Ministry for the Environment
Manatū Mō Te Taiao

PO Box 10362, Wellington 6143
Website: www.mfe.govt.nz
Freephone: 0800 499 700

20-D-00014

s 9(2)(a)

Dear s 9(2)(a)

Thank you for your email of 7 January 2020 requesting the following under the Official Information Act 1982 (the Act):

> *All models, including drafts or unpublished ones, that MfE holds, or has access to, for the allocation of water takes and discharges.Water issues are not new, there have been Court proceedings, Waitangi Tribunal hearings- the Ministry would not have been sitting idle during this time and surely has done a lot of work already about technical options to address Maori rights and interests for when politicians are ready to front up. This request covers any work done with the iwi leaders group, their advisors, any internal MfE work, or work with others, and includes work that gives the ability to analyse options, and/or provides different option/ approaches for addressing allocation of takes and discharges, including and particularly for Maori rights and interests, and the water itself.*
>
> *The form of response requested:*
>
> *1. The list of models (including drafts and unpublished ones) with: their status, their scale (e.g. national, catchment, subcatchment), whether for water takes or discharges (or both), the developer/s of model, and the options/approach it has for addressing Maori rights and interests each identified, and the water itself.*
>
> *2. Copies of the models themselves*
>
> *3. All reports, documents, communications that cover the scope, assumptions of each of the models 4. Any advice or memos associated with these models 5. Any advice, including drafts, on options to addressing Maori rights and interests in water.*
>
> *The Ministry has a public interest to release this information- particularly if successive governments keep postponing addressing Maori rights and interests, and also when the government is requiring all councils to have plan changes done by 2025 without addressing these issues.*

The Ministry for the Environment (the Ministry) contacted you on 24 January 2020 seeking clarification of your request. This was to attempt to narrow the scope of your request in order to assist the Ministry in responding to you, as initial searches undertaken highlighted thousands of documents as potentially being within scope of your request. At the time of writing the Ministry has not received a response to that clarification request.

On 11 February 2020, the Ministry extended the timeframe for responding to your request under section 15A(1)(b) of the Act to allow for consultation to be undertaken in relation to the material within scope of your request.

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A response was due to you on 12 March 2020, please accept my apologies for the delay in getting this response to you.

The Ministry has considered your request in the following two parts:

- The first part of the request, which seeks information relating to water models, the Ministry has interpreted the time period to mean from the introduction of the National Policy Statement – Freshwater Management 2011 onwards.
- The second part of the request, has been interpreted to include all work the Ministry has undertaken on freshwater allocation, as it relates to addressing Māori rights and interests in water.

As a result, the Ministry has identified 16 documents in scope of points 1, 2, and 3 of your request, these are listed in the attached document schedule. 11 of these documents are released to you in full, while the remaining five of these documents have been withheld in full under section 18(d) of the Act as the information is publicly available. The location of these documents is provided within the attached document schedule.

The Ministry is refusing points 4 and 5 of your request under section 18(f) of the Act, as this information cannot be made available without substantial collation or research.

The Government's current priority is improving water quality. Once policies are in place to address this, there will be a shift in focus to achieving efficient and fair allocation of freshwater and nutrient discharges, including having regard to Māori interests. Modelling is an important part of this work that will help to inform decisions. We are currently looking at the information we could get from modelling, and the information available to feed into this modelling.

In terms of section 9(1) of the Act, I am satisfied that, in the circumstances, the withholding of this information is not outweighed by other considerations that render it desirable to make the information available in the public interest.

You have the right to seek an investigation and review by the Office of the Ombudsman of my decision to withhold information relating to this request, in accordance with section 28(3) of the Act. The relevant details can be found on their website at: www.ombudsman.parliament.nz.

Please note that due to the public interest in our work the Ministry for the Environment publishes responses to requests for official information on our OIA responses page shortly after the response has been sent. If you have any queries about this, please feel free to contact our Executive Relations team: ministerials@mfe.govt.nz.

Yours sincerely

This response has been approved electronically by Annabelle Ellis

Annabelle Ellis
Acting Director, Water

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Document schedule

Doc no.	Document date	Content	Decisions	OIA sections applied	Notes
1	7 October 2018	National allocation model: Updates to draft model and 2nd tranche results	Released in full	N/A	N/A
2	28 January 2018	Water allocation economic analysis: Land/water use modelling	Released in full	N/A	N/A
3	26 October 2017	National allocation model tranche 1 presentation V4	Released in full	N/A	N/A
4	October 2017	National Allocation Model Part 2 Appendices to Main report	Released in full	N/A	N/A
5	October 2017	National Allocation Model – Draft Part 1 – Model Description and Results	Released in full	N/A	N/A
6	31 May 2017	Māori Land Spatial Dataset	Withheld in full	18(d)	This document can be accessed at: https://catalogue.data.govt.nz/dataset/maori-land-spatial-dataset/resource/0ca2fe56-598f-4679-ab7a-919a335115ea
7	28 September 2016	Waimea water allocation economic modelling – first tranche	Release in full	N/A	N/A
8	June 2015	Waimea Plains freshwater management case study: efficiency and over-allocation	Withheld in full	18(d)	This document can be accessed at: https://www.mpi.govt.nz/dmsdocument/9860/send
9	13 March 2015	Economics of managing within water quantity limits: Waimakariri District	Released in full	N/A	N/A
10	5 March 2015	Maori Land Project – Phase Two Analysis of Water Quality data on a National Scale.	Released in full	N/A	N/A
11	4 December 2014	Economics of managing within water quantity limits: Waimakariri District	Released in full	N/A	N/A
12	September 2013	Modelling Economic Impacts of Nutrient Allocation Policies in Canterbury: Hinds Catchment	Withheld in full	18(d)	This document can be accessed at: https://www.mfe.govt.nz/sites/default/files/modelling-economic-impacts-of-nutrient-allocation-policies-canterbury.pdf

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Doc no.	Document date	Content	Decisions	OIA sections applied	Notes
13	No date	Water allocation economic analysis; Waimea case study	Released in full	N/A	N/A
14	No date	Crop production, profit and nutrient losses in relation to irrigation water allocation and reliability – Waimea plains, Tasman District	Withheld in full	18(d)	This document can be accessed at: https://www.mpi.govt.nz/dmsdocument/9899/send
15	No date	Waimea Plains: A freshwater quantity management case study	Withheld in full	18(d)	This document can be accessed at: https://www.mpi.govt.nz/dmsdocument/9860/send
16	No date	Access to water on Maori owned land	Released in full	N/A	N/A

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Document 1

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NATIONAL ALLOCATION MODEL

Updates to draft model and 2nd tranche results

LWP
landwaterpeople

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Introduction

- MFE wishes to assess a range options for allocation of rights to take and discharge
- Model requires comprehensive national coverage, but sufficient detail to assess impacts of policies
- Analysis draws on a range of information sources, and is critically dependent on input data from Part B – economics of water use
- 4th set of reporting in series following methodology, prototype, Tranche 1 reporting.
- 2nd reporting using full datasets and comprehensive modelling
- The work since draft report has focused on improving the model based on findings from Tranche 1 and running some additional scenarios

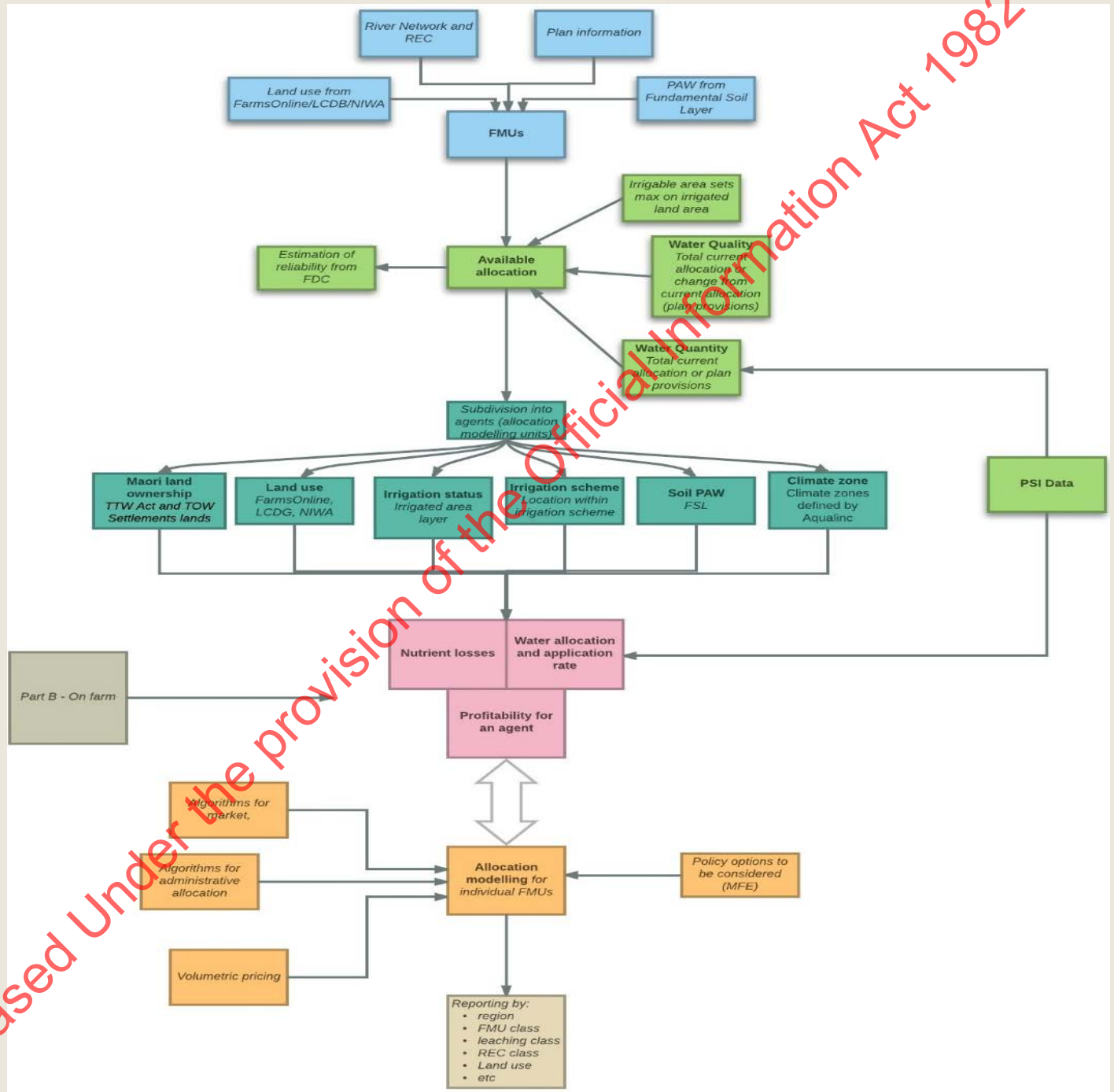
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Approach

- Definition of FMUs
- Estimate available allocation, reliability
- Subdivision of the FMU into modelling agents
- Integration of profit function
- Modelling the economic outcome of allocation
- Provision of outputs.

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Issues from Tranche 1

- Updated
  - *Overestimation of total profitability – associated with an overestimation in horticulture*
  - *Profitability curves and capital costs*
  - *Incomplete coverage of some datasets*
- Continuing
  - *Achievability of transfer market outcomes (and for other scenarios)*
  - *Conjunctive allocation*
  - *Land use change constraints*
  - *Volumetric pricing and behavioural impacts*

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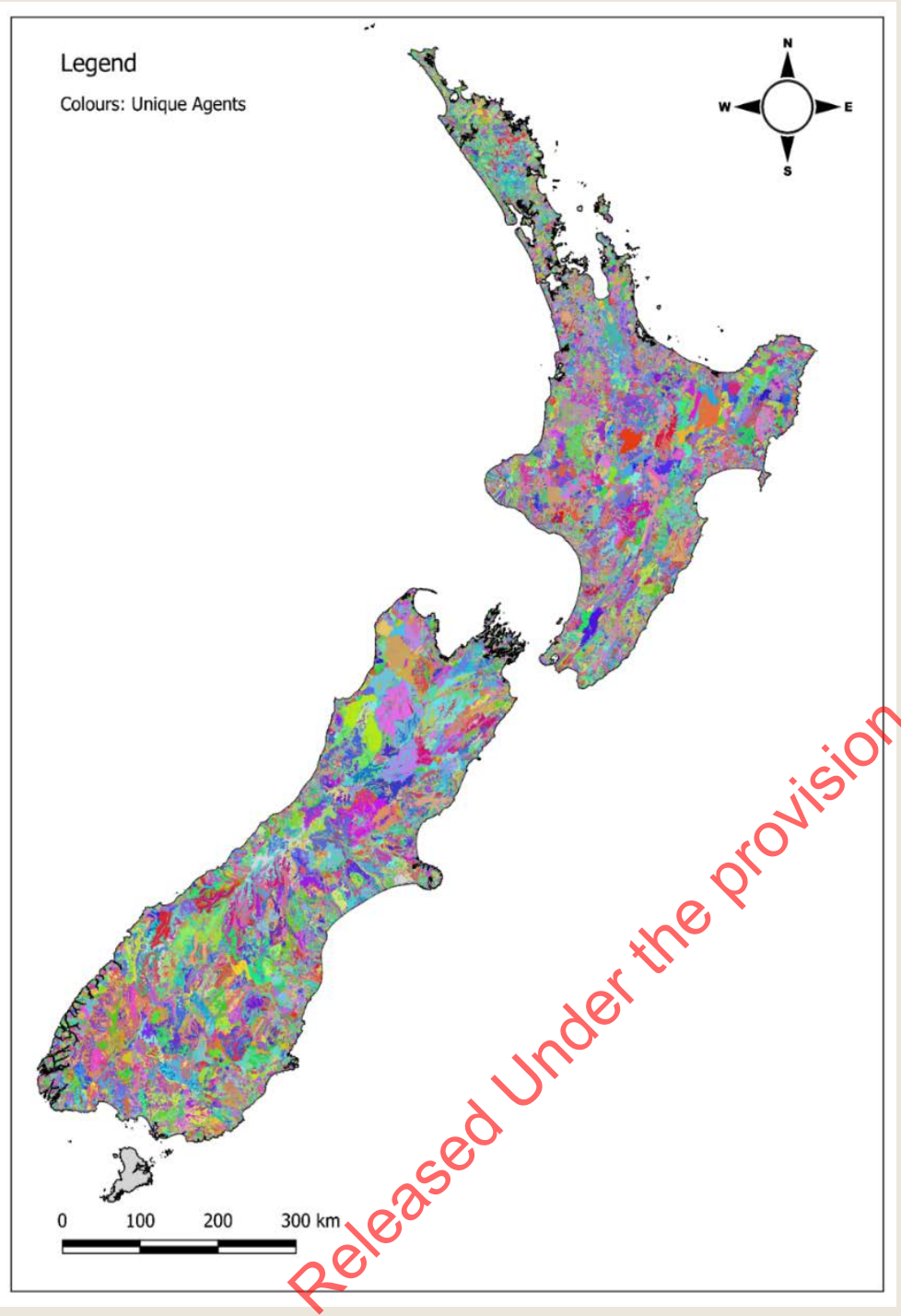
Defining agents

- Defining characteristics
  - *Updated*
    - Current land use
    - Current Irrigation
  - *Unchanged*
    - Climate zone
    - Soil type
    - Irrigability of the land
    - Surface water and Groundwater FMUs
    - Regional Council Boundaries
    - Ownership by Māori entity
    - Location within irrigation scheme command area
- 90,000 agents in current definition of model

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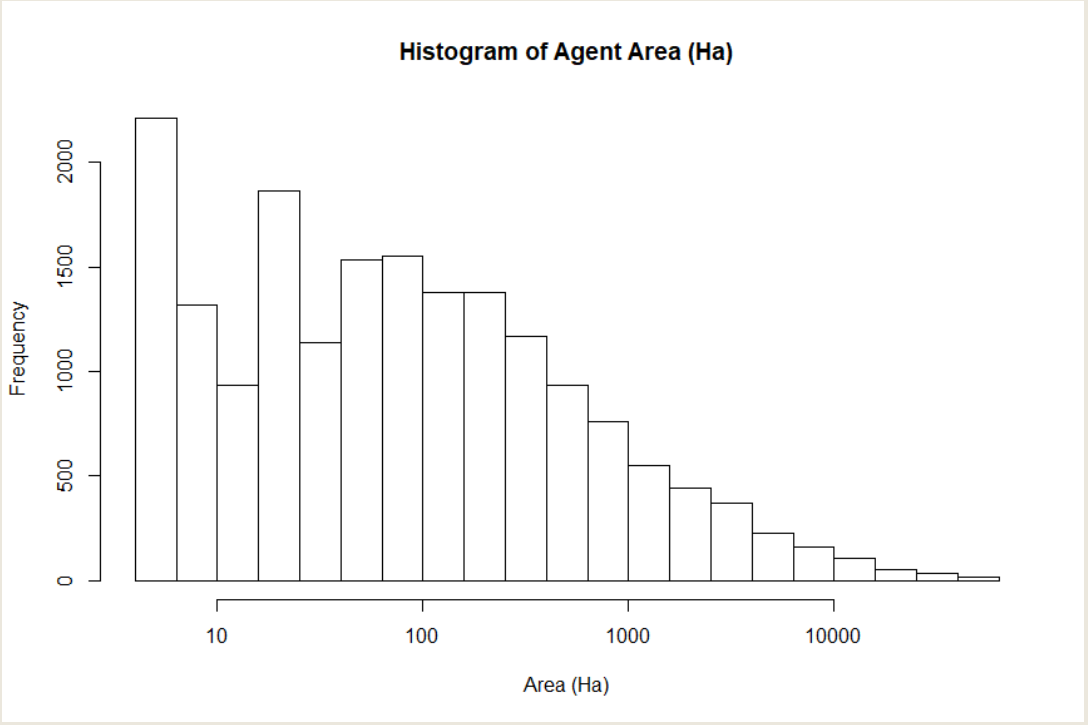
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Unique agents



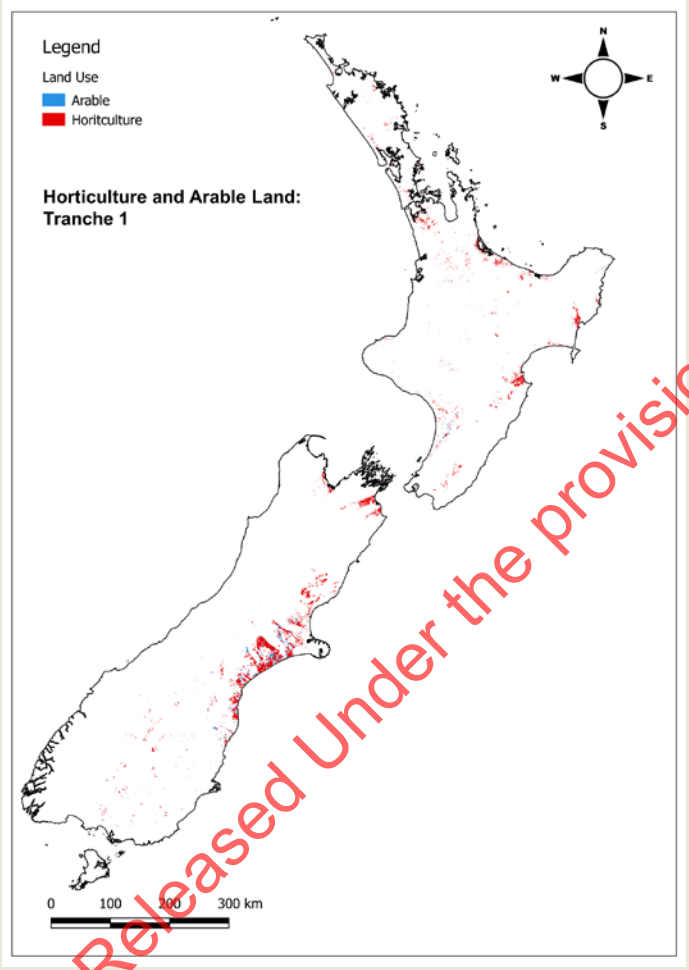
Distribution of agent size

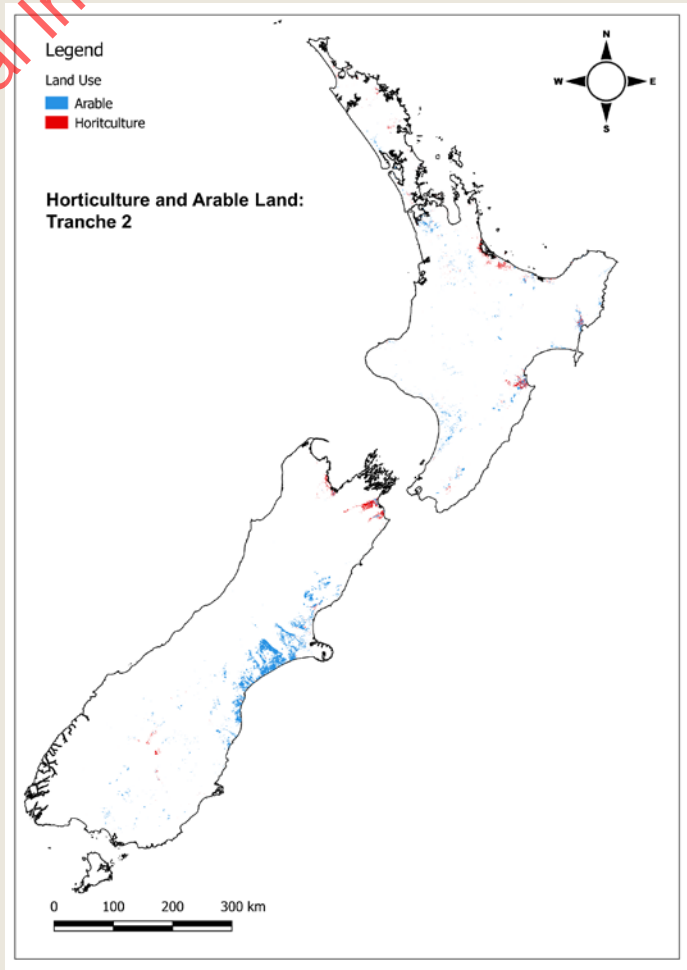
Active and non-zero agents only



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Comparison of OLD and NEW data: Land Use - changes to Horticulture

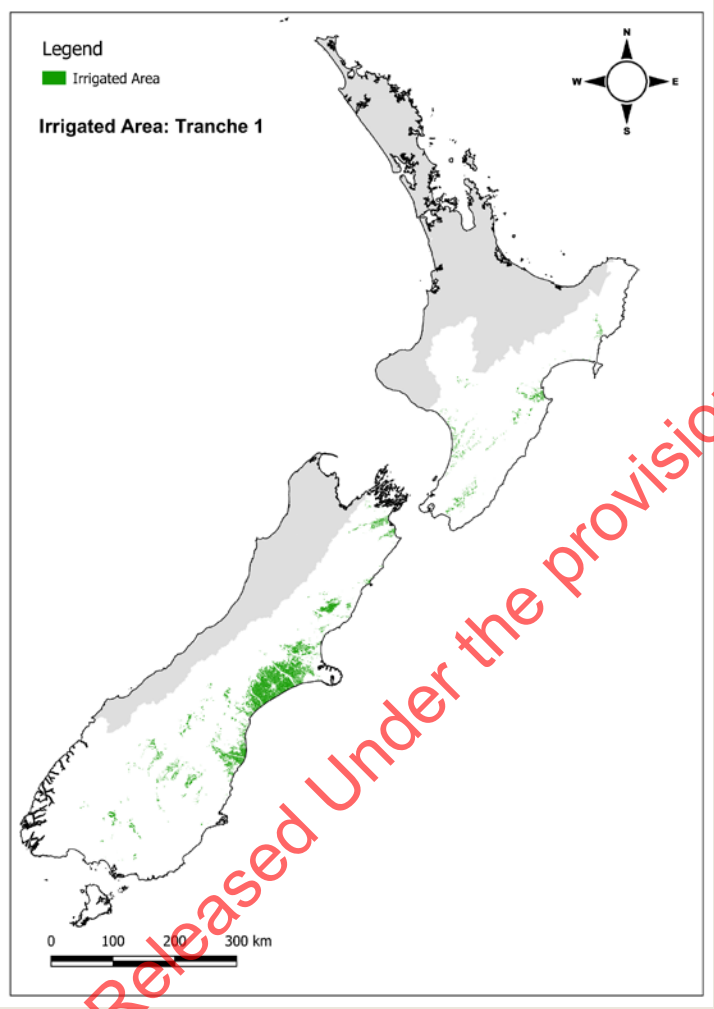


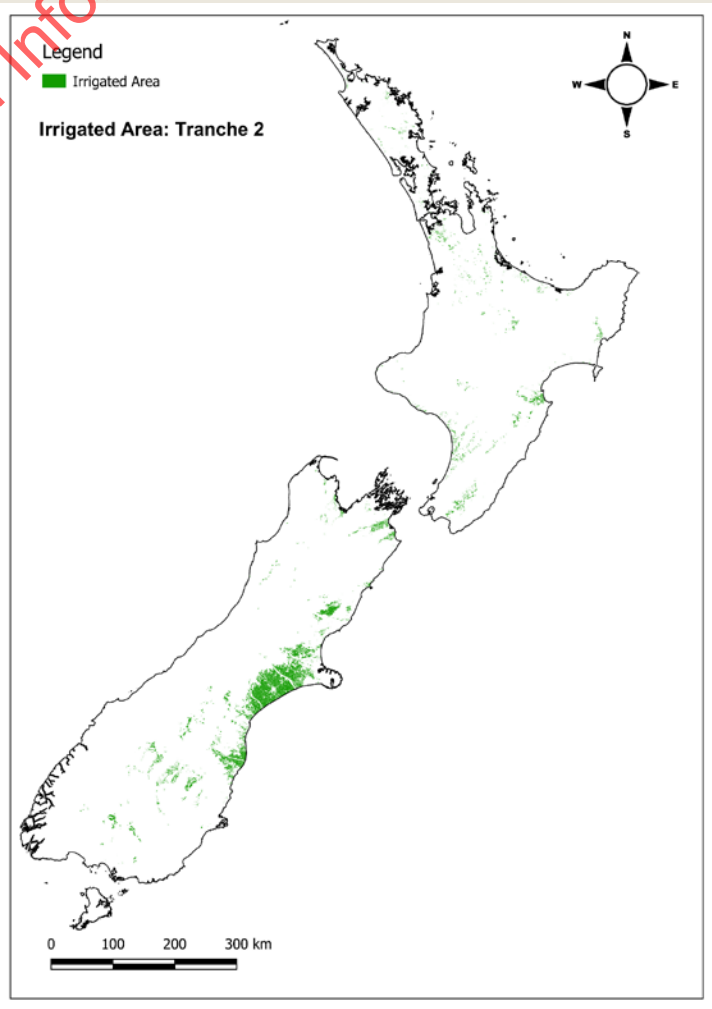


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Comparison of OLD and NEW data: Irrigated area





