second. The flow actually measured in March last was 230 cubic feet per second. A dam at this proposed point of intake would store a large quantity of water. In addition to this there is a large reservoir already constructed, known as Lake Onslow, 2·28 square miles in area; also some others. Onslow Lake controls sixty-six square miles of watershed, and this should be by far the best part of the river-basin for catchment purposes. The storage-capacity of the lake can be increased considerably. The power obtainable should be over 15,000 b.h.p. or more, depending on the amount of storage available, effects of frost, &c. These figures are for continuous working; for half-time full-power working about 30,000 b.h.p. should be available. A number of water-rights are held to take water from this stream to a total amount of 153 heads. Only about half of this quantity is used. Thirteen separate rights have been issued. Seven of these, for a total of sixty-five heads, expire at various times from 1940 to 1945; the remaining six, for a total of eighty-eight heads, expire at various times from the present year up to 1918, and of these, two for forty-seven heads in that year. The hillsides are not very suitable for the construction of water-races; the miners generally use flumes; and a large race for a power-station would therefore have to be in great part either flume or tunnel to avoid as much as possible all risk of failure. A complete survey of this river is required to determine the extent of storage available, the quantity of water flowing at various periods of the year, the best point of intake, length of race and pipes, frost-effects, &c. So far as the information available goes it seems to be a most promising scheme and is worthy of very complete investigation.

We drowned Dismal Swamp….



MĀIA
BOLD & BRAVE

PAE KAHURANGI
BUILD OUR FUTURE

MAHI TAHI
BETTER TOGETHER

PONO ME TE TIKA
OWN IT

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Named after a GG who flew the coop…

Earl of Onslow, GCMG

Term (in Years):	1889 to 1892
Role:	Governor of New Zealand

Born in 1853, Sir William Hillier Onslow, Bt. 4th Earl, was educated at Eton and Oxford. He inherited his title in 1874.

He was Lord-in-Waiting to Queen Victoria, Under-secretary of State for the Colonies, Vice-president of the Colonial Conference 1887 and Parliamentary Secretary to the Board of Trade.

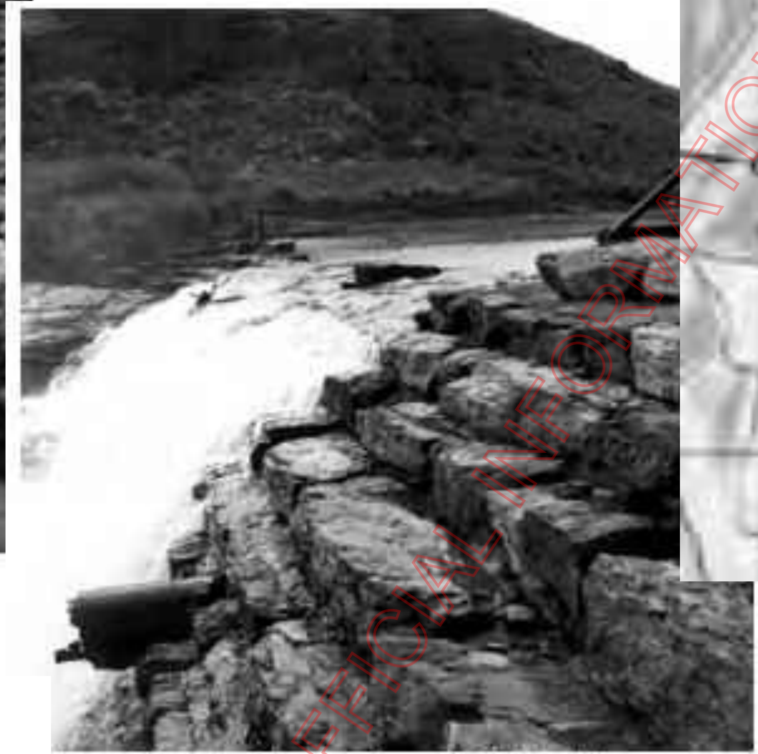
He was appointed Governor of New Zealand in 1889 but resigned in 1892 to return to England. He later became President of the Board of Agriculture with Cabinet rank,

For gold, food and juice....

Activity	Year	Height (m)
Dismal Swamp drowned under Lake Onslow after water rights disputes amongst gold mining enterprises. 5.5 m high dam was made from local schist rock cut into blocks	1891	5.48
Dam raised 1.5 m by extra rock courses	1894	7
Raised 1 m by a timber wall, prompted by the dry summer	1933	7.9
Further nine inches of wood - another dry summer	1938	8.1
Floods wrecked the wall and took some stone with it Concrete replaced stonework and the timber wall was rebuilt	1957	8.1
New dam drowned the old and raised the lake by 4.6 m	1982	12
1984 a 1.8KW generator installed in the dam to power gates and other equip.		

- Lake Onslow has modified lake level regime since the first dam (5.5m high) in 1891
- Raising (1894, 1933 and 1938)
- New dam (1982) have given an extra 7.2 m of lake level.
- Lake level managed for irrigation and hydroelectric generation and only lake level is currently recorded.

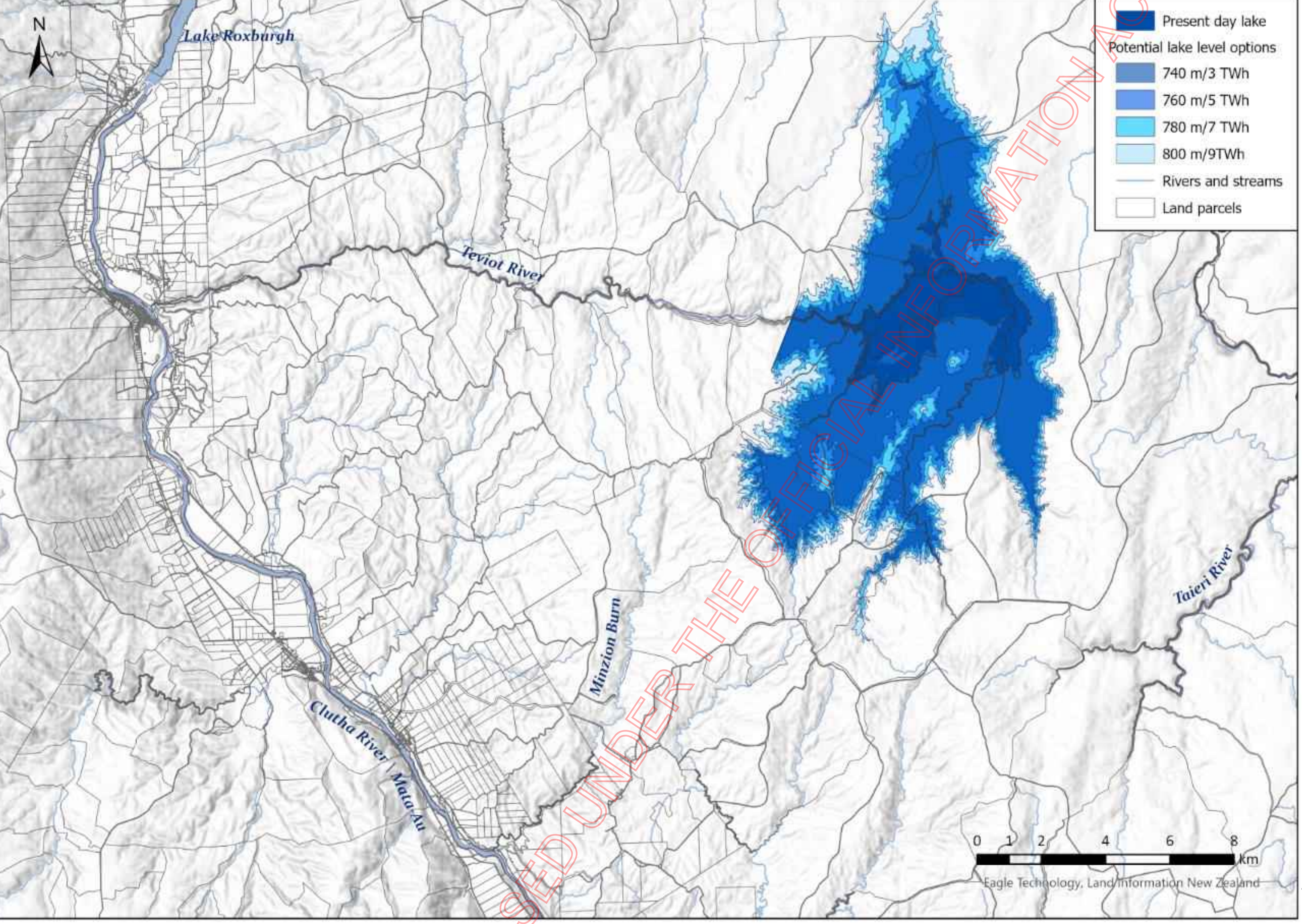
Figure 9. *Lake Onslow Rock Dam after 1894*



igure 18. Lake Onslow Dam 1968 flood damage and showing masonry construction

Onslow footprint prior to 1982

Figure 19. *Lake Onslow Dam 1971*


N
Lake Roxburgh
Teviot River
Minzion Burn
Clutha River / Mata-Au
Taieri River
Present day lake
Potential lake level options
740 m/3 TWh
760 m/5 TWh
780 m/7 TWh
800 m/9TWh
Rivers and streams
Land parcels
0 1 2 4 6 8
km
Eagle Technology, Land Information New Zealand

Ecology & species

What lives in the tribs?

University of Otago, Te Whare Wānanga o Otāgo, New Zealand
NIWA Taihoro Nukurangi
Cawthron Institute
Department of Conservation Te Papa Atawhai

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What lives in the lake?

Macrophytes

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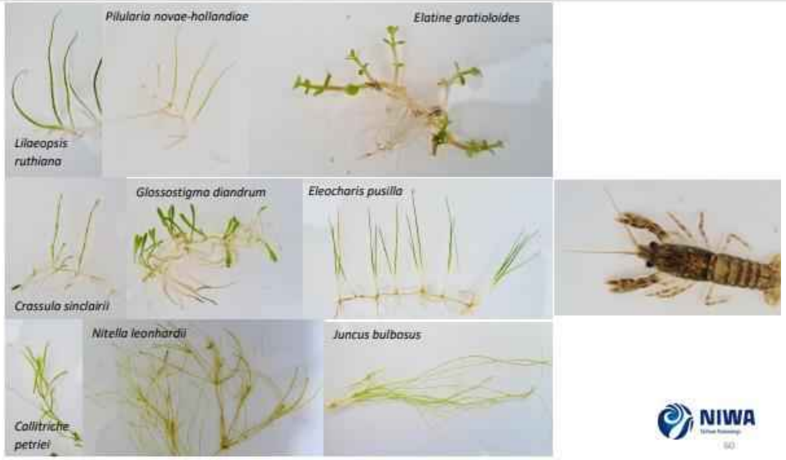

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MACROPHYTES- SITE B1

- Sheltered shoreline (near Huts)
- No turf (sandy and rocky shore)
- No macrophyte cover at depth

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What is the trophic level of the lake?

31 March 2021 lake water quality sampling

Oligotrophic: nutrient poor, clear, low primary production

Mesotrophic: some nutrients, some primary production

Eutrophic: nutrient rich, turbid, high primary production

Table 3.–Values of variables that define the boundaries of different Trophic Levels.

Lake Type	Trophic Level	Chla ($mg \cdot m^{-3}$)	Secchi Depth (m)	TP ($mg\ P \cdot m^{-3}$)	TN ($mg\ N \cdot m^{-3}$)
Ultra-microtrophic	0.0 - 1.0	0.13 - 0.33	33 - 25	0.84 - 1.8	16 - 34
Microtrophic	1.0 to 2.0	0.33 - 0.82	25 - 15	1.8 - 4.1	34 - 73
Oligotrophic	2.0 to 3.0	0.82 - 2.0	15 - 7.0	4.1 - 9.0	73 - 157
Mesotrophic	3.0 to 4.0	2.0 - 5.0	7.0 - 2.8	9.0 - 20	157 - 337
Eutrophic	4.0 to 5.0	5.0 - 12	2.8 - 1.1	20 - 43	337 - 725
Supertrophic	5.0 to 6.0	12 - 31.0	1.1 - 0.4	43 - 96	725 - 1558
Hypertrophic	6.0 to 7.0	>31	<0.4	>96	>1558

Burns et al. (1999)

TLI = 3.7 ± 0.2
→ mesotrophic

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FISH SURVEY FINDINGS

- Low diversity of species in Lake Onslow (Brown trout and common bully) Native diadromous species absent (e.g., longfin eel)
- Low abundances of common bullies compared to 22 South Island lakes
- Timing of the survey (late autumn) likely affected catch rates
- No evidence of Teviot galaxiids inhabiting the lake (either by catch or eDNA)
- Brown trout CPUE similar to other SI lakes sampled (Fykes only indicative)

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What about the fishery?

Lake Onslow fishery values

- Ca. **1,420 angler-days** per year (NAS; 2014-15 season)
- All between October and May
- Most (1,250 angler-days) between Dec and March
- Varies among years – as high as **3,450 angler-days** in 2001-02 season

- *Perspective (other remote-ish waters 2014-15 season):*
- Greenstone: 750 angler-days
- Routeburn: 300 angler days
- Nevis: 190 angler-days
- Caples: 350 angler-days

- *Much bigger lake easily accessible:*
- Lake Wanaka: 22,410 angler-days

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Taihoro Nukurangi

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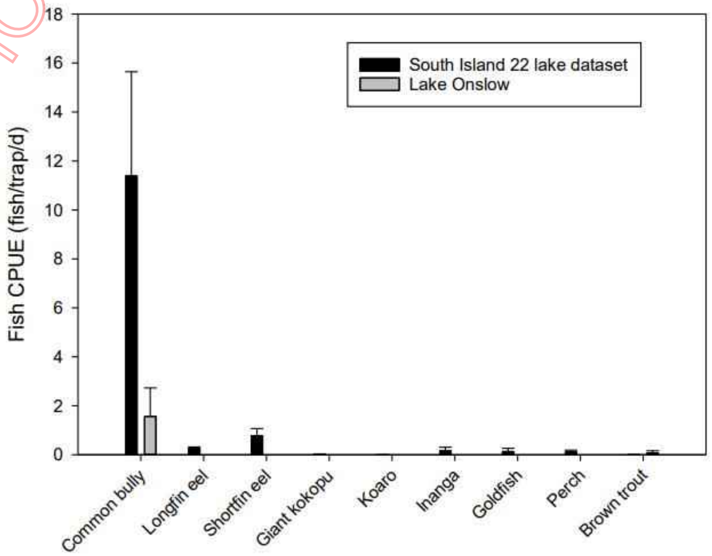
29

FISH SURVEY- COMPARISON TO OTHER SI LAKES



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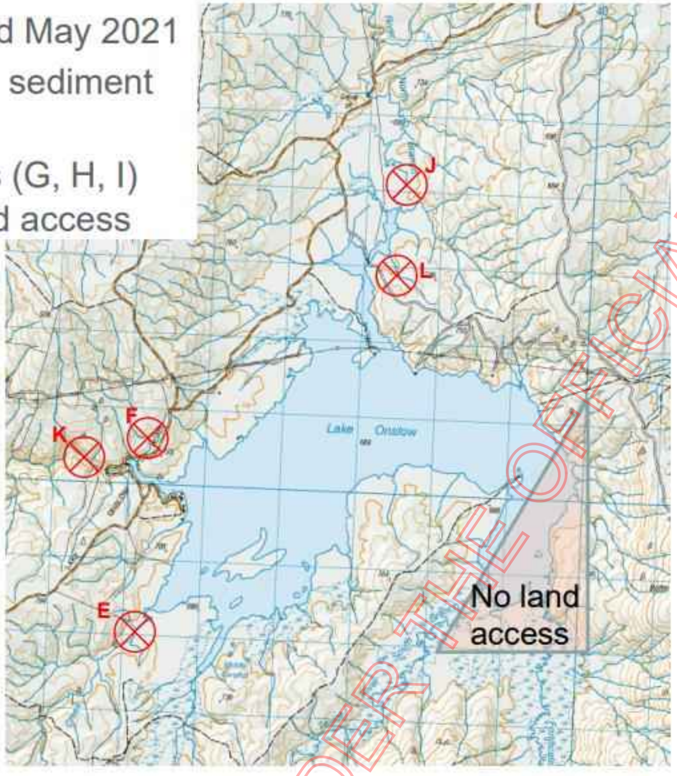
We need to know what is there…

DATA OVERVIEW –ONSLOW TRIBUTARIES WATER CHEMISTRY

Kelly and Stewart:

- 4 tributaries plus outflow sampled May 2021
- Nutrient suite, DOC, TSS, Chl-a, sediment nutrient, DOC
- Note that the West tributary sites (G, H, I) could not be sampled due to land access



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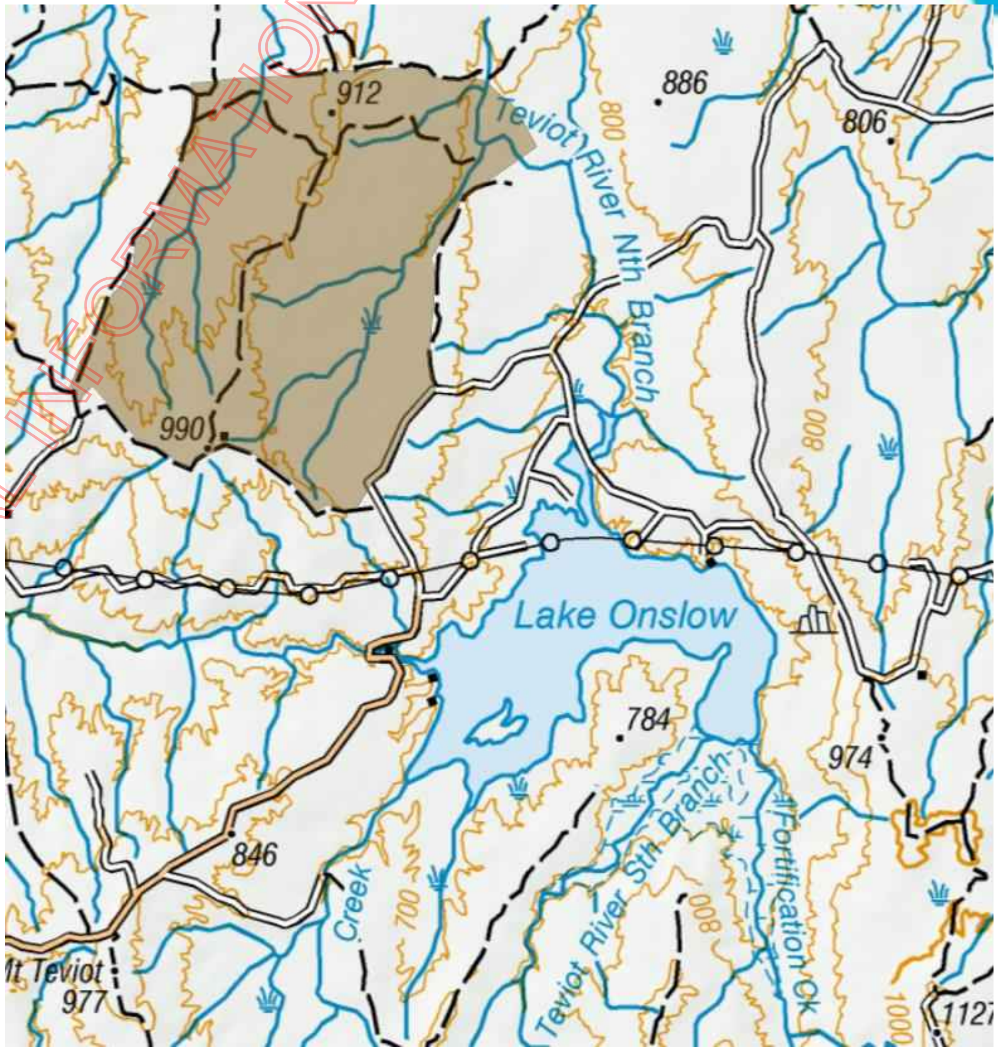
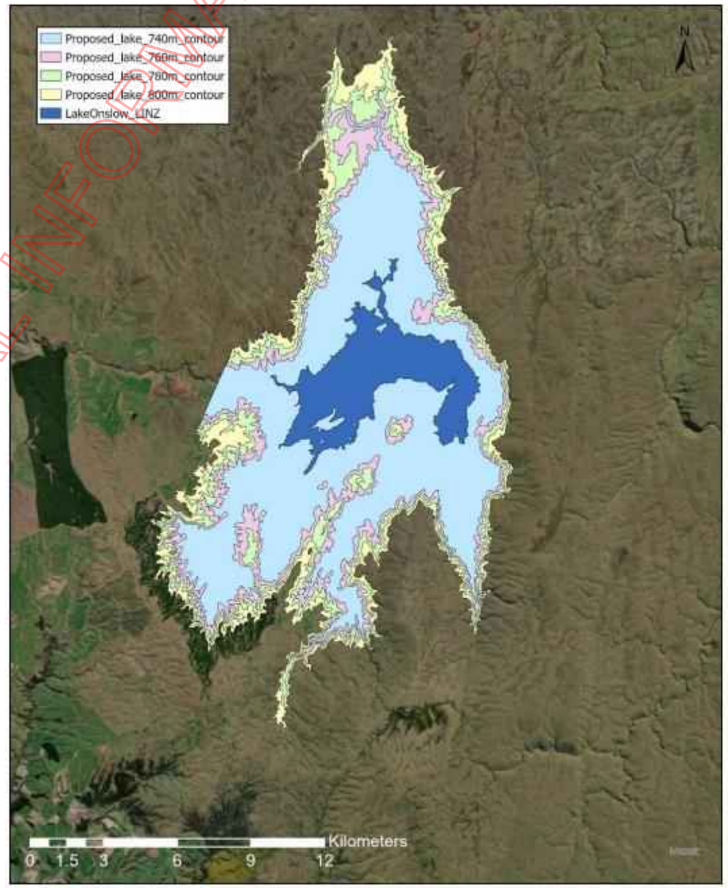


What happens?

As we don't know design yet…

Hydrodynamic modelling

- Existing lake
- Raised lake scenarios
  - Lake levels
  - Filling/discharge scenarios
  - Elevation of inlet/outlet
  - Water source – Roxburgh vs lower Clutha?
  - Budgeted for 5 scenarios



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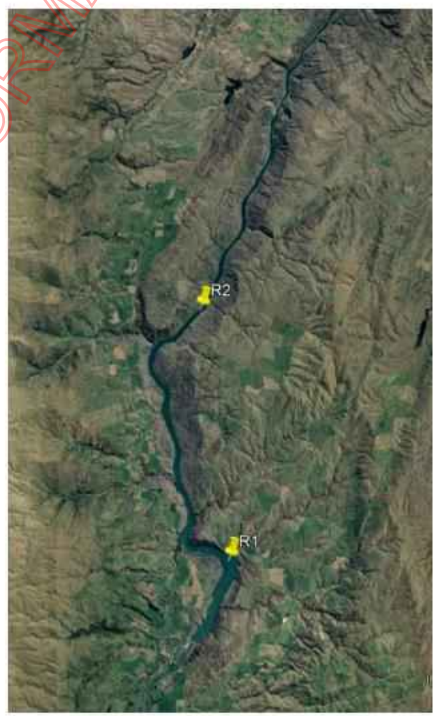
Mixing glacial flour with peaty waters....

Total suspended solids (preliminary results)

Date	Waterway	Site	TSS (mg/L)
7-May-21	Roxburgh	R1 surface	6.6
7-May-21	Roxburgh	R1 3 m	5.2
7-May-21	Roxburgh	R2 surface	5.2
7-May-21	Roxburgh	R2 3 m	5.6
6-May-21	Onslow	L1 surface	7.2
6-May-21	Onslow	L1 top 3 m	8.1
6-May-21	Onslow	L3 surface	5.3
6-May-21	Onslow	L3 3 m	6.5
6-May-21	Onslow	L4 surface	7.9
6-May-21	Onslow	L4 3 m	10.7
6-May-21	Onslow	L5 surface	5.4
6-May-21	Onslow	L5 3 m	6.2
6-May-21	Clutha	Millers Flat Bridge	5.6

TSS inputs from tributaries and potential future inflows (Lake Roxburgh or the lower Clutha River) will affect water clarity and sediment accumulation in Lake Onslow. These data are required to model sediment settling.



Lake Roxburgh TSS sampling locations

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Introducing weeds, rock snot and lake snow…

Biosecurity considerations

Risk of transfer of lagarosiphon, *Lindavia* ?

50% of lagarosiphon fragments containing buds with mean length of just 32 mm were found to regenerate (Redekop et al. 2016)

Lake Roxburgh described as dominated by lagarosiphon by 1992 over 1-6 m depth.

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Biosecurity considerations = lake snow

Risk of transfer of lagarosiphon, *Lindavia*?