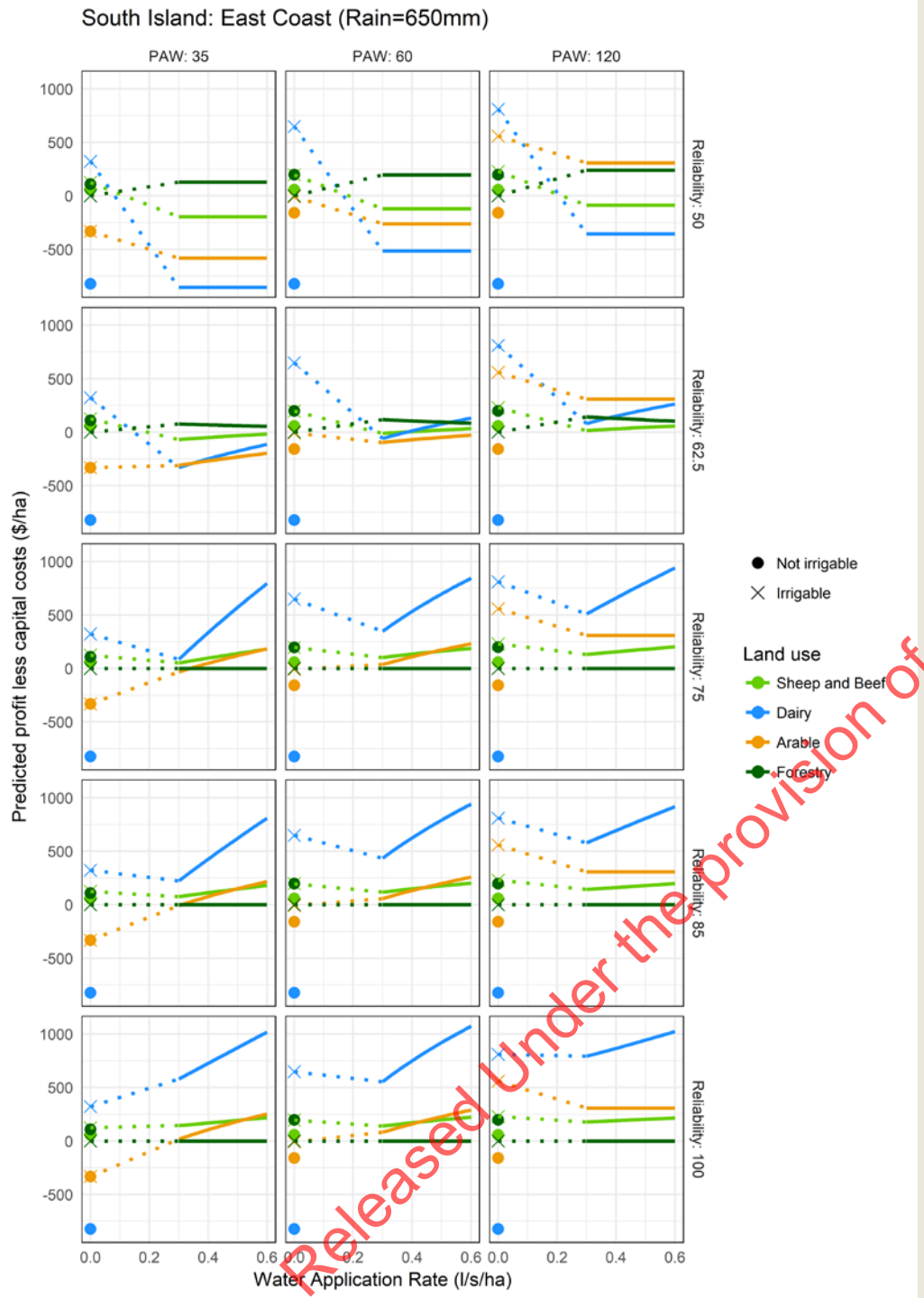
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Integrating profit functions

- Data from Part B project was turned into multidimensional continuous profit functions
- Capital costs were integrated so that differences in profitability weren't overestimated
- Constraints placed on increases in land use based on historic rates of change for dairy, horticulture and arable. No effective limits on forestry and sheep and beef to allow for balancing.
- Updated in TRANCHE 2:
  - *Sheep and Beef, Arable returns updated using Beef and Lamb NZ models.*
  - *Sheep and beef, Arable capital costs scaled for intensity.*
  - *Horticulture profits updated, and kiwifruit (Bay of Plenty) added to horticulture (AGFirst data)*
  - *Horticulture capital costs updated (AgFirst data)*
  - *Updates to forestry values from MPI/Scion national forest profitability assessment*
  - *All relativities between land uses checked for consistency, updated where necessary*

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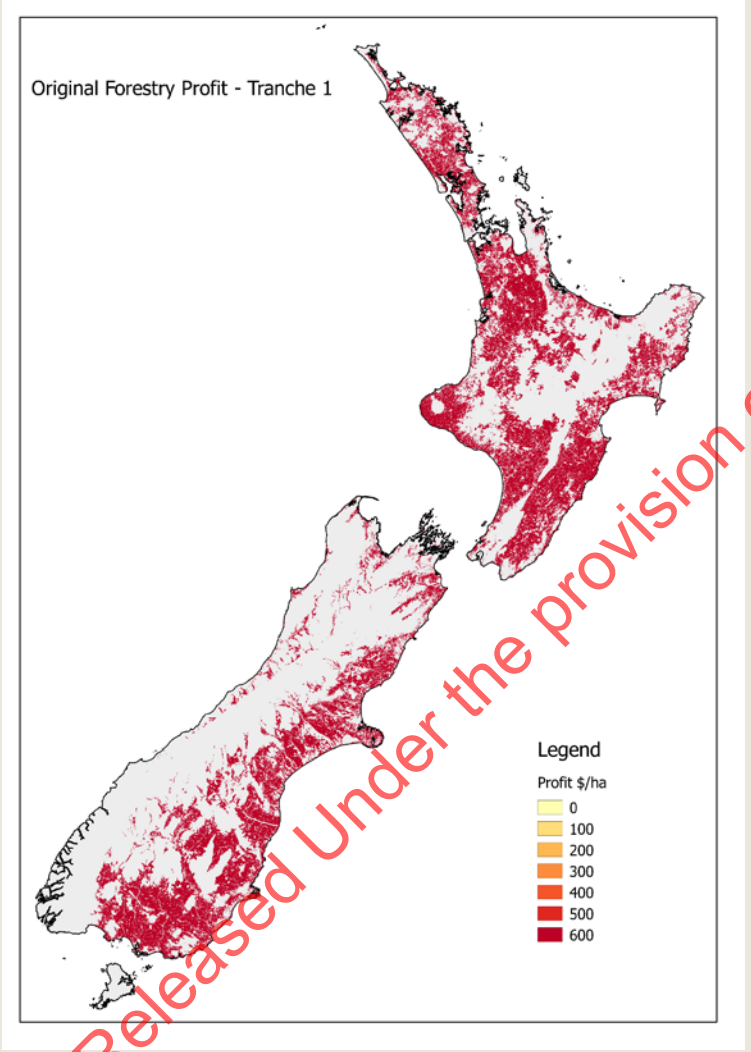
Profit curves for South Island East Coast (excl. horticulture) showing variation in after capital profit with reliability and application rate

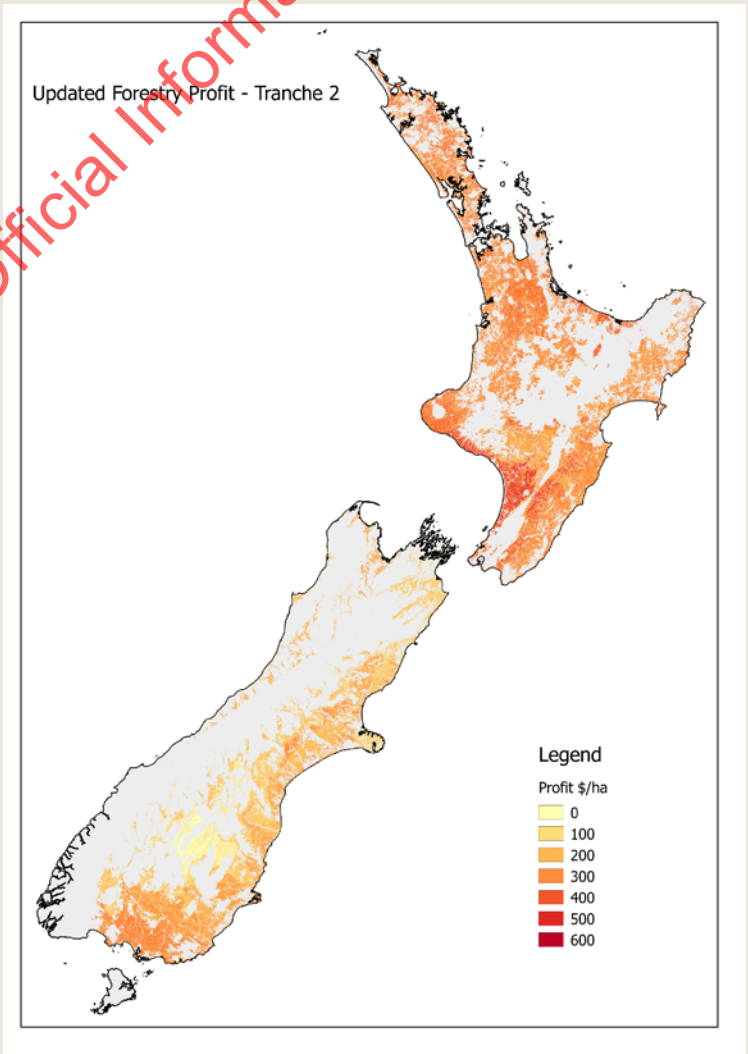
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Comparison of OLD and NEW: Forestry profit per ha

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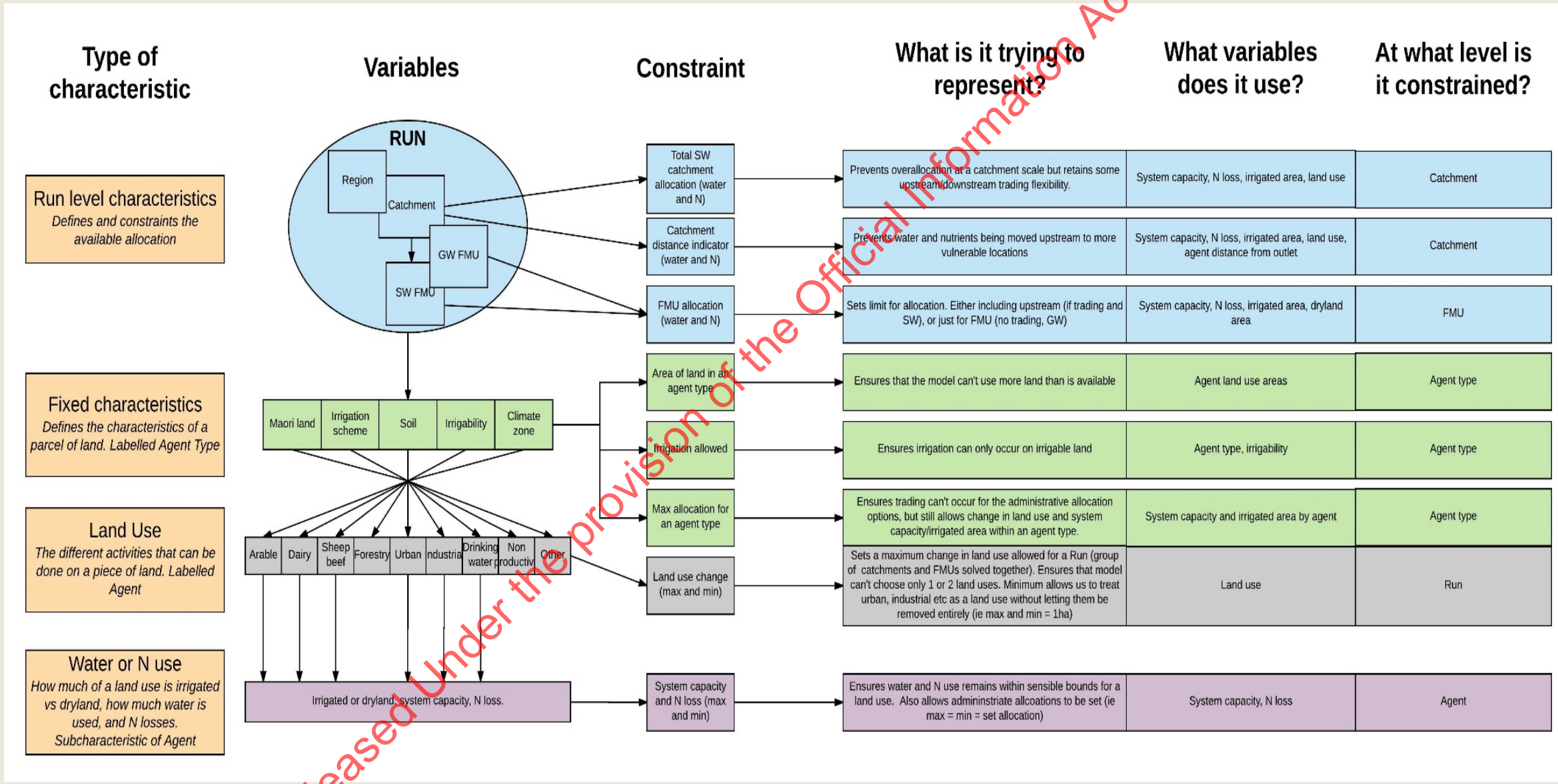
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Policy scenarios

- Original Scenarios tested
  - *Current Allocation Approach (NES minimum flows, 0.8-0.9 *MALF)*
  - *Transfer market*
  - *Maori land development*
  - *Land based allocation*
  - *Volumetric pricing*
- New Scenarios testing implications of NES for ecological flows
  - *Change minimum flows (lower: 0.5*MALF, higher: 1.5*MALF)*
  - *Change total allocation to NES allocation*
- Testing for water quantity allocation only. Water quality N loss mitigation not considered reliable enough for main scenarios.
- Conjunctive allocation – *tested Current Allocation approach with old N mitigation data to understand potential behaviour*
- Implemented in an optimisation module which chooses highest profit mix of land uses, water and nutrient use to match the scenario rules
- Movement of allocation cannot occur in a way that overloads upstream catchments.
- Scenario rules are implemented through constraints

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Details of NES Ecological flows scenarios

- NES specifies minimum flows and allocation to apply where no current plan limits in place.
  - *Minimum flows and allocation set at % of MALF – can increase or decrease.*
  - *Allocation is greater of current allocation or proportion of MALF – can only increase.*
- Change minimum flows (lower: 0.5*MALF, higher: 1.5*MALF)
  - *Applied to FMUs with existing allocation, no irrigation scheme, no nested FMUs.*
  - *Scenario specified as per "Current Allocation Approach" scenarios.*
  - *Reliabilities altered based on new minimum flows and current allocations*
- Change total allocation to NES allocation
  - *Applied to FMUs with existing allocation, no irrigation scheme, no nested FMUs.*
  - *Increases in total allocation applied (NES states that the allocation is the larger of the existing or NES allocations).*
  - *Reliabilities updated to reflect reliability if all possible allocated water is used with NES minimum flows (not dynamically updated within the simulations)*
  - *Water only allocated to agent types that currently use water.*

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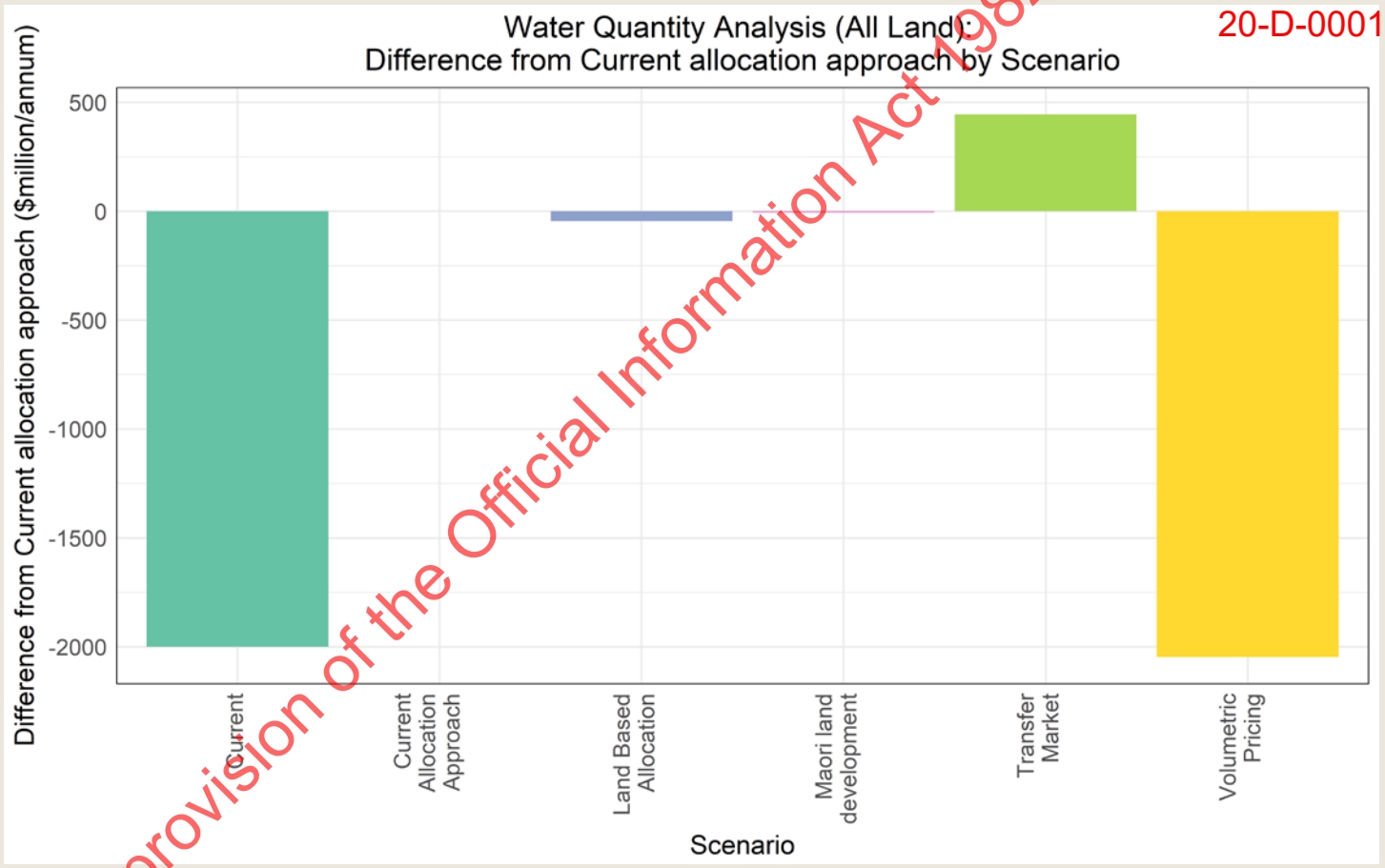
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Results

- Results are a comparison of what is achievable through different policy options
- They are NOT A PREDICTION of a future state
- Caveats around input data, ability to model policies, and ability to model individuals' responses
- These results allocate water only, and hold the N allocation constant.
- Treat the results as experiments in what potential gains exist with different interventions

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All Land – profit

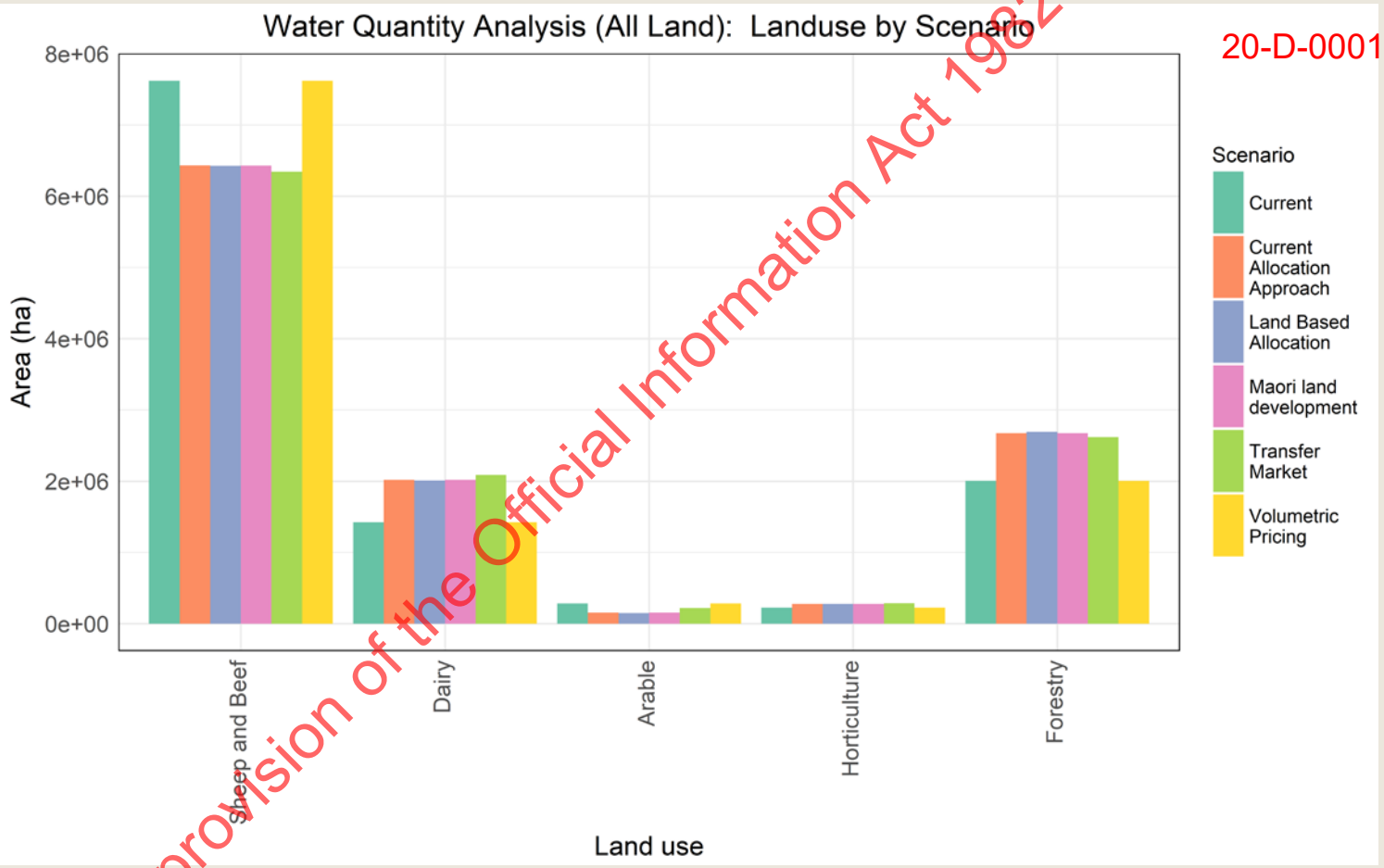


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- There are considerable gains in profit still possible with Current Allocation approach.
- The administrative allocations (Current Allocation approach, Land based, Maori land development) all achieve about the same profit overall. However there are significant differences for individuals.
- The transfer market is the only approach able to achieve significant gains above the Current Allocation approach.