- Lagarosiphon designated as an unwanted organism (capable of causing harm)
- ORC plan cites site-led management programme for lagarosiphon (where occurs)
- ORC prevent establishment in lakes where it is not already present
- Plan Rule 6.5.7.1 addresses transfer offence under section 154N(19) of the Act
- Sections 52 and 53 of the Biosecurity Act 1993, which prevent the communication, release, spread, sale and propagation of pests, must be complied with
- *Lindavia intermedia* registered an organism of interest under ORC plan

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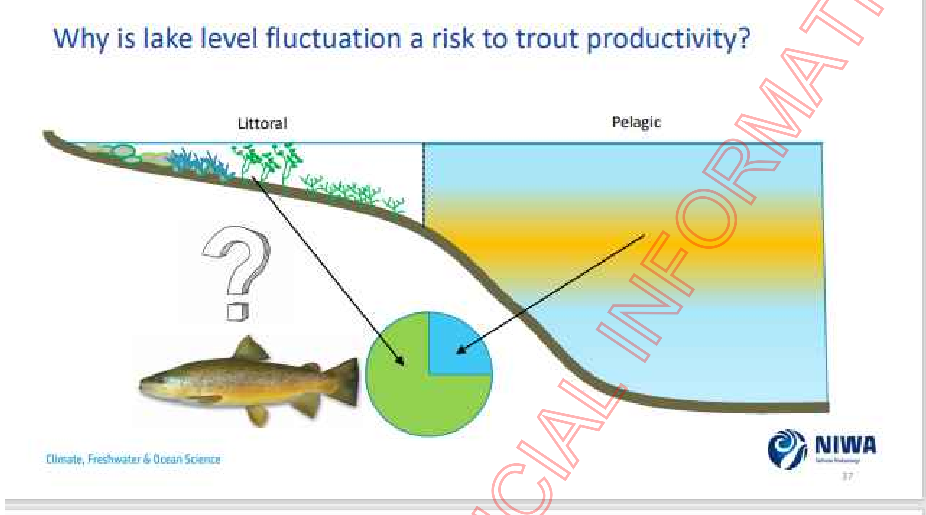
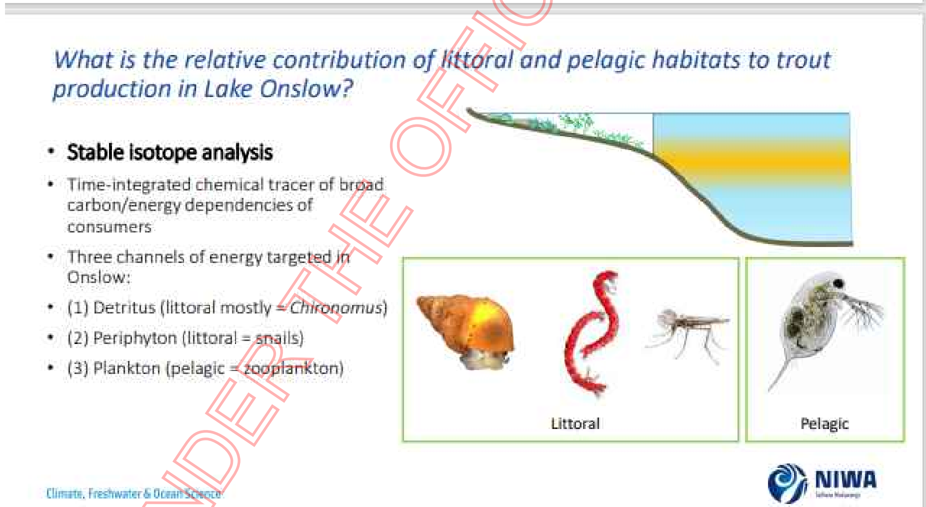
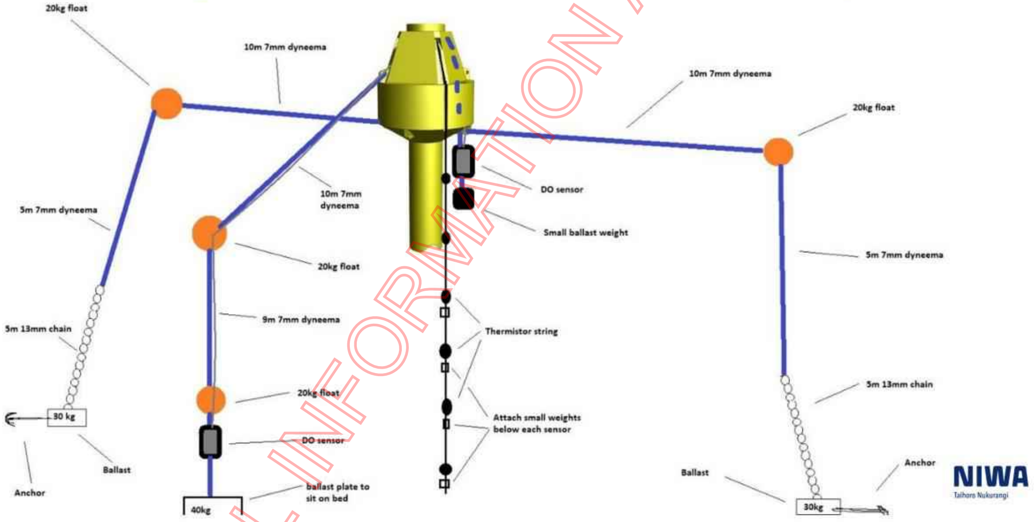
And food web study for fishery….





About a buoy…

Monitoring lake conditions: Does the lake stratify?



Buoy location

Depth ~ 6.5 m

NIWA

Hydrodynamic and water quality modelling

- Does (or when does) the current Lake Onslow stratify?
- Will (or when will) a future Lake Onslow stratify?
- How might nutrient, light, and primary production change?
- What will be the future trophic state of the lake?
- Will bottom waters remain oxygenated throughout summer? Or is there a danger of hypoxia/anoxia that could lead to the release of nutrients and greenhouse gases from the lake bottom?

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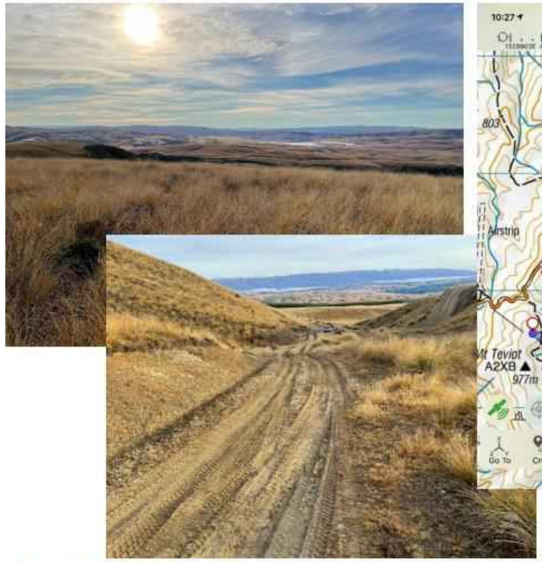
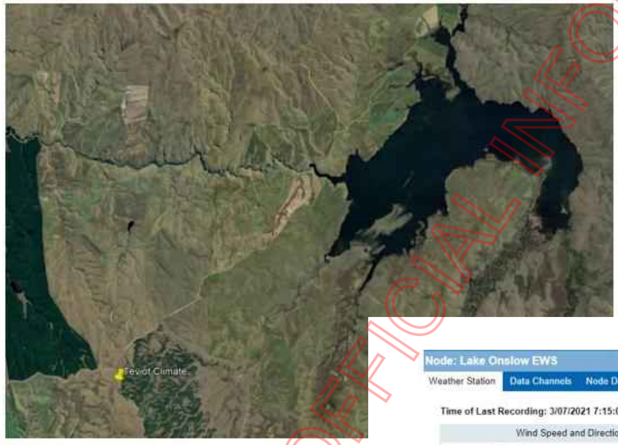
And met station…

Monitoring weather and climate effects on Lake Onslow

Meteorological station near Mt Teviot





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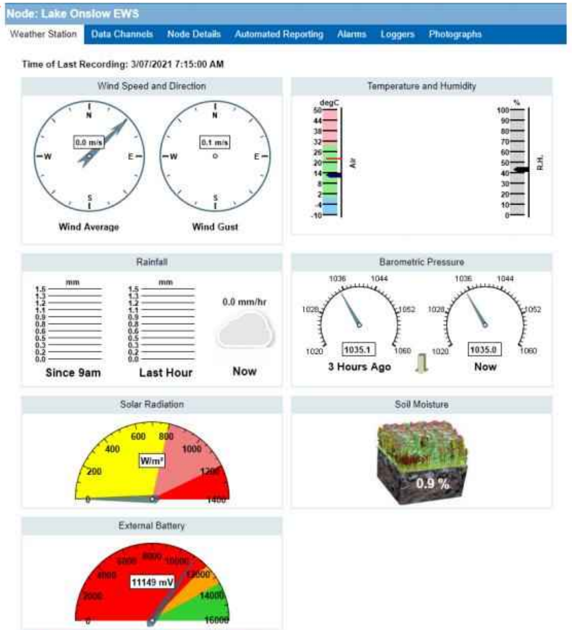

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MĀIA
BOLD & BRAVE

PAE KAHURANGI
BUILD OUR FUTURE

MAHI TAHI
BETTER TOGETHER

PONO ME TE
OWN IT

NIWA
Taihoro Nukurangi

July 2021 First of two NIWA workshops = next end Sept

University of Otago – Te Whare Wānanga o Otāgo – New Zealand | NIWA – Taihoro Nukurangi | Cawthron Institute | Department of Conservation – Te Papa Atawhai

Next steps and Qs for TRG

- Plan fieldwork for spring/summer/autumn
- Provide landowners with advice on what env fieldwork may mean for them
- Negotiate access agreements with landowners
- NIWA hosted workshop end Sept – purpose: to align & QA all planned freshwater work streams
- How to integrate Provider into env work streams?
- Should we continue to use CRIs – if further work needed – or use Provider's capability?
- Are there any Qs that we should ask at the next NIWA workshop from the TRG?
- Should DOC look at translocation of Teviot flathead?
- Would TRG like to hear directly from scientists in future?

Driving the Energy transition

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

For this session:

Purpose of this session

- Respond to TRG's request that we explain where the NZ Battery project in the context of the other work Government is doing to support energy decarbonisation

What we want from you

- Questions and discussion about wider work programme
- Discussion about how the wider work programme may affect the Battery project

Next steps from here

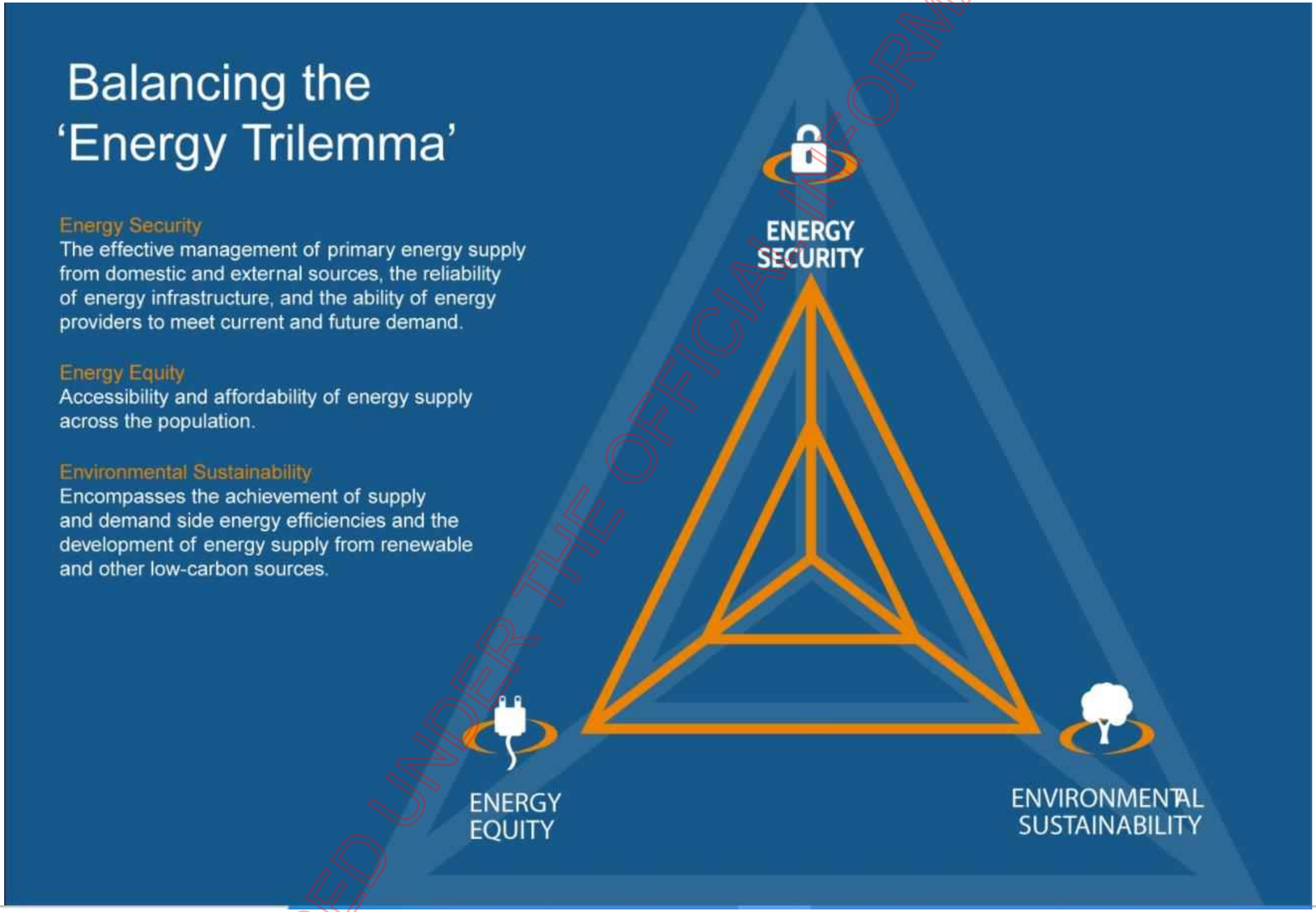
- Can incorporate new themes as we update the material when discussing MBIE's work programme with external stakeholders

The energy system is on the verge of unprecedented change…

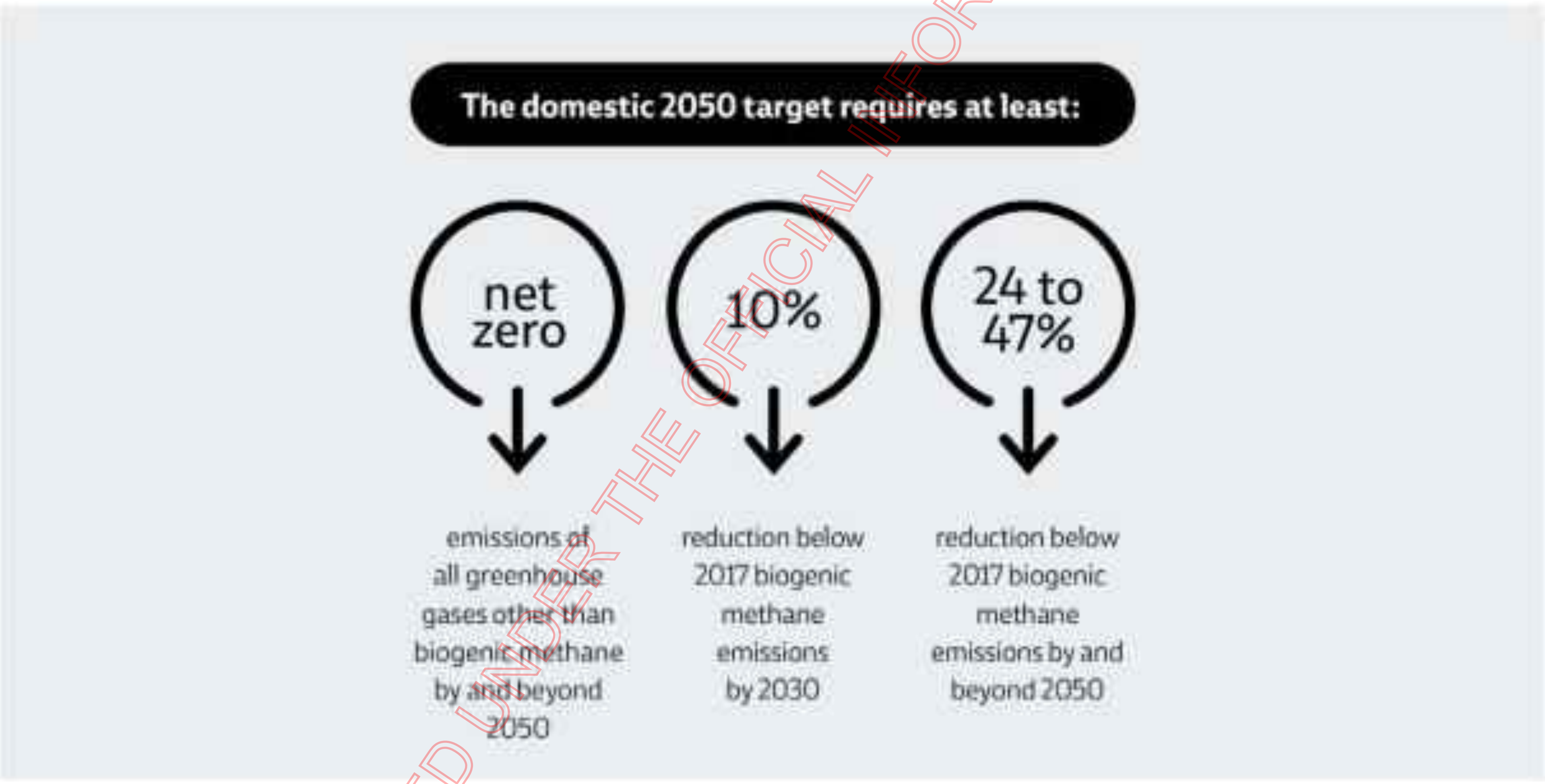
…driven in part by the "three D's":

1. **Decentralisation** – the increase in deployment and use of distributed energy resources (DERs), particularly by consumers, and the resulting shifts towards multi-directional power flows on networks, and increases in the number of consumers actively participating in energy markets
2. **Digitisation** – the use of smart, digital technology to harness, control and automate these DERs in particular, new ways for consumers to engage using technology, and increases in artificial intelligence
3. **Decarbonisation** – the global drive to reduce carbon emissions

…and our advice on responding to these trends is guided by the Energy Trilemma.



Decarbonisation and the Climate Change Response (Zero Carbon) Amendment Act sets important strategic context for the energy sector

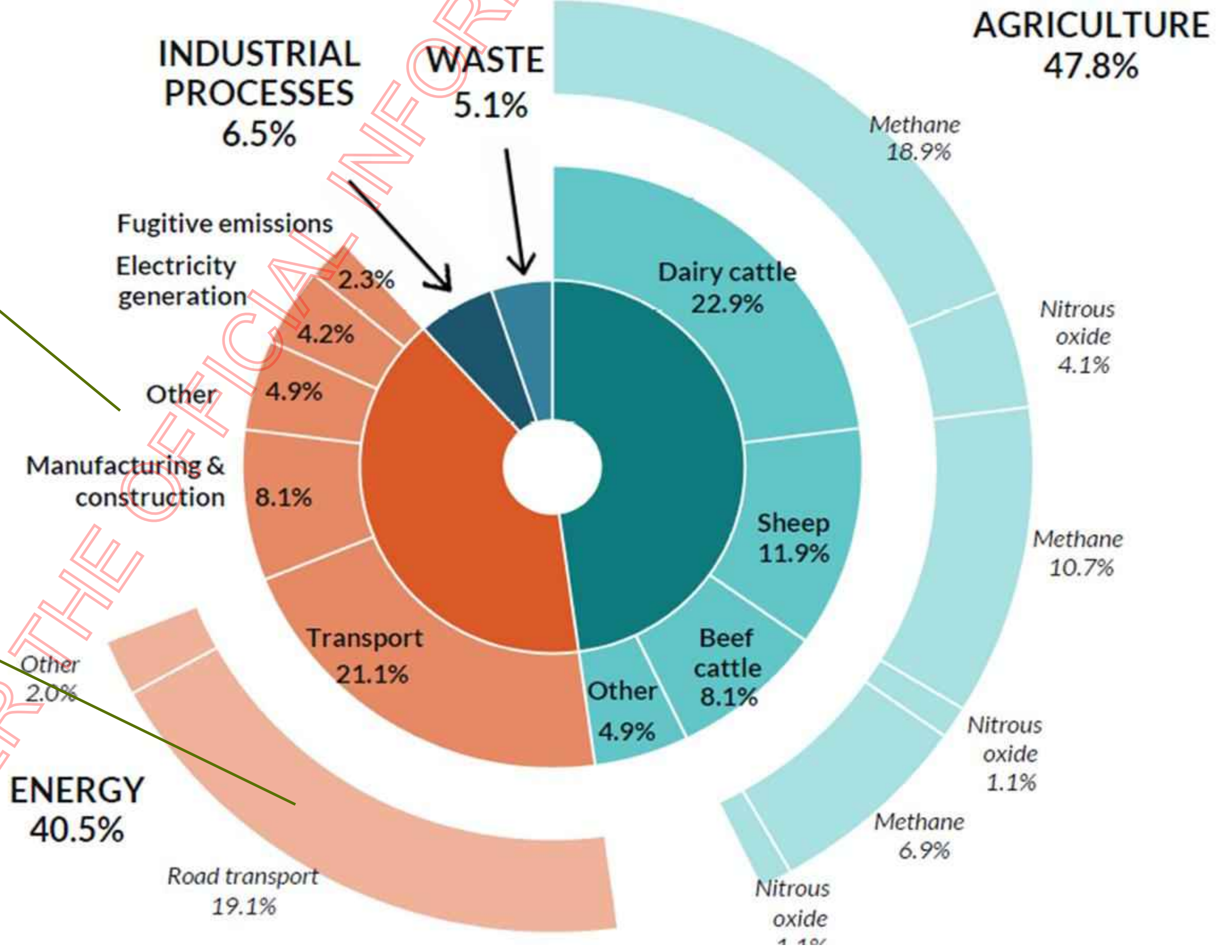


Energy sector emissions make up about 40% of NZ's gross emissions...

About half of NZ's energy emissions are from electricity, industry, residential and commercial

...and the other half are from transport

...but there are strong links between the two.



…and the Climate Change Commission has laid out it's recommended pathway to Net Zero Emissions.

For **energy and industry,** the key recommendations for energy by the Climate Change Commission are to (in partnership with Iwi/Maori):

(rec 20) Developing an energy strategy to decarbonise the energy system and ensure the electricity sector is ready to meet future needs, including:

- Supporting development and deployment of low-emissions fuel options such as bioenergy and hydrogen
- Enabling fast paced build of new renewable generation and phasing out coal
- Ensuring the electricity system is capable and technology ready

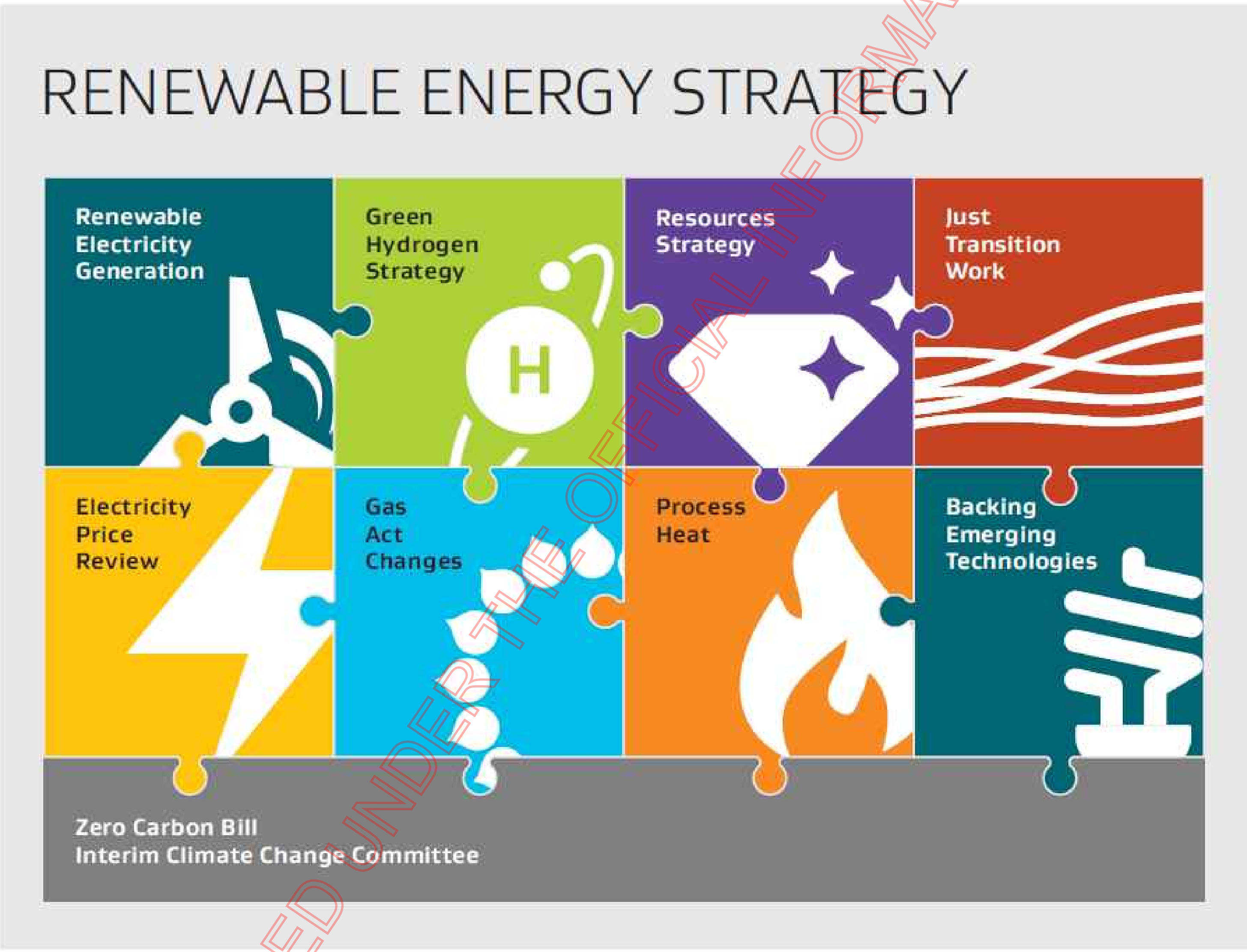
(rec 21) Reduce emissions from industry , including

- Accelerating industry switching to low-emissions fuels for process heat and uptake of energy efficiency measures
- Ensuring no new coal boilers are installed and setting a timetable for the phase out of fossil fuels used in boilers

ERM is developing the Emissions Reduction Plan (ERP) for Energy and Industry…

- By end 2021 the government must set emissions budgets for three periods from 2022 to 2035, following advice from the Climate Change Commission (CCC)
- The government must also set an emissions reduction plan (ERP) setting out policies and strategies to meet the budgets, including in the **transport, building and construction, land use, waste, and energy and industry (E&I)** sectors
- The E&I component of the ERP will set out the policy direction for reducing emissions in E&I, taking into account the CCC's recommendations

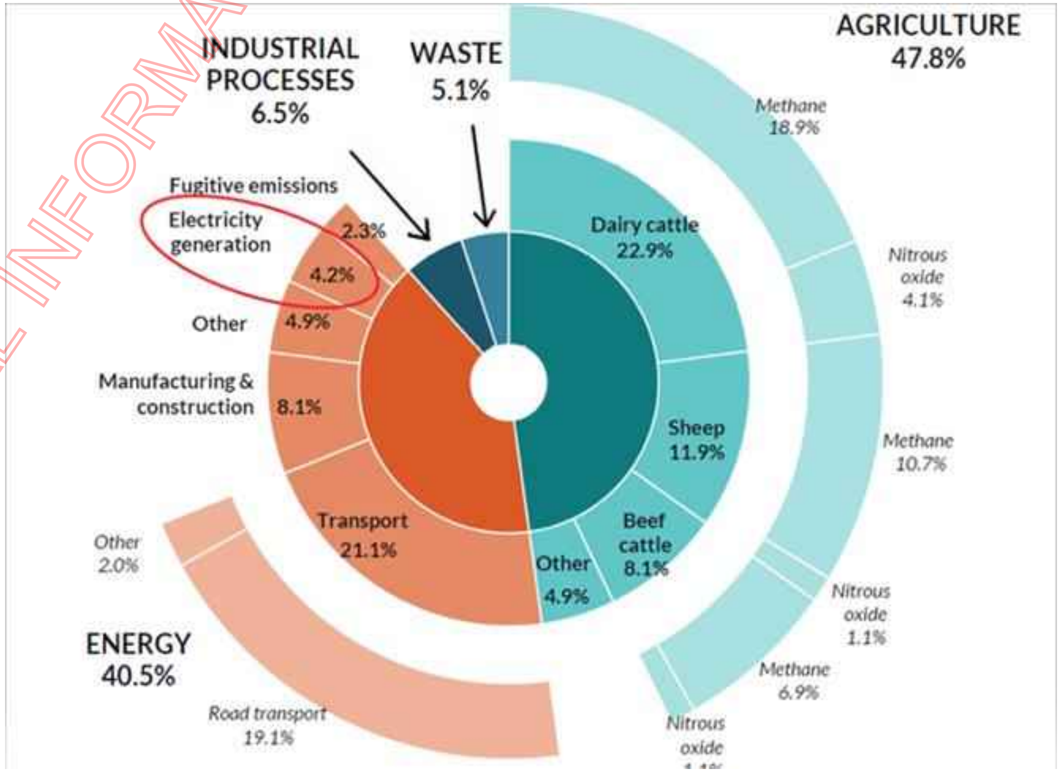
...leveraging the existing energy markets work programme.