All Land – land use



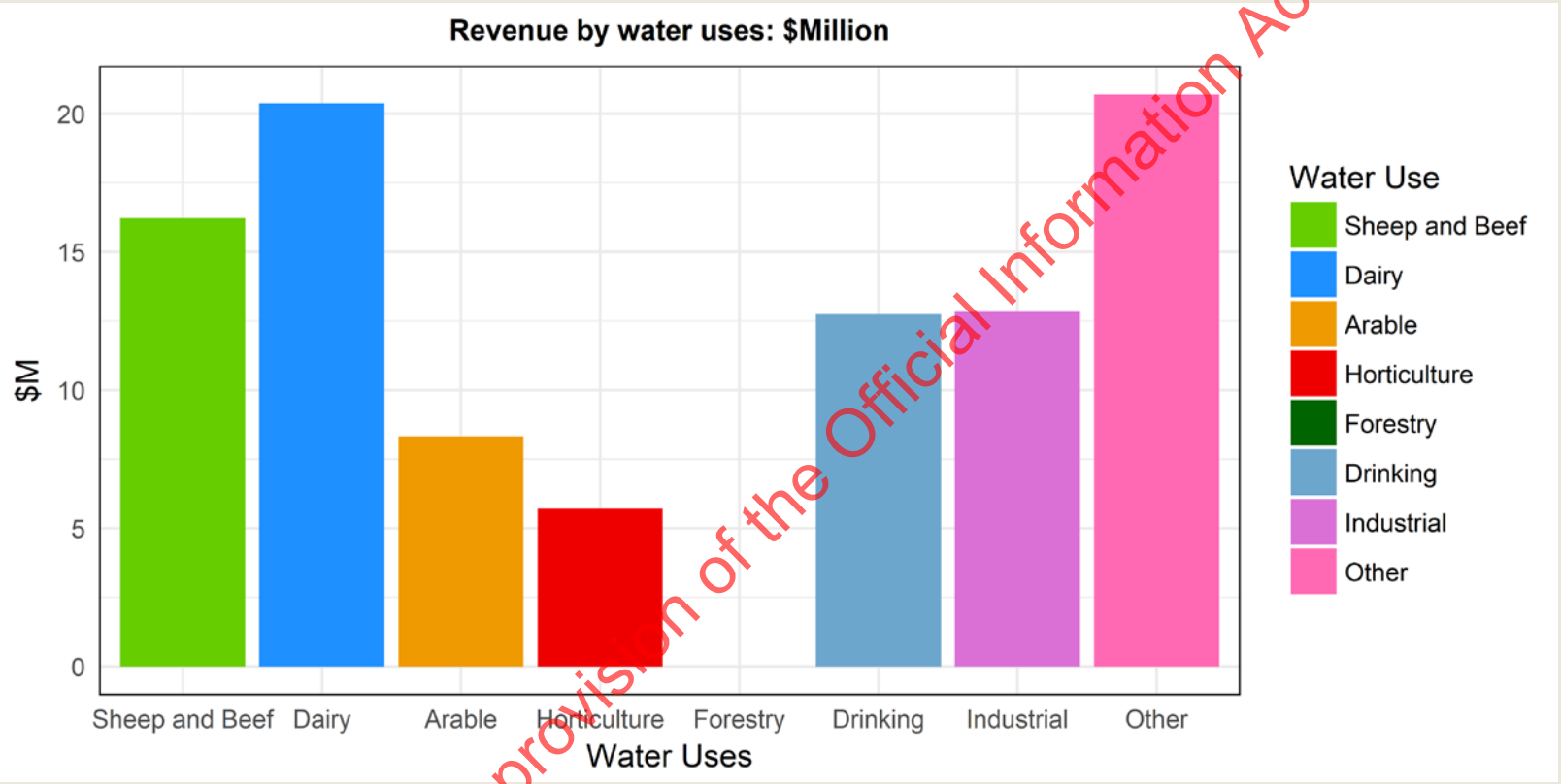
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- The model moves land use out of sheep and beef, into dairy and horticulture.
- The forestry appears to be incorporated so that N limits are met when conversion to dairy occurs.

Volumetric Pricing

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- Volumetric pricing was modelled based on allocation. On this basis would impact most on dairy land uses, although drinking, industrial and other water users would experience significant costs.
- Drinking, industrial and other uses are likely to be much lower based on actual consumptive use.
- Potential for revenue generation of ~$100 million per annum at 1c/1000m3.
- Does not include behavioural impact of the pricing approach.

Maori Land – profit

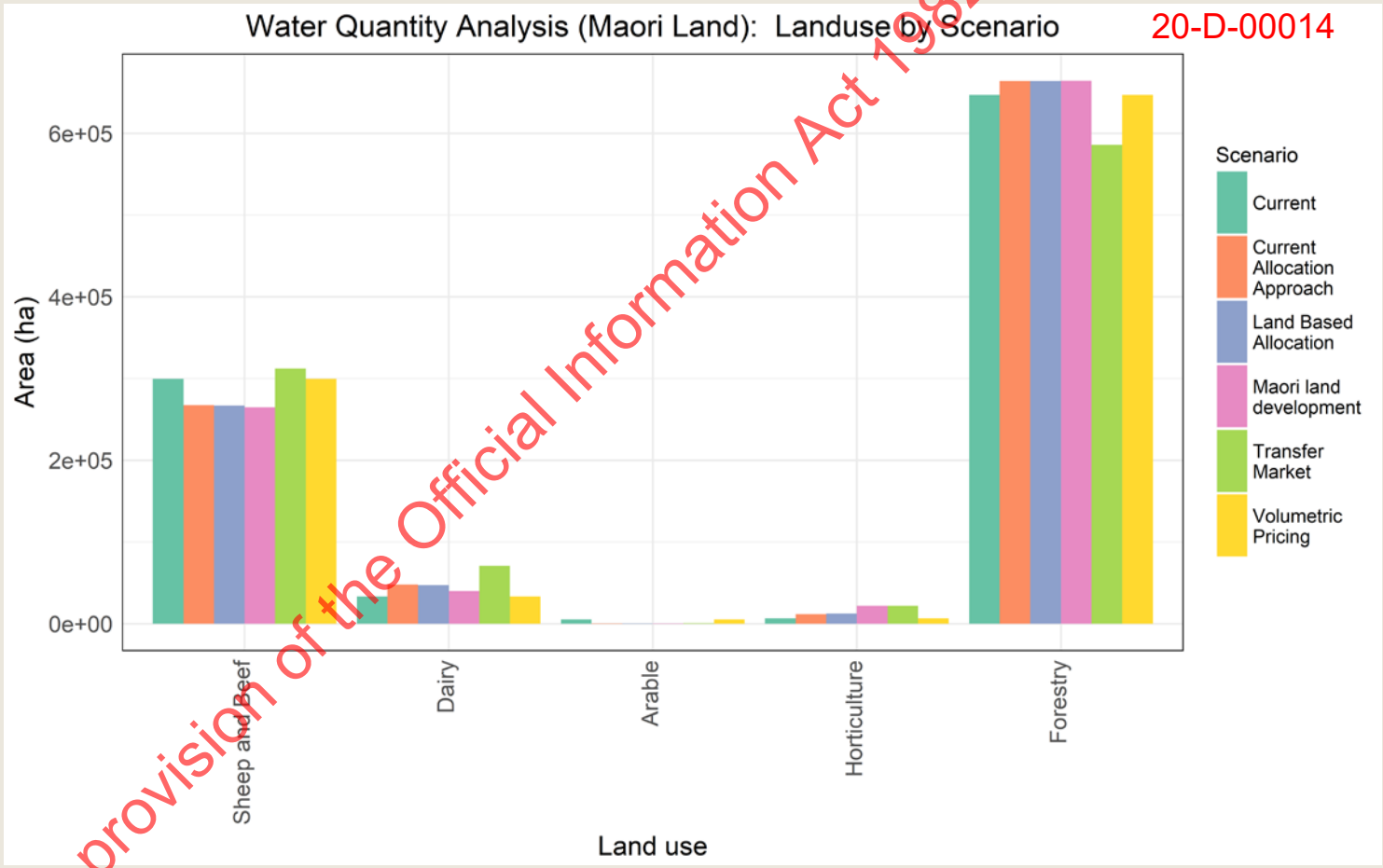


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- Maori land owners would benefit from land based allocation and Maori Land Development scenario.
- They would also potentially benefit from a transfer market if sufficiently resourced to participate.
- It is likely that the extent of their benefit is limited by availability of nutrients as well as water.

Maori Land – land use

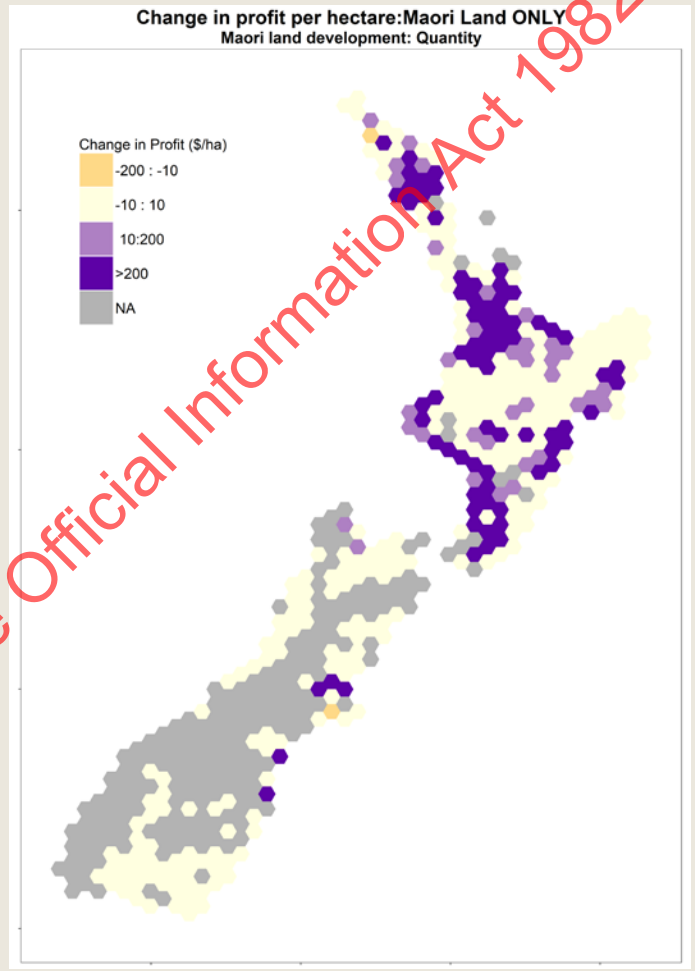


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- Most of the gains for Maori land would come from availability of water to undertake horticulture.

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Maori Land – change in profit with Maori land development scenario



- Maori land owners would benefit in most catchments, but there are some catchments where they would experience a reduction in profit.
- Where Maori are significant landholders in a catchment, they would be affected by the removal of water for redistribution.

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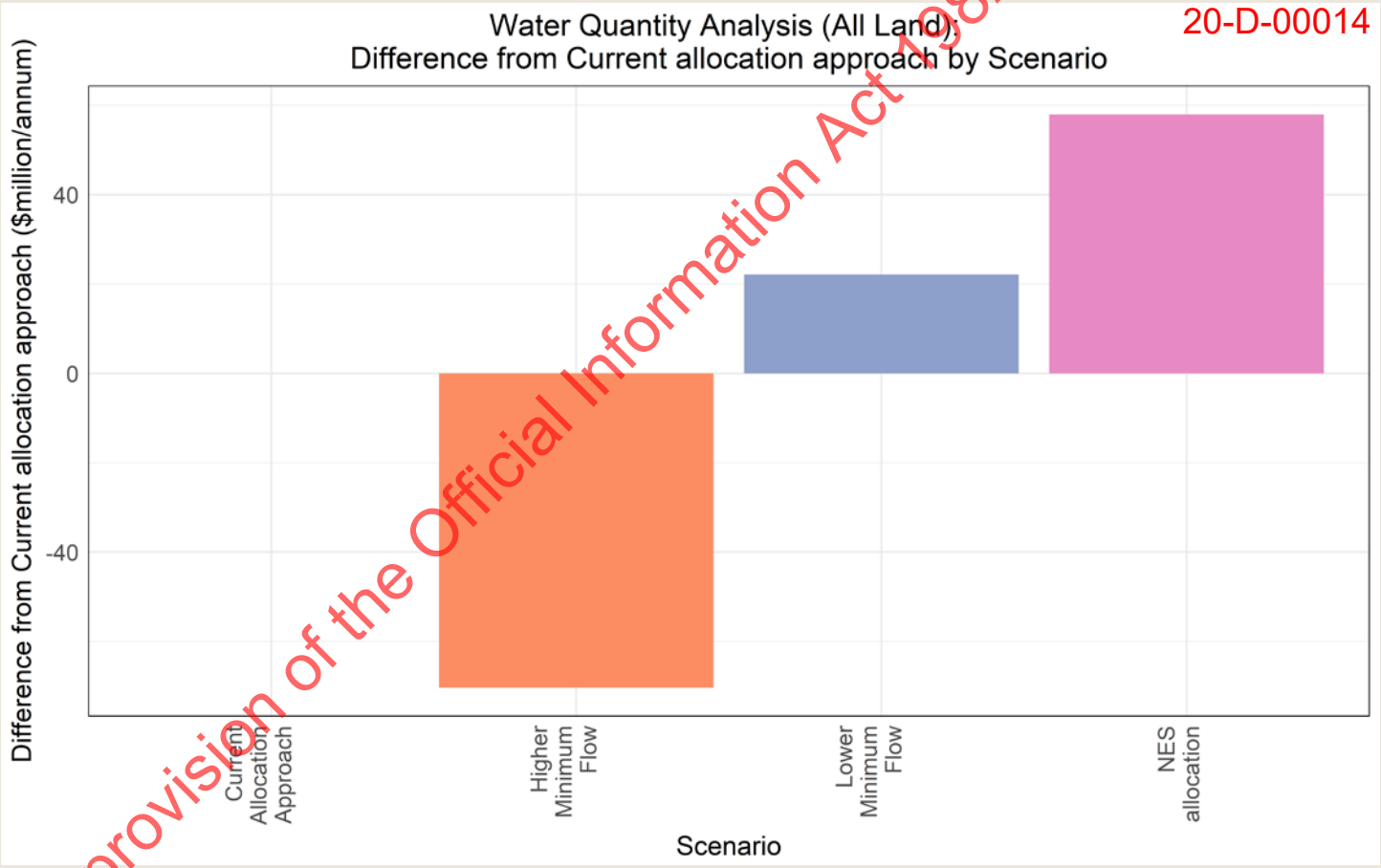
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Summary Main Scenarios

- Water quantity results suggest that the any administrative allocation approach does not impact much on the possible aggregate (national level) gains from use of water relative to the Current Allocation approach.
- Transfer markets demonstrate greater potential gains under the conditions tested and provide the greatest potential to increase the returns from use of water.
- At the individual level the winners and losers from different approaches to allocation are more significant.
- Policies to advantage Maori will need to be carefully designed to ensure negative consequences can be avoided.

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NES Scenarios – profit



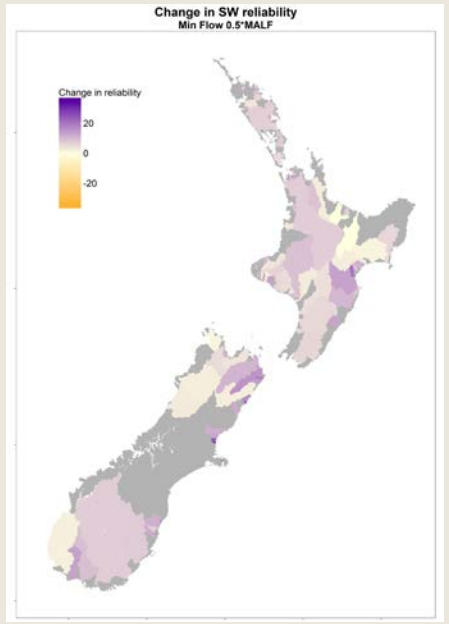
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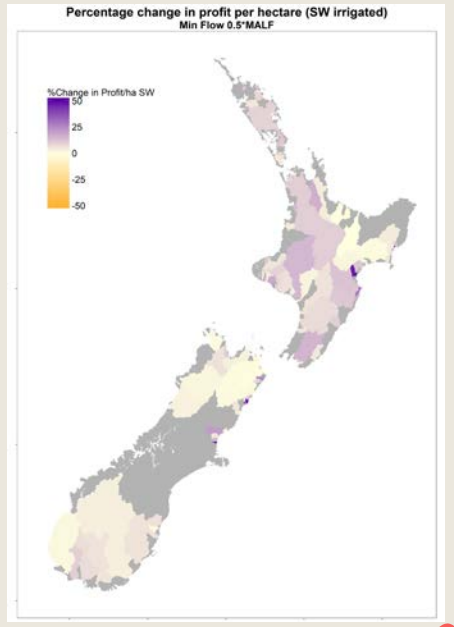
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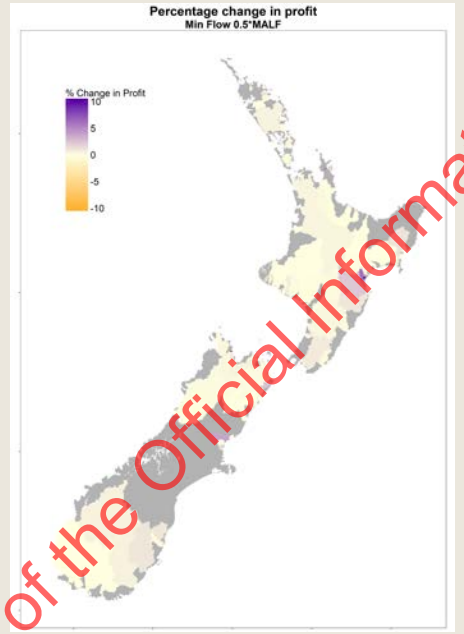
- The higher minimum flow results in ~$55 million in lower profits – driven by lower reliability.
- The lower minimum flows results in ~$22 million in higher profits – driven by higher reliability
- The higher allocation associated with the NES scenario results in ~$55 million in additional profit

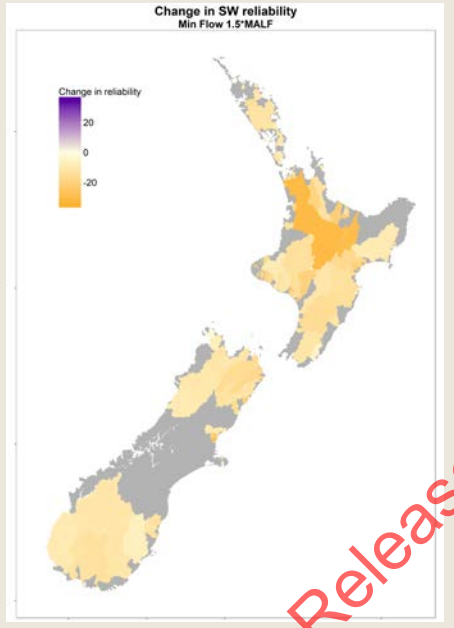
NES minimum flows – reliability and profit

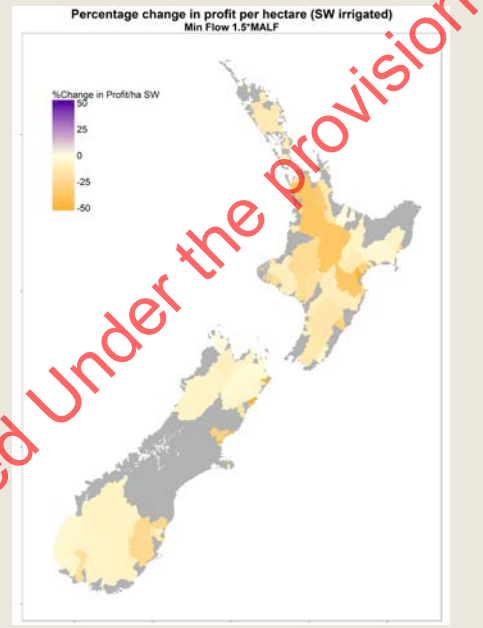
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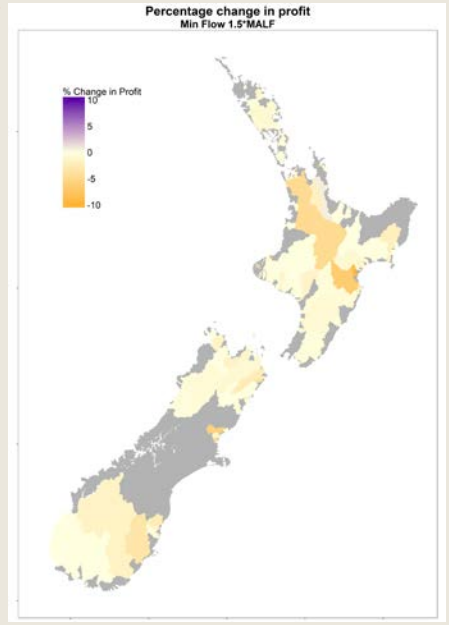










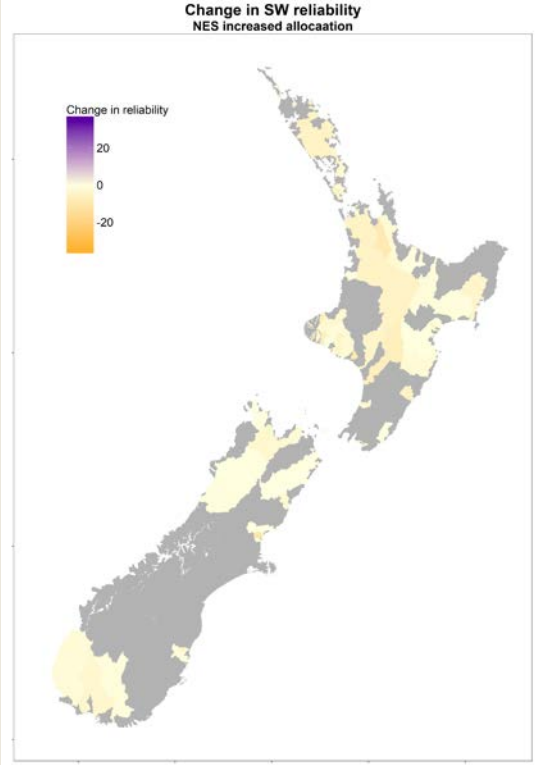


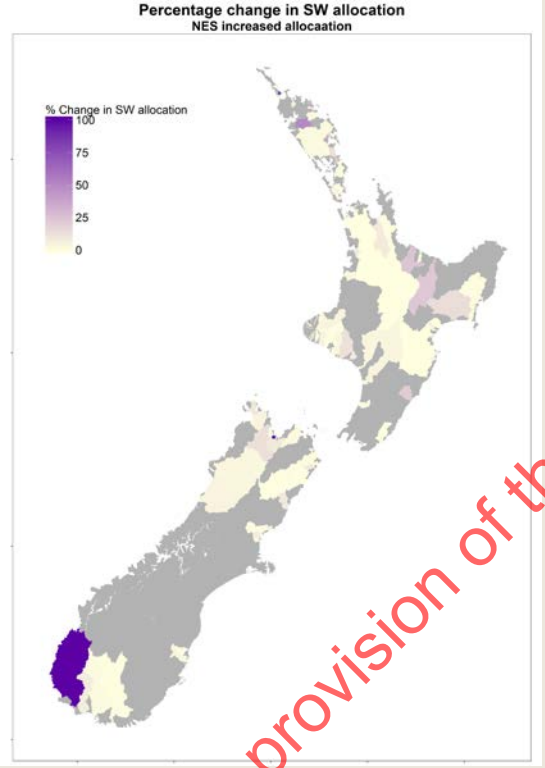
- The impacts of lower and higher reliability are not evenly distributed
- The changes in reliability are strongly related to the changes in the profit/ha for land irrigated by SW
- The changes in reliability are not directly relatable to changes in total profit, since the impact will be affected by the demand for irrigation . Where irrigation is important there are significant impacts on profit.