We are accelerating renewable electricity…

Addressing barriers and opportunities relating to accelerated investment in renewable electricity:

- The **New Zealand Battery Project** seeks to find a renewable solution to New Zealand's dry year electricity problem (which is currently solved with coal)
- Examining options to implement Government manifesto commitment to ban **new baseload thermal** electricity generation.
- Reviewing **national direction for renewable electricity generation** and transmission under the RMA
- The Māori and Public Housing Renewable Energy Fund aims to improve energy affordability and reliability through the provision of renewable energy solutions, such as small-scale community solar projects on Maori and Public housing.
- Working across government to **address barriers in the electricity transmission and distribution** systems



…And the Government has a target of 100 per cent renewable electricity generation by 2030, with a review at the 2025 emissions budget…

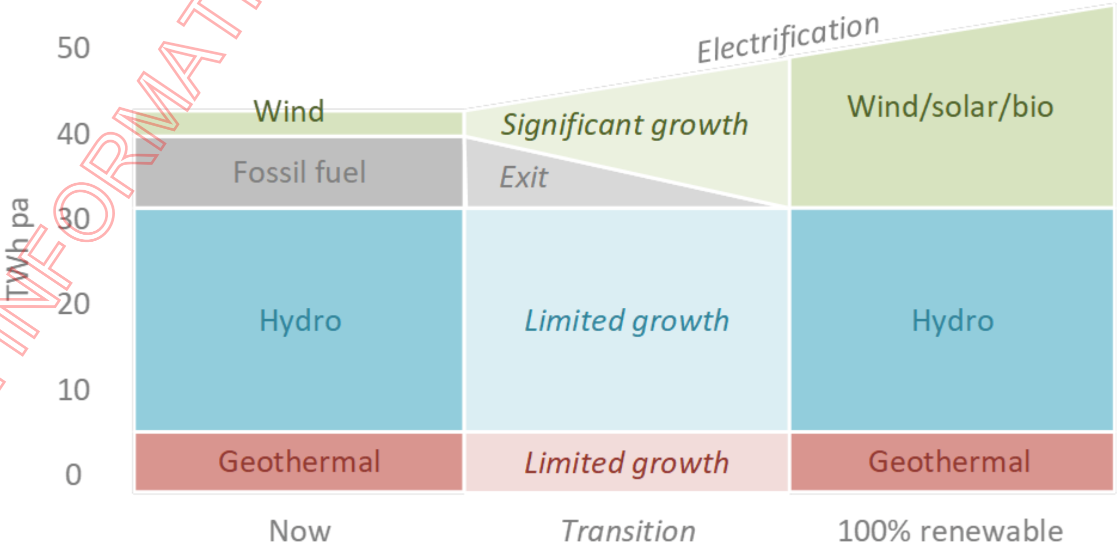
And working out how a transition to 100% renewable electricity could work…

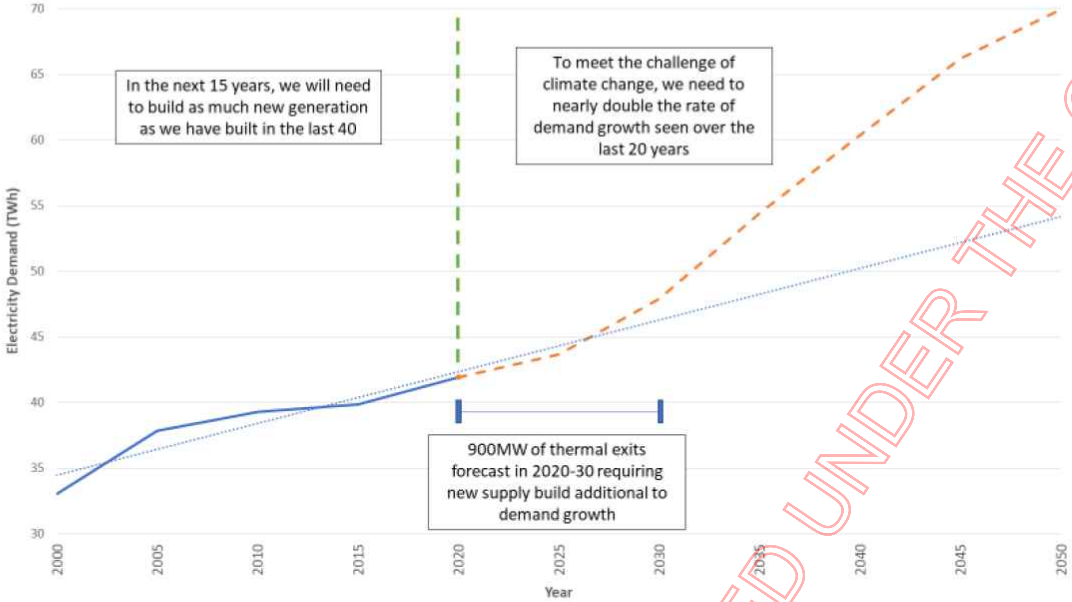
Achieving 100% renewable electricity will require:

- About 900MW existing fossil fuel-based generation retired or repurposed
- significant investment and build of new renewable generation
- enhanced transmission and distribution

While simultaneously:

- Managing security of supply and dry year risk
- Maintaining affordability and prices at levels that encourage fuel switching





- What will drive fossil fuel thermal retirement, and how will this be organised/sequenced?
- What will replace the "services" that thermal generation provides?
  - Daily/weekly balancing intermittency
  - Seasonal energy storage
  - Dry year security
- How to ensure secure, flexible fuels through the transition?
- How to maintain strong incentives to invest in new generation?
- How can the existing electricity market support the objective?

The New Zealand Battery project could address one of the main obstacles to 100% renewable electricity…

Investigating options to resolve New Zealand's 'dry year risk' problem in a highly renewable electricity system, with the aim of identifying the best option, or combination of options, to address this risk and support the move to 100% renewable electricity.

PHASE 1
Feasibility study
→ April/May 2022

A feasibility study identifying the best option or options to address dry year risk

Includes early field work (subject to procurement)

PHASE 2
Detailed business case
→ Late 2023/early 2024*

Further investigations, detailed engineering design and field work, leading to a final investment decision

PHASE 3
Implementation
Early 2024* onwards

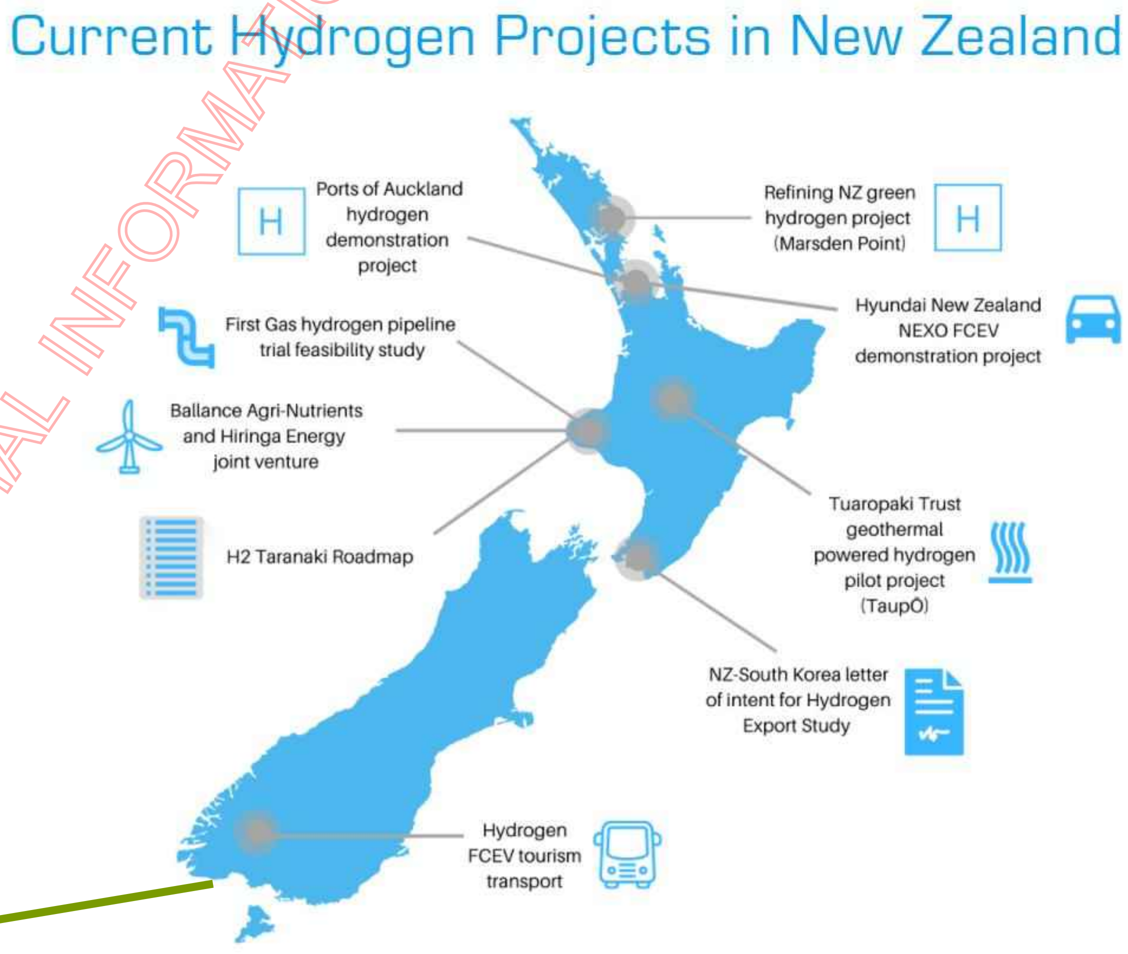
Contracting and construction

**Depending on chosen option or options*

…and Hydrogen could also play a role.

Our work programme focuses on developing the hydrogen market, including hydrogen production, transport, use in New Zealand and potential export. It concentrates on the following key objectives:

1. Removing regulatory and other barriers to hydrogen development and production
2. The first phase of a hydrogen roadmap, and
3. Liaison with local and international business, community and research interests in hydrogen.



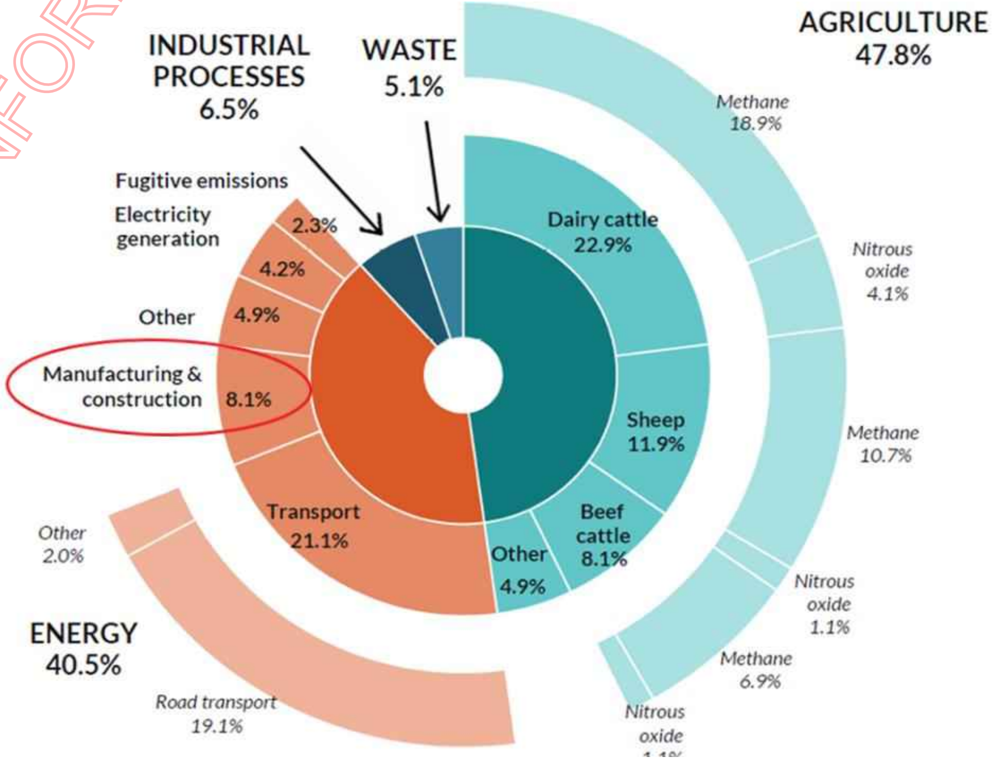
Meridian and Contact are spending up to $2m to investigate the potential of a large scale, renewable hydrogen production facility…

…and are working closely with the NZ Battery project, to understand its potential for large demand response

We are addressing industrial process heat emissions…

Our work in this area includes:

- Implementing **Government manifesto commitments to phase out fossil fuels** in low temperature process heat through national direction for greenhouse gas emissions under the Resource Management Act, to be in place by end 2021 (NB this Act is also under review).
- Investigating an **energy and emissions reporting regime** to help to understand opportunities for decarbonisation of process heat.
- Policy and working with EECA on the **Government Investment in Decarbonising Industry Fund (GIDI)** fund



…and working out how to phase out fossil natural gas from the energy system.

Our work will be informed by several pieces of work we have facilitated across industry and Government:

- The Gas Industry Company's gas market settings investigation to determine if current market, regulatory and commercial settings are fit-for-purpose for the transition.
- The industry-led Gas Infrastructure Future Working Group which intends to report to Government on key challenges for mass market consumers and infrastructure.
- Development of a Green Gas certification scheme to enable green gases to be used in the current gas infrastructure.
- Hydrogen feasibility work both across industry and within Government.

We are co-leading policy on a biofuels mandate…

- Public consultation on the biofuels mandate proposal likely this month.
- Between now and early 2022, more work on modelling and detailed policy design (for example, biofuels' sustainability criteria, certification and fuel specification requirements).
- Report back to Cabinet on the final policy design by 30 September.
- Subject to Cabinet approval, Bill introduction to the House in the first half of 2022, and legislation coming into effect from 1 January 2023.

…and reviewing New Zealand’s fuel security settings.

- MBIE has a role in ensuring domestic fuel security, and meeting New Zealand’s IEA treaty obligation on oil stockholding
- Refining NZ is actively considering the option of converting from a refinery to a fuel terminal import terminal, and is expected to make final decision on its future business model in the third quarter of 2021.
- ERM has commissioned work on the implications of Refining NZ’s potential conversion for fuel security, and measures for mitigating fuel security risks
- We expect to update Government on actions in response to the Auckland Fuel Supply Disruption Inquiry and Refining NZ’s final decision on its future business model, soon after RNZ’s decision
- MBIE is likely to consult on enhanced fuel security options later in 2022.

We continue to implement the recommendations of the Electricity Price Review

- The aim of the recommendations is to ensure a market which is fairer, more consumer focused, more affordable and more prepared for future challenges such as greater renewable generation and new technology
- We have work underway to progress the recommendations including:
  - Taking a Bill through the House to make **changes to the Electricity Industry Act**
  - Setting up a **Consumer Advisory Council, Energy Hardship Expert Panel** and a cross-sector **Energy Hardship Reference Group**
  - **Community-level support services -** Support for Energy Education in Communities (SEEC) Programme, funding community-led pilot projects
  - Enhancing the role of the **Council of Energy Regulators**
  - Reviewing the Electricity Authority's **compliance framework**
  - Work on the phase out **low fixed charge tariff regulations**
  - Cross-agency work to develop an agreed **definition and indicators of energy hardship**.
- MBIE now has a dashboard on the EPR website that outlines progress towards key work streams its leading.
- The Electricity Authority is leading a number of other work streams.

Our priority next steps in energy are clear…

- We have begun thinking on what a **National Energy Strategy** might look like
- Consultation on **Emission Reductions Plans** is likely to begin at the end of August
- The **NZ Battery Project** will provide an interim report-back to Minister of Energy and Resources in the fourth quarter
- We will advise on the **phase out of fossil fuels** from the energy system in December
- We will advise on the issues and options for achieving the **100% renewable electricity** target in the fourth quarter
- We will advise on the outcome of our **fuel security review** with a view to consulting in 2022 on options
- We will continue our work on the performance of the **wholesale electricity market**
- We continue to lead or support work related the **industrial sector,** including the broader outcomes of Refining New Zealand's strategic review (eg Sustainable Aviation Fuels)

Today's programme

No	Time	Item	Lead
	8.45am	**Arrival Tea and Coffee**	
1.	9.00am – 9.05am	Welcome / Karakia	Adrian Macey and Hoani Langsbury
2.	9.05am – 9.30am	Project news • Overall update	Andrew M and Adrian T
3.	9.30am – 10.00am	Stakeholder update • Industry meetings / Otago visit update	Maria Hernandez -Curry and Carl Walrond
4.	**10.00am – 10.15am**	**Coffee / Tea break**	
5.	10.15am – 11.30am	Operational Governance • Present first-draft NZ Battery operating models	Conrad Edwards
6.	11.30am – 12.30pm	Other hydro options • Present final GIS Scan and proposed short list of options	Malcolm Schenkel
7.	**12.30pm – 1.00pm**	**Lunch**	
8.	1.00pm – 2.00pm	Freshwater presentation • Next steps for Lake Onslow freshwater investigations	Carl Walrond, Karl Beckert and Kimberley Carter
9.	2.00pm – 2.45pm	Driving the energy transition • Discuss the MBIE wide approach to changing the energy system	Andrew Hume
10.	**2.45pm – 3.00pm**	**Coffee / Tea break**	
11.	3.00pm – 4.00pm	The energy transition and the NZ Battery Project • How we might frame the strategic business case for investment?	Andrew Millar and Bridget Moon
12.	4.00pm – 4.30pm	Q&A Summary	Adrian Macey

The energy transition and the NZ Battery Project

MAHI TAHI
BETTER TOGETHER

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

For this session:

Purpose of this session

- Developing an effective solution requires a clear view of the problem
- It's important everyone broadly agrees on the problem we're solving
- Eventually we'll need to articulate this for decision makers

What we want from you

- We welcome discussion on and/or challenges to the arguments we present and what it means for the solution

Next steps from here

- We will keep building and refining the arguments
- We will soon be engaging with Treasury to guide our initial business case

What problem is NZ Battery solving?

Fundamentally, it's a physical problem

… which intersects with an investment problem

… which isn't helped by a market problem

… and it's made even more challenging by the transition problem

… all under-pinned by an uncertainty problem

What problem is NZ Battery solving?

Weather-dependent generation creates a need for storage or extra energy input

→ The investment required is big and high-risk, but the market is small

→ The market struggles to align incentives to solve the extremes of the issue

→ … And renewable options are even higher risk

… as no one can really predict the future

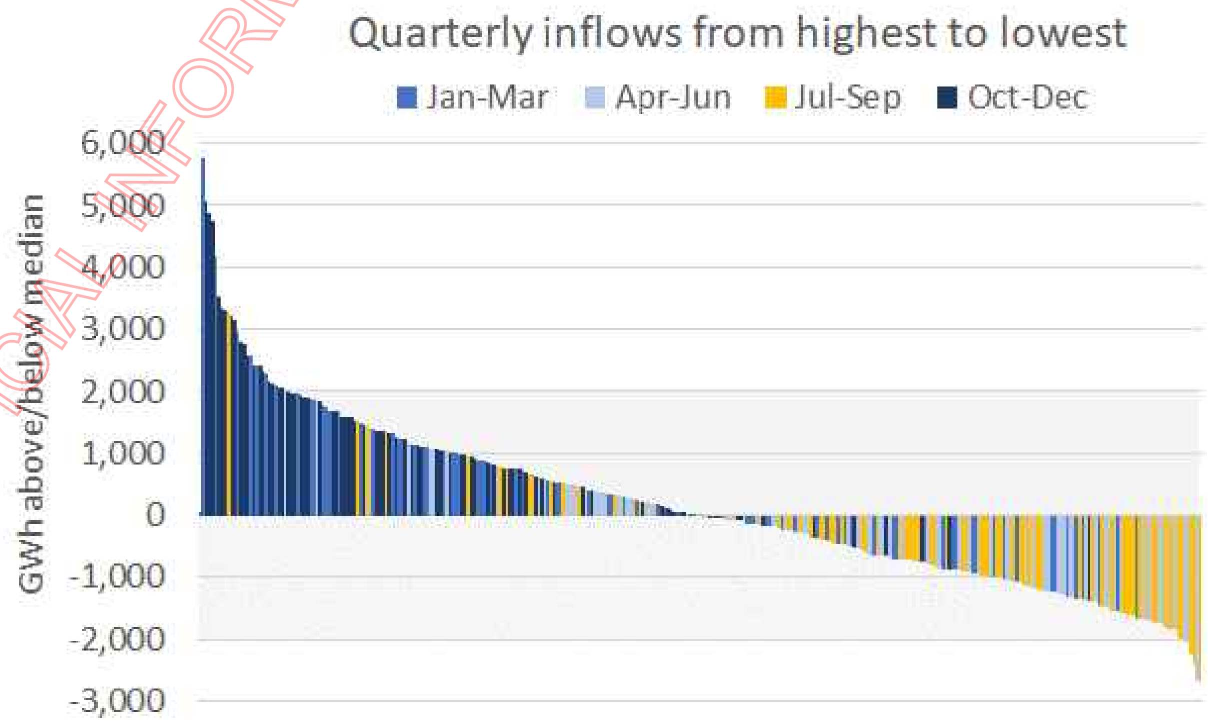
There is a physical system management challenge

- Supply and demand need to balance
- Largely uncontrolled variation in demand
- Met by controlled variation in supply
  - Traditionally just a couple of options:
    - Thermal with flexible fuel supply and/or storage
    - Hydro with storage

Renewable generation helps but can also hinder

- Dependent on the weather
  - Short-term -> long-term
  - Smooth with storage
  - Or fill the gaps with something else

- Inflow variation can be big and sustained
- Not enough storage to smooth
- But the extremes are rare



But variability is a certain uncertainty

- Probabilistic range of outcomes, but when / where / how much?
- Impact affected by other factors:
  - demand
  - other investments (timing)
  - availability of other generation
  - transmission constraints
- Don't know in the moment – only in hindsight

What problem is NZ Battery solving?