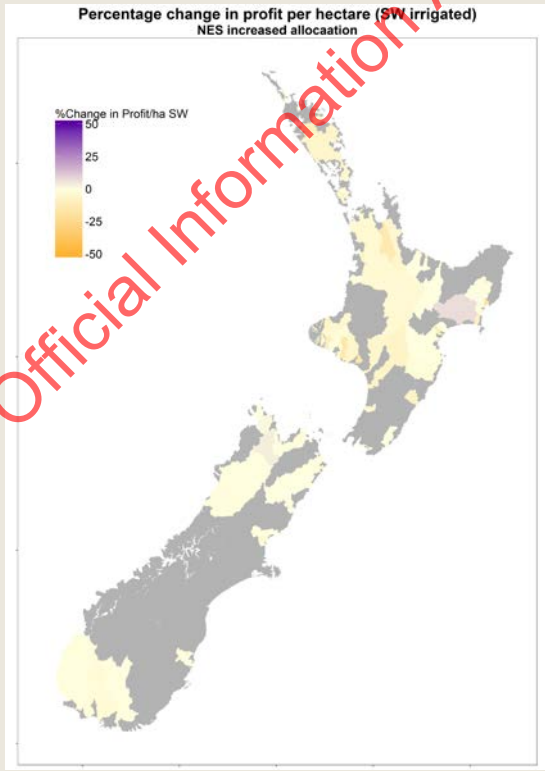
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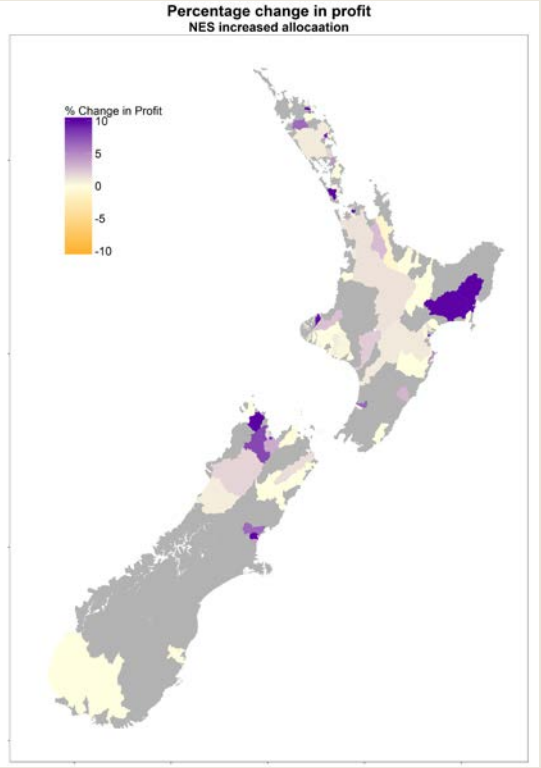
NES allocation – reliability, allocation and profit

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- The impacts of the NES allocation are very localised, because the current allocation exceeds the NES allocation.
- The increased allocation reduces reliability, which reduces the profit per ha.
- In most catchments the increased allocation makes up for the reduced reliability, but not always. There are some catchments where the reduction in reliability causes a reduction in total profit.

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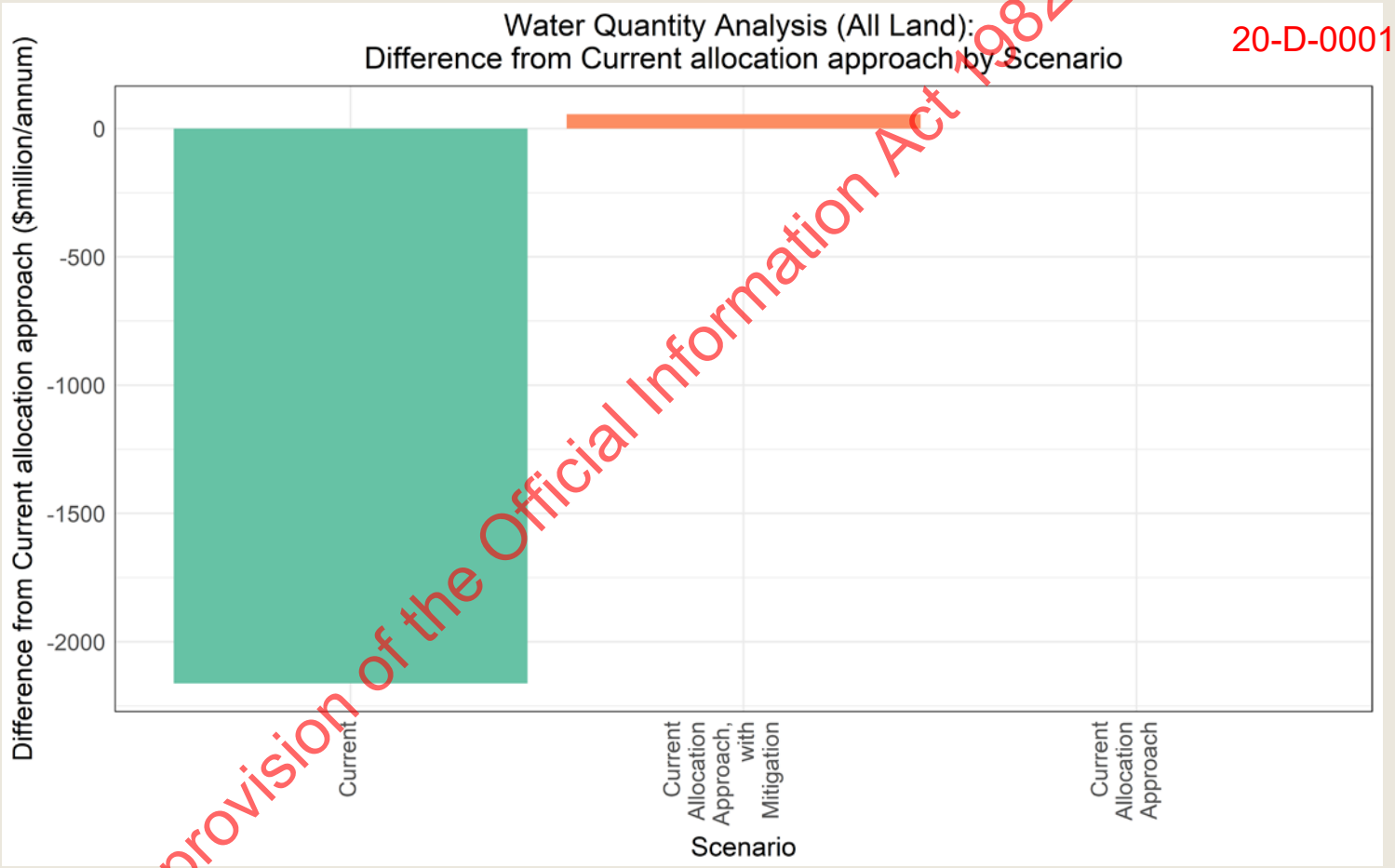
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Summary NES Ecological Flows

- Changes to minimum flows
  - *Can impact on reliability that affects the usefulness of the water and returns possible.*
  - *At the national scale these impacts are small, and are limited to a few catchments.*
  - *For these catchments impacted the changes can be significant. The changes are predictable in direction, but the magnitude is very catchment specific.*
- Changes to allocation
  - *Are complex because although more water is available, it is less reliable.*
  - *Impacts are also limited, but can be both positive and negative.*
  - *For some catchments the NES allocation is too high. It may be better to limit the allocation also by a reliability threshold to ensure negative impacts do not occur.*

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Conjunctive Allocation– profit

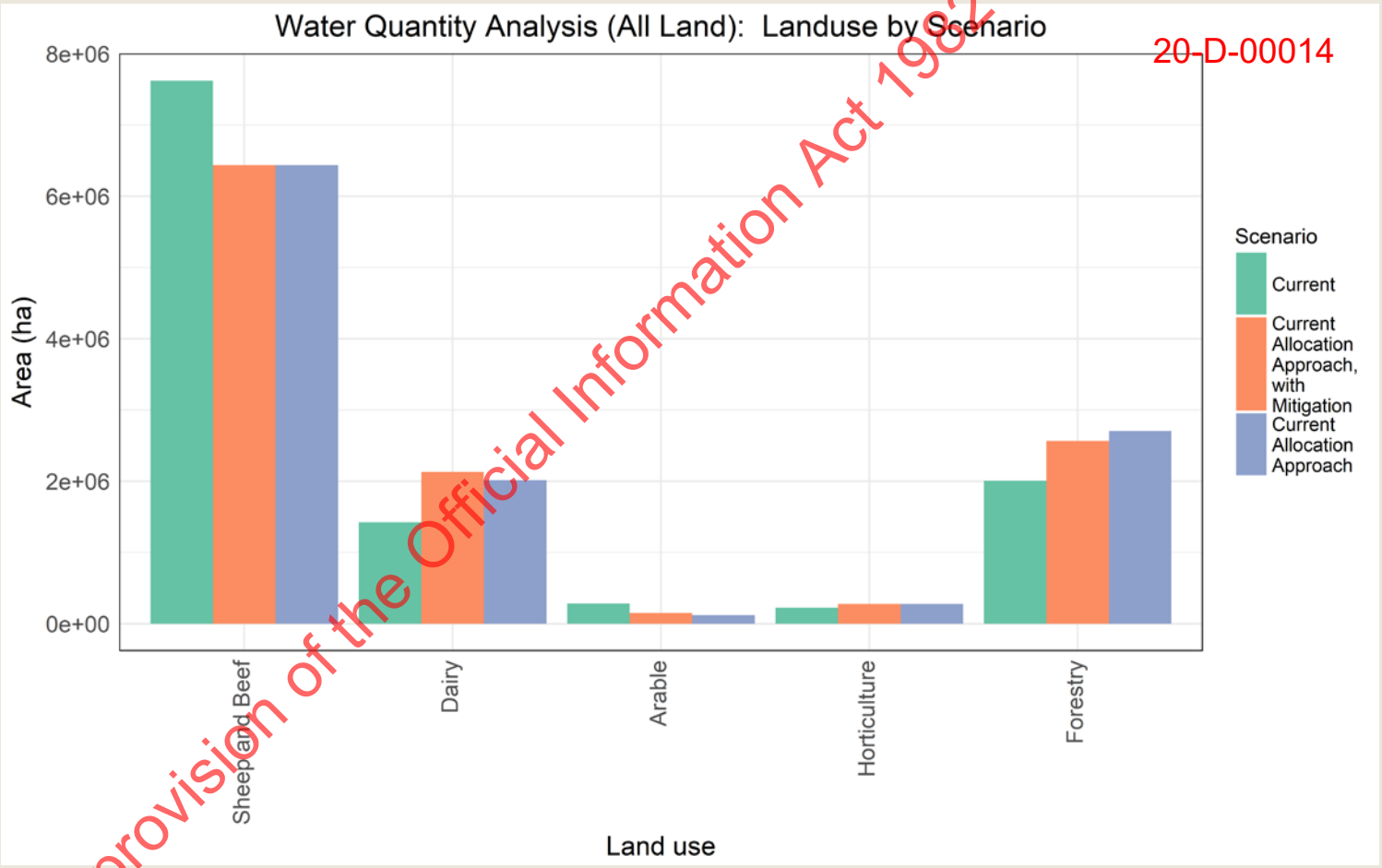


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- Allowing mitigation and conjunctive allocation increases profit slightly by allowing the water to be used on higher value land uses.
- The costs of mitigation are offset by the higher value, higher leaching land uses.

Conjunctive Allocation – land use



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- The conjunctive allocation allows dairy to increase without as much forestry having to be included to offset the higher leaching rates.

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Overall Summary

- Model input data is comprehensive and very detailed for modelling at this scale
- Model solves successfully over all feasible catchments, and produces results that are consistent with the way the policy scenarios are intended to work
- The issues with land use, irrigation layer and relative profitability have been resolved and the model now produces results that are more reflective of expected national results.
- Allocation is very complex and potential exists for negative outcomes if policies are not carefully thought through. Model can be used in a range of ways to experiment with the implications of individual and mixes of interventions.
- Conjunctive allocation can be assessed with the model. It is likely that water and nutrients need to be allocated together if gains from the use of resources are to be fully realised.
- Interventions can be in the biophysical space (changes to minimum flows, flow regimes, reliability banding etc) or policies (resource rentals, allocation options, transfers, redistributions etc).

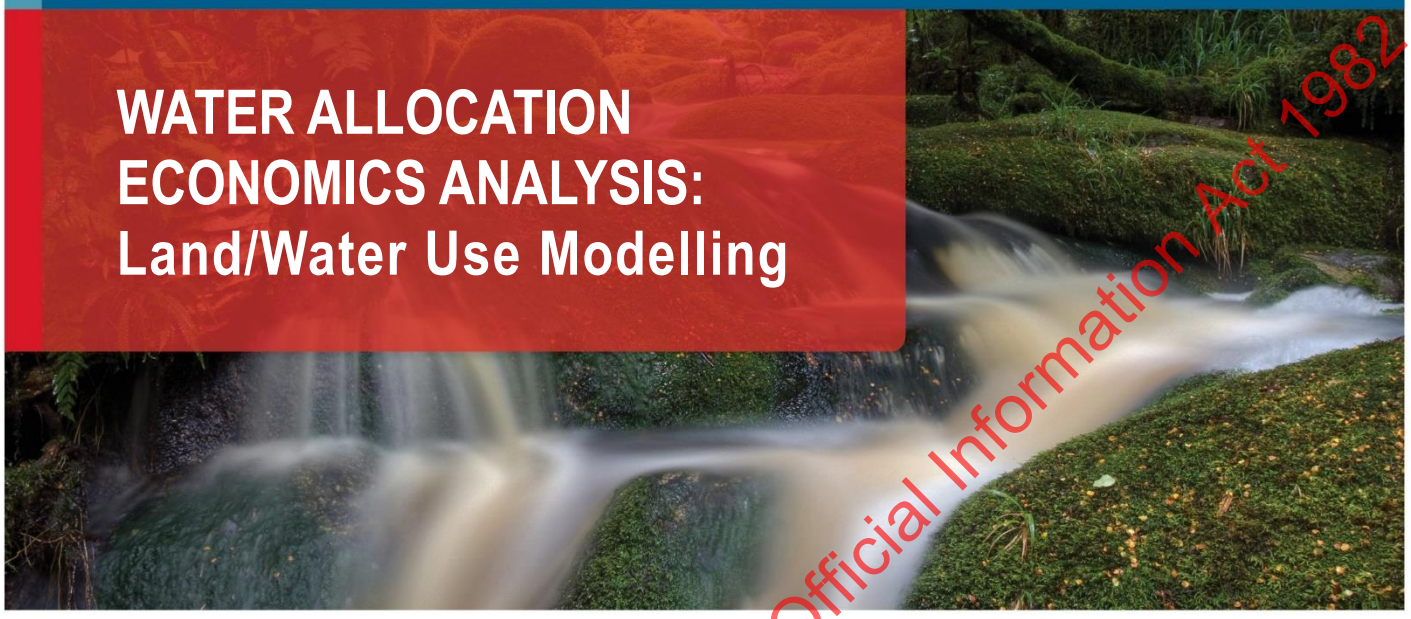
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Water Management REPORT

WATER ALLOCATION ECONOMICS ANALYSIS: Land/Water Use Modelling



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PREPARED FOR
Ministry for the Environment

C17020

28/01/2018

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EXECUTIVE SUMMARY

The purpose of this project was to develop quantitative relationships between water use, water supply reliability, contaminant discharges and profit (or cost) for different irrigation water users. These relationships were to be developed with a degree of generalisation appropriate for a national level analysis and capture broad regional and sectoral differences (e.g. climate variability, terrain, soil, land use, irrigation efficiency, etc.).

The Ministry for the Environment sought these relationships as an input to an economics model for assessing the direct benefits and costs of different possible central government policy approaches to allocating fresh water and assimilative capacity (e.g. transferable permits, pricing, or administrative allocation and re-allocation). The economics model was to be applied at multiple locations anywhere in New Zealand.

From the outset it was acknowledged that computer modelling is the best, if not the only, approach to developing the above relationships. The practicality of this approach had been proven in two prior projects which were essentially the prototypes for this larger scale project.

The financial effect of the key water allocation parameters – allocation rate and average water supply availability – were quantified by modelling the effects of different allocation parameters on production and, in turn, on the revenue, expenditure and operating profit of the water use activity. This extended prior work (Bright, 2016, Fenemor et al, 2015) in terms of geographical coverage and land use type. Water availability scenarios comprised all combinations of four irrigation allocation rates (e.g. 0.0 (unirrigated), 0.3, 0.45 and 0.6 l/s per ha irrigated), four supply availabilities (100%, 95%, 85% and 75%), and three classes of plant available soil water for each of the combinations of climate and land-use required to broadly represent more than 90% of New Zealand's irrigated area. More than 1100 scenarios were analysed to build up the relationships sought.

Quantitative relationships between Nitrate nitrogen loss and cash operating surplus were developed from prior work that has used Overseer™ to estimate N loss under Good Management Practice (GMP) and various bundles of mitigation options designed to reduce N loss. The annual cost of each mitigation bundle was deducted from the profit achieved assuming GMP (no mitigation) to build up a relationship between average annual contaminant discharge and average annual operating surplus.

Relationships between operating surplus and water allocation parameters were compared to the results from two recent small-scale studies. The shape of the relationships, when graphed, are very similar across all land uses, in spite of differences in the models used and variations in methodology between the three teams.

The relationships developed between operating profit and water allocation parameters, and profit and N loss, can be assigned to non-modelled areas on a nearest similar climate and land use basis to provide national coverage. However the relationships for non-modelled zones should be considered to be indicative.

The results of this work were supplied in tabular form to the economics team engaged by MfE to analyse the economic implications of different possible central government policy approaches to allocating fresh water and assimilative capacity.

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1 INTRODUCTION

This project contributed to the body of evidence sought by the Ministry for the Environment (MfE) to inform advice to the New Zealand government on a review of the freshwater allocation framework.

MfE required a quantitative analysis of the economic implications of different possible central government policy approaches (e.g. transferable permits, pricing, or administrative allocation and re-allocation) to allocate fresh water and assimilative capacity at a national level (or for multiple regions). The analysis needed to quantify the aggregate direct costs or benefits water users are likely to experience from changes in allocation policy.

There were two main components to the analysis:

- Component A: National economic analysis
- Component B: Land/Water use modelling

This report presents the methodology and results for Component B: Land/water use modelling.

The purpose of Component B was to develop quantitative relationships between water use, water supply reliability, contaminant discharges and profit (or cost) for different irrigation water users. These relationships were to be developed with a degree of generalisation appropriate for a national level analysis and capture broad regional and sectoral differences (e.g. climate variability, terrain, soil, land use, regional infrastructure, irrigation efficiency, etc.). The scope and degree of generalization of the relationships were developed in partnership with the Component A team and MfE.

These relationships were then to be used in an economics model that was applied nationally, or at multiple locations anywhere in New Zealand, to assess the direct benefits and costs of various allocation methods (Component A).

From the outset it was acknowledged that computer modelling is the best, if not the only, approach to developing the above relationships. The practicality of this approach had been proven in two prior economics projects which were essentially the prototypes for this larger scale project (Bright, 2016, Fenemor et al, 2015).

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2 METHODOLOGY

The method for developing quantitative relationships between water use, water supply reliability, contaminant discharges and profit for different irrigation water users is guided by the nature of what's being allocated. For water takes from rivers the 'inputs' to a land-based activity that are being allocated are flow rate (typically litres/sec) and water supply reliability (defined in terms of the allocation band the water take is assigned to and, for that band, the river flow rate at which takes must cease and the total amount of allocatable flow in that band). For groundwater takes the 'input' being allocated is typically the annual volume (cubic metres per year). Very few groundwater takes in NZ are subject to restriction as resource capacity drops so the reliability of groundwater takes is almost always 100%, and was considered as such in this project. Assimilative capacity is generally allocated as the maximum allowable average annual contaminant discharge from the land-based activity.

There is an important difference between allocation of water and allocation of assimilative capacity. Allocation parameters for water takes are constraints on water inputs to a water use activity. The allocation of assimilative capacity is a constraint on a water-borne contaminant output – there are no direct constraints on inputs. There are a multitude of ways in which inputs can be manipulated to achieve a given contaminant output. Each has a different cost and therefore effect on profit. This difference leads to differences in the way the financial impact of different allocation limits is usually calculated.

The financial effect of water allocation parameters can be quantified by modelling the effects of differing water availability scenarios on production and, in turn, on the revenue, expenditure and profit of the water use activity. This is the approach implemented previously (Bright, 2016, Fenemor et al, 2015) and in this project. Water availability scenarios comprised all combinations of four irrigation allocation rates (e.g. 0.0 (unirrigated), 0.3, 0.45 and 0.6 l/s per ha irrigated) and four supply availabilities (100%, 95%, 85% and 75%).

For assimilative capacity the usual approach is to use Overseer to quantify the average annual contaminant loss from a representative farm system for which average annual profit is known. The latter is either modelled or calculated from farm survey data. Progressively more 'aggressive' bundles of mitigation options are then applied to this farm system and the effects of them on contaminant loss are quantified using Overseer. The capital and annual cost of the bundles are also quantified. For each bundle of mitigation options, including no mitigation, the estimated contaminant loss and costs are thus determined. Prior analysis has provided much data on the relationship between mitigation options and associated nutrient loss reduction and costs. These data were used – the annual cost of each mitigation bundle was deducted from the profit achieved assuming no mitigation to build up a relationship between average annual contaminant discharge and average annual profit.

Relationships between water use, water supply reliability, contaminant discharges and profit (or cost) vary according to land-use type and location. Location determines climate, soil type, the farm system used for a particular land-use type, and water supply availability (with and without bulk water infrastructure). In any given catchment there are a large number of combinations of land-use type, location attributes and water availability scenarios, each of which would be modelled in a highly detailed analysis.

Given the national scale scope of this project and the very large number of combinations of climate, land-use and soil properties across New Zealand, we applied the following procedure to reduce the number of combinations to be modelled to develop the broadly applicable relationships MfE desired. In narrowing down the range of combinations to be modelled we gave priority to

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representing irrigated areas in Canterbury, Otago, Marlborough and Hawkes Bay (in decreasing irrigated area order), because these regions contain about 90% of NZ's irrigated area. We did this based on the presumption that the majority of the benefits from re-allocation will accrue in those areas where there is already a large amount of irrigation.

New Zealand was divided into a number of Zones, based on New Zealand Climate Regions from NZMS 1983, shown in the following figure.

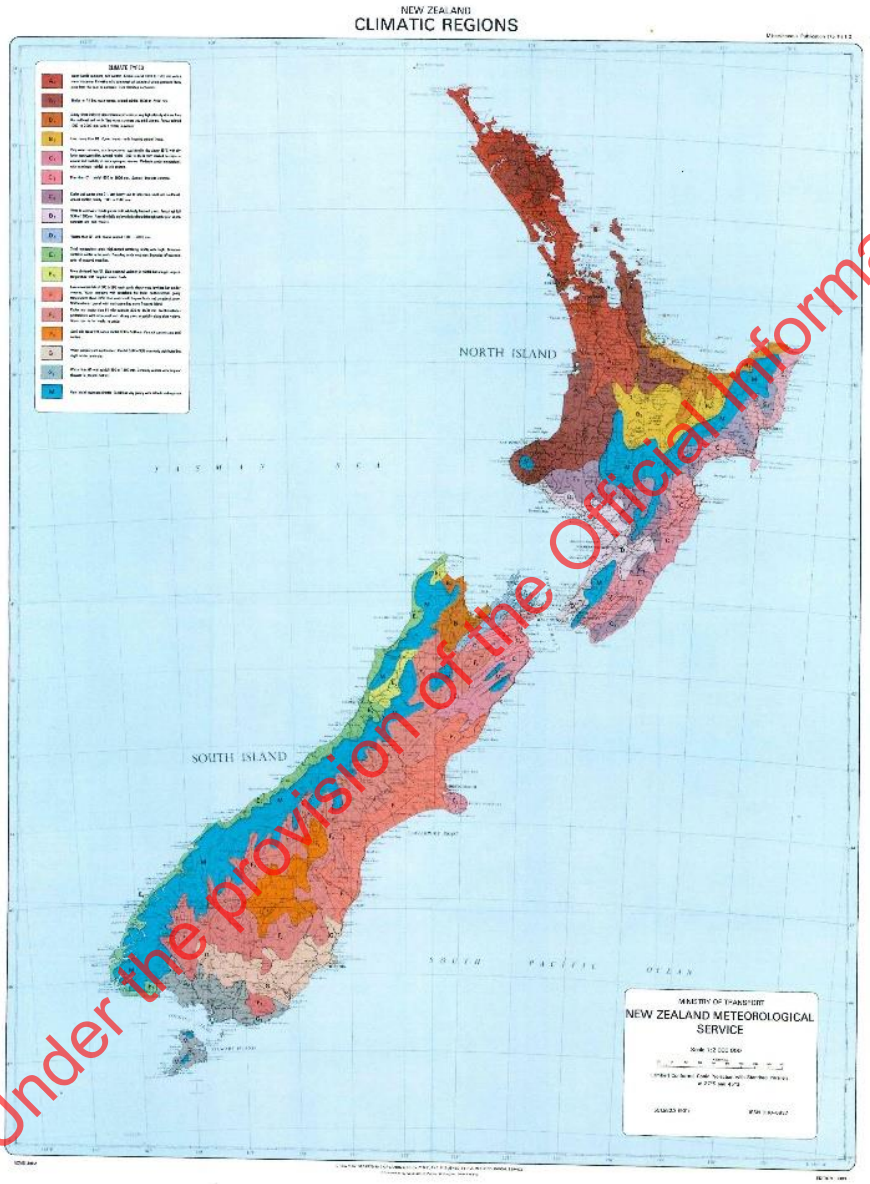


Figure 1: New Zealand Climate Regions (NZMS 315/2)

The number of Zones was reduced by aggregating some climate zones, based on the similarity of their irrigation water requirements, and the Canterbury Plains zone was subdivided to better capture the effects on irrigation requirements of the rainfall gradient across the Plains. The resulting Zones are presented in the following figure.