Weather-dependent generation creates a need for storage or extra energy input

… which intersects with an investment problem

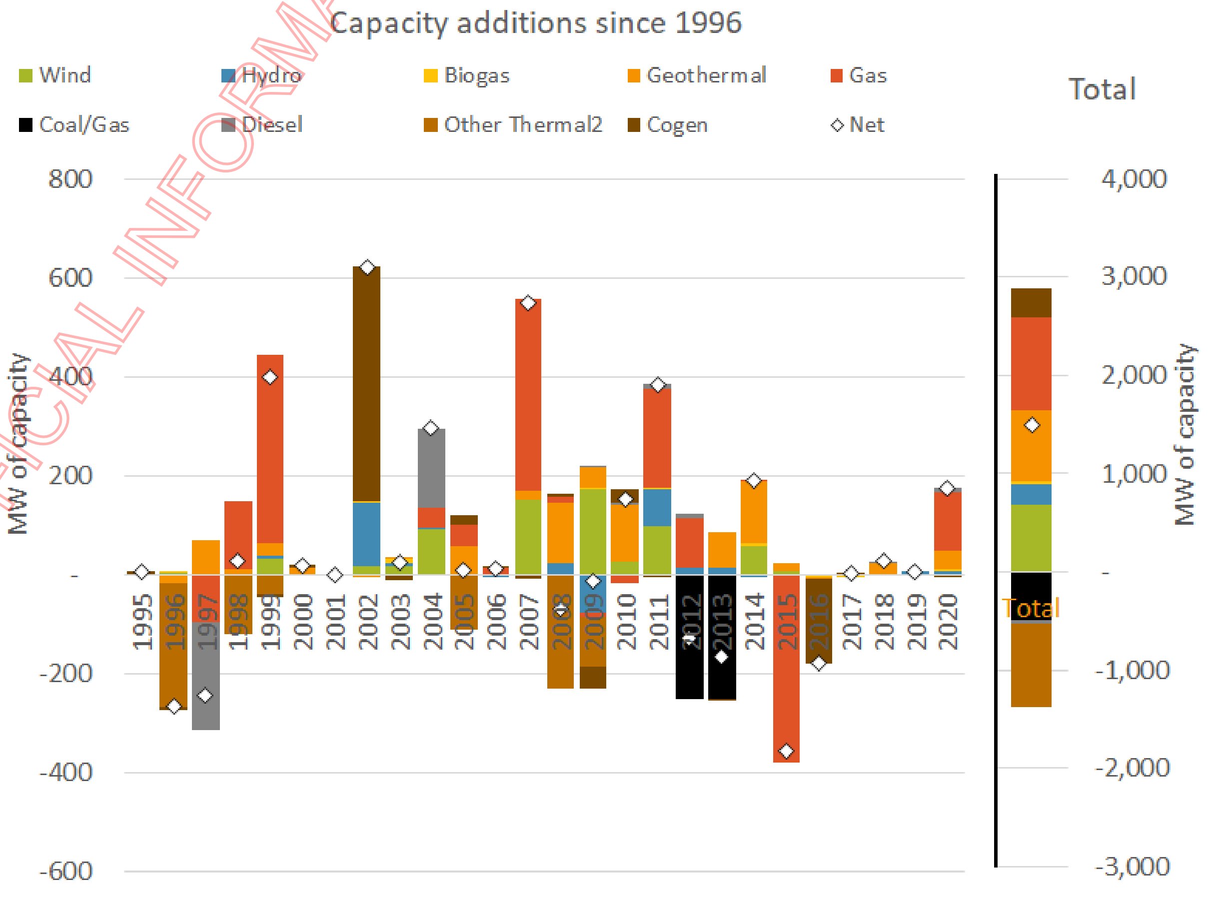
… under-pinned by an uncertainty problem

The energy market should incentivise an economic solution

- Energy-only market should allow adequate return for all necessary plant
  - recover LRMC across hours of operation
  - prices reflect thermal costs and hydro water values (opportunity costs)
- Should result in an economic level of supply
  - …in theory
    - step-ups mean periods of over-and under
    - won't account for all externalities

The market has supported significant investment over time

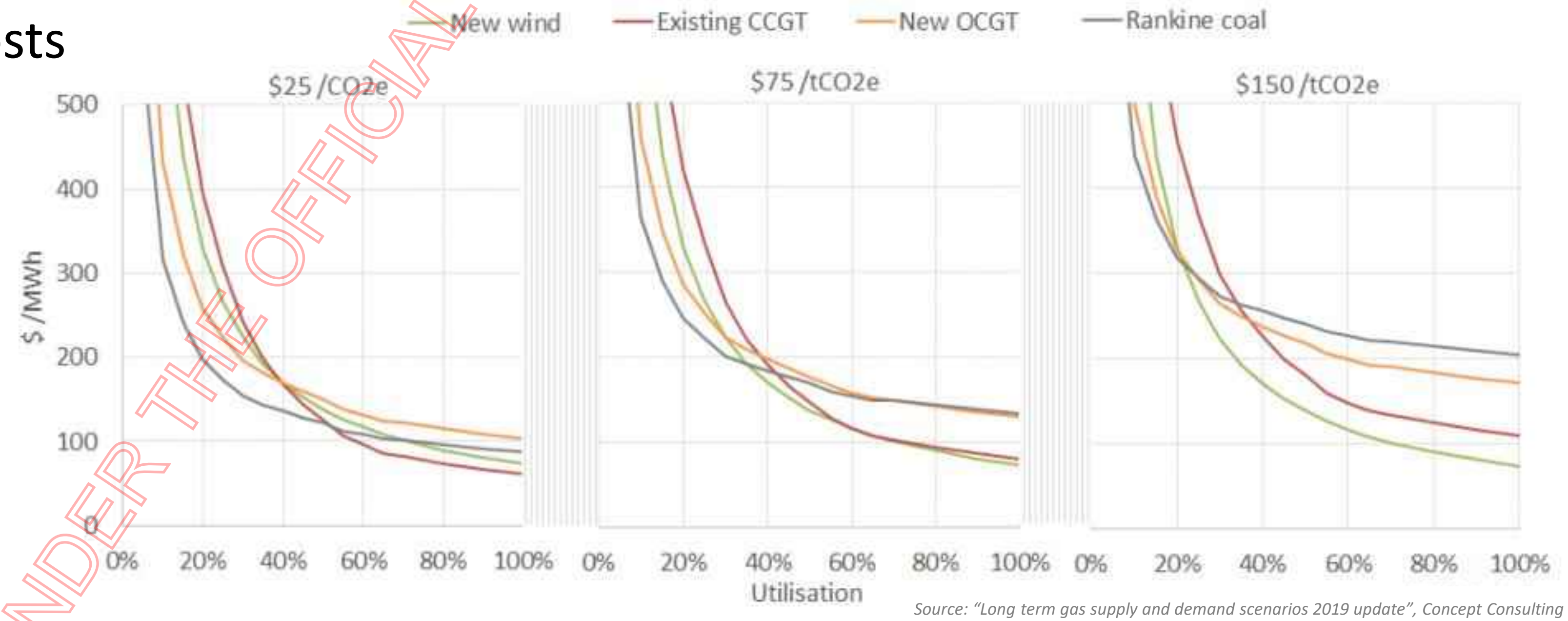
- New generation to
  - meet demand
  - displace uneconomic plant
- Has generally ensured security of supply



Source: BM analysis of Energy in New Zealand data

Plus Huntly, which is the most economic option for dry year

- Thermal cheapest option for low capacity-factor operation
- Coal cheapest option for large-scale storage
- Huntly an existing asset (govt investment)
  - Depreciated asset
  - Ongoing maintenance costs
  - 1,000 MW



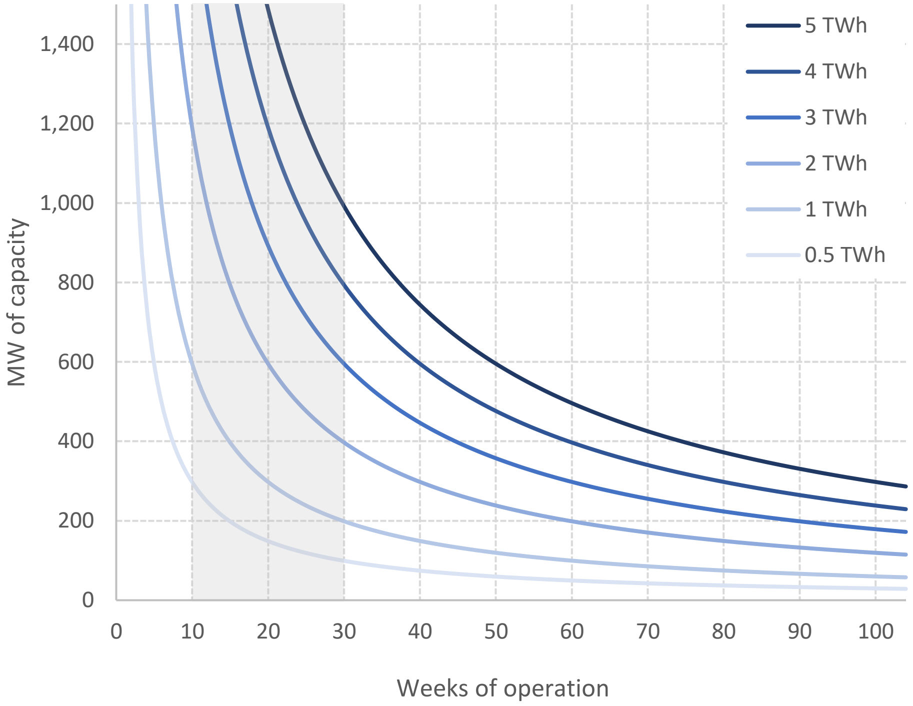
Source: *"Long term gas supply and demand scenarios 2019 update", Concept Consulting*

But would someone invest to replace Huntly?

- The less often we need something, the higher risk it is as an investment
- Variability goes beyond typical investment planning horizons
  - 80yr inflows vs 20yr NPV
  - Expect utilisation of <10%
- Can’t rely on revenue from spot
  - Significant uncertainty of cost recovery
  - Higher risk requires a higher return

The extremes of variation make for a challenging investment

- Size of issue is too big for any one participant to want to solve by themselves
- Big chunk of energy required
- Big relative to the size of participants
    - eg, 4 participants, 3 months = >100 MW each to get 1 TWh
    - not risking under-recovery on a bit, but a lot
    - would need multiple parties to invest



Source: BM analysis

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What problem is NZ Battery solving?

Weather-dependent generation creates a need for storage or extra energy input

The investment required is big and high-risk, but the market is small

… which isn't helped by a market problem

… under-pinned by an uncertainty problem

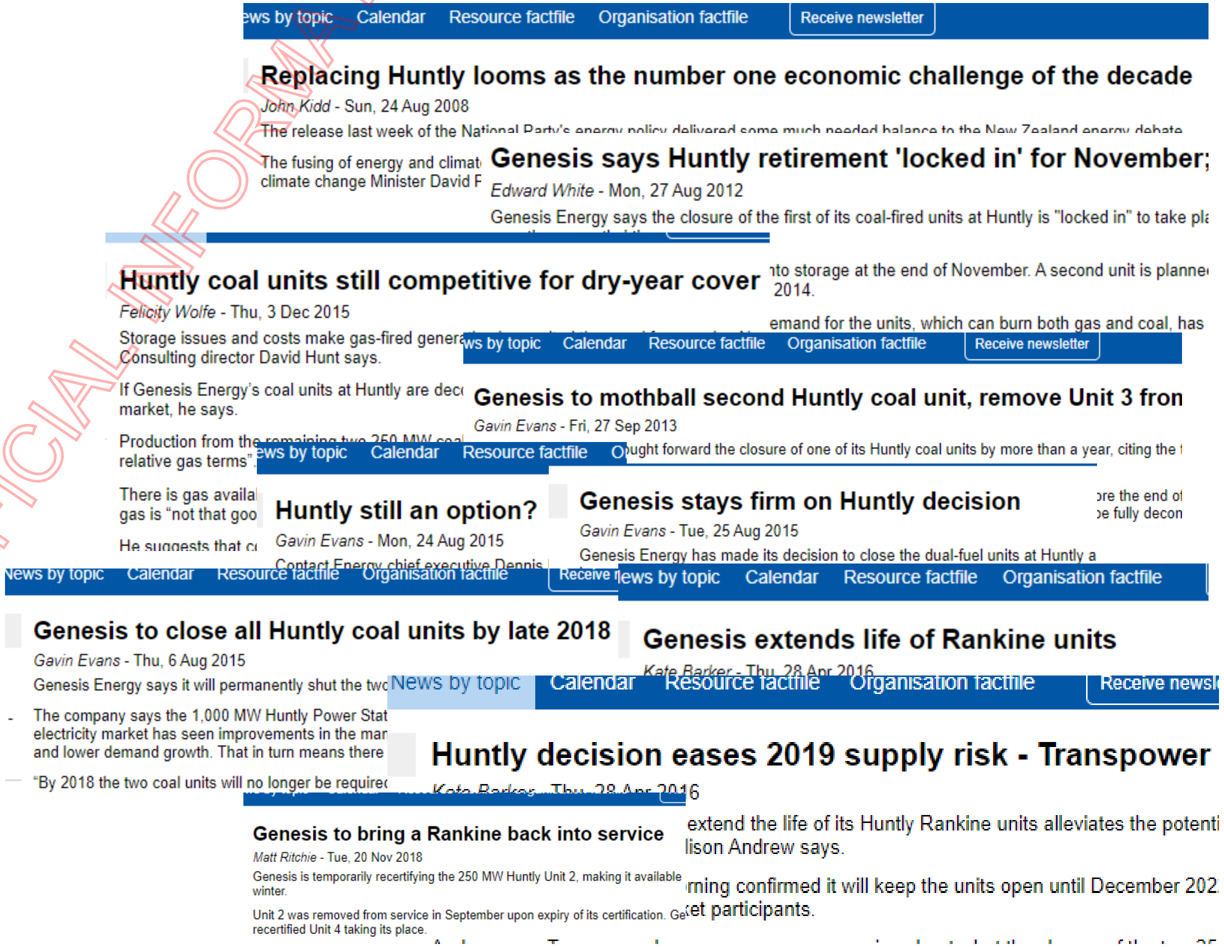
We've used policy tools to support good dry year management

- Ramped up after dry-years in the 90s and 00s
- Incentives
  - Customer compensation scheme
  - Hedge market developments (incl. market making)
- Information transparency
  - Stress test
  - Hydro risk curves
  - Energy margin, capacity margin

- Can't be conclusive, but seems to have improved

Even so, the Huntly arrangement is not necessarily a comfortable one

- Genesis planned to close Huntly more than once
- Meridian and Contact contracted with Genesis to keep open
    - ‘Encouraged’ to do so
- Others benefit but don’t contribute



There's a mismatch between incentives

- Investor wants high coverage from long-term contracts

- Not enough buyers at the price required
  - Buying a long-term contract for an unlikely event also a hard sell
  - Competitive retailers can't be assured of long-term customer-base
  - If a retailer can avoid paying, they have an advantage over others
  - Lobbying can seem a cheaper solution

- Provision of dry year security falls to those with most to lose
  - Free-rider issues

What problem is NZ Battery solving?

Weather-dependent generation creates a need for storage or extra energy input

The investment required is big and high-risk, but the market is small

The market struggles to align incentives to solve the extremes of the issue

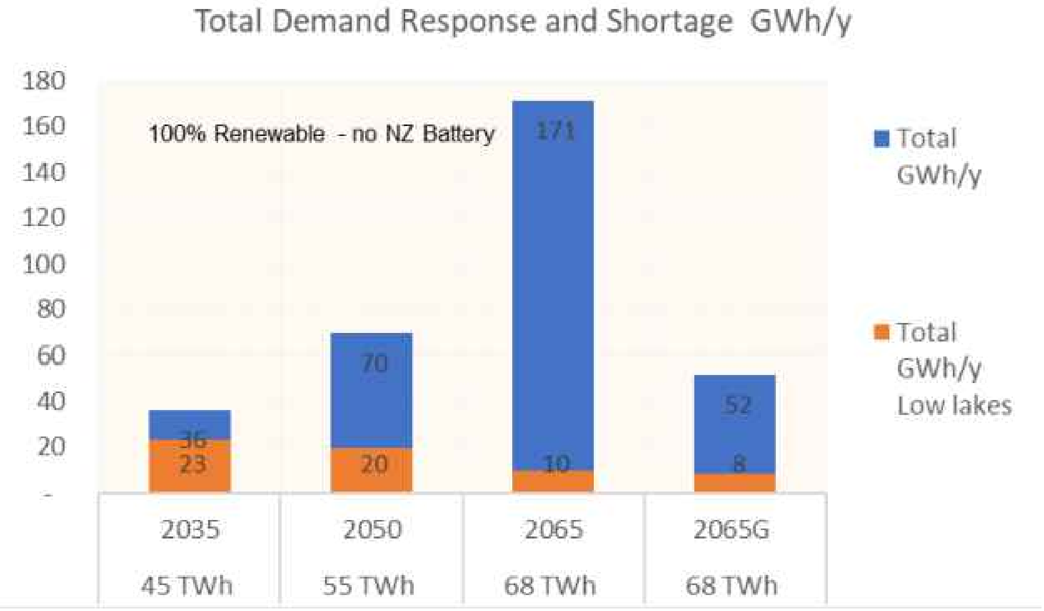
… and it's made even more challenging by the transition problem

… under-pinned by an uncertainty problem

Thermal will no longer be an option for flexibility

- Targeting net zero emissions by 2050 – 100% renewables, electrification of economy
- Need to replace thermal for short-term, medium-term and long-term variability

- Significant overbuild of solar and wind gen expected
- Wind and solar variability may come to dominate the problem
    - Hydro issues become smaller
    - Increasingly constrained capacity
    - Increasingly mismatched supply and demand
    - Dunkelflaute



Source: *"Estimated gross benefits of NZ Battery options", Concept consulting, 21 May 2021*

Renewable solutions to the need for flexibility are more challenging than thermal ones

- Renewables more likely to be high capex/low opex
  - Higher capital at risk
  - Less economic to flex
- Technological barriers to flexible options
  - Immature tech/markets
  - Reliance on landscapes/geography
    - limited options
    - RMA challenges

But the physical problem isn't the same as our problem

Short-term	Medium-term	Long-term
Market will address	**Market should address but how?**	**Market unlikely to address by itself**
• Lots of maturing technologies to solve this problem • Certainty of revenue • Regular cycling • Arbitrage opportunities • Suits small and incremental investments	• Could eventually exhaust hydro potential to manage • Opportunity for something else with medium-term flexibility • Revenue should be certain enough for market to meet the need • But maybe the technology won't be? Unclear what solution will be or when it will arrive • Just because we don't know the answer, doesn't mean there won't be one	• Already a challenging investment case • Renewable options even higher risk • Would need to ramp up the incentives to invest / consequences of not investing • would the result be efficient?

What problem is NZ Battery solving?

Weather-dependent generation creates a need for storage or extra energy input

The investment required is big and high-risk , but the market is small

The market struggles to align incentives to solve the extremes of the issue

… And renewable options are even higher risk

… as no one can really predict the future

Questions for discussion

Does the TRG agree with the problem as laid out?

What does it mean for the design of a NZ Battery?

Today's programme

No	Time	Item	Lead
	8.45am	**Arrival Tea and Coffee**	
1.	9.00am – 9.05am	Welcome / Karakia	Adrian Macey and Hoani Langsbury
2.	9.05am – 9.30am	Project news • Overall update	Andrew M and Adrian T
3.	9.30am – 10.00am	Stakeholder update • Industry meetings / Otago visit update	Maria Hernandez -Curry and Carl Walrond
4.	**10.00am – 10.15am**	**Coffee / Tea break**	
5.	10.15am – 11.30am	Operational Governance • Present first-draft NZ Battery operating models	Conrad Edwards
6.	11.30am – 12.30pm	Other hydro options • Present final GIS Scan and proposed short list of options	Malcolm Schenkel
7.	**12.30pm – 1.00pm**	**Lunch**	
8.	1.00pm – 2.00pm	Freshwater presentation • Next steps for Lake Onslow freshwater investigations	Carl Walrond, Karl Beckert and Kimberley Carter
9.	2.00pm – 2.45pm	Driving the energy transition • Discuss the MBIE wide approach to changing the energy system	Andrew Hume
10.	**2.45pm – 3.00pm**	**Coffee / Tea break**	
11.	3.00pm – 4.00pm	The energy transition and the NZ Battery Project • How we might frame the strategic business case for investment?	Andrew Millar and Bridget Moon
12.	4.00pm – 4.30pm	Q&A Summary	Adrian Macey

ClimateWorks

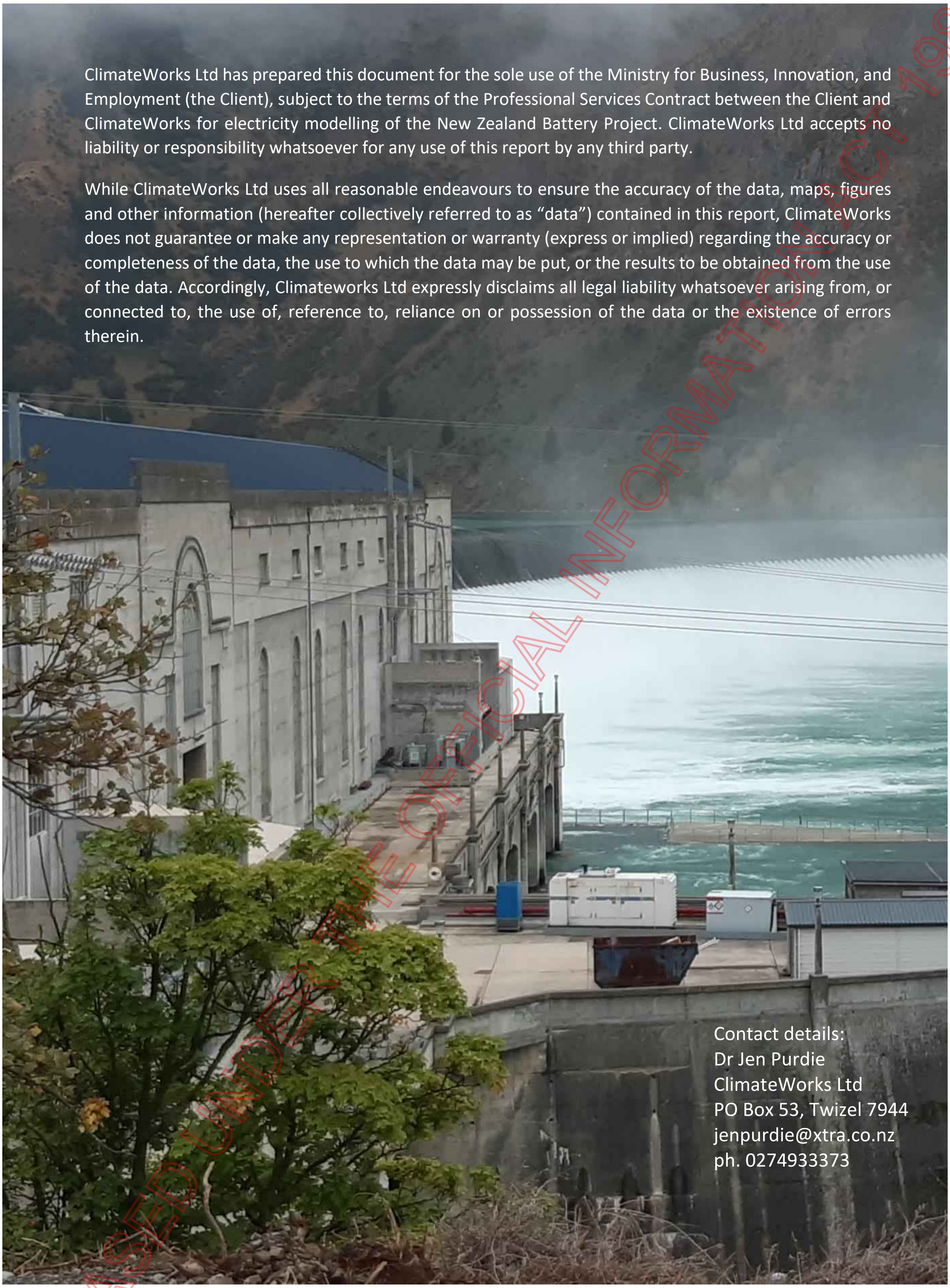
Climate change impacts on New Zealand hydro catchment inflows & wind speeds

- **2020-2050 adjustments to wind and hydro records for electricity modelling purposes**
- **a report to MBIE**

Dr Jen Purdie

ClimateWorks Ltd

February 2022



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Executive summary

Climate change is affecting water resources internationally, and the decarbonisation imperative is resulting in increasing levels of intermittent renewable electricity globally. Electricity demand is also predicted to increase as electrification of transport and industry increases. These factors will have significant impacts on the management of renewable electricity generation. Incorporating knowledge of future changes to wind speeds and water resources under climate change into electricity systems modelling is important as we transition to a 100% renewable electricity future.

In New Zealand, where 55% of electricity currently comes from hydro generation, rainfall in the major South Island hydro lakes is expected to increase in coming decades. The seasonality and volatility of that rainfall is also expected to change. Wind speeds over New Zealand are also expected to increase as atmospheric circulation changes occur over time.

This report outlines research which uses a change factor methodology linked to a model cascade to estimate changes to hydro catchment inflows in 12 regions of New Zealand where electricity is generated from river and lake inflows. A similar methodology is employed to estimate changes to wind resource over time in 12 different regions of New Zealand where wind farms are likely to be located in coming decades.

This report was written for MBIE's New Zealand Battery Project, to assist in their electricity system modelling by providing change factors to historical hydro lake inflows and wind capacity records to represent changes that are likely to occur between current conditions and 2050 conditions. These change factors can be found in Tables 2 and 3.

The results of this modelling, when applied to long term river flow records, show an overall 2% increase in annual hydro catchment inflows over New Zealand between 2020 and 2050. Seasonal impacts are projected to be larger, with total New Zealand hydro catchment inflows projected to be 10% higher in winter and 6% lower in summer by 2050. These seasonal changes are larger in the snow-fed catchments in the South Island, where significant reductions to snow storage are predicted in coming decades. Winter inflows in these catchments are expected to increase by 15 to 26% by mid-century. Summer inflows are expected to decrease by 1 to 10% over this period, with a 4-6% increase in annual flows. These changes are commensurate with other similar studies in the region.

Nationally, annual average wind speeds are predicted to increase in the south of the South Island by mid-century, with the largest annual average change being in Otago (4.2%). In the north of the North Island they are expected to decrease over time, with the biggest annual average reduction in wind speed by mid-century predicted to occur in Auckland (-2.8%). Winter and spring wind speeds in New Zealand are predicted to increase by mid-century, with Summer and Autumn wind speeds expected to decrease.

For both hydro and wind changes out to 2050, the greatest projected impacts are not in annual volume changes, (all of which remain below 5%) but in changes to the seasonal distribution of the arrival of renewable energy "fuel". These changes are generally in a beneficial direction, moving "fuel" from summer arrival now, when it is less needed for generation, to winter arrival in future, when it is more needed. This has significant implications for electricity generation, where the current hydro inflows are anti-correlated with demand.

Contents

1. Introduction

1.1 Climate change

Projected changes to temperatures and rainfall as a result of climate change have been well documented globally (IPCC 2021), and in New Zealand (Ackerly et al 2012, MfE 2018). The impacts of climate change on water resources are highly spatially varied globally, with some areas expected to receive less rainfall and others more in future (Shu et al 2018). Generally, New Zealand is expected to get wetter in the West and South over time, and drier in the North and East (MfE 2018). Temperatures are expected to increase between 0.7 and 1 degree Celsius by mid-century, relative to 1986-2005 (MfE 2018).

Seasonal changes to runoff regimes will be particularly noticeable in future in mountainous regions with significant glacier and snow cover, as changes to both temperature and precipitation are predicted to impact snow cover extent, and therefore melt regimes (Bombelli et al 2018, Soncini et al 2016). Climate change in snow fed catchments is likely to influence both the timing and magnitude of runoff. Many rivers in New Zealand are significantly impacted by snow melt, and in particular the large hydro catchments in the South Island. Snow cover extent in these catchments is projected to reduce by approximately 20% by the 2040s, and 40% to 80% by the 2090s (Hendrikx et al 2012).

A phenomenon of reducing wind speeds internationally called “global stilling” has been observed since the 1980s, but has been noted to have changed direction about a decade ago, and projections are generally for increased wind speeds in future (Kim & Paik 2015, Zeng et al 2019). The impacts of climate change on wind speeds are still an area of active research, and changes to wind speeds are expected to be spatially diverse (Moemken et al 2018, Chang et al 2015). Potential changes to wind speeds, combined with the expected large growth in wind capacity globally, results in a growing need to understand likely changes in wind resource. The error surrounding projections of wind from Global Circulation Models and downscaling from Regional Climate Models is higher than for rainfall or temperature projections (Solaun & Cerda 2019). Despite this, they are still the most trusted source for projections (Fant & Strzepek 2019). Less research has been published on wind projections in New Zealand than on rainfall and temperature projections.

1.2 Energy

Energy production in hydro catchments globally has been shown to decrease under climate change in parts of the world, due to decreases in rainfall, while other studies have projected increases to production (Bombelli et al 2018, Vliet et al 2016). Seasonal changes to energy generation due to seasonal changes in streamflow under climate change have also been projected (Vicuna et al 2011, Savelsberg et al 2018), and changes to wind energy capacity due to changes in wind speeds is projected (Carvalho et al 2017, Chang et al 2015, Moemken et al 2018, Tobin et al 2015).

This report conveys the results of research that has been conducted to quantify the expected changes to wind and hydro lake inflows in New Zealand between 2020 and 2050, for electricity modelling purposes. The report was commissioned by MBIE’s New Zealand Battery Project. The research outlined here was begun at Meridian Energy Ltd, and is being continued at the University of Otago, under the project: “Simulation of climate change impacts on the New Zealand energy system”, a Deep South Science Challenge funded project (MBIE contract number C01X19011).

2. Hydro lake inflow projections

In this study a modelling chain is applied, which is based on the combined use of Global Circulation Model (GCM) and Regional Climate Model (RCM) output of rainfall projections (Ackerley et al 2012), snow model output of melt estimates (Fitzharris & Garr 1995), projections of changes to snow water equivalent in the New Zealand mountains under climate change (Hendrikx et al 2012), and a Change Factor Model (CFM) to predict lake inflows. This chain of models is used to project changes to hydro catchment inflows in twelve hydrological regions around New Zealand, for each week, for the period 2020-2050.

2.1 Methodology

2.1.1 Study Area

LPCon (Meridian Energy owned electricity system model licensed to University of Otago for use) synthesises generation from forty different hydro electricity generation stations, but for modelling purposes each station is allotted to one of twelve distinct hydrological regions throughout New Zealand. The twelve hydrological regions can be seen in figure 1. The term "RoR" denotes "run of river", which generally denotes a region with run of river hydro stations, and little hydro storage.

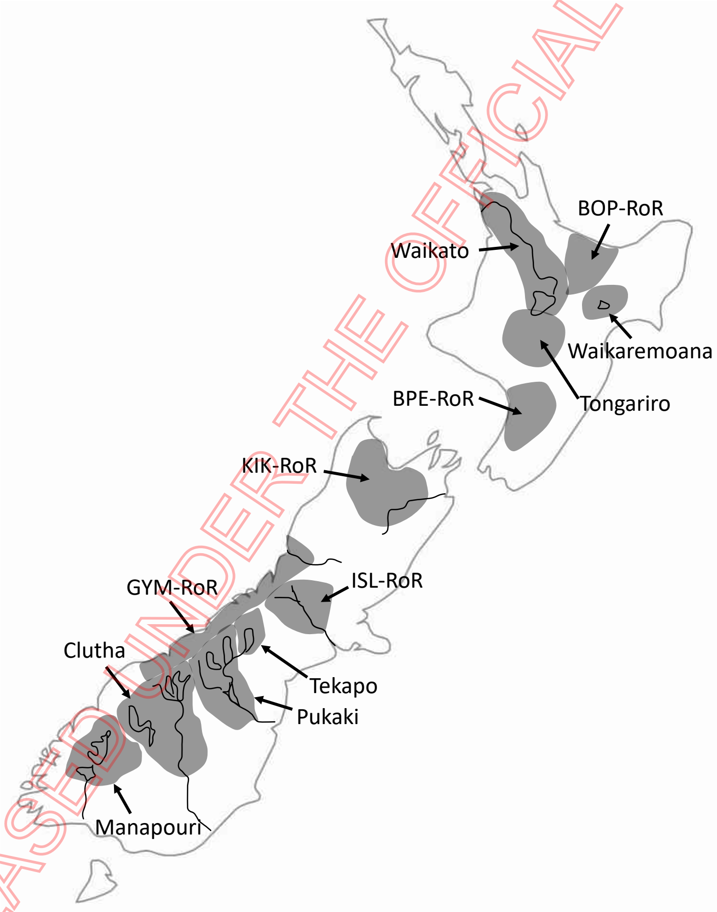


Figure 1: Locations of the 12 New Zealand hydro catchment regions used in this study

Some LPCon regions used projections from more than one National Institute of Water and Atmosphere (NIWA) region. In these cases NIWA projections from constituent regions are averaged to create LPCon region rainfall projections. This methodology acknowledges the spatial coherence of river flow records within regions, and also the regional nature of projected climate change impacts. Each of the 12 regions has an 87 year history of observed hydrological flows.

2.1.2 Rainfall changes

The International Panel on Climate Change (IPCC) uses five Shared Socioeconomic Pathways (SSPs 1-5) to represent the impact on the climate from low (1) to high (5) emissions pathways. The Sixth Assessment Report (AR6) (IPCC 2021) scientific literature denotes SSP2 as the most likely scenario. This pathway has a radiative forcing of 4.5 Wm^{-2} (equivalent to Representation Concentration Pathway (RCP) 4.5 from IPCC (2013) and IPCC (2014)) and a projected temperature range by end of century of 2.5-2.7 degC above pre-industrial levels. This study uses this "most likely" middle of the road scenario as the basis for river flow projections, and refers to it in this document as "RCP4.5".

To estimate the impact of climate change on New Zealand, NIWA derives data from six GCMs, for the four RCPs, as part of the Coupled Model Intercomparison Project Phase 5 (CMIP5) (IPCC 2013). The global models have a resolution of approximately 100-300km, and GCM output variables are downscaled initially with the HadRM3P regional atmosphere model (resolution ~27km) (Ackerley et at 2012, Sood and Mullan 2020). This process produces projections of such variables as rainfall and temperature out to 2100, to enable the closer examination of the regional impacts of climate change (MfE 2018, NIWA 2022).

2.1.3 Snow melt changes

Snow accumulation and melt is modelled using Snowsim, a model that calculates seasonal snow accumulation and ablation in the Southern Alps, New Zealand (Fitzharris and Garr 1995). The model is based on daily temperature and precipitation data from long-established climate stations proximal to the Southern Alps. Output is given as a daily specific net balance of Snow Water Equivalent (SWE) stored at five elevation bands from 1000 to >2200 metres over several major river catchments. Daily decreases to modelled storage of snow water equivalent are used as daily melt estimates for this study for the snow-fed catchments of the Waitaki, Clutha, and Waiau rivers.

Recent estimates (1998-2018) of daily melt (in GWh) from Snowsim at different times of the year for the Waitaki catchment are used as the baseline measure of snow melt in the catchment. Under climate change, some of the water that would historically have melted from the snowpack in summer will appear as throughflow in winter instead. Using the average estimate of a 25% reduction in snow water equivalent (SWE) by 2050 (from Hendrik et al 2012), 25% of modelled melt water is redistributed from summer melt water to winter throughflow in the projected 2050 inflow record. The water is subtracted from the historical inflow record proportionate to the rate it would have melted (in summer), and redistributed to the 2050 projected inflows proportionate to the rate it would have accumulated in the recent past (in winter).

South Island glacial ice melt input to hydro lake inflows is predicted to remain fairly constant in coming decades (Anderson et al 2021), so is not explicitly accounted for here.

2.1.4 Floods

Flood volumes in New Zealand's Southern Alps are expected to increase in coming decades, but significant uncertainty exists around the magnitude of these changes (MfE 2018). An increase of 1 degC of a parcel of air results in an 8% increase in moisture carrying ability of that air (MfE 2008). In addition to this thermal forcing, dynamic forcing is likely with increased wind speeds, projected in coming decades (MfE 2018), expected to enhance orographic uplift and spillover over the Southern Alps (Sinclair et al 1997).

The combined result of the above climate change forcing is that larger extreme rain volumes are expected in the headwaters of the South Island hydro catchments in future, and therefore bigger floods are expected in the Waitaki catchment in coming decades (MfE 2008, Collins 2020). A recommended conservative estimate for modelling purposes (MfE 2010) is that most rain events are likely to be 8% larger under a 1 degree warming from current temperatures, which is expected by mid-century (MfE 2010). This methodology is adopted for this study, and the historical inflow records are adapted for 2050 conditions by increasing peaks and rising and falling limbs of flood hydrographs by 8%, as a 1 degree temperature increase over recent antecedent conditions is expected by 2050 (MfE 2018).

Generally, little change in drought depth or duration is expected in New Zealand's largest hydro catchments over the next 3 decades (MfE 2018) (although drier conditions ARE projected in parts of the East Coast and Northland in the future). Therefore low flows in the hydro catchments are not particularly adjusted for, except for the mean flow adjustments already discussed.

2.1.5 Model cascade methodology

A model cascade is employed to encapsulate climate change impacts in the 2050 projected inflow record for each regional dataset. This process is outlined in figure 2.

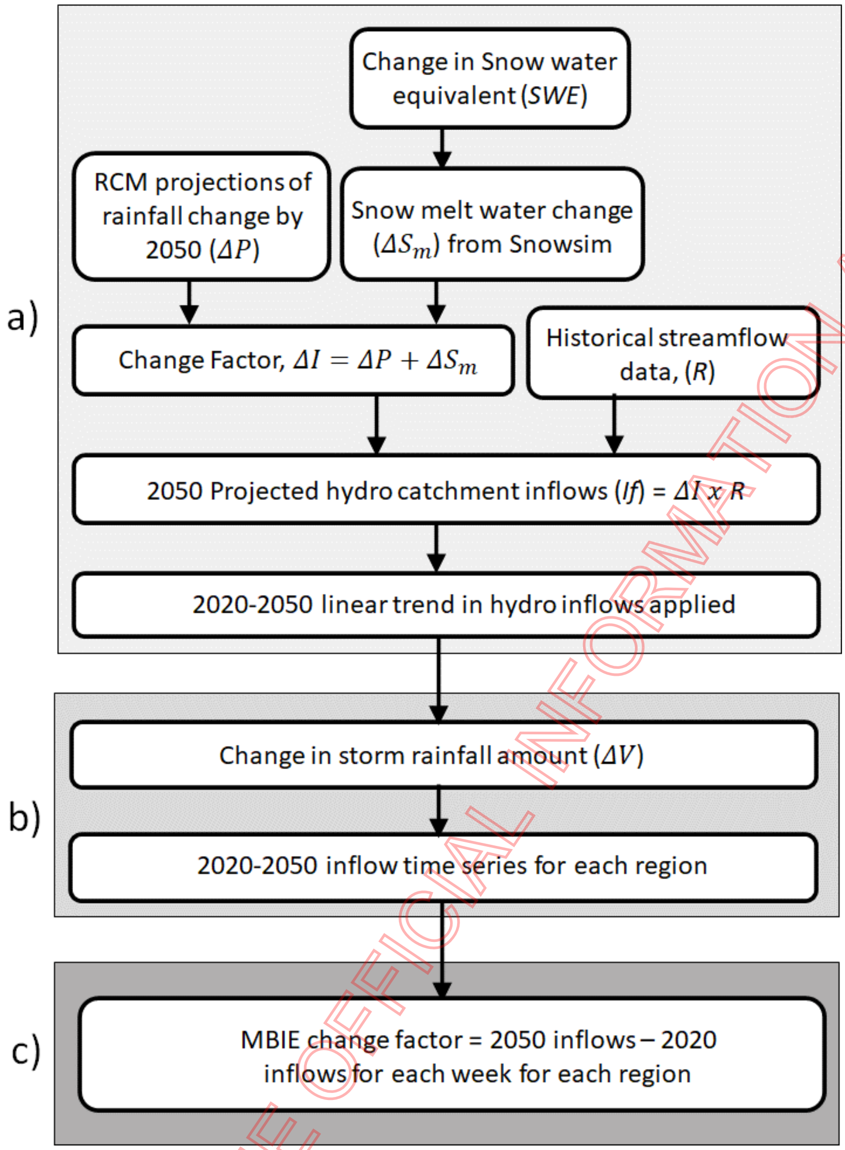


Figure 2: the model cascade for determining projected 2050 hydro catchment inflows for input to the LPCon, and the electricity system inputs and outputs, for each hydro catchment region, for each week of the year. a) is the process to capture seasonal and annual changes to inflows, b) is the process to capture increased short term rainfall amounts, and c) is the conversion from a 30 year hydro catchment inflow time series to a change factor that MBIE can apply to their own river flow records.

a) seasonal and annual changes to inflows from rainfall and snow melt:

Firstly, multiplicative change factors are used to encapsulate the seasonal and annual changes to inflows from projected changes to rainfall and snow melt. These are calculated using the following general equations, for each region and each week of the 2050 year (relative to recent history):

$$CF(\Delta I)_i = \frac{Future_i}{Base_i} \quad \text{(Eq. 1)}$$

$$If_i = CF(\Delta I)_i \times R_i \quad \text{(Eq. 2)}$$

where $CF(\Delta I)_i$ is the multiplicative change factor (in this case change in inflows, ΔI), for the ith time step (week) in the future time period, which is a ratio calculated from the difference between the future value and the base value for each constituent variable (in this case, seasonal rainfall (ΔP) and snow melt (ΔS_m), summed). If_i is future (2050) inflow for the ith time step (week), and R_i is the recent historical average inflow (adapted from Hansen 2017).

b) increased rainfall amounts:

Secondly, increased volatility is incorporated to represent projected increases to rainfall events. A representation of projected changes to flood peaks is important to assess the ability of the hydro storage lake to capture and store inflows, and to optimise generation and minimise spill in future. However, adjustments to annual and seasonal changes to rainfall and snow melt have already been addressed in step a). Therefore when 2050 inflow events are increased by 8% relative to the historical record, a corresponding amount is taken out of the inflow "troughs", so that seasonal and annual totals are not changed again. An example of a one year period (2020-2021) of the weekly Lake Pukaki inflow record with adjustments applied can be seen in figure 3.

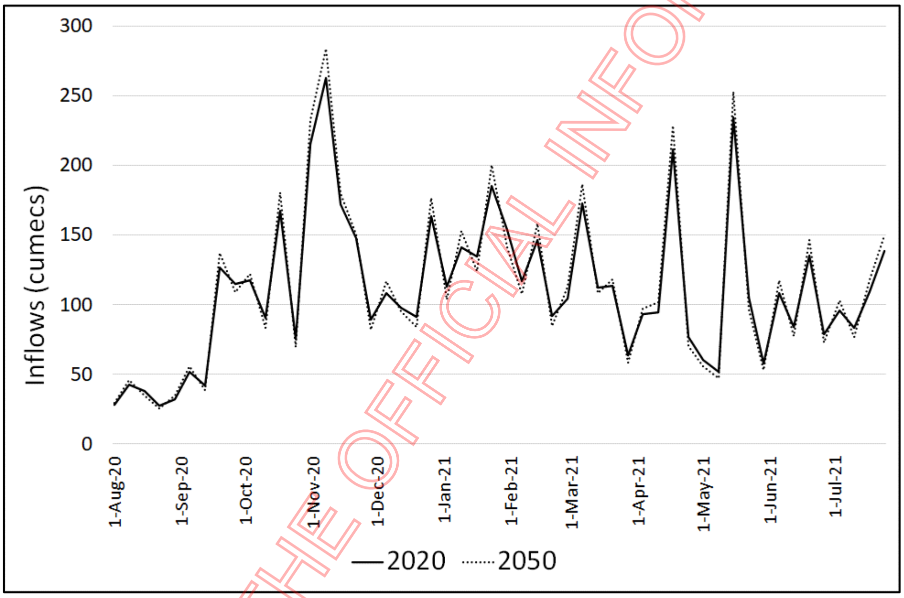


Figure 3: Lake Pukaki weekly mean inflows (cumecs) Aug 2020 to July 2021, and inflows adjusted to make inflow peaks 8% larger (and troughs 8% smaller)

These 8% changes are applied to the 2050 weekly record. A linear trend is applied to adapt the 2020-2050 record, from 0% change in volatility in 2020, to 8% change by 2050, for each region.

It should be noted that the only change to annual volume of water into catchments is precipitation changes from RCM projections. Changes to volatility and snow melt simply redistribute catchment inflows in time. However, this redistribution in time is particularly important in relation to electricity generation modelling, as hydro storage capacity is limited, flood events are optimally captured in storage rather than spilled, and seasonal hydro inflows are currently anti-correlated with demand, with peak inflows occurring in summer and peak demand occurring in winter.

2.2 Results

2.2.1 Rainfall projections

Rainfall changes for each region, for each week of 2050 relative to 2020, can be seen in Table 1.

Table 1: Change in rainfall (%) in each of the LPCon regions 2020 – 2050, and their constituent rainfall projection region from NIWA 2022.

LPCon region	Manapouri	Clutha	Pukaki	Tekapo	GYM-RoR	ISL-RoR	KIK-RoR	BPE-RoR	Tongariro	Waikaremoana	BOP-RoR	Waikato
Niwa (2022) region used	Queenstown / Invercargill	Queenstown	Westport	Westport	Westport	Westport	Nelson/ Westport	Wellington / New Plymouth	Taupo	Napier	Tauranga	Taupo
1-Jul	4.5	4.2	3.4	3.4	3.4	3.4	3.1	0.8	0.5	0.1	-0.5	0.5
8-Jul	4.6	4.3	3.6	3.6	3.6	3.6	3.3	0.7	0.5	0.0	-0.6	0.5
15-Jul	4.7	4.4	3.7	3.7	3.7	3.7	3.3	0.7	0.6	-0.1	-0.7	0.6
22-Jul	4.7	4.3	3.6	3.6	3.6	3.6	3.2	0.6	0.5	-0.1	-0.8	0.5
29-Jul	4.5	4.1	3.4	3.4	3.4	3.4	3.0	0.5	0.4	-0.3	-0.9	0.4
5-Aug	4.3	3.9	3.1	3.1	3.1	3.1	2.6	0.2	0.2	-0.6	-1.1	0.2
12-Aug	4.1	3.6	2.7	2.7	2.7	2.7	2.1	0.0	0.0	-0.9	-1.2	0.0
19-Aug	3.7	3.2	2.2	2.2	2.2	2.2	1.6	-0.3	-0.3	-1.2	-1.4	-0.3
26-Aug	3.4	2.8	1.6	1.6	1.6	1.6	1.0	-0.7	-0.6	-1.5	-1.6	-0.6
2-Sep	3.0	2.2	1.0	1.0	1.0	1.0	0.2	-1.0	-0.9	-2.0	-1.9	-0.9
9-Sep	2.7	1.8	0.4	0.4	0.4	0.4	-0.4	-1.4	-1.2	-2.3	-2.1	-1.2
16-Sep	2.4	1.5	0.0	0.0	0.0	0.0	-0.9	-1.7	-1.5	-2.6	-2.3	-1.5
23-Sep	2.1	1.1	-0.5	-0.5	-0.5	-0.5	-1.4	-1.9	-1.7	-2.9	-2.4	-1.7
30-Sep	1.8	0.8	-0.8	-0.8	-0.8	-0.8	-1.8	-2.1	-1.9	-3.1	-2.6	-1.9
7-Oct	1.7	0.6	-1.1	-1.1	-1.1	-1.1	-2.0	-2.3	-2.0	-3.2	-2.6	-2.0
14-Oct	1.6	0.6	-1.2	-1.2	-1.2	-1.2	-2.1	-2.3	-2.1	-3.2	-2.6	-2.1
21-Oct	1.6	0.5	-1.2	-1.2	-1.2	-1.2	-2.1	-2.3	-2.1	-3.2	-2.6	-2.1
28-Oct	1.6	0.6	-1.1	-1.1	-1.1	-1.1	-2.0	-2.2	-2.1	-3.0	-2.4	-2.1
4-Nov	1.6	0.6	-1.0	-1.0	-1.0	-1.0	-1.8	-2.1	-2.0	-2.7	-2.2	-2.0
11-Nov	1.6	0.7	-0.9	-0.9	-0.9	-0.9	-1.5	-1.9	-1.9	-2.3	-2.0	-1.9
18-Nov	1.6	0.8	-0.7	-0.7	-0.7	-0.7	-1.1	-1.7	-1.8	-1.8	-1.6	-1.8
25-Nov	1.7	1.0	-0.4	-0.4	-0.4	-0.4	-0.7	-1.5	-1.7	-1.3	-1.3	-1.7
2-Dec	1.7	1.1	-0.2	-0.2	-0.2	-0.2	-0.3	-1.2	-1.6	-0.8	-0.9	-1.6
9-Dec	1.8	1.3	0.1	0.1	0.1	0.1	0.1	-1.0	-1.5	-0.3	-0.6	-1.5
16-Dec	1.8	1.4	0.3	0.3	0.3	0.3	0.5	-0.8	-1.4	0.2	-0.3	-1.4
23-Dec	1.8	1.5	0.4	0.4	0.4	0.4	0.8	-0.6	-1.3	0.6	0.0	-1.3
30-Dec	1.9	1.6	0.6	0.6	0.6	0.6	1.0	-0.4	-1.2	0.9	0.3	-1.2
6-Jan	1.9	1.6	0.6	0.6	0.6	0.6	1.2	-0.3	-1.2	1.2	0.4	-1.2
13-Jan	1.9	1.6	0.7	0.7	0.7	0.7	1.2	-0.2	-1.1	1.3	0.5	-1.1
20-Jan	1.8	1.6	0.6	0.6	0.6	0.6	1.2	-0.2	-1.1	1.3	0.6	-1.1
27-Jan	1.8	1.6	0.6	0.6	0.6	0.6	1.2	-0.1	-1.1	1.4	0.7	-1.1
3-Feb	1.7	1.6	0.4	0.4	0.4	0.4	1.1	0.0	-1.2	1.4	0.8	-1.2
10-Feb	1.7	1.5	0.3	0.3	0.3	0.3	1.0	0.1	-1.2	1.5	0.8	-1.2
17-Feb	1.6	1.4	0.1	0.1	0.1	0.1	0.8	0.2	-1.2	1.5	0.9	-1.2
24-Feb	1.5	1.3	-0.2	-0.2	-0.2	-0.2	0.6	0.3	-1.2	1.5	1.0	-1.2
2-Mar	1.3	1.3	-0.4	-0.4	-0.4	-0.4	0.4	0.4	-1.3	1.5	1.1	-1.3
9-Mar	1.2	1.2	-0.7	-0.7	-0.7	-0.7	0.2	0.5	-1.3	1.5	1.2	-1.3
16-Mar	1.2	1.1	-0.9	-0.9	-0.9	-0.9	0.0	0.6	-1.3	1.6	1.3	-1.3
23-Mar	1.1	1.0	-1.0	-1.0	-1.0	-1.0	-0.1	0.7	-1.3	1.6	1.3	-1.3
30-Mar	1.0	1.0	-1.1	-1.1	-1.1	-1.1	-0.2	0.8	-1.3	1.6	1.4	-1.3
6-Apr	1.0	1.0	-1.2	-1.2	-1.2	-1.2	-0.2	0.8	-1.3	1.6	1.4	-1.3
13-Apr	1.1	1.0	-1.2	-1.2	-1.2	-1.2	-0.2	0.9	-1.3	1.5	1.4	-1.3
20-Apr	1.1	1.1	-1.1	-1.1	-1.1	-1.1	-0.2	0.9	-1.3	1.5	1.4	-1.3
27-Apr	1.3	1.3	-0.8	-0.8	-0.8	-0.8	0.0	0.9	-1.2	1.4	1.3	-1.2
4-May	1.6	1.5	-0.5	-0.5	-0.5	-0.5	0.3	0.9	-1.0	1.3	1.1	-1.0
11-May	1.9	1.8	0.0	0.0	0.0	0.0	0.6	0.9	-0.9	1.2	1.0	-0.9
18-May	2.3	2.2	0.4	0.4	0.4	0.4	1.0	0.9	-0.7	1.1	0.8	-0.7
25-May	2.7	2.5	1.0	1.0	1.0	1.0	1.4	0.9	-0.5	0.9	0.5	-0.5
1-Jun	3.1	3.0	1.6	1.6	1.6	1.6	1.8	0.8	-0.2	0.7	0.3	-0.2
8-Jun	3.5	3.3	2.2	2.2	2.2	2.2	2.2	0.8	0.0	0.5	0.0	0.0
15-Jun	3.9	3.7	2.7	2.7	2.7	2.7	2.6	0.8	0.2	0.4	-0.2	0.2
22-Jun	4.2	4.0	3.1	3.1	3.1	3.1	2.9	0.8	0.3	0.3	-0.3	0.3

As the table generally moves from south (left of table) to north (right of table). It can be seen that rainfall generally gets wetter in the South and West over time, and drier in the North and East. The biggest seasonal shifts in rainfall occur in the Pukaki, Tekapo, GYM-RoR and ISL-RoR regions (drier in spring and autumn, and wetter in winter), as well as the Waikaremoana and BOP-RoR regions (drier in spring, wetter in autumn). The biggest absolute change is a 4.7% increase in July rainfall in the Manapouri catchment by 2050, and the biggest negative change is a move to 3.2% drier in Waikaremoana in spring.

2.2.2 Snow melt projections

Snow melt adjustments are needed for the Waitaki (Pukaki, Tekapo), Clutha, and Waiau regions, because these regions have a non-negligible portion of annual lake inflows derived from snow melt (McKerchar et al 1998, Kerr 2013). Other regions did not need adjustments for snow melt changes, as it is assumed there is negligible or no snow melt portion to inflows.

Figure 4 shows the average modelled snow accumulation and ablation rates from Snowsim for the Waitaki catchment. These rates of accumulation and ablation are used to redistribute the snow melt water in the modelling.