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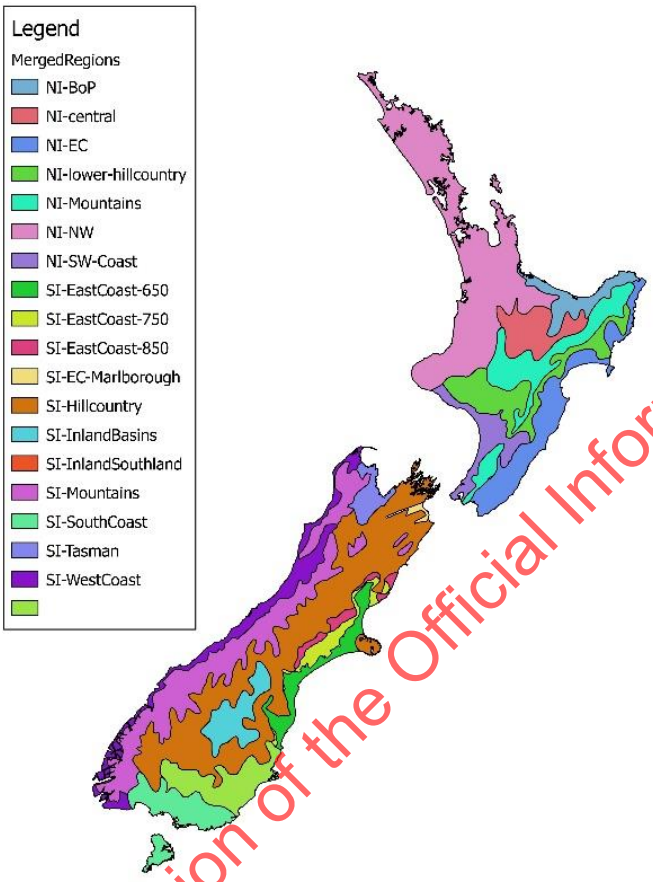


Figure 2: Zone Map

Of these Zones, farm systems were modelled for only the following zones to keep the scope of work within the project budget: NI-EastCoast, NI-Central, NI-SW-Coast, SI-EastCoast-Marlborough, SI-EastCoast-650 (mean annual rainfall in mm), SI-EastCoast-750, SI-EastCoast-850, SI-InlandBasins.

More than 90% of New Zealands irrigated area lies within these Zones and within them the dominant irrigated land-uses are pasture-based (eg dairy, dairy support, sheep&beef finishing), followed by arable, viticulture, and pip fruit. Not all of these land-uses are heavily represented in each Zone - the type of farm system modelled was therefore a function of the Zone in which the land-use occurred. The combinations of Zone and land uses that were modelled are set out in the following table.

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Table 1: Combinations of Zone and Land-Use that were modelled

Zone	Land-Uses			
NI-EastCoast	Sheep&Beef	Dairy	Arable	Pip Fruit
NI-Central	Sheep&Beef	Dairy		
NI-SW-Coast	Sheep&Beef	Dairy		
SI-EastCoast-Marlborough				Viticulture
SI-EastCoast-650	Sheep&Beef	Dairy	Arable	Vegetables
SI-EastCoast-750	Sheep&Beef	Dairy	Arable	Vegetables
SI-EastCoast-850	Sheep&Beef	Dairy	Arable	Vegetables
SI-InlandBasins	Sheep&Beef	Dairy		Viticulture

Across New Zealand, the bulk of the potentially irrigable soils have a capacity to store plant available water (PAW) of between 30mm and 120mm, with a predominance in the range 60mm to 80mm (assuming a root depth of 600mm). Accordingly, we modelled three PAW classes: 35mm, 60mm and 120mm.

Irrigation water use and pasture/crop production was modelled for each combination of Zone, land-use/farm system type and soils selected as described above, under different levels of maximum rate of take and of water supply availability. Differences in Irrigation methods due to differences in land-use were represented through differences in the irrigation management rules used, which results in differences in irrigation efficiency. For each combination, Aqualinc's IrriCalc-MP simulation model was used to determine the irrigation amounts for each paddock, for each day of the simulation period. This period ran from 1 July 1972 to at least the 30 June 2013, depending on the availability of climate and river flow data. This irrigation time series, along with rainfall and other climate data, were put into DairyMod to simulate plant growth on a daily time step, or into an FAO crop yield prediction model.

Modelled production output statistics from the farm simulations were entered into The AgriBusiness Group's spreadsheet models of farm revenue and expenditure. The principal output from these spreadsheet models was average annual cash operating surplus, as the measure of 'profit'.

In total more than 1100 scenarios were modelled.

A considerable amount of recent prior work existed on the effects of different mitigation bundles on contaminant loss rates and the capital and annual costs of implementing them (e.g. MPI funded economic impact analysis projects in Southland, Northland and Wairarapa; nutrient performance and financial analysis of horticultural systems in various regions conducted by The AgriBusiness Group for Horticulture NZ, MGM project for Canterbury). This prior work was reviewed and relationships between % reduction in contaminant loss and the costs of implementing the mitigation bundles that deliver that reduction were draws from it. These relationships we then updated to a common time base and used with the modelled profit and contaminant loss for the 'no mitigation' baseline to produce the relationships between contaminant loss and profit required for Component A. No new Overseer modelling was required.

The relationships between water and nutrient allocation parameters and profit were supplied to the Component A team as tabular data.

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3 DESCRIPTION OF MODELS USED

3.1 Irrigation Modelling

IrriCalc-MP simulates the irrigation of, and drainage and pasture/crop production from, each paddock or field-unit in a farm. The simulation operates on a daily time step. Soil type, crop rotation, climate and irrigation method are specified at the field-unit level. This enables both the spatial and temporal variability in the farms key physical characteristics, operating environment and management to be represented explicitly in the model.

Irrigation management rules are specified for each crop. This means that as the type of crop grown in a specific field-unit changes the irrigation rules applying to that field-unit also change.

The maximum amount of irrigation water that can be used on the farm on any particular day is constrained by the irrigation system capacity or the amount of water available from the farm's water source that day, whichever is the most limiting. The amount of water available from the water source depends on the state of the water source, river flow rate for example, and the applicable consent conditions. If irrigation demand is greater than the supply on any day the water available is allocated to field units in order of priority until the available water is fully committed. The field units that need irrigation, but which are not allocated water because there isn't sufficient, are not irrigated that day. In the current version of the model the field units are assigned a priority order that is fixed for the simulation. This means the same field units are dropped first when water supply is short, regardless of the crop being grown in them at the time.

Irrigation system capacity, maximum allowable seasonal water use and a daily time series of water availability are key inputs to IrriCalc-MP because of their influence on farm-scale irrigation water use, drainage (and therefore leaching) and pasture/crop production.

IrriCalc-MP models the soil water balance for each of the field-units in a farm using the following equation to update the calculated soil water content on a daily basis given daily measurements or estimates of rainfall, irrigation, drainage and actual evapotranspiration.

$$S_{t_2} = S_{t_1} + R_{(t_2-t_1)} + I_{(t_2-t_1)} - D_{(t_2-t_1)} - AET_{(t_2-t_1)}$$

Where:

$AET_{(t_2-t_1)}$ = Actual evapotranspiration between time t_2 and t_1

$R_{(t_2-t_1)}$ = Rain between time t_2 and t_1

$I_{(t_2-t_1)}$ = Irrigation between time t_2 and t_1

$D_{(t_2-t_1)}$ = Drainage between time t_2 and t_1

S_{t_2} = Soil water content at time t_2

S_{t_1} = Soil water content at time t_1

$$AET_{(t_2-t_1)} = K_c \times f(S_{t_1}, a) \times ETref_{(t_2-t_1)}$$

K_c = Crop factor applicable over time t_1 to t_2

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$f(S_{t_1}, a)$ = Evapotranspiration reduction function

$ETref$ = Evapotranspiration for a well-watered reference crop

The evapotranspiration reduction function is an empirical function that takes a value in the range 0 to 1, depending on the ratio of soil water content on day t_1 to the "field capacity" and the parameter "a". The parameter "a" is related to the volume of soil water that is readily available to the plant. Actual evapotranspiration occurs at the potential rate until the readily available water has been used up. As the soil dries from this point, actual evapotranspiration becomes a progressively smaller fraction of the potential evapotranspiration. The particular empirical function used in IrriCalc-MP is described in Minhas *et al.* (1974), and has been used in New Zealand by Heiler (1981) and Bright (1986, 2008).

Drainage is assumed to occur whenever the soil water content is calculated to be greater than "field capacity". The volume of drainage is set equal to the volume required to reduce the soil water content to "field capacity", and it is assumed that drainage occurs within the same daily time period as the rainfall or irrigation that raised soil water content above "field capacity".

Reference crop evapotranspiration is calculated from daily climate measurements using the Penman-Monteith method (Allen et al, 1998), with parameters appropriate for estimating evapotranspiration from a well-watered grass sward of 120 mm height.

Irrigation amounts are calculated by an irrigation system model on each day of the user-defined irrigation season. The irrigation system model enables key irrigation system design and irrigation management parameters or constraints to be specified. These include the depth and spatial uniformity of irrigation applications, the return period, the soil water level at which irrigation is triggered, the beginning and end of the irrigation season, irrigation system capacity and the maximum allowable seasonal irrigation water use.

Table 2 shows the various combinations of irrigation system parameters that can be applied to replicate a wide range of irrigation systems and practices.

Table 2: Irrigation management options available in IrriCalc-MP

	When to irrigate			
Application depth	Never	Every X days from the beginning of the irrigation season, where X = Return Period	Trigger on soil moisture, providing the number of days since the last irrigation event equals or exceeds the Return Period	User supplied time series
Zero	✓			
Fixed depth (user defined)		✓	✓	
Variable depth (return soil moisture to a specified level)		✓	✓	
User supplied time series				✓

The application depth is the spatial average of the water depth applied across the wetted width and run length of the irrigation application device. The spatial uniformity of the irrigation application is specified by Christiansen's Uniformity Coefficient.

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The amount of water that is retained in the soil due to an irrigation event is calculated using the method described in Bright (1986). Implicit in this calculation is the assumption that the spatial distribution of application depth can be represented by the Normal distribution. The amount of irrigation water retained, and the amount that drains, is a function of the soil water deficit at the time of irrigation, the average application depth, and the uniformity of irrigation application. The relationship between application efficiency (which is the ratio of volume of water retained to volume of water applied to the land surface), average application depth, and uniformity is illustrated in the following figure:

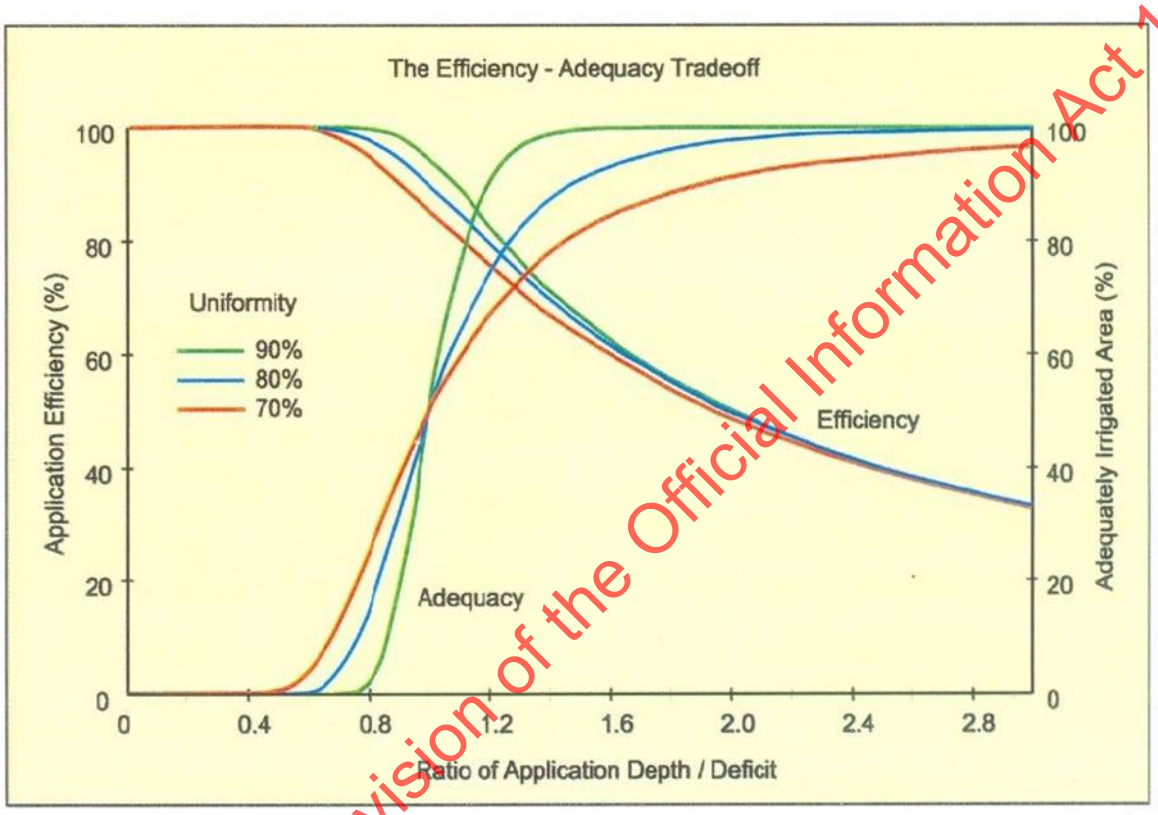


Figure 3: Relationship between irrigation application efficiency and average application depth

The application efficiency varies from irrigation event to irrigation event, depending on the ratio of application depth to soil water deficit at the time of irrigation.

3.2 Farm Production Modelling

3.2.1 Pasture growth modelling

The effect of soil water content, and thus irrigation events, on pasture growth was estimated using the pasture growth simulation model 'DairyMod'. In recent years both DairyMod (Chapman et al., 2009; Cichota et al., 2008; Cullen et al., 2008; White et al., 2008) and APSIM (Brown et al., 2010; Li et al., 2011; Moot et al., 2014; Snow & White, 2013; White & Snow, 2012) have been widely tested

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within New Zealand. The pasture model within APSIM (AgPasture) is an adaptation of the pasture model from DairyMod (White & Snow, 2012).

DairyMod (version 5.3.13) is a biophysical pasture simulation model that includes modules for pasture growth and utilisation by grazing animals, animal physiology including animal production, water and nutrient dynamics, as well as a range of options for pasture management, irrigation and fertilizer application. A mathematical description of the model is presented in Johnson (2013).

The pasture growth module includes calculations of light interception and photosynthesis, growth and maintenance respiration, nutrient uptake and nitrogen fixation, partitioning of new growth into the various plant parts, plant development, tissue turnover and senescence, and the influence of atmospheric CO2 on growth. The model allows up to five pasture species in any simulation; in this work the pasture was assumed to be comprised of perennial ryegrass and white clover.

In general, pasture growth is calculated firstly by determining the daily transpiration rate and the effect of water stress. Daily photosynthesis is then calculated in response to light, temperature, atmospheric CO2 concentration, canopy architecture, available water, and leaf nitrogen status. Potential nutrient uptake is described in relation to root distribution and soil nutrient status and the plant mass flux is calculated, incorporating tissue turnover, senescence, shoot and root growth. Pasture growth is constrained by both temperature stress and water stress functions.

Cullen et al. (2008) tested the ability of DairyMod to simulate net herbage accumulation rates of ryegrass-based pastures in Australia and New Zealand. Overall, close agreement was achieved between the observed and simulated data with herbage mass differences of 0.4-30.3% for ryegrass based pastures under varying environmental and management conditions. For fertilised plots (with or without irrigation), simulated yields were between 0.4-15.9% of those measured, while differences of up to 30.3% were predicted for unfertilised pastures.

White et al. (2008) used EcoMod, which has the same pasture growth model as DairyMod, to test how well the model simulated the changes in growth rate and plant composition of dryland and irrigated pasture production in a temperate climate through comparison with a long-term (1966–2003) data set measured in New Zealand. In general, close agreement was achieved between the measured and modelled total annual and monthly growth rates. This was particularly so following modifications to some of the parameters of plant growth to more accurately represent the characteristics of dominant species present in dryland and irrigated pastures in New Zealand.

Van Housen (2017) calibrated DairyMod for use under Canterbury Plains conditions using pasture growth data from Larundel Dairy Farm. Simulated total herbage yield for the lysimeter-grown pasture was 10.3 t DM/ha, 3% less than that measured.

Over the experiment period, the mean daily bias was 1.6 kg DM/h/d, within the range reported by Cullen et al. (2008) of -3.7 to 6.3 kg DM/h/d. The difference of 3% between the total measured and simulated lysimeter herbage yield over the experiment period was comparable to the accuracy achieved by White et al. (2008) of 2.5% for irrigated, fertilised ryegrass pasture, and at the lower end of the differences (0.4-30.3%) published by Cullen et al. (2008).

3.2.2 Crop production modelling

Crop production is simulated using the FAO water production function described by Doorenbos and Kassam's (1979). In summary the relative yield reduction due to soil moisture stress is related to the relative reduction in evapotranspiration by the following equation:

$$(1 - Y_a/Y_x) = K_y (1 - ET_a/ET_x) \quad \text{where}$$

Y_x and Y_a are the potential and actual yields, ET_x and ET_a are the potential and actual evapotranspiration, and K_y is a yield response factor representing the effect of a reduction in evapotranspiration on yield loss due to soil moisture deficit.

IrriCalc calculates the potential yield for each growing season using the equation

$$Y_x = WUE * ET_x \quad \text{where}$$

WUE is the crop's water use efficiency (kg harvested / mm of evapotranspiration).

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The calculated potential crop yield therefore varies from year to year in response to variations in climate. IrriCalc's crop yield model operates on a daily time step and outputs pasture growth as a daily time-series and crop yield at the user specified harvest date.

Crop yields modelled by IrriCalc were tuned to match yields being achieved on irrigated farms in the relevant Zones. These are summarised in Section 3.3 Financial Modelling.

3.3 Financial Modelling

Six farm systems were modelled, in terms of their gross farm revenue, total farm operating expenses and cash operating surplus, as follows:

- Dairy
- Sheep and beef
- Arable
- Horticulture (Vegetable production)
- Viticulture
- Pip fruit

The farm financial models were based on the regional Ministry of Primary Industries (MPI) Farm Monitoring reports, excluding the horticulture and arable models which were based on previous work carried out by The AgriBusiness Group (TAG). The project required a financial model for most regions, therefore each farm system had a range of regional models to represent the regional climatic and productive differences. Consideration was given to the MPI report that best represented the particular region.

There were three significant changes made to the MPI models:

- The most recent dairy and sheep and beef MPI reports were released in 2012, therefore all expenditure items in the dairy and sheep and beef models were inflated by 4 percent to account for the inflation in these prices since 2012.
- Revenue differed slightly from the MPI models, as the prices ($/ kg MS, $/ kg lamb, mutton and prime beef, $/ kg wool, $/ crop ha) were set to the average long-term price from the Situation and Outlook for Primary Industries (SOPI) data. These prices (see Tables 1 to 3) were consistent across all the regional models.
- Production (revenue) and expenses was based on the MPI reports, however it was driven by kilograms of dry matter per hectare data in the case of the pastoral systems and product yields in the arable and horticultural models that were received from Aqualinc for irrigated and dryland farm systems.

As a result of these changes, farm cash operating surplus was slightly different across the models relative to the MPI Farm Monitoring reports.

The method of developing the models for each land use is detailed in the following sub-sections.

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Table 3: Prices used for the dairy and sheep and beef models

Commodity	Price ($)
Milk solid ($/kg MS)	6.40
Lamb ($/kg)	5.09
Mutton ($/kg)	2.40
Prime beef ($/kg)	4.68
Cull cow ($/kg)	3.40
Ewe purchase ($/head)	100.00
Lamb purchase ($/head)	68.72
Wool ($/kg)	3.50

Table 4: Prices used for the arable model

Commodity	Price ($)
Dairy grazing ($/kgDM)	0.30
Ryegrass seed ($/tDM)	2,200
Peas ($/t)	400
Barley ($/t)	390
Maize silage ($/t)	200
Wheat ($/t)	440

Table 5: Prices used for the horticulture models

Commodity	Price ($)
Potatoes ($/t)	450
Onions ($/t)	500
Carrots ($/t)	350
Squash ($/export fruit)	500-700
Tomato ($/t)	210
Beetroot ($/t)	285
Sweet corn ($/cob)	350
Cauliflower ($/t)	1,150
Spinach ($/t)	2,200
Broccoli ($/t)	1,667
Cabbage ($/t)	1,150

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3.3.1 Dairy

The regional dairy models were based on two production system models, the 'system 3 model' (i.e. 10% of total feed imported) and the 'system 4 model' (i.e. 25% of total feed imported), developed by TAG. The typical dairy production system for each dairy region was chosen from these two options. The North Island South-West coast, North Island Central and South Island Inland Southland regions were assumed to typically be a 'system 3', while the North Island East Coast, South Island inland basins, South Island East Coast and South Island Inland Otago Southland were assumed to be 'system 4'. All imported supplement was assumed to be pasture silage ($0.30/kgDM).

The dairy models were driven by kg DM/ha data that was received from Aqualinc, to quantify the effects of irrigation water allocation parameters on farm financials. Number of cows were calculated by dividing the total feed available (total kg DM grown plus kg DM imported supplements) by 6,000 kg DM (400 kg MS/cow x 15 kg DM to produce 1 kg MS). This calculation accounts for the utilisation rate of feed available. The total kg MS was calculated by multiplying the number of cows by 400 kg MS/cow. 'Net livestock sales' and 'other dairy cash income', and variable expenses were set on a per cow basis; in effect, these items varied when pasture production (kg DM/ha) varied. Fixed expenses were entered into the model on a per hectare basis.

Dryland pasture production data was not received for North Island Central, North Island East coast, South Island West Coast/ Tasman, North Island North West and South Island South Coast, therefore there was only one financial result from this region. This result was adapted from the regional MPI Farm Monitoring reports.

3.3.2 Sheep and beef

The sheep and beef models were derived from the MPI Farm Monitoring Reports. The revenue in these reports generally lacked robust details as to how it was calculated (i.e. the number of stock sold and purchased and the weight of the stock). This meant that assumptions were made about the number of stock sold and purchased by referring to the revenue and other production factors given in the MPI reports. The following assumptions were consistent across all the regional models:

- 15 percent of the breeding ewes were culled at 30 kg carcass weight and $2.40/kg mutton ($72/cull ewe sold)
- Total lambs born = breeding ewes x lambing percentage
- Total lambs purchased = sheep purchases / lamb purchases ($68.72/head). All purchased lambs were sold as prime.
- Total lambs sold = total lambs – replacement hoggets.
- The number of store and prime lambs, as a proportion of the total lambs, were calculated off the differences between the average lamb price and the store lamb and prime lamb price in the MPI models. The store lambs were expected to weigh 30 kg (at 45% dressing out) ($66.72/ store lamb). The prime lambs were expected to weigh 18.5 kg ($99.78/ prime lamb).

The irrigated sheep and beef models were also driven by kg DM/ha. Stock unit equivalents derived from annual DM requirements were calculated on the basis that one stock unit consumes 550 kg DM/year, and were used to determine the number of sheep and/or cattle that the property could support. Cattle were assumed to be 5.5 stock units on average. Given sheep are generally heavier than the original stock unit (1 SU= 1 sheep), lambing percentages are now higher (assumed to be 135%), and lambs were finished past weaning, the assumption was made that one sheep stock unit consumed 770 kg DM (1.4 stock unit equivalents). Average utilisation of pasture was assumed to be

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80%. Variable expenses were set on a per stock unit basis and therefore changed when pasture production (kgDM/ha) was altered.

3.3.3 Viticulture

The Marlborough vineyard model was based on the 'Viticulture Model Vineyard Benchmarking Report Marlborough 2016', and the Hawkes Bay model was based on the 2014-15 budget in the 2014 MPI Viticulture Monitoring Report. Both models were consistent with these reports, in terms of vineyard production, revenue and expenditure (Tables 6 and 7). Total hand and machine harvesting expenses were set on the basis of tonnes of grapes, using the above models as a base, therefore changes in grape production impacted both revenue and expenditure.

Table 6: Marlborough vineyard production and revenue

	Hectares	t/ha	Total (t)	Gross yield (%)	Return ($/t)	Total $
Sauvignon Blanc	23	16.5	380	84%	1,805	684,998
Pinot Noir- Table	3	8.6	26	6%	3,085	79,593
Pinot Gris	1.5	11.8	18	4%	1,885	33,365
Chardonnay - Mendoza and Clone 15	1.5	10.6	16	4%	2,130	33,867
Chardonnay - all other clones	0.5	14	7	2%	2,000	14,000
Riesling	0.5	11.5	6	1%	1,775	10,206
Total/ average	**30**	**12.2**	**452**	**100%**		**856,028**

Table 7: Hawkes Bay vineyard production and revenue

[Click here and enter text]	Hectares	t/ha	Total (t)	Gross yield (%)	Return ($/t)	Total $
Merlot	3.0	10	30.0	25%	1,930	57,900
Sauvignon Blanc	2.5	11.7	29.3	24%	1,490	43,583
Chardonnay - Mendoza and Clone 15	2.3	8.2	18.9	15%	2,090	39,417
Other reds	2.0	8.1	16.2	13%	2,100	34,417
Pinot Gris	1.8	10.5	18.9	15%	1,510	28,539
Total/ average	12.6	9.6	122	100%		223,751

3.3.4 Arable

The arable model rotation was based on the 'standard arable rotation with >10% of time in forages/fodder' used for the arable modelling in the Matrix of Good Management. Crop yields and expenditure was based on previous TAG work.

The rotation, crop yields and $/t DM are shown in table 6. The kale and forage oats crops were assumed to be used for contract dairy grazing at 30c/kg DM. The revenue in the model was driven

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off crop yields, which were received from Aqualinc. Expenditure was set as a fixed cost (on a per hectare basis), therefore changes in yields had no impact on expenditure. Changes in crop yields did however impact revenue.

Table 8: Arable crop details

	Hectares	Average yield (t DM/ha)	Total yield (t DM)	Price ($/ t DM)	Total $
Ryegrass seed	40	1.5	60	2,200	132,000
Peas	40	50.0	360	400	144,000
Kale	(40)*	12.0	480	400	144,000
Barley	40	8.0	320	390	124,000
Forage oats	(40)*	3.5	1,400	390	42,000
Maize silage	40	20.0	800	200	160,000
Wheat	40	10.0	400	440	176,000
Total/ average	200	15	4,060	4,420	922,800

*The kale and barley crops did not contribute to the total hectares as they rotated through the crop area.

3.3.5 Horticulture

The horticulture models were based on models that were developed in previous TAG work and were driven off crop yields. The three different models used represent crop rotations used in Pukekohe, Hawkes Bay and a more general rotation which was used in Canterbury and other regions. The rotations, crop yield, price / tonne and the total revenue generated are all shown in Table 5,Table 6 and Table 7.

The revenue in the model was driven off modelled crop yields, which were received from Aqualinc. Expenditure was set as a fixed cost, on a per hectare basis for all expenditure items except harvest wages, grading, packing and freight which all varied according to the yields which were projected therefore changes in yields had an impact on expenditure.

Table 9: Horticulture crop details for the Pukekohe area

	Hectares	Average yield (t DM/ha)	Total yield (t DM)	Price ($/ t DM)	Total $
Potatoes (summer)	10	50	500	450	225,000
Onions	10	45	450	500	225,000
Carrots	10	60	600	350	210,000
Squash	10	25	250	500	125,000
Oats and rye*					
Barley (grain)	10	7	70	420	29400

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	Hectares	Average yield (t DM/ha)	Total yield (t DM)	Price ($/ t DM)	Total $
Oats and rye*					
Total/ average	50	37	1,870		814,400

*The oats and rye crop did not contribute to the total hectares as it rotated through the crop area.

Table 10: Horticulture crop details for the Heretaunga area

	Hectares	Average yield (t DM/ha)	Total yield (t DM)	Price ($/ t DM)	Total $
Onions	10	60	600	500	300,000
Tomato	10	100	1,000	210	210,000
Beetroot	10	60	600	285	171,000
Sweetcorn	10	22	220	350	77,000
Squash	10	21	210	700	147,000
Total/ average	50	53	2,630	2,045	905,000

Table 11: Horticulture crop details for the Canterbury area

	Hectares	Average yield (t DM/ha)	Total yield (t DM)	Price ($/ t DM)	Total $
Cauliflower	10	30	300	1,150	345,000
Spinach	10	22	220	2,200	484,000
Onions	10	70	700	500	350,000
Brocolli	10	8	80	1,667	133,360
Forage oats/ annual ryegrass*		3.5	-	300	-
Squash	10	25	250	700	175,000
Spinach	10	22	220	2,200	484,000
Cabbage	10	60	600	1,150	690,000
Sweetcorn	10	22	220	350	77,000
Total/ average	80	29	2,590		2,738,360

*The forage oats/annual ryegrass crop did not contribute to the total hectares as it rotated through the crop area.

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3.3.6 Pip fruit

The Hawkes Bay and Nelson pip fruit models were based on both the 2006 and 2015 MPI horticulture models, as the 2015 model did not contain data on orchard production by pip fruit type, export return or the expenditure on individual items.

The proportion of total tray carton equivalents (TCE) and the proportion of total area of each pip fruit type was taken from the 2006 model, as well as the export pack out percentage. The proportion of total TCE of each fruit type was multiplied by the total TCE in the 2015 model, while the proportion of total area of each fruit type was multiplied by the total effective hectares in the 2015 model. The 2015 model did not contain the export return ($/TCE) by pip fruit type. Therefore, the percentage change of weighted average export return ($/TCE) between the 2006 and 2015 models was calculated, from which the 2006 figure was multiplied by percentage change to get the estimated 2015 figure for the average export return by fruit type. Revenue of each pip fruit type was then calculated by multiplying the estimated gross TCE, export pack out (%) and 2016 estimated export return ($/TCE).

The proportion of total expenditure of each expenditure item was calculated from the 2006 model. These figures were then multiplied by the 2015 total expenditure in order to estimate the 2015 expenditure for each item. Total pruning and post-harvest (packing, packaging, cool storage and freight) expenses were set on the basis of TCE, therefore changes in TCE production impacted revenue and expenditure.

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4 NITROGEN LOSS AND MITIGATION

Aqualinc provided TAG with a spreadsheet which detailed Land Use, Farm Model Region, Climate Zone, Soil PAW (30,60,120), Irrigated or Dryland, System Capacity (l / sec / ha), Supply Reliability (%) and requested that we populated data on the N loss (Kg / ha / yr) and Cash Operating Surplus ($ / ha) for three levels of performance Good Management Practice, and two levels of mitigation activity.

The data that was supplied by Aqualinc is shown in Table 5.

Table 12: Example of N loss data table

Land use	Farm Model Region	Climate zone	Soil PAW (mm)	Irr (1) /Dry (0)	System Capacity (l/s/ha)	Supply Reliability (%)	N loss	Cash Operating Surplus ($/ha)	Mitigation
Sheep Beef	NI-central	2	35	1	0.6	100			GMP
Sheep Beef	NI-central	2	35	1	0.6	100			M1
Sheep Beef	NI-central	2	35	1	0.6	100			M 2

4.1 Populating the N loss column.

4.1.1 For GMP

TAG has a considerable amount of experience in calculating N loss for different farming systems throughout New Zealand using Overseer for both irrigated and dryland scenarios. The TAG experience encompasses carrying out Overseer nutrient budgeting in the Regions as shown in Table 6.

Table 13: Regional location of TAG's nutrient budgeting experience

Sector	Overseer Modelling
Dairy	Waikato Horizons Canterbury
Arable	Canterbury Hawkes Bay
Sheep and Beef	Canterbury Waikato
Horticulture	Auckland Waikato Hawkes Bay Horizons Nelson Canterbury Southland

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This experience also includes a comprehensive range of nutrient modelling of different systems at a range of soil PAW's, irrigation system capacities and different climatic zones.

This experience was added to by access to Agresearch's report "Modelling Farm scale mitigation options for the Ruamahanga Whaitua Collaborative Modelling Project: June 2006" which also was able to provide data on a significant range of farming systems, soil PAWS and climate zones.

From this data source we were able to populate the N loss column for all of the GMP designated requirements either by direct application of the available data or by extrapolation from the available data.

4.1.2 Calculating the Mitigations

The majority of the TAG experience in calculating nutrient budgeting exercises has also encompassed calculating the impacts of various mitigation strategies and the Agresearch's report also reported on the impact of various mitigation strategies. From this experience and by reference to the Agresearch report we determined that the most appropriate mitigation strategies to use are as detailed in Table 7.

Table 14: N mitigation strategies used

Sector	Mitigation Strategy	% Reduction in N loss
Dairy		
Mitigation 1	Reduce SR	6
Mitigation 2	Reduce autumn N	16
Arable		
Mitigation 1	Cover Crops	11
Mitigation 2	Align N	15
Sheep and Beef		
Mitigation 1	Reduce SR	9
Mitigation 2	Reduce N	2
Horticulture		
Mitigation 1	Limiting N application to 80	6
Mitigation 2	Reducing total N by 10%	12

4.2 Populating the Cash Operating Surplus Column

The GMP cash operating surplus data was transferred directly across from the financial modelling results. The impact of the mitigation strategies was calculated by multiplying the GMP data by the reductions shown in Table 14. The reductions chosen to represent the financial impacts were taken from the mitigation exercises carried out by TAG and AgResearch.

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Table 15: Financial reductions of each mitigation strategy

Sector	Mitigation Strategy	Financial reduction %
Dairy		
Mitigation 1	Reduce SR	10
Mitigation 2	Reduce autumn N	5
Arable		
Mitigation 1	Cover Crops	2
Mitigation 2	Align N	25
Sheep and Beef		
Mitigation 1	Reduce SR	10
Mitigation 2	Reduce N	2
Horticulture		
Mitigation 1	Limiting N application to 80	2
Mitigation 2	Reducing total N by 10%	5

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5 RESULTS

The quantitative relationships between irrigation allocation rate, water supply availability, contaminant discharges and profit for different irrigation water users that were developed using the approach and models described in the preceding sections were supplied to the Component A team as tables. These data are presented in full in Appendix A of this report.

The relationship between allocation rate, water supply availability and profit are presented in graphical form for selected irrigation water users in the figures that follow. The graphs for Sheep and Beef, Dairy, Arable and Vegetable production are for enterprises that have the same water source (Waimakariri river), plant available soil water capacity (60mm) and average annual rainfall (representative of the middle of the Canterbury Plains). The graph for pip fruit is for an enterprise supplied from the Tukituki River. The plant available soil water capacity is 60mm and the rainfall is representative of the Ruataniwha Basin. The vineyard graph is for a property supplied from the Wairau River and has a plant available soil water capacity of 60mm and rainfall representative of middle Wairau Plains.

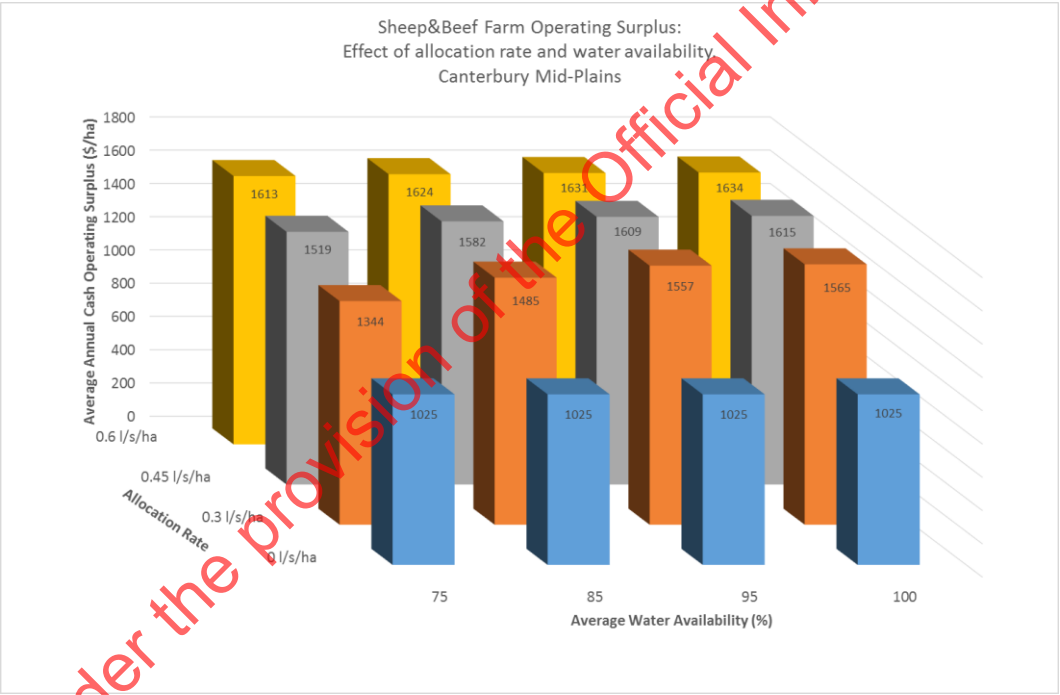


Figure 4: Sheep and Beef farm average annual operating surplus – Canterbury example.

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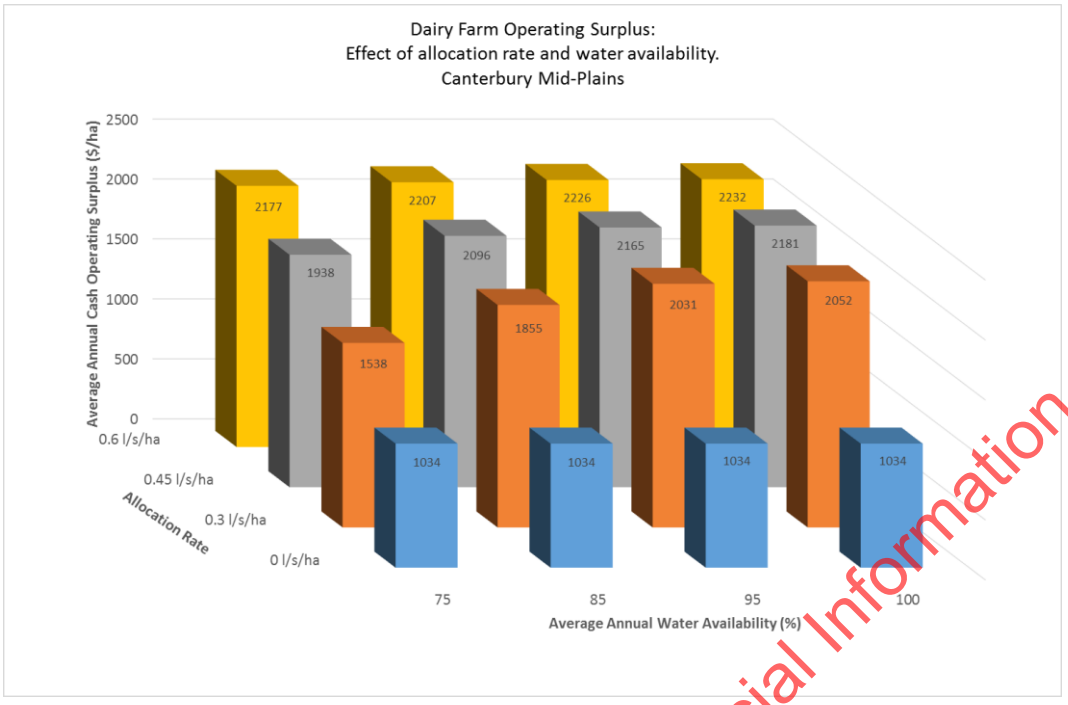


Figure 5: Dairy farm operating surplus

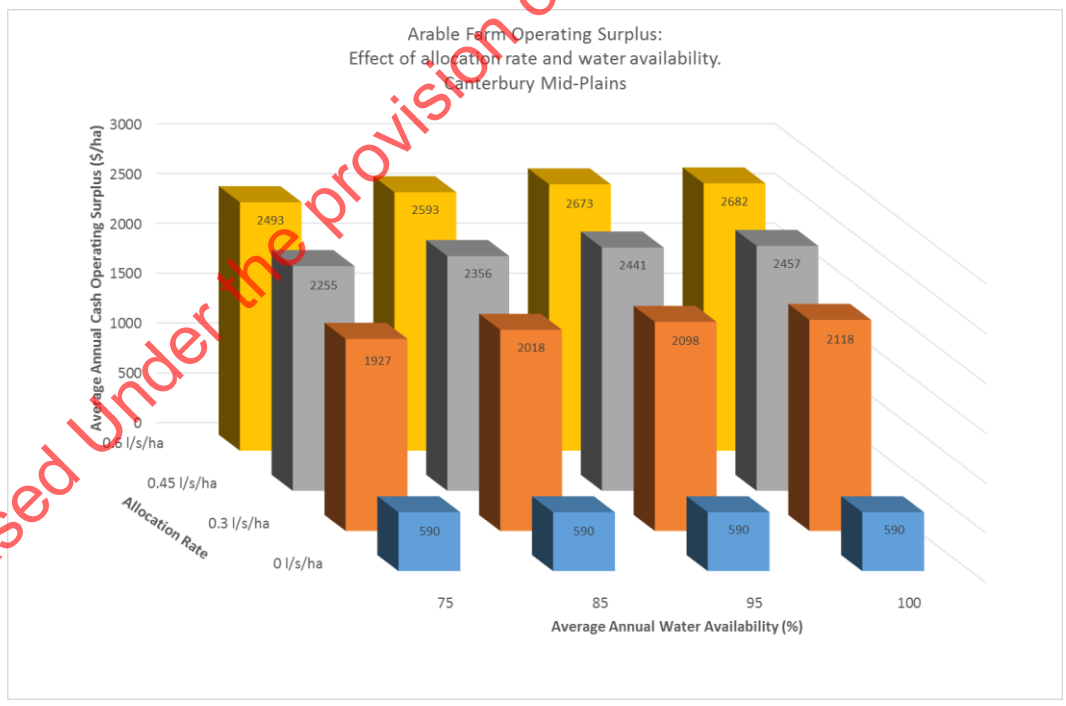


Figure 6: Arable farm operating surplus

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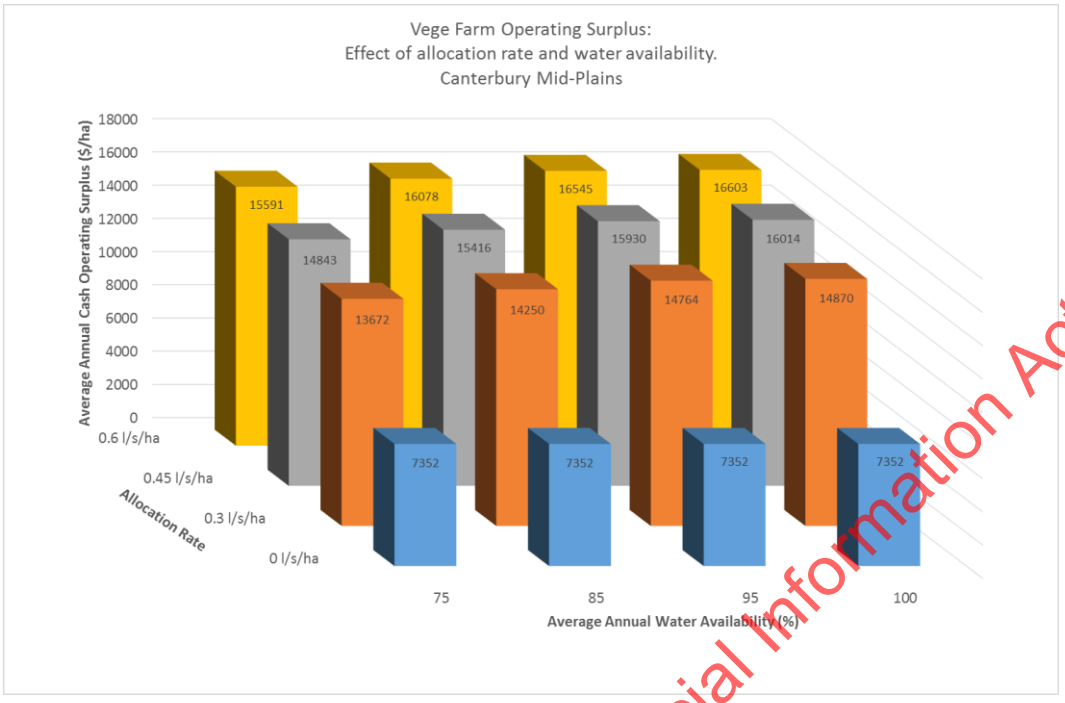


Figure 7: Vegetable production operating surplus

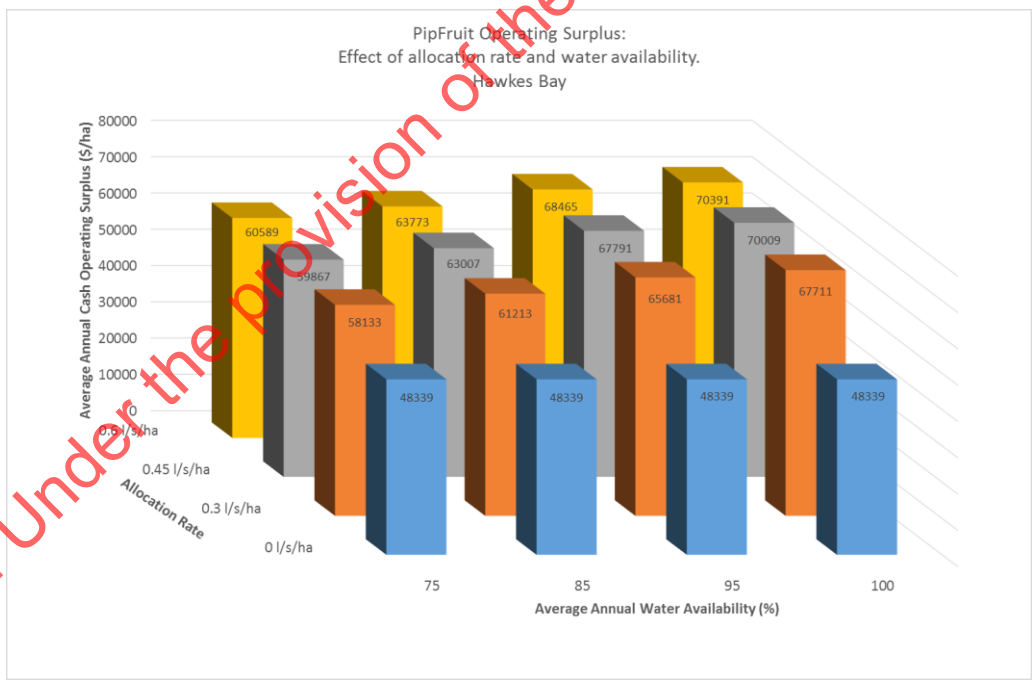


Figure 8: Pip Fruit operating surplus

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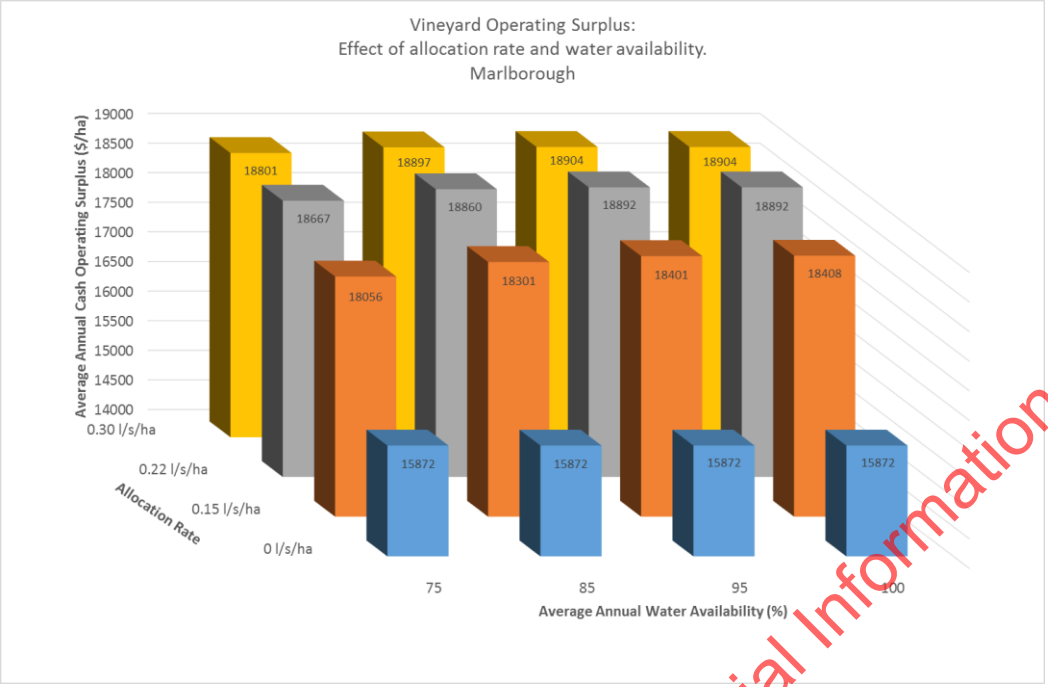


Figure 9: Vineyard operating surplus

The data presented in the above figures were normalised for each enterprise by dividing the operating surplus by the operating surplus achieved at a water availability of 100% and the highest irrigation allocation rate.

All of the normalised data is presented in the following figure to enable comparison and identification of relative sensitivity to water availability and irrigation allocation rate across land uses.

Average annual operating surplus for the pasture-based farm systems modelled is very resilient to changes in average annual water availability if the irrigation allocation rate is 0.6 l/s/ha. However it reduces more rapidly with reducing water availability as the irrigation allocation rate reduces.

The rate of decrease in average annual operating surplus for the modelled arable and vegetable crop production systems as water availability decreases is very similar across all three allocation rates. At any given water availability the average annual operating surplus decreases at an increasing rate as the irrigation water allocation rate reduces.

The change in average annual operating surplus for a pip fruit enterprise with change in average annual water availability follows a different pattern to the previous four enterprises. The surplus drops rapidly from that at 100% water availability and the rate of decline reduces as water availability approaches 75%.