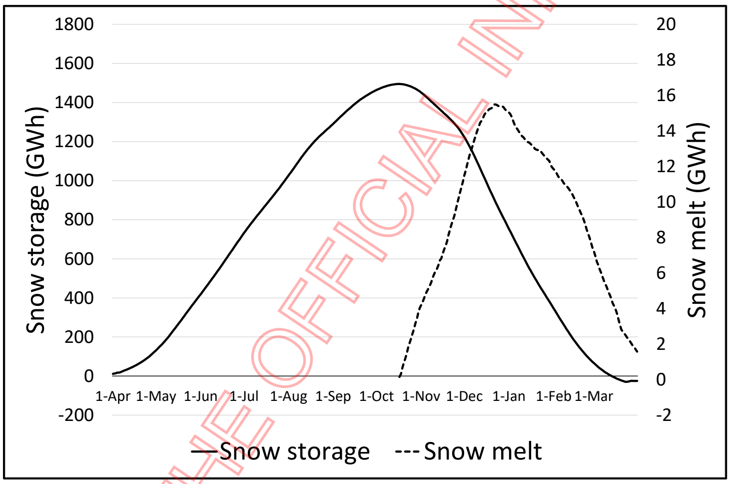


Figure 4: average modelled snow storage (solid line) and melt (dashed line) rates for the Waitaki catchment, 1998-2018, from Snowsim, in GWh.

Following Hendrikx et al (2012) projections of changes to snow pack over time, twenty-five percent of snow melt in the Waitaki, Clutha, and Waiau catchments is subtracted from the historical inflow record proportionate to the rate it would have melted, and redistributed to the 2050 projected inflows proportionate to the rate it would have accumulated in the recent past. This adjustment results in rain water flowing through into the hydro lakes in winter rather than in summer. The proportion of snow melt redistributed in each of the snow fed catchments is shown in figure 5.

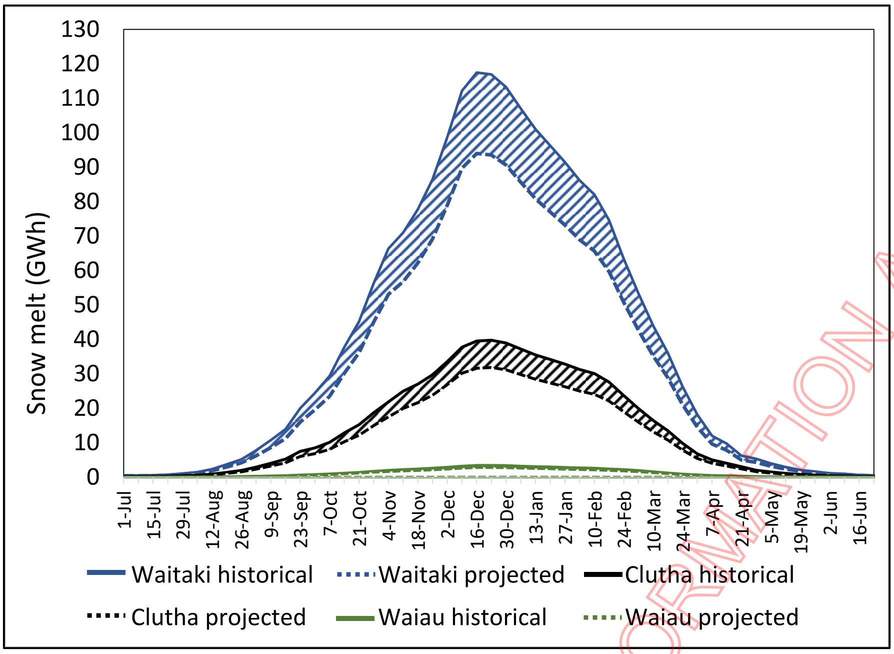


Figure 5: Historical modelled snow melt in the Waitaki, Clutha, and Waiau catchments (GWh) from Snowsim, and projected 2050 snow melt. Shaded areas show volume of water needing seasonal redistribution.

The reassigned snow melt water equated to 409 GWh of water in the Waitaki catchment, 146GWh in the Clutha catchment, and 13 GWh in the Waiau catchment. The 409 GWh that needed to be redistributed seasonally in the Waitaki catchment is assigned to the Tekapo and Pukaki catchments proportional to their average annual inflows, so 60% of the 409 GWh of melt water (245 GWh) is redistributed in the Pukaki catchment, and 40% of the 409 GWh (164 GWh) is redistributed in the Tekapo catchment.

Water is expressed as GWh of potential energy in this study to align with the use of the electricity system model. A GWh of water in a given catchment is the amount of water that results in 1GWh being generated when the water is routed through the generation turbines in that catchment.

2.2.3 Inflow projections

Following the Change Factor Methodology outlined in the methods section, change factors for each week of each of the twelve LPCon regions are calculated. These can be seen in Table 2. These change factors are applied to each of the 87 historical hydro sequences for 2050. A linear trend is then applied between each hydro sequence in 2020 and that hydro sequence in 2050.

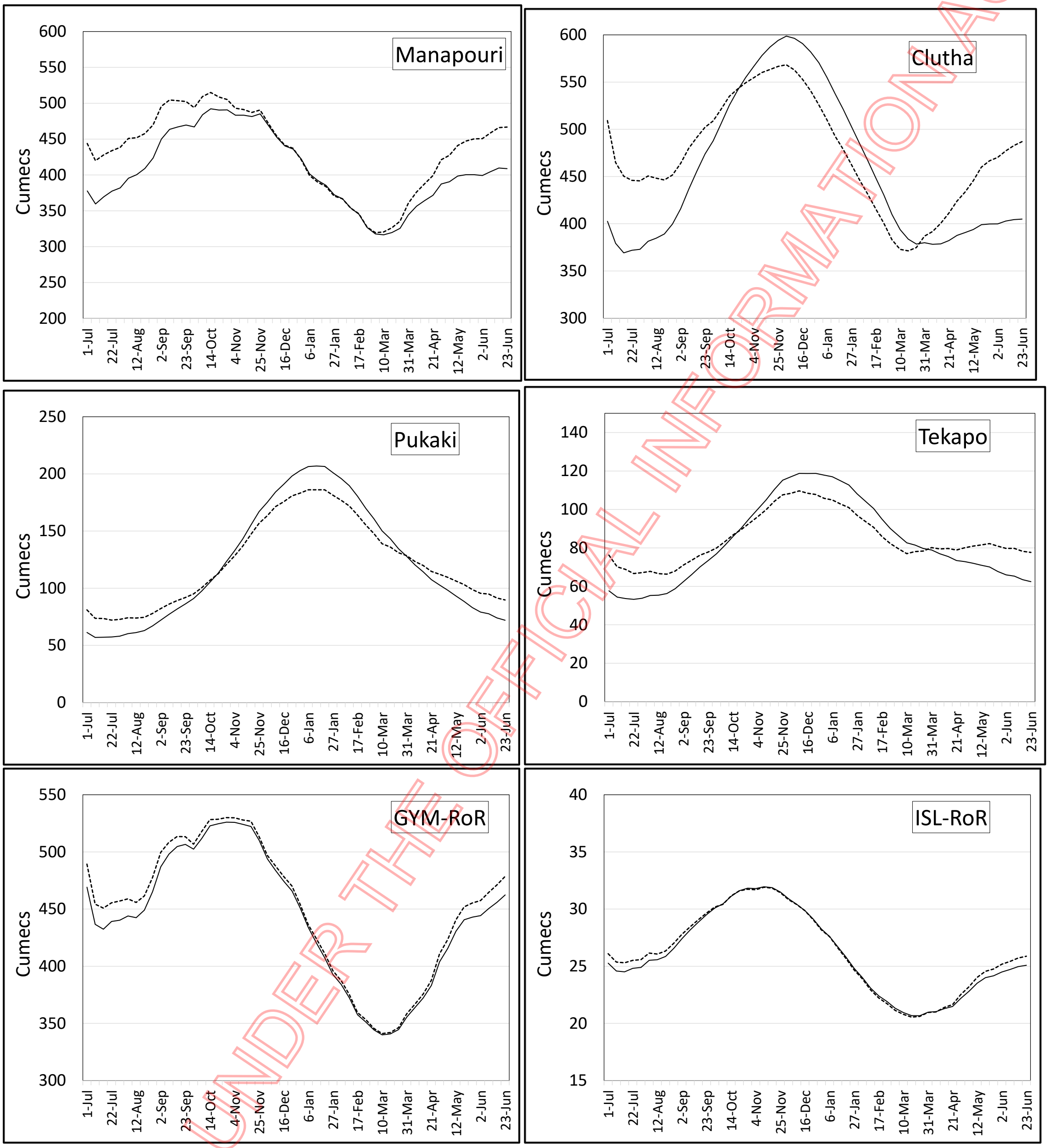
The biggest changes between 2020 and 2050 inflows are seen in the seasonal adjustments to inflows in the snow fed catchments of Manapouri, Clutha, Pukaki, and Tekapo. Although all regions showed reductions in inflows in spring and summer and increases in winter, the timing and magnitude of these changes varied from region to region.

Table 2: Inflow change factors for each LPCon catchment and week of the year (% change)

Week	Manapouri	Clutha	Pukaki	Tekapo	GYM-RoR	ISL-RoR	KIK-RoR	BPE-RoR	Tongariro	Waikaremoana	BOP-RoR	Waikato
1-Jul	18%	27%	32%	32%	4%	3%	3%	2%	1%	3%	-1%	2%
8-Jul	17%	23%	29%	29%	4%	3%	3%	2%	1%	3%	-1%	2%
15-Jul	16%	22%	29%	28%	4%	3%	3%	2%	1%	3%	-1%	2%
22-Jul	16%	21%	27%	27%	4%	3%	3%	2%	1%	2%	-2%	1%
29-Jul	15%	19%	25%	24%	4%	3%	3%	2%	0%	2%	-2%	1%
5-Aug	14%	17%	23%	22%	3%	2%	2%	2%	0%	2%	-2%	1%
12-Aug	14%	17%	22%	22%	3%	2%	2%	2%	0%	1%	-2%	0%
19-Aug	13%	16%	21%	20%	3%	2%	2%	2%	0%	1%	-2%	0%
26-Aug	12%	15%	19%	18%	3%	2%	2%	1%	-1%	0%	-2%	0%
2-Sep	11%	13%	16%	15%	2%	1%	1%	1%	-1%	0%	-3%	-1%
9-Sep	9%	11%	13%	12%	2%	1%	1%	1%	-1%	0%	-3%	-1%
16-Sep	8%	10%	11%	10%	2%	1%	0%	0%	-2%	-1%	-3%	-1%
23-Sep	7%	8%	9%	9%	1%	1%	0%	0%	-2%	-1%	-3%	-2%
30-Sep	6%	6%	6%	5%	1%	0%	0%	0%	-2%	-1%	-3%	-2%
7-Oct	5%	3%	3%	3%	1%	0%	-1%	0%	-2%	-1%	-4%	-2%
14-Oct	3%	1%	1%	0%	1%	0%	-1%	0%	-2%	-1%	-3%	-2%
21-Oct	3%	0%	-1%	-1%	1%	0%	-1%	0%	-2%	-1%	-3%	-2%
28-Oct	2%	-2%	-2%	-3%	1%	0%	-1%	0%	-2%	-1%	-3%	-2%
4-Nov	2%	-3%	-4%	-4%	1%	0%	-1%	0%	-2%	-1%	-3%	-2%
11-Nov	1%	-4%	-5%	-6%	1%	0%	-1%	0%	-2%	-1%	-3%	-2%
18-Nov	1%	-5%	-6%	-7%	1%	0%	-1%	0%	-2%	-1%	-3%	-2%
25-Nov	0%	-5%	-7%	-8%	1%	0%	-1%	0%	-2%	0%	-3%	-2%
2-Dec	1%	-6%	-7%	-8%	1%	0%	-1%	1%	-2%	0%	-3%	-2%
9-Dec	0%	-6%	-7%	-8%	1%	0%	-1%	1%	-2%	1%	-3%	-2%
16-Dec	0%	-6%	-8%	-9%	1%	0%	0%	1%	-2%	1%	-2%	-2%
23-Dec	0%	-6%	-8%	-9%	1%	0%	0%	1%	-2%	2%	-2%	-1%
30-Dec	0%	-6%	-8%	-9%	1%	0%	0%	2%	-2%	2%	-2%	-1%
6-Jan	0%	-7%	-9%	-10%	1%	0%	0%	2%	-1%	3%	-2%	-1%
13-Jan	0%	-8%	-10%	-11%	1%	0%	0%	2%	-1%	3%	-1%	-1%
20-Jan	-1%	-9%	-11%	-12%	1%	0%	0%	2%	-1%	4%	-1%	-1%
27-Jan	-1%	-10%	-12%	-12%	1%	-1%	0%	2%	-1%	5%	-1%	-1%
3-Feb	-2%	-10%	-12%	-12%	1%	-1%	1%	3%	-1%	5%	-1%	-1%
10-Feb	-1%	-11%	-12%	-12%	1%	-1%	0%	3%	-1%	6%	-1%	-1%
17-Feb	-1%	-10%	-12%	-12%	1%	-1%	0%	3%	-1%	7%	-1%	0%
24-Feb	0%	-8%	-10%	-10%	1%	-1%	0%	3%	-1%	7%	0%	0%
2-Mar	0%	-6%	-8%	-8%	0%	-1%	0%	4%	-1%	7%	0%	0%
9-Mar	2%	-4%	-5%	-5%	0%	-1%	0%	4%	-1%	7%	0%	0%
16-Mar	2%	-2%	-4%	-4%	0%	-1%	0%	4%	-1%	7%	0%	0%
23-Mar	3%	-1%	-2%	-2%	1%	0%	0%	4%	-1%	7%	0%	0%
30-Mar	3%	1%	0%	0%	1%	0%	0%	4%	0%	7%	0%	0%
6-Apr	5%	2%	2%	3%	1%	0%	0%	4%	0%	7%	0%	0%
13-Apr	5%	4%	5%	5%	1%	0%	1%	4%	0%	6%	0%	0%
20-Apr	7%	7%	8%	8%	1%	1%	1%	4%	0%	6%	0%	1%
27-Apr	8%	9%	11%	10%	2%	1%	2%	4%	1%	6%	0%	1%
4-May	9%	11%	14%	13%	2%	2%	2%	4%	1%	5%	0%	1%
11-May	10%	14%	16%	15%	2%	2%	2%	3%	1%	5%	0%	1%
18-May	12%	15%	19%	18%	3%	2%	2%	3%	1%	5%	0%	1%
25-May	13%	17%	21%	20%	3%	3%	2%	3%	1%	4%	0%	2%
1-Jun	14%	19%	23%	23%	3%	3%	3%	3%	1%	4%	0%	2%
8-Jun	15%	21%	26%	26%	3%	3%	3%	3%	1%	4%	0%	2%
15-Jun	15%	22%	27%	28%	3%	3%	3%	3%	1%	4%	0%	2%
22-Jun	16%	22%	28%	28%	4%	3%	3%	2%	1%	4%	-1%	2%

Increased volatility is then applied to the daily time series, enhancing inflow peaks and reducing inflow troughs by a commensurate amount. The resulting inflow records are formed for 12 hydrological regions, for 87 hydrological scenarios, on a weekly time resolution, for the period 2020-2050.

Summary graphs of the inflows for each region in 2020 and 2050 can be seen in figure 6.



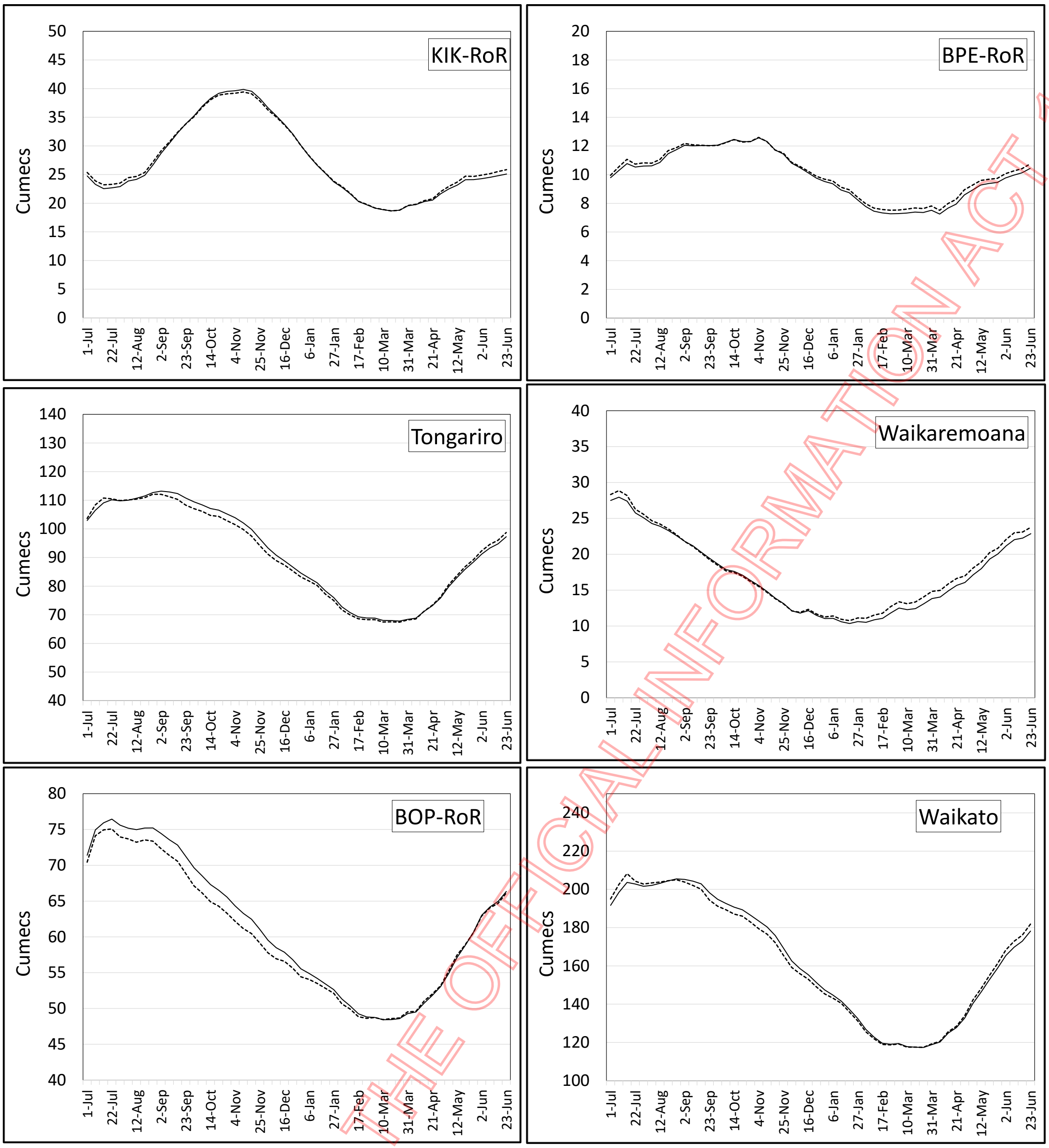


Figure 6: Current (solid line) and 2050 (dotted line) smoothed average weekly hydro lake inflows for 12 hydrological regions, in cumecs. Note different x-axis scales.

Using regionalised k-factors for each hydrological region (calculated from known k-factors for each constituent hydro scheme within the region), cumec values are converted to GWh of potential energy for input into LPCon.

The total change, in GWh, of New Zealand hydro inflows between 2020 and 2050 is shown in figure 7.

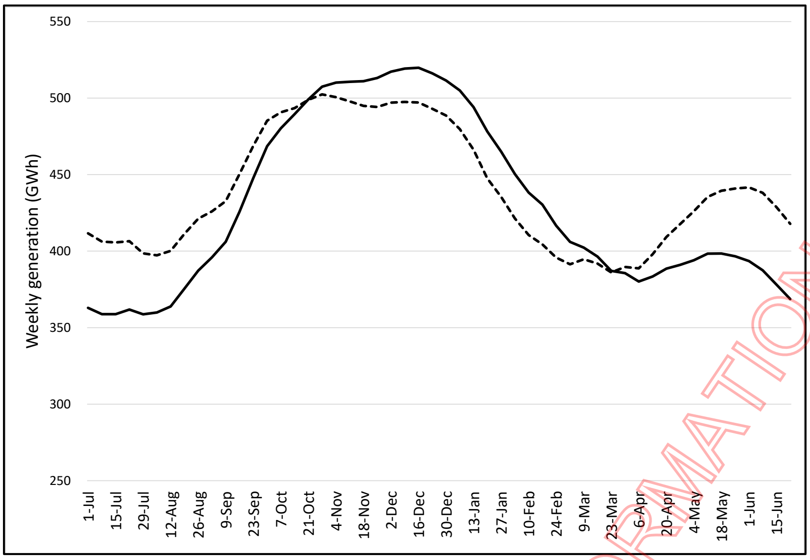


Figure 7: Total weekly New Zealand hydro inflows (smoothed), averaged over all 87 hydrological scenarios, 2020 (solid line) vs 2050 (dashed line).

Annual New Zealand total hydro catchment inflows (approx. 23,000 GWh) are projected to increase by 2% by 2050 (to 23,500), which equates to an increase of 500 GWh. This is significant when compared with the total annual generation in 2020 of 43,000 GWh.

However, it is projected that seasonal impacts will be larger, with total New Zealand hydro catchment inflows projected to be 10% higher in winter and 6% lower in summer (see figure 8).

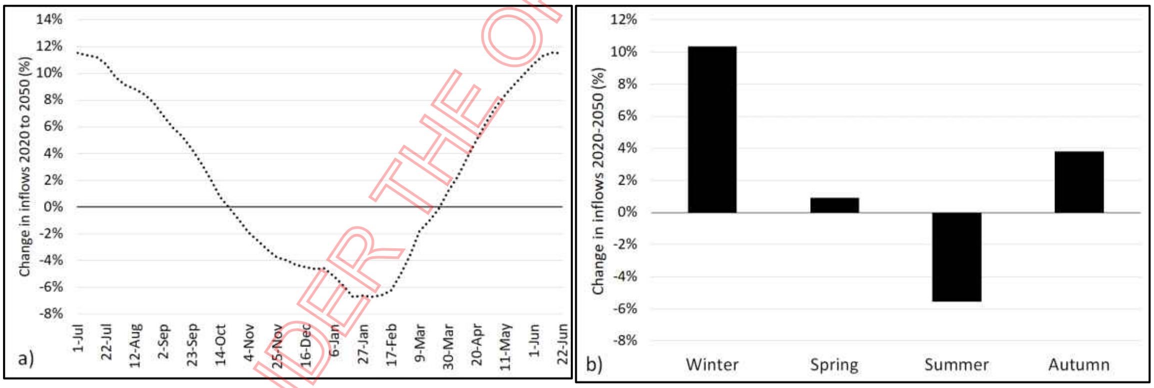


Figure 8: Difference between total weekly New Zealand hydro inflows in 2020 and in modelled 2050 inflows, with a) weekly smoothed differences, and b) seasonal total differences.

3. Wind capacity projections

The methodology applied by NIWA to project changes to wind speeds is the same applied to projecting temperature and rainfall changes, and involves downscaling GCM outputs with an RCM, as outlined in the previous section.

Projected changes to wind speeds over New Zealand in the next few decades are closely linked to changes to atmospheric circulation as a result of climate change. Mean sea level pressure (MSLP) is projected to increase in summer, especially to the south-east of New Zealand, leading to more north-easterly airflow in summer (MfE 2018). In winter, MSLP is projected to decrease in future, especially over and south of the South Island, resulting in stronger westerlies, particularly over central New Zealand. These increased westerlies are linked to increased precipitation on the West Coast, and will also impact wind generation over New Zealand in future.

Nationally, wind speeds are expected to increase in the South Island and lower North Island, and decrease in the north half of the North Island over coming decades. A 5-10% increase in New Zealand annual mean East-West winds is expected by 2040, with no change to the annual average Southerly-Northerly component (MfE 2008). Figure 9 shows projections of high (99^{th}%ile) wind speeds in the 2040s and 2090s, relative to a 1986-2005 base period. This study focussed on the most likely, RCP4.5, outcomes.

Strong winds are expected to be 1-4% higher by the 2040s (relative to the base period) in the South Island, and 1-3% lower by the 2040s in Northland, as is shown in figure 9 (MfE 2016).

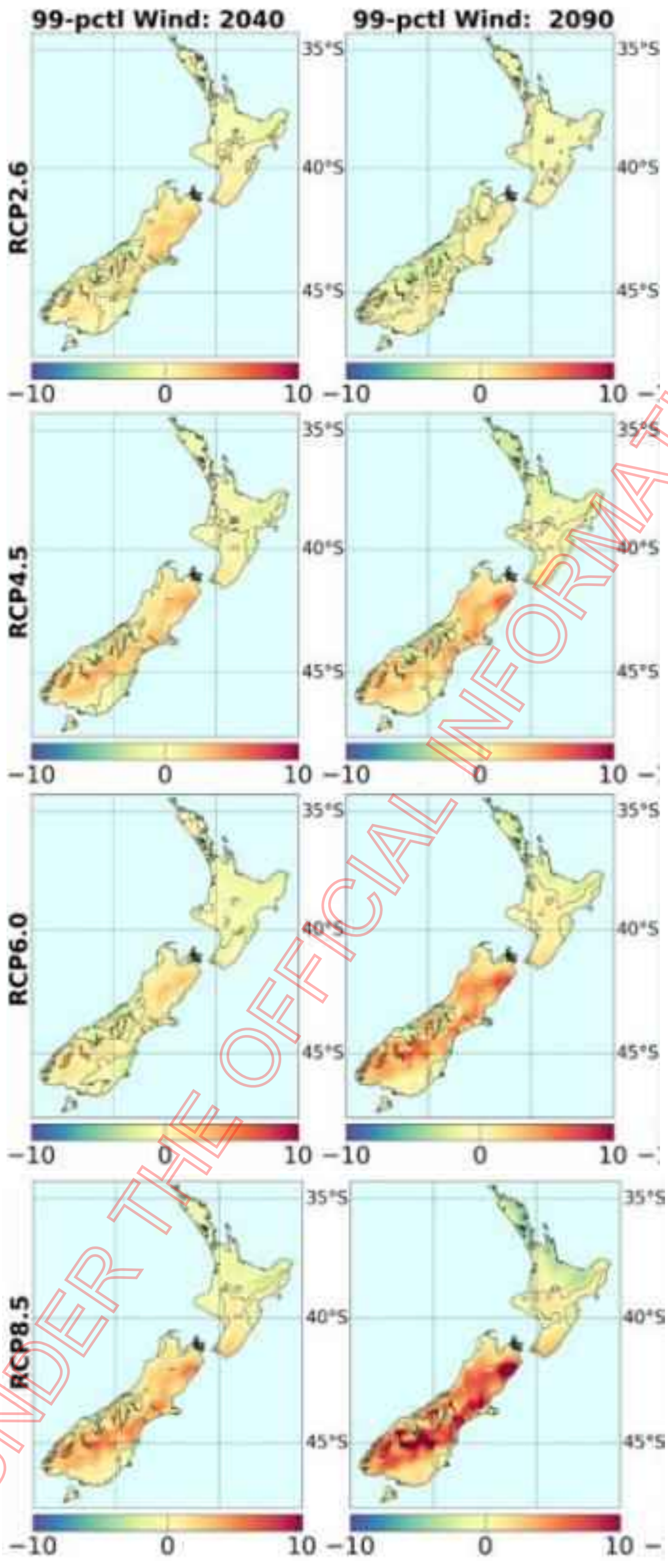


Figure 9: Change in the magnitude of the 99th percentile of daily-mean wind speed, for RCPs 2.6 (low emissions), 4.5 (mid-range-low) and 6.0 (mid-range-high) and RCP8.5 (high emissions), for the 2040s and 2090s, relative to the daily 99th percentile in the baseline 1986–2005 period (MfE 2016).

Winds over New Zealand are expected to increase the most in winter, and decrease in summer and autumn, in coming decades. Figure 10 shows long term average wind speeds over New Zealand (in metres per second) and the projected changes to those wind speeds by the 2040s for each season and annually.

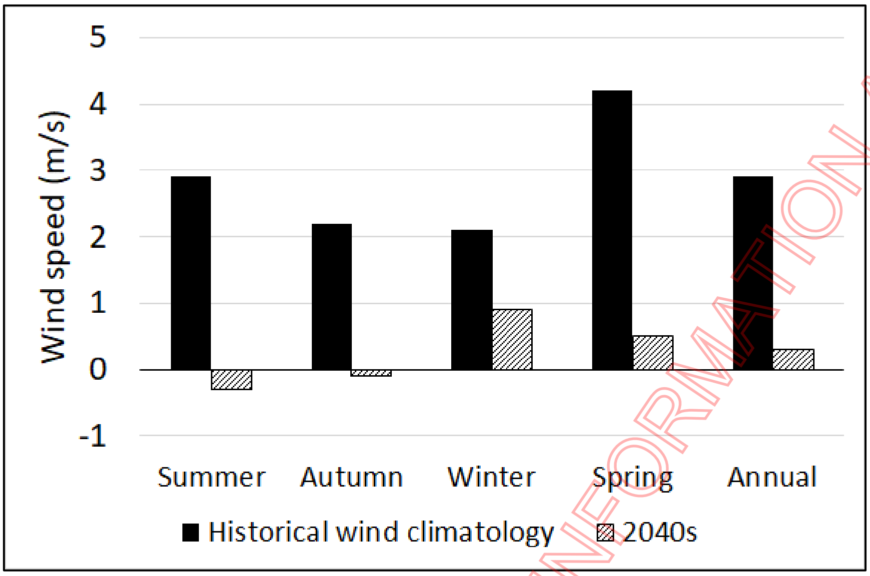


Figure 10: New Zealand historical average wind speeds for each season and annually compared to projected 2040s wind speeds (data from MfE 2008).

3.1 Methodology

The electricity model (LPCon) models wind generation in 12 separate regions (different to the hydrological regions), with individual wind farms in the model located in these regions utilising the same historical wind dataset to inform wind distribution and variability at the wind farm site.

The regions are Southland, Otago, Canterbury, Wellington, Wairarapa, Manawatu, Hawkes Bay, Taranaki, Central North Island, Waikato, Auckland, and Northland. These regions can be seen in figure 11.

Although all regions of New Zealand are not covered in this dataset, it covers all current, consented, and anticipated wind farm sites currently in LPCon modelling.

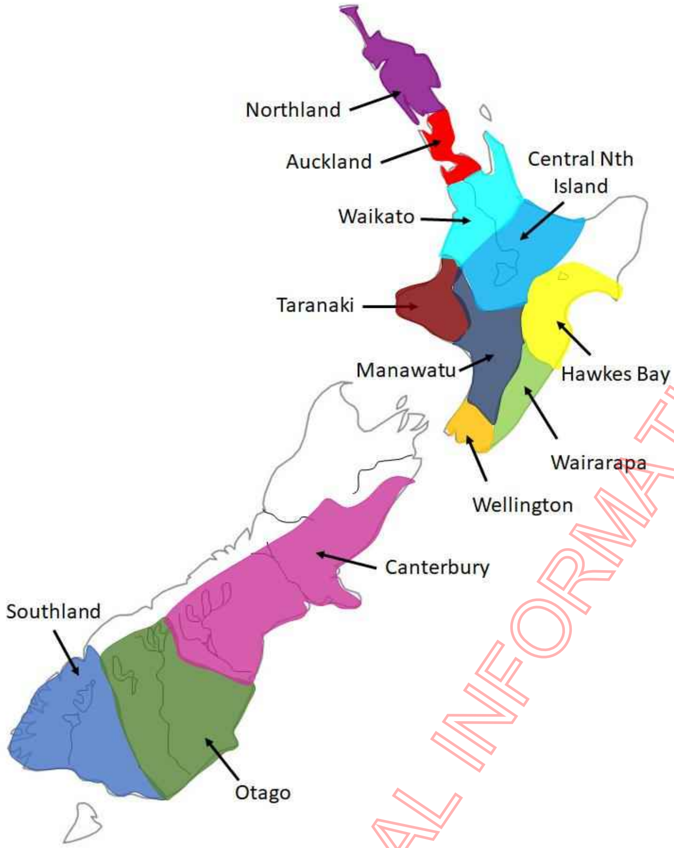


Figure 11: Locations of the 12 New Zealand wind energy regions used in this study

Each region has a distinct historical weekly wind record from 1932 to 2020 in LPCon. This wind data is compiled from historical datasets from the region from various sources (NIWA Clidb, actual wind mast data, Renewable Ninja). Historical wind speed data from these regions is used to represent wind variability in future years in electricity system modelling. However, the 2020-2050 record is adjusted to represent projected changes due to climate change.

There is limited research on detailed regional, seasonal wind projections in New Zealand. This study amalgamated wind projections from various studies (MfE 2008, MfE 2010, MfE 2016, MfE 2018, Pearce et al 2017, Macara et al 2019, NIWA 2020) and used New Zealand annual and seasonal wind speed projections for RCP4.5 for mid-century from MfE 2008, and apportioned those changes regionally following MfE (2016) and other studies (MfE 2010, MfE 2018, Pearce et al 2017, Macara et al 2019, NIWA 2020).

Weekly regional changes in windiness are projected as change factors. These are designed to be utilised to adjust historical wind records for 2050 conditions, and do not account for mast height, wind direction, elevation, or topography. It is intended that these adjustment factors are applied to an already existing wind record in the region, and will therefore encompass the variance, range, etc of the existing dataset. An assumption is made that the shape of the distribution will not change into the future.

Once the wind record has been adjusted using the change factors to relect a 2050 wind record, a linear trend is then applied between the 2020 record and the 2050 record.

3.2 Results

Annual average wind speeds are predicted to increase in the south of the South Island, with the largest change being in Otago (4.2%). In the northern half of the North Island they are expected to decrease, with the biggest reduction in annual average wind speed predicted to occur in Auckland (-2.8%). Changes to annual average wind speeds between 2020 and 2050 for each modelled region can be seen in figure 12.

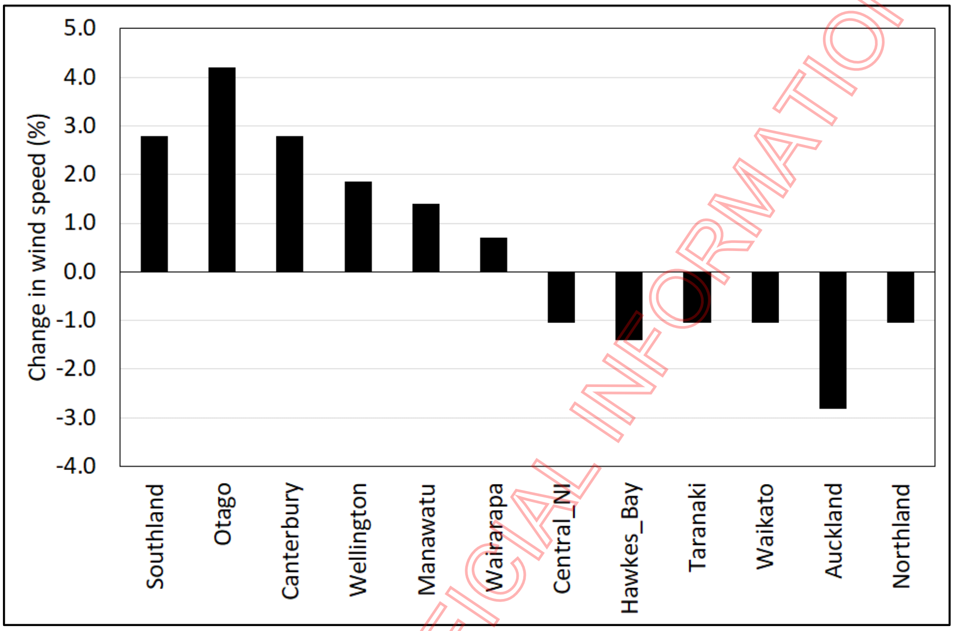
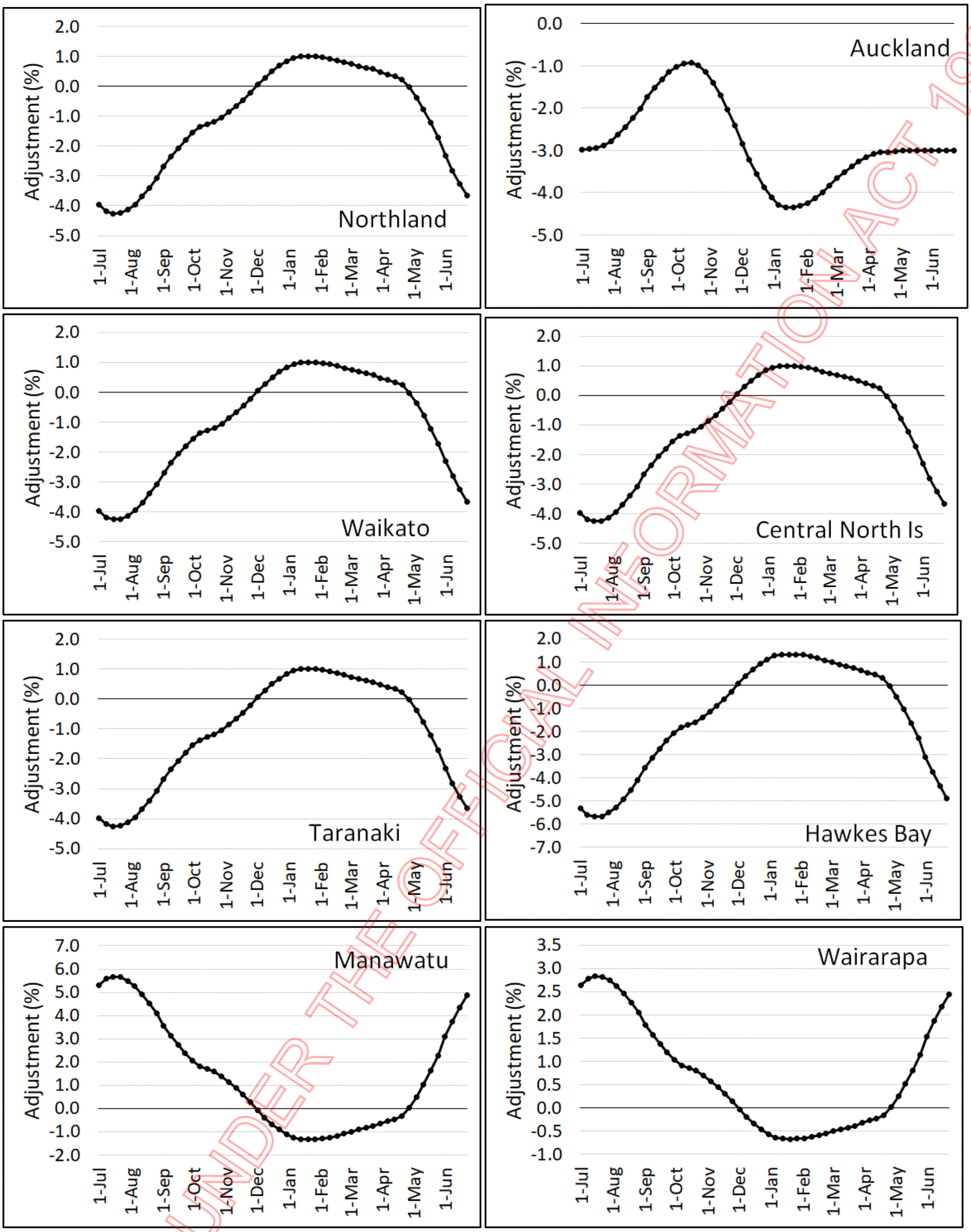


Figure 12: Modelled change (%) in annual average wind speed between 2020 and 2050.

However, the seasonal changes are expected to be larger than the annual changes. The weekly change factors that are needed to adjust 2020 wind capacity records to reflect 2050 conditions can be seen in the graphs in figure 13. Regions that are north of the middle of the North Island show the general pattern of windier summers and less windy winters, although Auckland is less windy all year. Auckland shows a slightly different pattern to other northern regions, and this is because data for this region comes from a specific higher resolution study conducted for Auckland council by NIWA (Pearce et al 2017). Projections for other sites come from other studies. From Manawatu south, including the South Island, regions show predictions of windier winters and less windy summers. Note the different y-axis scales in figure 13. The largest changes are expected to occur in Southland, Otago, and Canterbury.


Northland
Auckland
Waikato
Central North Is
Taranaki
Hawkes Bay
Manawatu
Wairarapa
Adjustment (%)
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun

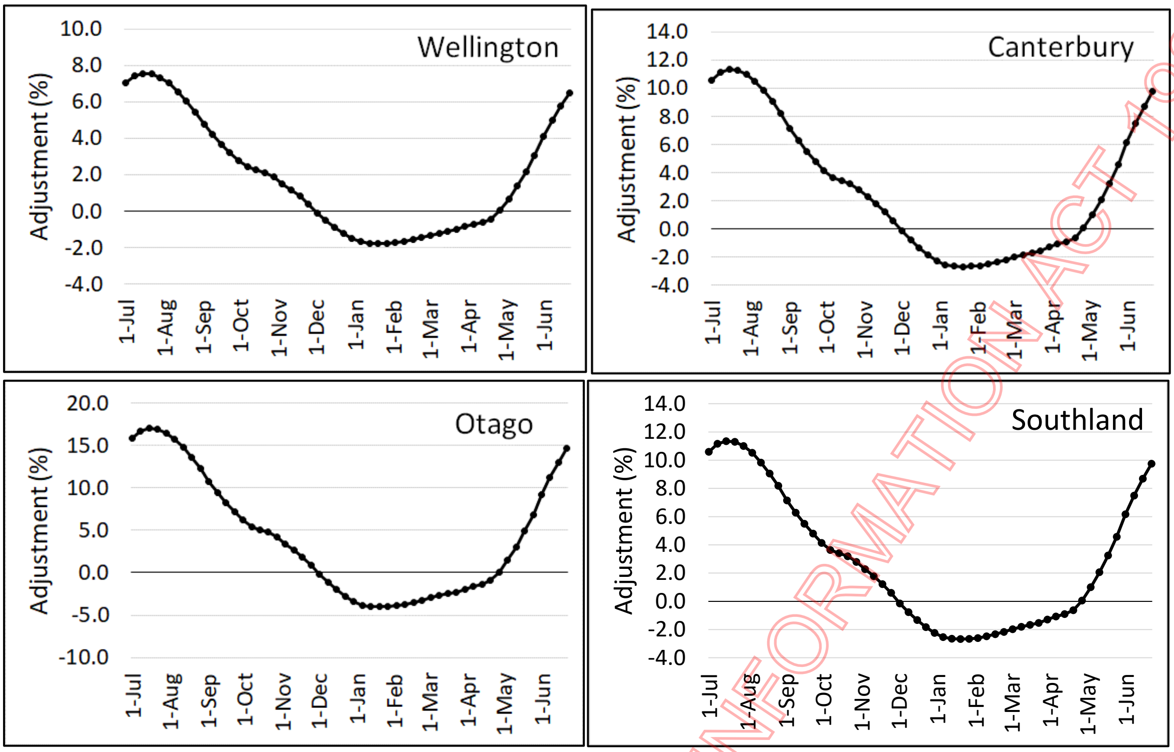


Figure 13: Weekly wind speed change factors for 12 regions representing change between 2020 and 2050, to adjust for climate change.

These change factors are listed in Table 3. It can be seen that the biggest increases in projected wind speeds are in winter in Southland, Otago and Canterbury. The biggest decreases in projected wind speeds are in the north of the North Island.

Table 3: Change factors (%) to convert 2020 wind capacity records to 2050 predicted values to adjust for climate change.

	Southland	Otago	Canterbury	Wellington	Manawatu	Waikato	Wairarapa	Central_NI	Taranaki	Hawkes_Bay	Auckland	Northland
1-Jul	10.6	15.9	10.6	7.1	5.3	-4.0	2.6	-4.0	-4.0	-5.3	-3.0	-4.0
8-Jul	11.2	16.7	11.2	7.4	5.6	-4.2	2.8	-4.2	-4.2	-5.6	-3.0	-4.2
15-Jul	11.3	17.0	11.3	7.6	5.7	-4.3	2.8	-4.3	-4.3	-5.7	-2.9	-4.3
22-Jul	11.3	17.0	11.3	7.5	5.7	-4.2	2.8	-4.2	-4.2	-5.7	-2.9	-4.2
29-Jul	11.0	16.5	11.0	7.3	5.5	-4.1	2.8	-4.1	-4.1	-5.5	-2.8	-4.1
5-Aug	10.5	15.8	10.5	7.0	5.3	-3.9	2.6	-3.9	-3.9	-5.3	-2.6	-3.9
12-Aug	9.8	14.7	9.8	6.6	4.9	-3.7	2.5	-3.7	-3.7	-4.9	-2.4	-3.7
19-Aug	9.1	13.6	9.1	6.0	4.5	-3.4	2.3	-3.4	-3.4	-4.5	-2.2	-3.4
26-Aug	8.2	12.3	8.2	5.5	4.1	-3.1	2.0	-3.1	-3.1	-4.1	-2.0	-3.1
2-Sep	7.1	10.7	7.1	4.8	3.6	-2.7	1.8	-2.7	-2.7	-3.6	-1.7	-2.7
9-Sep	6.3	9.4	6.3	4.2	3.1	-2.4	1.6	-2.4	-2.4	-3.1	-1.5	-2.4
16-Sep	5.5	8.2	5.5	3.7	2.7	-2.1	1.4	-2.1	-2.1	-2.7	-1.3	-2.1
23-Sep	4.8	7.2	4.8	3.2	2.4	-1.8	1.2	-1.8	-1.8	-2.4	-1.1	-1.8
30-Sep	4.1	6.2	4.1	2.8	2.1	-1.6	1.0	-1.6	-1.6	-2.1	-1.0	-1.6
7-Oct	3.6	5.5	3.6	2.4	1.8	-1.4	0.9	-1.4	-1.4	-1.8	-0.9	-1.4
14-Oct	3.4	5.1	3.4	2.3	1.7	-1.3	0.9	-1.3	-1.3	-1.7	-0.9	-1.3
21-Oct	3.2	4.8	3.2	2.1	1.6	-1.2	0.8	-1.2	-1.2	-1.6	-1.0	-1.2
28-Oct	2.8	4.2	2.8	1.9	1.4	-1.0	0.7	-1.0	-1.0	-1.4	-1.1	-1.0
4-Nov	2.3	3.4	2.3	1.5	1.1	-0.9	0.6	-0.9	-0.9	-1.1	-1.4	-0.9
11-Nov	1.8	2.7	1.8	1.2	0.9	-0.7	0.4	-0.7	-0.7	-0.9	-1.7	-0.7
18-Nov	1.2	1.8	1.2	0.8	0.6	-0.5	0.3	-0.5	-0.5	-0.6	-2.0	-0.5
25-Nov	0.6	0.9	0.6	0.4	0.3	-0.2	0.1	-0.2	-0.2	-0.3	-2.4	-0.2
2-Dec	-0.1	-0.2	-0.1	-0.1	-0.1	0.1	0.0	0.1	0.1	0.1	-2.9	0.1
9-Dec	-0.8	-1.2	-0.8	-0.5	-0.4	0.3	-0.2	0.3	0.3	0.4	-3.2	0.3
16-Dec	-1.3	-2.0	-1.3	-0.9	-0.7	0.5	-0.3	0.5	0.5	0.7	-3.6	0.5
23-Dec	-1.8	-2.7	-1.8	-1.2	-0.9	0.7	-0.5	0.7	0.7	0.9	-3.9	0.7
30-Dec	-2.2	-3.4	-2.2	-1.5	-1.1	0.8	-0.6	0.8	0.8	1.1	-4.1	0.8
6-Jan	-2.5	-3.8	-2.5	-1.7	-1.3	1.0	-0.6	1.0	1.0	1.3	-4.3	1.0
13-Jan	-2.6	-4.0	-2.6	-1.8	-1.3	1.0	-0.7	1.0	1.0	1.3	-4.3	1.0
20-Jan	-2.7	-4.0	-2.7	-1.8	-1.3	1.0	-0.7	1.0	1.0	1.3	-4.4	1.0
27-Jan	-2.7	-4.0	-2.7	-1.8	-1.3	1.0	-0.7	1.0	1.0	1.3	-4.3	1.0
3-Feb	-2.6	-3.9	-2.6	-1.7	-1.3	1.0	-0.7	1.0	1.0	1.3	-4.2	1.0
10-Feb	-2.5	-3.7	-2.5	-1.7	-1.2	0.9	-0.6	0.9	0.9	1.2	-4.1	0.9
17-Feb	-2.3	-3.5	-2.3	-1.6	-1.2	0.9	-0.6	0.9	0.9	1.2	-4.0	0.9
24-Feb	-2.2	-3.3	-2.2	-1.4	-1.1	0.8	-0.5	0.8	0.8	1.1	-3.8	0.8
2-Mar	-2.0	-3.0	-2.0	-1.3	-1.0	0.7	-0.5	0.7	0.7	1.0	-3.7	0.7
9-Mar	-1.8	-2.7	-1.8	-1.2	-0.9	0.7	-0.5	0.7	0.7	0.9	-3.5	0.7
16-Mar	-1.7	-2.5	-1.7	-1.1	-0.8	0.6	-0.4	0.6	0.6	0.8	-3.4	0.6
23-Mar	-1.5	-2.3	-1.5	-1.0	-0.8	0.6	-0.4	0.6	0.6	0.8	-3.3	0.6
30-Mar	-1.3	-1.9	-1.3	-0.9	-0.6	0.5	-0.3	0.5	0.5	0.6	-3.2	0.5
6-Apr	-1.1	-1.6	-1.1	-0.7	-0.5	0.4	-0.3	0.4	0.4	0.5	-3.1	0.4
13-Apr	-0.9	-1.4	-0.9	-0.6	-0.5	0.3	-0.2	0.3	0.3	0.5	-3.0	0.3
20-Apr	-0.6	-0.9	-0.6	-0.4	-0.3	0.2	-0.2	0.2	0.2	0.3	-3.0	0.2
27-Apr	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-3.0	0.0
4-May	1.0	1.5	1.0	0.7	0.5	-0.4	0.2	-0.4	-0.4	-0.5	-3.0	-0.4
11-May	2.1	3.1	2.1	1.4	1.0	-0.8	0.5	-0.8	-0.8	-1.0	-3.0	-0.8
18-May	3.2	4.9	3.2	2.2	1.6	-1.2	0.8	-1.2	-1.2	-1.6	-3.0	-1.2
25-May	4.6	6.9	4.6	3.1	2.3	-1.7	1.1	-1.7	-1.7	-2.3	-3.0	-1.7
1-Jun	6.2	9.2	6.2	4.1	3.1	-2.3	1.5	-2.3	-2.3	-3.1	-3.0	-2.3
8-Jun	7.5	11.2	7.5	5.0	3.7	-2.8	1.9	-2.8	-2.8	-3.7	-3.0	-2.8
15-Jun	8.7	13.0	8.7	5.8	4.3	-3.3	2.2	-3.3	-3.3	-4.3	-3.0	-3.3
22-Jun	9.7	14.6	9.7	6.5	4.9	-3.7	2.4	-3.7	-3.7	-4.9	-3.0	-3.7

The biggest seasonal increase to wind speeds is expected to be faster wind speeds in winter, and the biggest decrease is expected with lower wind speeds in summer (see figure 14).

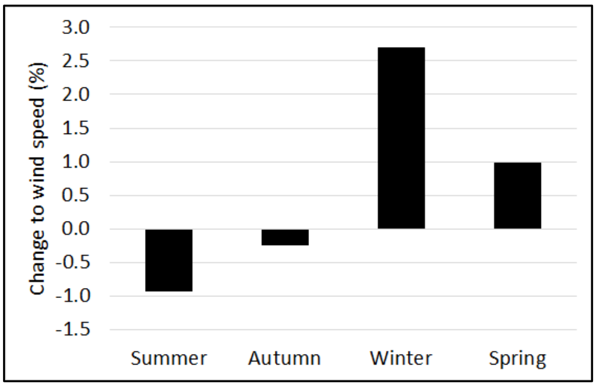


Figure 14: Seasonal average New Zealand changes to predicted wind speeds between 2020 and 2050.

Annual average changes are projected to be small (-2.8% to +4.2%) (figure 12), but the seasonal changes are significant, with the largest weekly change to wind speeds expected for July in Otago (17% stronger by mid-century).

4. Discussion

Climate change impacts on inflows to forty New Zealand hydro generation stations, encompassed in twelve regions, are modelled using a model cascade. A similar methodology is employed to estimate changes to wind resource over time in 12 different regions of New Zealand where wind farms are likely to be located in coming decades. These changes are designed to be included in electricity system modelling in New Zealand.

4.1 Hydro inflows

Results show an overall 2% increase in annual hydro catchment inflows over the whole of New Zealand between 2020 and 2050, which equates to an increase of 520 GWh. This increase in generation is significant when compared with the total annual generation in 2020 of 43,000 GWh, but less so when projected increases to electricity demand over this time (14,000-29,000 GWh) are considered.