Two significant differences between the pip fruit enterprise and the previous four are the water source and the absence of mitigation options for when water supply shortages occur. It is thought that these differences act together to produce the different pattern.

The water source for the pip fruit enterprise is the Tukituki River. When the cease take flow was raised to the level required to produce 95% average annual water availability it resulted in a very small number of long duration cease-take periods that reduced production substantially. When faced with the same circumstances pasture-based farm systems have the option of buying in feed to maintain production and revenue. Arable and vegetable cropping systems grow a range of crops during each irrigation season and thus spread the production risk attributable to water supply shortfalls. Pip fruit enterprises don't have equivalent mitigation options.

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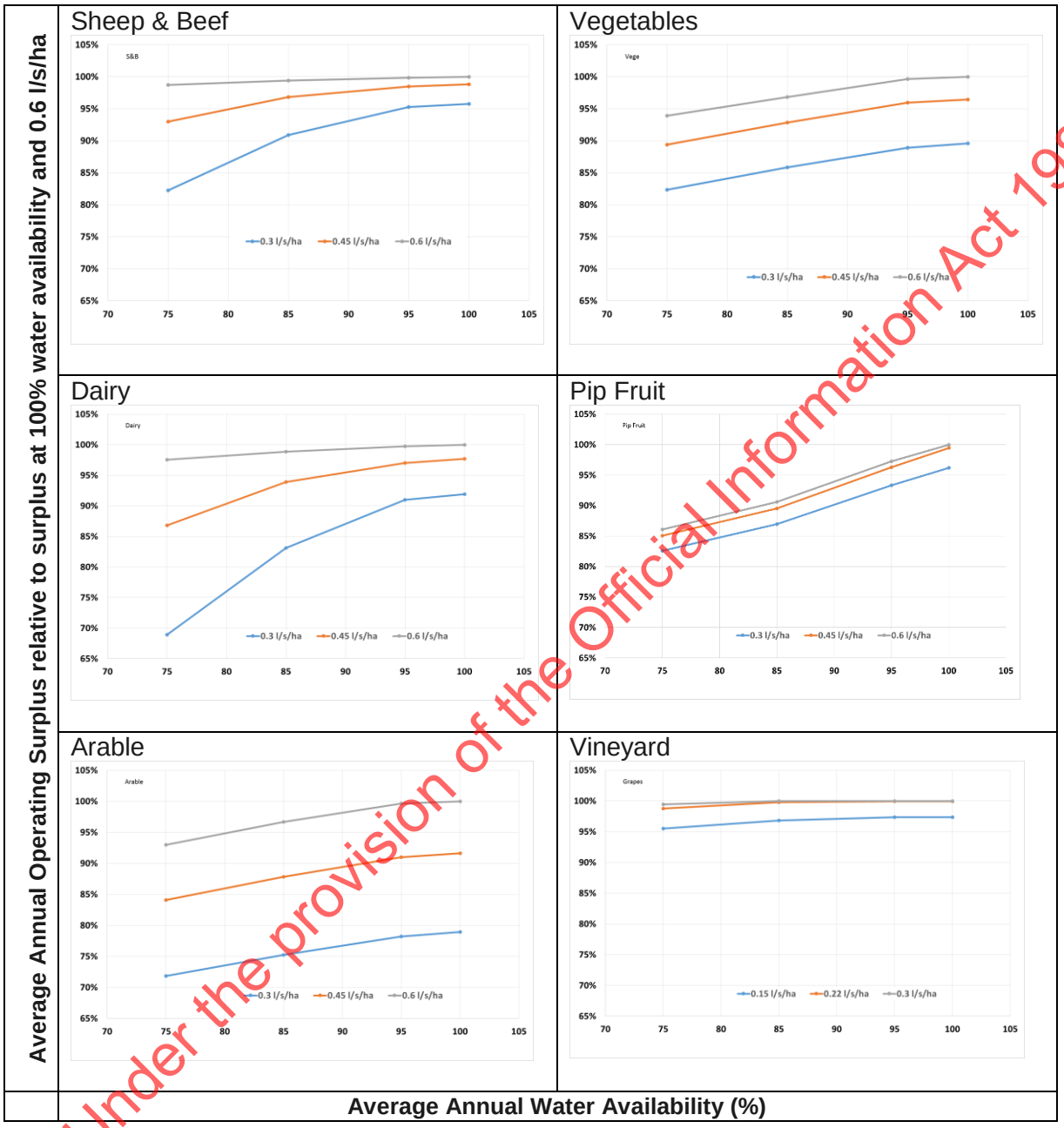


Figure 10: Relative sensitivity of operating surplus to water availability and irrigation allocation rate

The modelled vineyard's average annual operating surplus is very resilient to changes in water availability. The operating surplus is reduced on slightly when irrigation water allocation is reduced from 0.3 to 0.22 l/s/ha, and then by about 5% when the allocation rate is dropped to 0.15 l/s/ha. The irrigation rule modelled aims to maintain high soil water storage. This, in combination with the low rate of evapotranspiration per hectare compared to other crops, enables production to be maintained through water supply shortages of up to moderate length.

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The relationship between N loss and average annual cash operating surplus for selected crops are shown in the following figure. The full set of relationships are presented in tabular form in Appendix B.

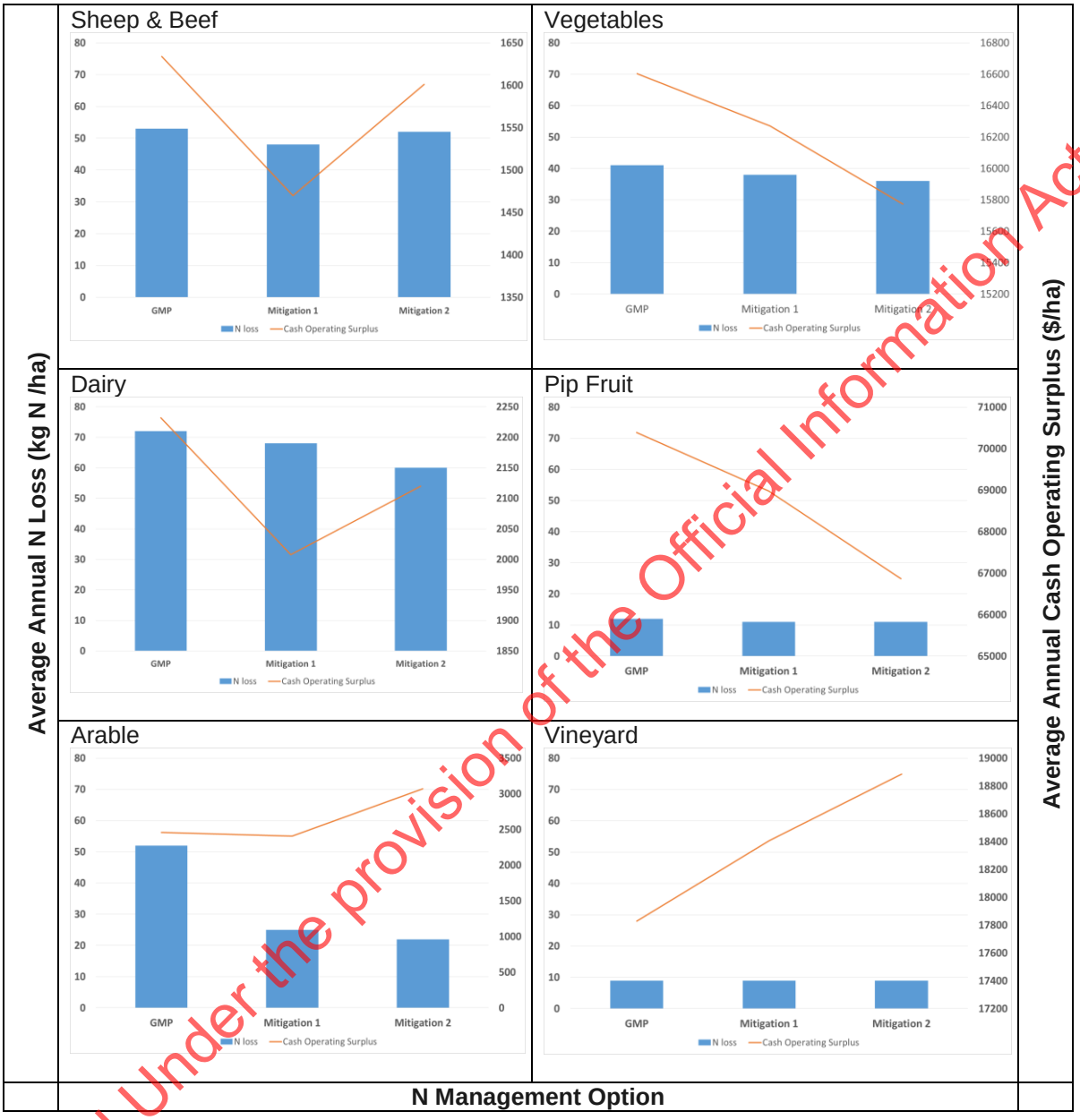


Figure 11: Selected N Loss – Cash Operating Surplus relationships

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6 COMPARISON WITH PREVIOUS ANALYSES

In two recent studies Bright (2016) and Fenemor et.al. (2015) developed relationships between farm or orchard operating profit and irrigation allocation rate, using computer modelling in a manner that enables comparison with this project's results. They also made a preliminary assessment of the effect of average annual water availability on operating profit but the way their results are presented prevents meaningful comparison.

The land uses for which direct comparison is possible are dairy, arable, grapes and apples. Figure 11 compares the results of the current work with those of the prior studies.

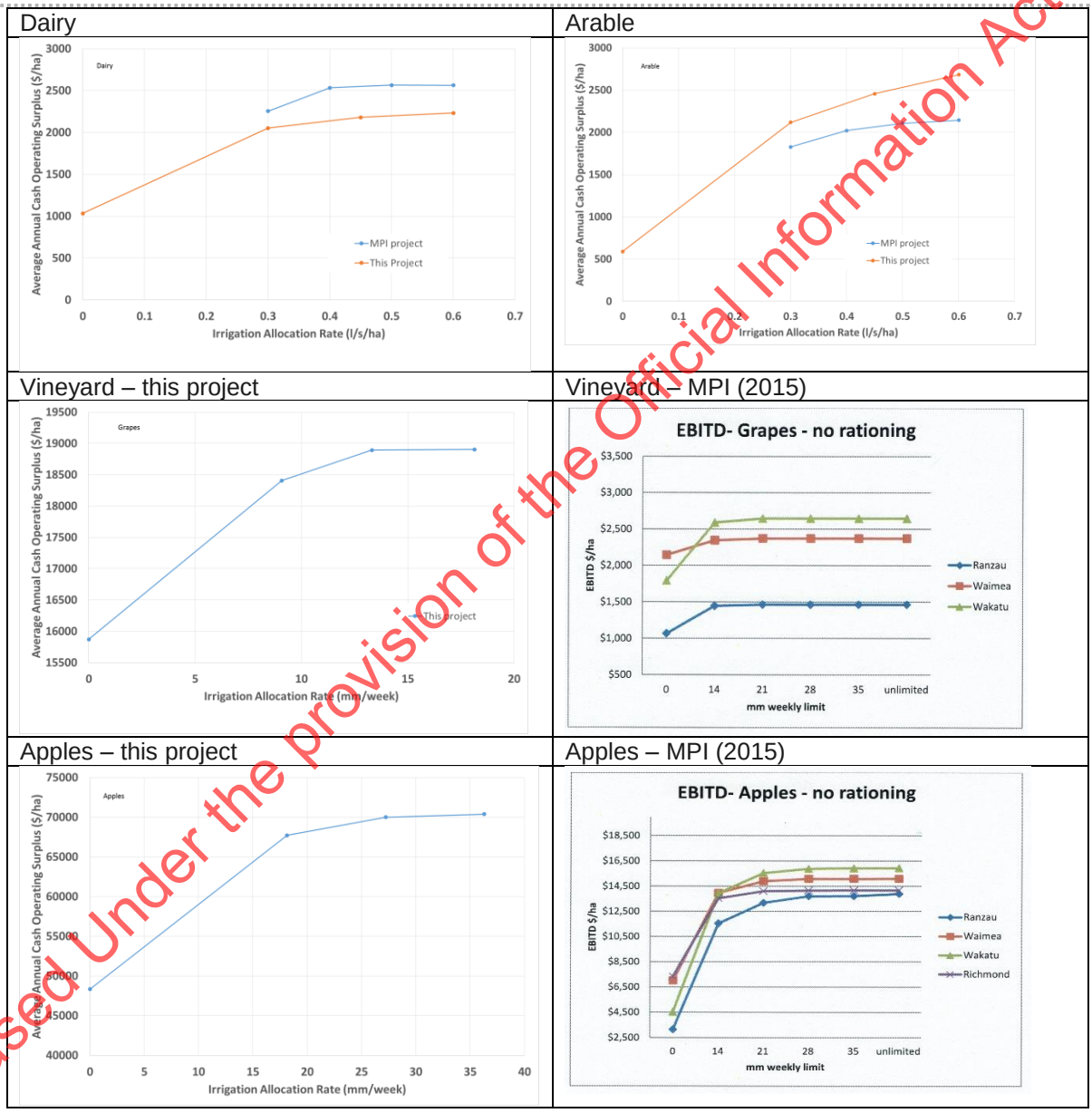


Figure 12: Comparison between this projects results, Bright (2016) and Fenemor et.al. (2015)

The metric used for operating profit differs between the studies resulting in differences in the magnitude, as can be seen in Figure 11. The key things to compare, however, are the shapes of the

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graphs and the allocation rate at which operating profit begins to drop sharply as allocation rate is reduced (the inflection point).

The shape of the graphs is very similar across all land uses. This is in spite of differences in the models used and variations in methodology between the three teams. There is an interesting difference in the shape of the graphs for the arable farms. Bright's 2016 analysis for the Ministry for Primary Industries (MPI) resulted in operating profit almost reaching a plateau at an allocation rate of 0.5 l/s/ha whereas the present work shows a more significant rise in operating profit as allocation rate increases to 0.6 l/s/ha. This difference is attributed to the different arable crop rotation modelled in this project. The crop rotation modelled by Bright (2016) is a fairly traditional, conservative, cereal-based crop rotation. The crop rotation modelled for this project has a greater proportion of higher value crops, this increasing the sensitivity of operating profit to the consequences of water supply shortfalls.

The allocation rate at which the inflection point occurs is also very similar across all land uses, there being no note-worthy differences.

Relationships between N loss and operating profit were assembled from all available prior work. There were therefore no independent sources with which to compare the relationships we developed.

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7 SUMMARY

The financial effect of the key water allocation parameters – allocation rate and average water supply availability – were quantified by modelling the effects of different allocation parameters on production and, in turn, on the revenue, expenditure and operating profit of the water use activity. This extended prior work (Bright, 2016, Fenemor et al, 2015) in terms of geographical coverage and land use type. Water availability scenarios comprised all combinations of four irrigation allocation rates (e.g. 0.0 (unirrigated), 0.3, 0.45 and 0.6 l/s per ha irrigated), four supply availabilities (100%, 95%, 85% and 75%), and three classes of plant available soil water for each of the combinations of climate and land-use required to broadly represent more than 90% of New Zealand's irrigated area. More than 1100 scenarios were analysed to build up the relationships sought.

Quantitative relationships between Nitrate nitrogen loss and cash operating surplus were developed from prior work that has used Overseer™ to estimate N loss under Good Management Practice (GMP) and various bundles of mitigation options designed to reduce N loss. The annual cost of each mitigation bundle was deducted from the profit achieved assuming GMP (no mitigation) to build up a relationship between average annual contaminant discharge and average annual operating surplus.

Relationships between operating surplus and water allocation parameters were compared to the results from two recent small-scale studies. The shape of the relationships, when graphed, are very similar across all land uses, in spite of differences in the models used and variations in methodology between the three teams.

The relationships developed between operating profit and water allocation parameters, and profit and N loss, can be assigned to non-modelled areas on a nearest similar climate and land use basis to provide national coverage. However the relationships for non-modelled zones should be considered to be indicative.

The results of this work were supplied in tabular form to the economics team engaged by MfE to make a quantitative analysis of the economic implications of different possible central government policy approaches to allocate fresh water and assimilative capacity at a national level.

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Appendix A: Water Allocation – Cash Operating Surplus Tables

North Island-Central

Land use	Soil PAW (mm)	Irrigable (1) / Not-Irrigable (0)	System Capacity (l/s/ha).	Supply Reliability (%)	Cash Operating Surplus ($/ha)
Dairy	35	0	0	100	1084
Dairy	35	1	0	75	1084
Dairy	35	1	0	85	1084
Dairy	35	1	0	95	1084
Dairy	35	1	0	100	1084
Dairy	35	1	0.3	75	1592
Dairy	35	1	0.3	85	1681
Dairy	35	1	0.3	95	1768
Dairy	35	1	0.3	100	1801
Dairy	35	1	0.45	75	1734
Dairy	35	1	0.45	85	1853
Dairy	35	1	0.45	95	1959
Dairy	35	1	0.45	100	1994
Dairy	35	1	0.6	75	1812
Dairy	35	1	0.6	85	1949
Dairy	35	1	0.6	95	2065
Dairy	35	1	0.6	100	2098
Dairy	60	0	0	100	1363
Dairy	60	1	0	75	1363
Dairy	60	1	0	85	1363
Dairy	60	1	0	95	1363
Dairy	60	1	0	100	1363
Dairy	60	1	0.3	75	1784
Dairy	60	1	0.3	85	1861
Dairy	60	1	0.3	95	1929
Dairy	60	1	0.3	100	1949
Dairy	60	1	0.45	75	1881
Dairy	60	1	0.45	85	1980
Dairy	60	1	0.45	95	2060
Dairy	60	1	0.45	100	2082
Dairy	60	1	0.6	75	1921
Dairy	60	1	0.6	85	2032
Dairy	60	1	0.6	95	2114
Dairy	60	1	0.6	100	2132

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Dairy	120	0	0	100	1669
Dairy	120	1	0	75	1669
Dairy	120	1	0	85	1669
Dairy	120	1	0	95	1669
Dairy	120	1	0	100	1669
Dairy	120	1	0.3	75	1734
Dairy	120	1	0.3	85	1853
Dairy	120	1	0.3	95	1959
Dairy	120	1	0.3	100	1994
Dairy	120	1	0.45	75	1976
Dairy	120	1	0.45	85	2054
Dairy	120	1	0.45	95	2113
Dairy	120	1	0.45	100	2124
Dairy	120	1	0.6	75	1995
Dairy	120	1	0.6	85	2078
Dairy	120	1	0.6	95	2133
Dairy	120	1	0.6	100	2141
Sheep and Beef	35	0	0	100	1051
Sheep and Beef	35	1	0	75	1051
Sheep and Beef	35	1	0	85	1051
Sheep and Beef	35	1	0	95	1051
Sheep and Beef	35	1	0	100	1051
Sheep and Beef	35	1	0.3	75	1299
Sheep and Beef	35	1	0.3	85	1339
Sheep and Beef	35	1	0.3	95	1377
Sheep and Beef	35	1	0.3	100	1391
Sheep and Beef	35	1	0.45	75	1362
Sheep and Beef	35	1	0.45	85	1413
Sheep and Beef	35	1	0.45	95	1457
Sheep and Beef	35	1	0.45	100	1471
Sheep and Beef	35	1	0.6	75	1396
Sheep and Beef	35	1	0.6	85	1453
Sheep and Beef	35	1	0.6	95	1499
Sheep and Beef	35	1	0.6	100	1512
Sheep and Beef	60	0	0	100	1191
Sheep and Beef	60	1	0	75	1191
Sheep and Beef	60	1	0	85	1191
Sheep and Beef	60	1	0	95	1191
Sheep and Beef	60	1	0	100	1191
Sheep and Beef	60	1	0.3	75	1384
Sheep and Beef	60	1	0.3	85	1416
Sheep and Beef	60	1	0.3	95	1445
Sheep and Beef	60	1	0.3	100	1453
Sheep and Beef	60	1	0.45	75	1425
Sheep and Beef	60	1	0.45	85	1465

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Sheep and Beef	60	1	0.45	95	1497
Sheep and Beef	60	1	0.45	100	1506
Sheep and Beef	60	1	0.6	75	1442
Sheep and Beef	60	1	0.6	85	1486
Sheep and Beef	60	1	0.6	95	1518
Sheep and Beef	60	1	0.6	100	1525
Sheep and Beef	120	0	0	100	1333
Sheep and Beef	120	1	0	75	1333
Sheep and Beef	120	1	0	85	1333
Sheep and Beef	120	1	0	95	1333
Sheep and Beef	120	1	0	100	1333
Sheep and Beef	120	1	0.3	75	1362
Sheep and Beef	120	1	0.3	85	1413
Sheep and Beef	120	1	0.3	95	1457
Sheep and Beef	120	1	0.3	100	1471
Sheep and Beef	120	1	0.45	75	1464
Sheep and Beef	120	1	0.45	85	1495
Sheep and Beef	120	1	0.45	95	1518
Sheep and Beef	120	1	0.45	100	1522
Sheep and Beef	120	1	0.6	75	1472
Sheep and Beef	120	1	0.6	85	1505
Sheep and Beef	120	1	0.6	95	1526
Sheep and Beef	120	1	0.6	100	1529

North Island-SW-Coast

Land use	Soil PAW (mm)	Irrigable (1) / Not-Irrigable (0)	System Capacity (l/s/ha).	Supply Reliability (%)	Cash Operating Surplus ($/ha)
Dairy	35	0	0	100	1040
Dairy	35	1	0	75	1040
Dairy	35	1	0	85	1040
Dairy	35	1	0	95	1040
Dairy	35	1	0	100	1040
Dairy	35	1	0.3	75	1784
Dairy	35	1	0.3	85	2050
Dairy	35	1	0.3	95	2455
Dairy	35	1	0.3	100	2598
Dairy	35	1	0.45	75	1885
Dairy	35	1	0.45	85	2283
Dairy	35	1	0.45	95	2495
Dairy	35	1	0.45	100	2640
Dairy	35	1	0.6	75	2045
Dairy	35	1	0.6	85	2313

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Dairy	35	1	0.6	95	2656
Dairy	35	1	0.6	100	2638
Dairy	60	0	0	100	1436
Dairy	60	1	0	75	1436
Dairy	60	1	0	85	1436
Dairy	60	1	0	95	1436
Dairy	60	1	0	100	1436
Dairy	60	1	0.3	75	2023
Dairy	60	1	0.3	85	2438
Dairy	60	1	0.3	95	2662
Dairy	60	1	0.3	100	2789
Dairy	60	1	0.45	75	2283
Dairy	60	1	0.45	85	2571
Dairy	60	1	0.45	95	2751
Dairy	60	1	0.45	100	2826
Dairy	60	1	0.6	75	2335
Dairy	60	1	0.6	85	2579
Dairy	60	1	0.6	95	2765
Dairy	60	1	0.6	100	2833
Dairy	120	0	0	100	1562
Dairy	120	1	0	75	1562
Dairy	120	1	0	85	1562
Dairy	120	1	0	95	1562
Dairy	120	1	0	100	1562
Dairy	120	1	0.3	75	2092
Dairy	120	1	0.3	85	2474
Dairy	120	1	0.3	95	2712
Dairy	120	1	0.3	100	2790
Dairy	120	1	0.45	75	2423
Dairy	120	1	0.45	85	2600
Dairy	120	1	0.45	95	2745
Dairy	120	1	0.45	100	2797
Dairy	120	1	0.6	75	2521
Dairy	120	1	0.6	85	2682
Dairy	120	1	0.6	95	2772
Dairy	120	1	0.6	100	2805
Sheep and Beef	35	0	0	100	1028
Sheep and Beef	35	1	0	75	1028
Sheep and Beef	35	1	0	85	1028
Sheep and Beef	35	1	0	95	1028
Sheep and Beef	35	1	0	100	1028
Sheep and Beef	35	1	0.3	75	1384
Sheep and Beef	35	1	0.3	85	1493
Sheep and Beef	35	1	0.3	95	1642
Sheep and Beef	35	1	0.3	100	1690

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Sheep and Beef	35	1	0.45	75	1426
Sheep and Beef	35	1	0.45	85	1582
Sheep and Beef	35	1	0.45	95	1656
Sheep and Beef	35	1	0.45	100	1703
Sheep and Beef	35	1	0.6	75	1491
Sheep and Beef	35	1	0.6	85	1593
Sheep and Beef	35	1	0.6	95	1709
Sheep and Beef	35	1	0.6	100	1703
Sheep and Beef	60	0	0	100	1227
Sheep and Beef	60	1	0	75	1227
Sheep and Beef	60	1	0	85	1227
Sheep and Beef	60	1	0	95	1227
Sheep and Beef	60	1	0	100	1227
Sheep and Beef	60	1	0.3	75	1483
Sheep and Beef	60	1	0.3	85	1637
Sheep and Beef	60	1	0.3	95	1710
Sheep and Beef	60	1	0.3	100	1749
Sheep and Beef	60	1	0.45	75	1582
Sheep and Beef	60	1	0.45	85	1681
Sheep and Beef	60	1	0.45	95	1738
Sheep and Beef	60	1	0.45	100	1760
Sheep and Beef	60	1	0.6	75	1600
Sheep and Beef	60	1	0.6	85	1684
Sheep and Beef	60	1	0.6	95	1742
Sheep and Beef	60	1	0.6	100	1762
Sheep and Beef	120	0	0	100	1285
Sheep and Beef	120	1	0	75	1285
Sheep and Beef	120	1	0	85	1285
Sheep and Beef	120	1	0	95	1285
Sheep and Beef	120	1	0	100	1285
Sheep and Beef	120	1	0.3	75	1510
Sheep and Beef	120	1	0.3	85	1649
Sheep and Beef	120	1	0.3	95	1726
Sheep and Beef	120	1	0.3	100	1750
Sheep and Beef	120	1	0.45	75	1631
Sheep and Beef	120	1	0.45	85	1691
Sheep and Beef	120	1	0.45	95	1736
Sheep and Beef	120	1	0.45	100	1752
Sheep and Beef	120	1	0.6	75	1665
Sheep and Beef	120	1	0.6	85	1717
Sheep and Beef	120	1	0.6	95	1744
Sheep and Beef	120	1	0.6	100	1754