Seasonal impacts are projected to be larger, with total New Zealand hydro catchment inflows projected to be 10% higher in winter and 6% lower in summer by 2050, and this is an important and beneficial shift, with New Zealand electricity demand currently anti-correlated with inflows.

South Island hydro storage catchment inflows are particularly affected, as in addition to expected rainfall changes, they receive a significant proportion of their inflows from snowmelt, resulting in large seasonal changes to inflows as temperatures warm in coming decades. The two Waitaki catchments modelled are predicted to get higher inflows in winter (+26%), and lower inflows in summer (-10%), with a 6% increase in annual flows. The Clutha catchment has a smaller proportion of inflows from snowmelt, and it is modelled to get higher inflows in winter (+19%) and lower inflows in summer (-9%), with a small increase in annual inflows over this time (+4%). Manapouri catchment is also expected to receive higher winter inflows by 2050 (+15%) and lower summer inflows (-1%), with 6% higher annual inflows.

These projected changes are compared to other recent studies projecting changes to South Island river flows, in Figure 15.

	Period	Emissions scenario	Catchment
Poyck et al (2011)	2040s	mid-range	Clutha
Jobst et al (2018)	2050	mid-range	Clutha
Collins (2020)	2050	RCP4.5 (mid-range)	Southern Alps
Zammit & Woods (2011)	2040	mid-range	Waimakariri
Caruso (2017b)	2040s	mid-range	Waitaki
This study	2050s	RCP4.5 (mid-range)	Waitaki, Clutha,

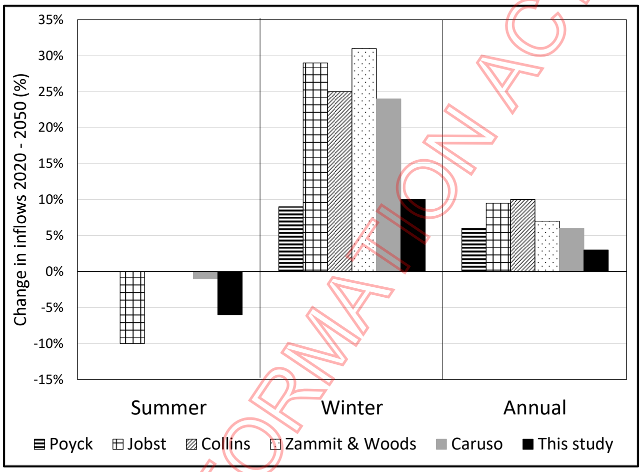


Figure 15: Comparison of seasonal and annual changes to catchment inflows by 2040s or 2050 – various New Zealand studies

Although the studies differ in catchments, periods of projections, and methodologies, it can be seen that all studies project catchment streamflows in large, eastward flowing rivers sourced in the Southern Alps with some snow component changing in the same direction. That is, increasing flows in winter and decreasing or static flows in summer, and small increases (3-10%) in annual flows.

4.2 Wind speed

Annual average wind speeds are predicted to increase in the south of the South Island, with the largest change being in Otago (4.2%). In the north half of the North Island they are expected to decrease, with the biggest reduction in wind speed predicted to occur in Auckland (-2.8%).

Weekly changes are greater, with 17% stronger winds expected in Otago in July by 2050, and 5.7% weaker winds in Hawkes Bay in July.

It should be noted, but is out of the scope of this study, that increasing wind speeds may actually lead to less generation as wind turbines may be forced into cutoff speeds more often, resulting in turbine shut down and less generation.

For both hydro and wind changes out to 2050, the greatest projected impacts are not in annual volume changes (all of which remain below 5%) but in changes to the seasonal distribution of the arrival of renewable energy "fuel". These changes are generally in a beneficial direction, moving "fuel" from summer arrival, when it is less needed for generation, to winter arrival, when it is more needed. This has significant implications for electricity generation, where the current hydro inflows are anti-correlated with demand.

5. Acknowledgements & Future work

This research was able to be completed by the support of Meridian Energy Ltd. The work was partly undertaken while the author was employed at Meridian Energy, and finished while employed as a research fellow at the University of Otago, funded by a Deep South Science Challenge Domains funding grant (MBIE contract number C01X19011). The author would like to acknowledge the generosity of Meridian Energy in granting a license to use their electricity system model, LPCon, for the duration of the research fellowship, and in particular Grant Telfar, architect and creator of LPCon, for his generosity and assistance.

Future work in the Deep South Science funded project involves working with NIWA to compile high resolution NIWA Topnet hydrological river flow projections and NIWA RCM wind projections for inclusion in LPCon electricity system scenario modelling. This work is currently underway and should be published in late 2023 or early 2024.

6. Appendix

Error analysis

Detailed error assessments around projections have not been undertaken for this study. However, some assessment of potential spread of projections is needed by users of the data. Forward looking inflow projections are formed from composite models and cannot be compared with actuals. Error around inflow projections is not available at this stage.

However, the error of rainfall projections can be examined. Rainfall error is represented in two ways here, for two representative catchments: Westport and Wellington. Firstly, rainfall projections from GCM and RCMs are estimated back to 1971, and so can be compared with observed values over the period 1971-2021, the assumption being that error statistics for this period should equate to error statistics in projected values. No such modelling is available for wind speed projections, although this will become available in the next couple of years.

Secondly, the ensemble spread of model projections from different GCMs (& RCMs) can be shown for rainfall, for different emissions scenarios (RCPs), to give some idea of the spread of projections from different models and emissions pathways. Rainfall projections are derived from 6 global models for four RCPs. This study uses a six model average projection, for RCP4.5 (a middle of the road scenario). The graphs below go into more detail than this, and show the spread of rainfall projections for all six model outputs, for a low emissions scenario (RCP2.6) and a high emissions scenario (RCP8.5) for 2 locations: the West Coast and Wellington. This information gives an indication of how aligned the model projections are.

Westport

Projections compared to observed rainfall

The minimum, mean, and maximum model projections from the six GCM-RCM projections can be seen for RCP2.6 in figure A1, and RCP8.5 in figure A2 for Westport. Observed rainfall for Westport for the period 1971-2021 can also be seen.

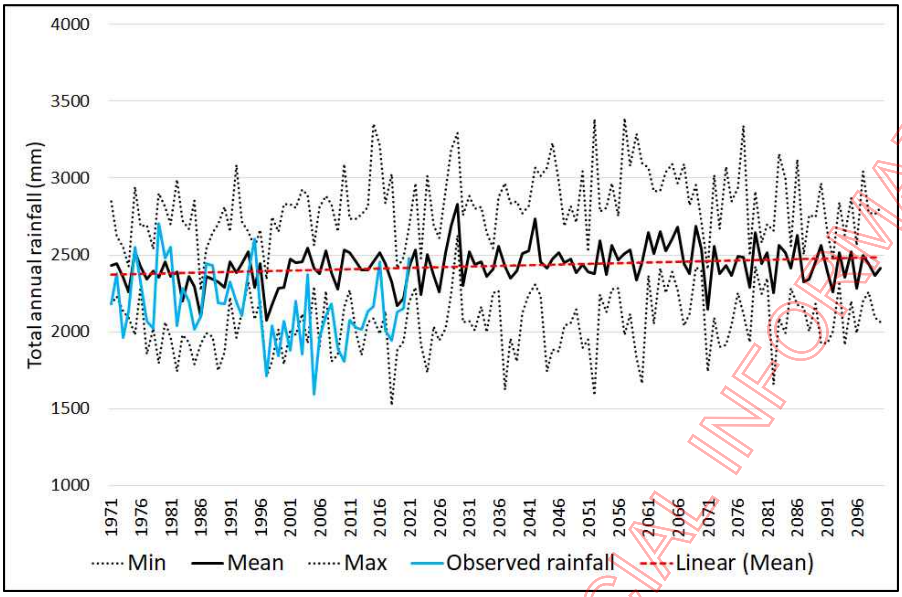


Figure A1: Model spread of RCP2.6 West Coast rainfall projections. Min, mean, and max of 6 GCM projections of West Coast Annual rainfall, 1971-2100, linear least squares regression of mean, and observed rainfall (1971-2021).

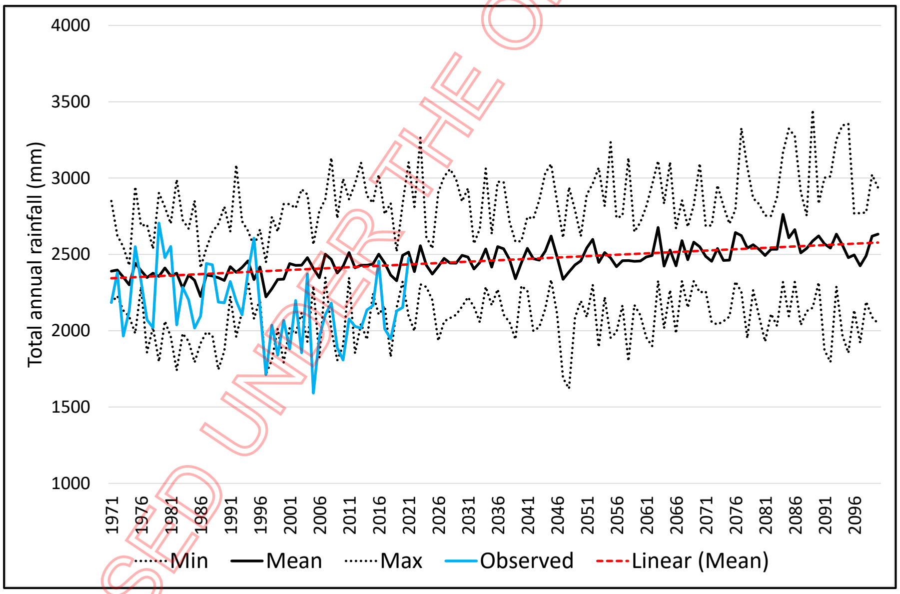


Figure A2: Model spread of RCP8.5 West Coast rainfall projections. Min, mean, and max of 6 GCM projections of West Coast Annual rainfall, 1971-2100, linear least squares regression of mean, and observed rainfall (1971-2021).

The Mean Absolute Percentage Error (MAPE) of observed rainfall vs mean predicted rainfall from the six model average for 1971-2021 for both RCPs is 13%.

The graphs show that all model projections for both low and high emissions show increases in West Coast rainfall. The RCP2.6 scenario shows an average increase over the 120 year period of 5%, and the RCP8.5 scenario shows an average increase over the 120 year period of 10%.

Spread of projections from different global models

The spread of projections of rainfall for 2050 from different global models are shown in figure A3.

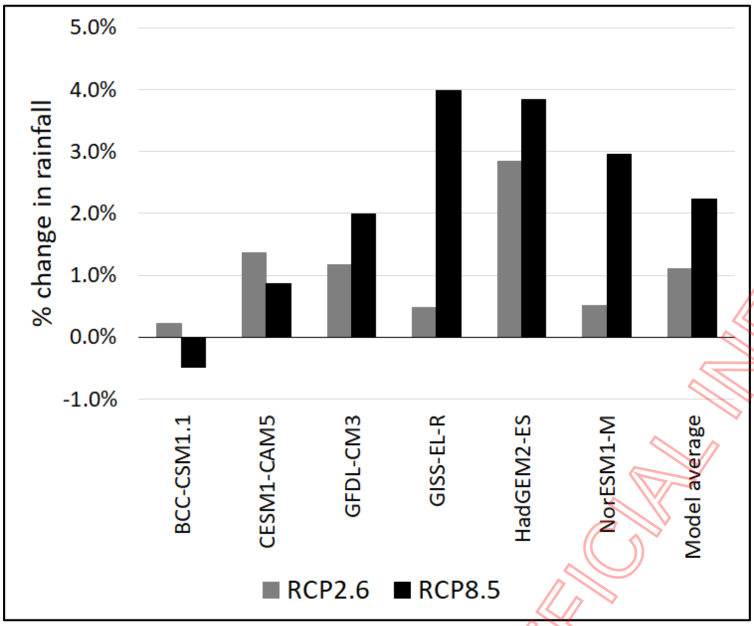


Figure A3: Projected change in Westport rainfall between 2020 and 2050 for six global models (downscaled using an RCM), for RCP2.6 and RCP8.5.

It can be seen that almost all changes are for increased rainfall, and that RCP8.5 changes are higher than RCP 2.6 changes. It can be seen that the spread of model projections ranges from a -0.5% change in annual rainfall between 2020 and 2050, to a +4% change. The models are almost all consistent (11 out of 12 predictions) in their projection of the direction of change (wetter). This graph shows that some representation of wetter conditions in Westport by 2050 should be shown in the electricity system modelling.

Extrapolating beyond 2050

The error around 2050 projections means that extrapolating trends out to 2060 or beyond should be undertaken with caution. The spread of projections about the mean projection can be seen in figure A4. It can be seen that difference between mean projections for 2050 and 2065 is small relative to the spread of projections from the 6 different models.

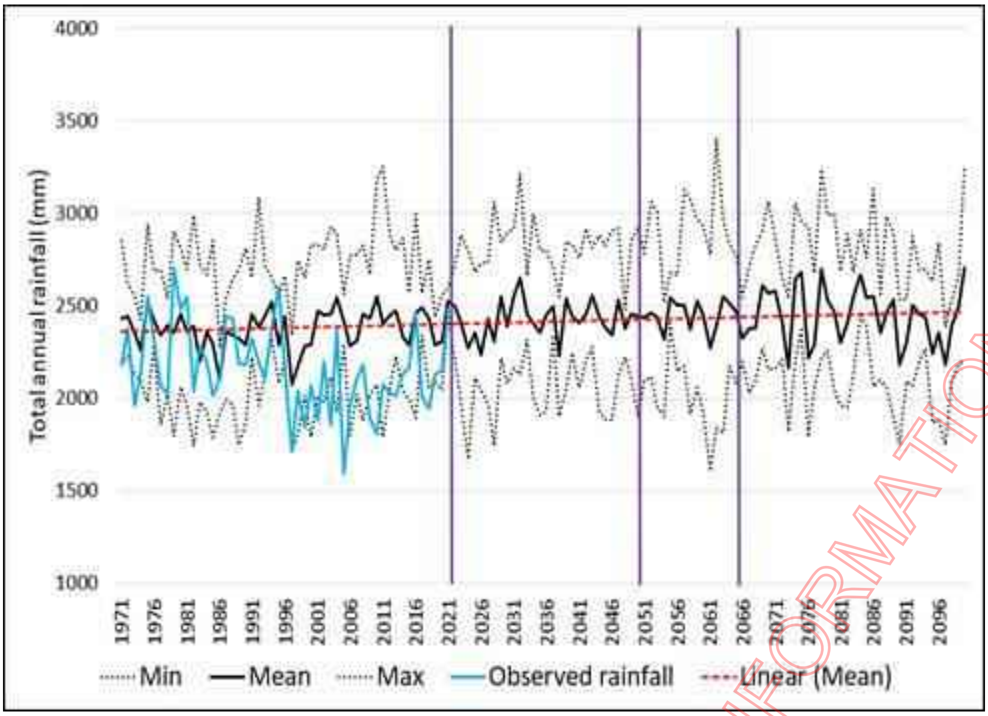


Figure A4: Annual rainfall projection for Westport from 1971 to 2100 for RCP4.5, with the min, mean, and max projections from the six models shown, as well as observed values in blue. Purple lines occur at 2021, 2050, and 2065.

Projections of seasonal Westport annual rainfall for 2030, 2040, 2050, and 2065 are shown in figure A5.

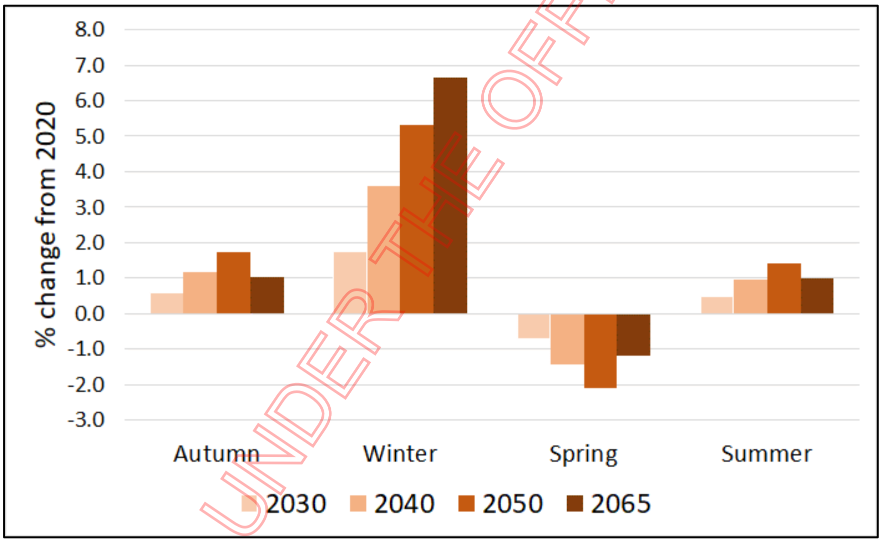


Figure A5: Projections of Westport annual rainfall for 2030, 2040, 2050, and 2065 for each season.

It can be seen that 2065 winter values are 20% higher than 2050 values, but projections counterintuitively decrease between 2050 and 2065 for Autumn, Spring, and Summer. This should be considered the noise in the model projections, where the general trend (see figure A4) is a gently upward trend over time.

Wellington

Projections compared to observed rainfall

The minimum, mean, and maximum model projections from the six GCM-RCM projections can be seen for RCP2.6 in figure A6, and RCP8.5 in figure A7 for Wellington. Observed rainfall for Wellington for the period 1971-2021 can also be seen.

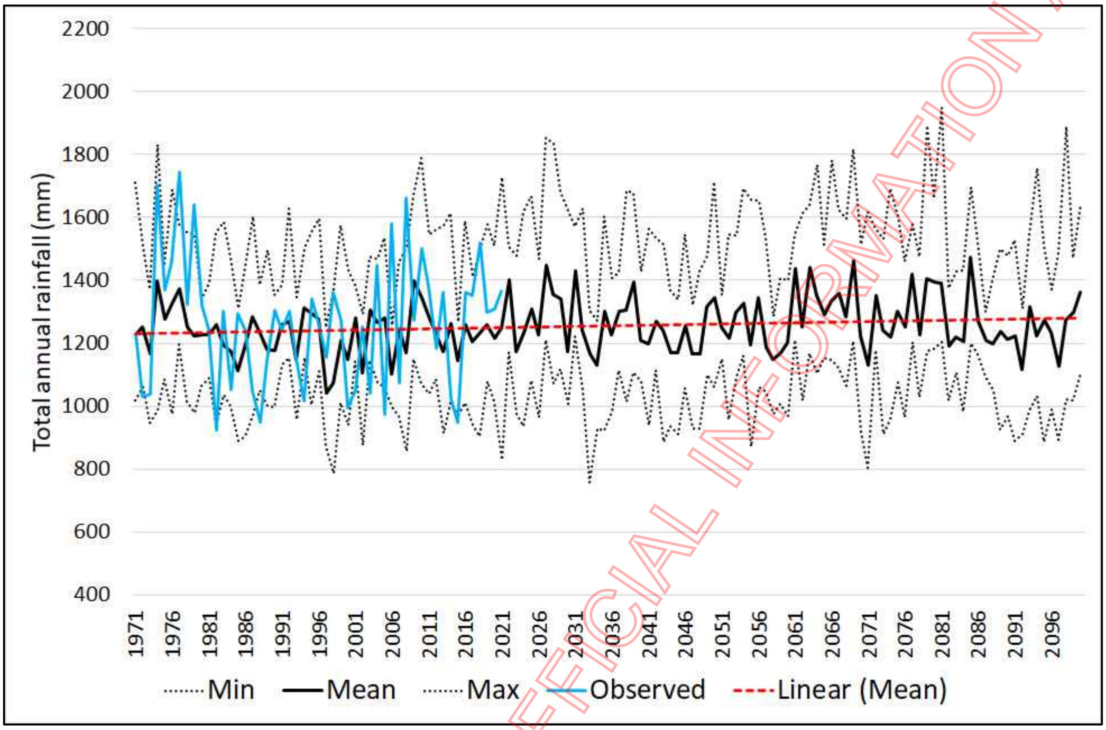


Figure A6: Model spread of RCP2.6 Wellington rainfall projections. Min, mean, and max of 6 GCM projections of Wellington annual rainfall, 1971-2100, linear least squares regression of mean, and observed rainfall (1971-2021).

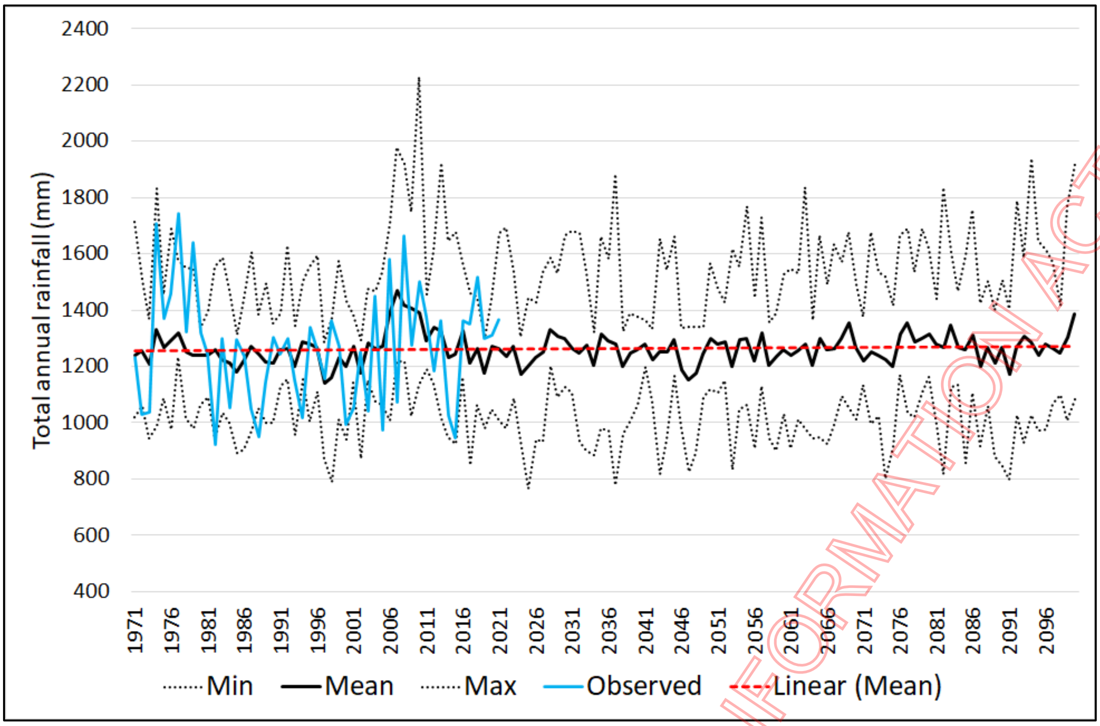


Figure A7: Model spread of RCP8.5 Wellington rainfall projections. Min, mean, and max of 6 GCM projections of West Coast Annual rainfall, 1971-2100, linear least squares regression of mean, and observed rainfall (1971-2021).

The Mean Absolute Percentage Error (MAPE) of observed rainfall vs rainfall predicted from the six model average for 1971-2021 for both RCPs is 13%.

The graphs show fairly flat projections of Wellington rainfall. The RCP2.6 scenario shows an average increase over the 120 year period of 4%, and the RCP8.5 scenario shows an average increase over the 120 year period of 1%.

Spread of projections from different global models

The spread of projections of Wellington rainfall for 2050 from different global models are shown in figure A8.

It can be seen that projections between different models for the period 2020-2050 vary in both magnitude and direction, and that RCP8.5 changes are not necessarily higher than RCP 2.6 changes, as would be expected.

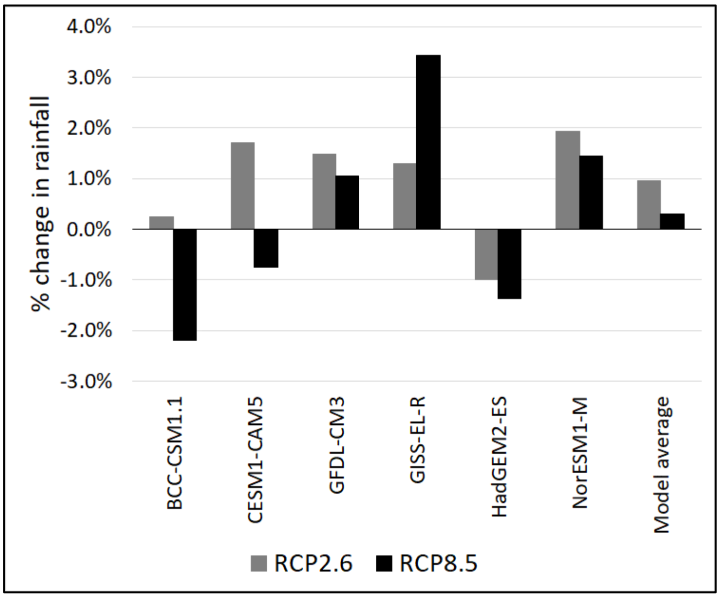


Figure A8: Projected change in Wellington rainfall between 2020 and 2050 for six global models (downscaled using an RCM), for RCP2.6 and RCP8.5.

It can be seen that the spread of model projections is larger in Wellington (ie. less certainty), ranging from a -2.2% change in annual rainfall between 2020 and 2050, to a +3.4% change.

Summary of Error

An appropriate methodology for representing multi-model, multi-RCP projections over long time periods is to use the average of the ensemble of models, for a middle of the road emissions scenario, and to smooth projections over time periods or use linear or non-linear trends rather than individual datapoints.

It is important that, for the adjustments in Table 2 and Table 3 of this document:

- The DIRECTION of change (+ve or -ve) for each week for each region should be maintained.
- The RELATIVE change between seasons and regions should be maintained.
- However, the MAGNITUDES can be toned down a bit, as long as the direction of change and relativity between regions is maintained.

So, for example, all adjustments in Tables 2 or 3 could be multiplied by 0.95 before use in modelling, if a lesser impact on model outcomes was required, as long as ALL data in the tables was adjusted in a similar fashion. Similarly, using 2050 projections to represent 2060 or 2065 would also be an appropriate way to “tone down” impacts in downstream modelling.

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