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North Island – EC

Land use	Soil PAW (mm)	Irrigable (1) / Not-Irrigable (0)	System Capacity (l/s/ha).	Supply Reliability (%)	Cash Operating Surplus ($/ha)
Arable	35	0	0	100	-71
Arable	35	1	0	75	-71
Arable	35	1	0	85	-71
Arable	35	1	0	95	-71
Arable	35	1	0	100	-71
Arable	35	1	0.3	75	1036
Arable	35	1	0.3	85	1271
Arable	35	1	0.3	95	1532
Arable	35	1	0.3	100	1668
Arable	35	1	0.45	75	1228
Arable	35	1	0.45	85	1520
Arable	35	1	0.45	95	1836
Arable	35	1	0.45	100	2004
Arable	35	1	0.6	75	1335
Arable	35	1	0.6	85	1664
Arable	35	1	0.6	95	2017
Arable	35	1	0.6	100	2210
Arable	60	0	0	100	183
Arable	60	1	0	75	183
Arable	60	1	0	85	183
Arable	60	1	0	95	183
Arable	60	1	0	100	183
Arable	60	1	0.3	75	1292
Arable	60	1	0.3	85	1511
Arable	60	1	0.3	95	1745
Arable	60	1	0.3	100	1871
Arable	60	1	0.45	75	1456
Arable	60	1	0.45	85	1714
Arable	60	1	0.45	95	1984
Arable	60	1	0.45	100	2133
Arable	60	1	0.6	75	1554
Arable	60	1	0.6	85	1819
Arable	60	1	0.6	95	2105
Arable	60	1	0.6	100	2256
Arable	120	0	0	100	593
Arable	120	1	0	75	593
Arable	120	1	0	85	593
Arable	120	1	0	95	593
Arable	120	1	0	100	593

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Arable	120	1	0.3	75	1587
Arable	120	1	0.3	85	1762
Arable	120	1	0.3	95	1955
Arable	120	1	0.3	100	2066
Arable	120	1	0.45	75	1708
Arable	120	1	0.45	85	1899
Arable	120	1	0.45	95	2104
Arable	120	1	0.45	100	2217
Arable	120	1	0.6	75	1787
Arable	120	1	0.6	85	1966
Arable	120	1	0.6	95	2173
Arable	120	1	0.6	100	2267
Dairy	35	0	0	100	849
Dairy	35	1	0	75	849
Dairy	35	1	0	85	849
Dairy	35	1	0	95	849
Dairy	35	1	0	100	849
Dairy	35	1	0.3	75	1655
Dairy	35	1	0.3	85	1676
Dairy	35	1	0.3	95	1745
Dairy	35	1	0.3	100	1999
Dairy	35	1	0.45	75	1981
Dairy	35	1	0.45	85	2097
Dairy	35	1	0.45	95	2211
Dairy	35	1	0.45	100	2272
Dairy	35	1	0.6	75	2516
Dairy	35	1	0.6	85	2589
Dairy	35	1	0.6	95	2681
Dairy	35	1	0.6	100	2694
Dairy	60	0	0	100	1164
Dairy	60	1	0	75	1164
Dairy	60	1	0	85	1164
Dairy	60	1	0	95	1164
Dairy	60	1	0	100	1164
Dairy	60	1	0.3	75	1871
Dairy	60	1	0.3	85	1878
Dairy	60	1	0.3	95	1924
Dairy	60	1	0.3	100	2132
Dairy	60	1	0.45	75	2096
Dairy	60	1	0.45	85	2248
Dairy	60	1	0.45	95	2396
Dairy	60	1	0.45	100	2438
Dairy	60	1	0.6	75	2635
Dairy	60	1	0.6	85	2724
Dairy	60	1	0.6	95	2775

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Dairy	60	1	0.6	100	2789
Dairy	120	0	0	100	1345
Dairy	120	1	0	75	1345
Dairy	120	1	0	85	1345
Dairy	120	1	0	95	1345
Dairy	120	1	0	100	1345
Dairy	120	1	0.3	75	2173
Dairy	120	1	0.3	85	2308
Dairy	120	1	0.3	95	2422
Dairy	120	1	0.3	100	2460
Dairy	120	1	0.45	75	2471
Dairy	120	1	0.45	85	2661
Dairy	120	1	0.45	95	2704
Dairy	120	1	0.45	100	2710
Dairy	120	1	0.6	75	2678
Dairy	120	1	0.6	85	2720
Dairy	120	1	0.6	95	2758
Dairy	120	1	0.6	100	2767
Horticulture:Pip fruit	35	0	0	100	41976
Horticulture:Pip fruit	35	1	0	75	41976
Horticulture:Pip fruit	35	1	0	85	41976
Horticulture:Pip fruit	35	1	0	95	41976
Horticulture:Pip fruit	35	1	0	100	41976
Horticulture:Pip fruit	35	1	0.3	75	52796
Horticulture:Pip fruit	35	1	0.3	85	56387
Horticulture:Pip fruit	35	1	0.3	95	61486
Horticulture:Pip fruit	35	1	0.3	100	63645
Horticulture:Pip fruit	35	1	0.45	75	54791
Horticulture:Pip fruit	35	1	0.45	85	58659
Horticulture:Pip fruit	35	1	0.45	95	64432
Horticulture:Pip fruit	35	1	0.45	100	66985
Horticulture:Pip fruit	35	1	0.6	75	55622
Horticulture:Pip fruit	35	1	0.6	85	59556

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Horticulture:Pip fruit	35	1	0.6	95	65249
Horticulture:Pip fruit	35	1	0.6	100	67642
Horticulture:Pip fruit	60	0	0	100	48339
Horticulture:Pip fruit	60	1	0	75	48339
Horticulture:Pip fruit	60	1	0	85	48339
Horticulture:Pip fruit	60	1	0	95	48339
Horticulture:Pip fruit	60	1	0	100	48339
Horticulture:Pip fruit	60	1	0.3	75	58133
Horticulture:Pip fruit	60	1	0.3	85	61213
Horticulture:Pip fruit	60	1	0.3	95	65681
Horticulture:Pip fruit	60	1	0.3	100	67711
Horticulture:Pip fruit	60	1	0.45	75	59867
Horticulture:Pip fruit	60	1	0.45	85	63007
Horticulture:Pip fruit	60	1	0.45	95	67791
Horticulture:Pip fruit	60	1	0.45	100	70009
Horticulture:Pip fruit	60	1	0.6	75	60589
Horticulture:Pip fruit	60	1	0.6	85	63773
Horticulture:Pip fruit	60	1	0.6	95	68465
Horticulture:Pip fruit	60	1	0.6	100	70391
Horticulture:Pip fruit	120	0	0	100	57990
Horticulture:Pip fruit	120	1	0	75	57990
Horticulture:Pip fruit	120	1	0	85	57990
Horticulture:Pip fruit	120	1	0	95	57990
Horticulture:Pip fruit	120	1	0	100	57990
Horticulture:Pip fruit	120	1	0.3	75	65562
Horticulture:Pip	120	1	0.3	85	67983

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fruit					
Horticulture:Pip fruit	120	1	0.3	95	71463
Horticulture:Pip fruit	120	1	0.3	100	73186
Horticulture:Pip fruit	120	1	0.45	75	66974
Horticulture:Pip fruit	120	1	0.45	85	69427
Horticulture:Pip fruit	120	1	0.45	95	72870
Horticulture:Pip fruit	120	1	0.45	100	74593
Horticulture:Pip fruit	120	1	0.6	75	67685
Horticulture:Pip fruit	120	1	0.6	85	70182
Horticulture:Pip fruit	120	1	0.6	95	73385
Horticulture:Pip fruit	120	1	0.6	100	89864
Sheep and beef	35	0	0	100	926
Sheep and beef	35	1	0	75	926
Sheep and beef	35	1	0	85	926
Sheep and beef	35	1	0	95	926
Sheep and beef	35	1	0	100	926
Sheep and beef	35	1	0.3	75	1527
Sheep and beef	35	1	0.3	85	1547
Sheep and beef	35	1	0.3	95	1600
Sheep and beef	35	1	0.3	100	1676
Sheep and beef	35	1	0.45	75	1569
Sheep and beef	35	1	0.45	85	1593
Sheep and beef	35	1	0.45	95	1645
Sheep and beef	35	1	0.45	100	1743
Sheep and beef	35	1	0.6	75	1583
Sheep and beef	35	1	0.6	85	1665
Sheep and beef	35	1	0.6	95	1737
Sheep and beef	35	1	0.6	100	1789
Sheep and beef	60	0	0	100	1092
Sheep and beef	60	1	0	75	1092
Sheep and beef	60	1	0	85	1092
Sheep and beef	60	1	0	95	1092
Sheep and beef	60	1	0	100	1092
Sheep and beef	60	1	0.3	75	1597
Sheep and beef	60	1	0.3	85	1624
Sheep and beef	60	1	0.3	95	1684
Sheep and beef	60	1	0.3	100	1763

Released Under the provision of the Official Information Act 1982

Sheep and beef	60	1	0.45	75	1631
Sheep and beef	60	1	0.45	85	1678
Sheep and beef	60	1	0.45	95	1717
Sheep and beef	60	1	0.45	100	1786
Sheep and beef	60	1	0.6	75	1622
Sheep and beef	60	1	0.6	85	1723
Sheep and beef	60	1	0.6	95	1788
Sheep and beef	60	1	0.6	100	1810
Sheep and beef	120	0	0	100	1183
Sheep and beef	120	1	0	75	1183
Sheep and beef	120	1	0	85	1183
Sheep and beef	120	1	0	95	1183
Sheep and beef	120	1	0	100	1183
Sheep and beef	120	1	0.3	75	1585
Sheep and beef	120	1	0.3	85	1607
Sheep and beef	120	1	0.3	95	1670
Sheep and beef	120	1	0.3	100	1763
Sheep and beef	120	1	0.45	75	1601
Sheep and beef	120	1	0.45	85	1705
Sheep and beef	120	1	0.45	95	1758
Sheep and beef	120	1	0.45	100	1781
Sheep and beef	120	1	0.6	75	1717
Sheep and beef	120	1	0.6	85	1735
Sheep and beef	120	1	0.6	95	1770
Sheep and beef	120	1	0.6	100	1804

SI-EastCoast-Marlborough

Land use	Soil PAW (mm)	Irrigable (1) / Not-Irrigable (0)	System Capacity (l/s/ha).	Supply Reliability (%)	Cash Operating Surplus ($/ha)
Horticulture:Grapes	35	0	0	100	13817
Horticulture:Grapes	35	1	0	75	13817
Horticulture:Grapes	35	1	0	85	13817
Horticulture:Grapes	35	1	0	95	13817
Horticulture:Grapes	35	1	0	100	13817
Horticulture:Grapes	35	1	0.15	75	17069
Horticulture:Grapes	35	1	0.15	85	17544
Horticulture:Gr	35	1	0.15	95	17817

Released Under the provision of the Official Information Act 1982

apes					
Horticulture:Grapes	35	1	0.15	100	17829
Horticulture:Grapes	35	1	0.22	75	18167
Horticulture:Grapes	35	1	0.22	85	18647
Horticulture:Grapes	35	1	0.22	95	18822
Horticulture:Grapes	35	1	0.22	100	18824
Horticulture:Grapes	35	1	0.3	75	18519
Horticulture:Grapes	35	1	0.3	85	18835
Horticulture:Grapes	35	1	0.3	95	18901
Horticulture:Grapes	35	1	0.3	100	18901
Horticulture:Grapes	60	0	0	100	15872
Horticulture:Grapes	60	1	0	75	15872
Horticulture:Grapes	60	1	0	85	15872
Horticulture:Grapes	60	1	0	95	15872
Horticulture:Grapes	60	1	0	100	15872
Horticulture:Grapes	60	1	0.15	75	18056
Horticulture:Grapes	60	1	0.15	85	18301
Horticulture:Grapes	60	1	0.15	95	18401
Horticulture:Grapes	60	1	0.15	100	18408
Horticulture:Grapes	60	1	0.22	75	18667
Horticulture:Grapes	60	1	0.22	85	18860
Horticulture:Grapes	60	1	0.22	95	18892
Horticulture:Grapes	60	1	0.22	100	18892
Horticulture:Grapes	60	1	0.3	75	18801
Horticulture:Grapes	60	1	0.3	85	18897
Horticulture:Grapes	60	1	0.3	95	18904

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Horticulture:Grapes	60	1	0.3	100	18904
Horticulture:Grapes	120	0	0	100	18031
Horticulture:Grapes	120	1	0	75	18031
Horticulture:Grapes	120	1	0	85	18031
Horticulture:Grapes	120	1	0	95	18031
Horticulture:Grapes	120	1	0	100	18031
Horticulture:Grapes	120	1	0.15	75	18754
Horticulture:Grapes	120	1	0.15	85	18785
Horticulture:Grapes	120	1	0.15	95	18792
Horticulture:Grapes	120	1	0.15	100	18885
Horticulture:Grapes	120	1	0.22	75	18890
Horticulture:Grapes	120	1	0.22	85	18899
Horticulture:Grapes	120	1	0.22	95	18901
Horticulture:Grapes	120	1	0.22	100	18901
Horticulture:Grapes	120	1	0.3	75	18897
Horticulture:Grapes	120	1	0.3	85	18901
Horticulture:Grapes	120	1	0.3	95	18904
Horticulture:Grapes	120	1	0.3	100	18904

SI-EastCoast-650 (mean annual rainfall in mm)

Land use	Soil PAW (mm)	Irrigable (1) / Not-Irrigable (0)	System Capacity (l/s/ha).	Supply Reliability (%)	Cash Operating Surplus ($/ha)
Arable	35	0	0	100	-71
Arable	35	1	0	75	-71
Arable	35	1	0	85	-71
Arable	35	1	0	95	-71
Arable	35	1	0	100	-71
Arable	35	1	0.3	75	1502

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Arable	35	1	0.3	85	1590
Arable	35	1	0.3	95	1660
Arable	35	1	0.3	100	1668
Arable	35	1	0.45	75	1902
Arable	35	1	0.45	85	2003
Arable	35	1	0.45	95	2085
Arable	35	1	0.45	100	2093
Arable	35	1	0.6	75	2206
Arable	35	1	0.6	85	2311
Arable	35	1	0.6	95	2395
Arable	35	1	0.6	100	2402
Arable	60	0	0	100	183
Arable	60	1	0	75	183
Arable	60	1	0	85	183
Arable	60	1	0	95	183
Arable	60	1	0	100	183
Arable	60	1	0.3	75	1713
Arable	60	1	0.3	85	1797
Arable	60	1	0.3	95	1863
Arable	60	1	0.3	100	1871
Arable	60	1	0.45	75	2089
Arable	60	1	0.45	85	2184
Arable	60	1	0.45	95	2256
Arable	60	1	0.45	100	2263
Arable	60	1	0.6	75	2357
Arable	60	1	0.6	85	2439
Arable	60	1	0.6	95	2504
Arable	60	1	0.6	100	2507
Arable	120	0	0	100	593
Arable	120	1	0	75	593
Arable	120	1	0	85	593
Arable	120	1	0	95	593
Arable	120	1	0	100	593
Arable	120	1	0.3	75	1954
Arable	120	1	0.3	85	2025
Arable	120	1	0.3	95	2084
Arable	120	1	0.3	100	2091
Arable	120	1	0.45	75	2265
Arable	120	1	0.45	85	2342
Arable	120	1	0.45	95	2349
Arable	120	1	0.45	100	2405
Arable	120	1	0.6	75	2451
Arable	120	1	0.6	85	2507
Arable	120	1	0.6	95	2546
Arable	120	1	0.6	100	2546

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Dairy	35	0	0	100	464
Dairy	35	1	0	75	464
Dairy	35	1	0	85	464
Dairy	35	1	0	95	464
Dairy	35	1	0	100	464
Dairy	35	1	0.3	75	1078
Dairy	35	1	0.3	85	1610
Dairy	35	1	0.3	95	1796
Dairy	35	1	0.3	100	1817
Dairy	35	1	0.45	75	1930
Dairy	35	1	0.45	85	2009
Dairy	35	1	0.45	95	2107
Dairy	35	1	0.45	100	2143
Dairy	35	1	0.6	75	2051
Dairy	35	1	0.6	85	2112
Dairy	35	1	0.6	95	2143
Dairy	35	1	0.6	100	2172
Dairy	60	0	0	100	790
Dairy	60	1	0	75	790
Dairy	60	1	0	85	790
Dairy	60	1	0	95	790
Dairy	60	1	0	100	790
Dairy	60	1	0.3	75	1563
Dairy	60	1	0.3	85	1669
Dairy	60	1	0.3	95	1721
Dairy	60	1	0.3	100	1875
Dairy	60	1	0.45	75	1972
Dairy	60	1	0.45	85	2206
Dairy	60	1	0.45	95	2241
Dairy	60	1	0.45	100	2246
Dairy	60	1	0.6	75	2121
Dairy	60	1	0.6	85	2216
Dairy	60	1	0.6	95	2239
Dairy	60	1	0.6	100	2242
Dairy	120	0	0	100	952
Dairy	120	1	0	75	952
Dairy	120	1	0	85	952
Dairy	120	1	0	95	952
Dairy	120	1	0	100	952
Dairy	120	1	0.3	75	1616
Dairy	120	1	0.3	85	1900
Dairy	120	1	0.3	95	2053
Dairy	120	1	0.3	100	2063
Dairy	120	1	0.45	75	2171
Dairy	120	1	0.45	85	2191

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Dairy	120	1	0.45	95	2208
Dairy	120	1	0.45	100	2215
Dairy	120	1	0.6	75	2192
Dairy	120	1	0.6	85	2208
Dairy	120	1	0.6	95	2226
Dairy	120	1	0.6	100	2239
Horticulture: Vegetables	35	0	0	100	3496
Horticulture: Vegetables	35	1	0	75	3496
Horticulture: Vegetables	35	1	0	85	3496
Horticulture: Vegetables	35	1	0	95	3496
Horticulture: Vegetables	35	1	0	100	3496
Horticulture: Vegetables	35	1	0.3	75	11539
Horticulture: Vegetables	35	1	0.3	85	12165
Horticulture: Vegetables	35	1	0.3	95	12755
Horticulture: Vegetables	35	1	0.3	100	12881
Horticulture: Vegetables	35	1	0.45	75	13117
Horticulture: Vegetables	35	1	0.45	85	13756
Horticulture: Vegetables	35	1	0.45	95	14383
Horticulture: Vegetables	35	1	0.45	100	14490
Horticulture: Vegetables	35	1	0.6	75	14030
Horticulture: Vegetables	35	1	0.6	85	14645
Horticulture: Vegetables	35	1	0.6	95	15265
Horticulture: Vegetables	35	1	0.6	100	15358
Horticulture: Vegetables	60	0	0	75	5044
Horticulture: Vegetables	60	0	0	85	5044
Horticulture: Vegetables	60	0	0	95	5044
Horticulture: Vegetables	60	0	0	100	5044
Horticulture: Vegetables	60	0	0	100	5044

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Horticulture: Vegetables	60	1	0.3	75	12537
Horticulture: Vegetables	60	1	0.3	85	13099
Horticulture: Vegetables	60	1	0.3	95	13627
Horticulture: Vegetables	60	1	0.3	100	13733
Horticulture: Vegetables	60	1	0.45	75	13922
Horticulture: Vegetables	60	1	0.45	85	14469
Horticulture: Vegetables	60	1	0.45	95	14964
Horticulture: Vegetables	60	1	0.45	100	15036
Horticulture: Vegetables	60	1	0.6	75	14684
Horticulture: Vegetables	60	1	0.6	85	15120
Horticulture: Vegetables	60	1	0.6	95	15536
Horticulture: Vegetables	60	1	0.6	100	15585
Horticulture: Vegetables	120	0	0	75	7196
Horticulture: Vegetables	120	0	0	85	7196
Horticulture: Vegetables	120	0	0	95	7196
Horticulture: Vegetables	120	0	0	100	7196
Horticulture: Vegetables	120	0	0	100	7196
Horticulture: Vegetables	120	1	0.3	75	13609
Horticulture: Vegetables	120	1	0.3	85	14071
Horticulture: Vegetables	120	1	0.3	95	14479
Horticulture: Vegetables	120	1	0.3	100	14555
Horticulture: Vegetables	120	1	0.45	75	14683
Horticulture: Vegetables	120	1	0.45	85	15060
Horticulture: Vegetables	120	1	0.45	95	15359
Horticulture: Vegetables	120	1	0.45	100	15395
Horticulture:	120	1	0.6	75	15144

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Vegetables					
Horticulture: Vegetables	120	1	0.6	85	15399
Horticulture: Vegetables	120	1	0.6	95	15616
Horticulture: Vegetables	120	1	0.6	100	15629
Sheep and beef	35	0	0	100	703
Sheep and beef	35	1	0	75	703
Sheep and beef	35	1	0	85	703
Sheep and beef	35	1	0	95	703
Sheep and beef	35	1	0	100	703
Sheep and beef	35	1	0.3	75	1112
Sheep and beef	35	1	0.3	85	1377
Sheep and beef	35	1	0.3	95	1460
Sheep and beef	35	1	0.3	100	1469
Sheep and beef	35	1	0.45	75	1516
Sheep and beef	35	1	0.45	85	1548
Sheep and beef	35	1	0.45	95	1587
Sheep and beef	35	1	0.45	100	1600
Sheep and beef	35	1	0.6	75	1565
Sheep and beef	35	1	0.6	85	1589
Sheep and beef	35	1	0.6	95	1601
Sheep and beef	35	1	0.6	100	1611
Sheep and beef	60	0	0	100	893
Sheep and beef	60	1	0	75	893
Sheep and beef	60	1	0	85	893
Sheep and beef	60	1	0	95	893
Sheep and beef	60	1	0	100	893
Sheep and beef	60	1	0.3	75	1355
Sheep and beef	60	1	0.3	85	1404
Sheep and beef	60	1	0.3	95	1427
Sheep and beef	60	1	0.3	100	1493
Sheep and beef	60	1	0.45	75	1533
Sheep and beef	60	1	0.45	85	1624
Sheep and beef	60	1	0.45	95	1637
Sheep and beef	60	1	0.45	100	1639
Sheep and beef	60	1	0.6	75	1592
Sheep and beef	60	1	0.6	85	1628
Sheep and beef	60	1	0.6	95	1636
Sheep and beef	60	1	0.6	100	1638
Sheep and beef	120	0	0	100	981
Sheep and beef	120	1	0	75	981
Sheep and beef	120	1	0	85	981
Sheep and beef	120	1	0	95	981

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Sheep and beef	120	1	0	100	981
Sheep and beef	120	1	0.3	75	1380
Sheep and beef	120	1	0.3	85	1504
Sheep and beef	120	1	0.3	95	1566
Sheep and beef	120	1	0.3	100	1570
Sheep and beef	120	1	0.45	75	1611
Sheep and beef	120	1	0.45	85	1619
Sheep and beef	120	1	0.45	95	1625
Sheep and beef	120	1	0.45	100	1627
Sheep and beef	120	1	0.6	75	1619
Sheep and beef	120	1	0.6	85	1625
Sheep and beef	120	1	0.6	95	1632
Sheep and beef	120	1	0.6	100	1636

SI-EastCoast-750

Land use	Soil PAW (mm)	Irrigable (1) / Not-Irrigable (0)	System Capacity (l/s/ha).	Supply Reliability (%)	Cash Operating Surplus ($/ha)
Arable	35	0	0	100	318
Arable	35	1	0	75	318
Arable	35	1	0	85	318
Arable	35	1	0	95	318
Arable	35	1	0	100	318
Arable	35	1	0.3	75	1703
Arable	35	1	0.3	85	1804
Arable	35	1	0.3	95	1898
Arable	35	1	0.3	100	1925
Arable	35	1	0.45	75	2067
Arable	35	1	0.45	85	2180
Arable	35	1	0.45	95	2282
Arable	35	1	0.45	100	2306
Arable	35	1	0.6	75	2338
Arable	35	1	0.6	85	2457
Arable	35	1	0.6	95	2564
Arable	35	1	0.6	100	2584
Arable	60	0	0	100	590
Arable	60	1	0	75	590
Arable	60	1	0	85	590
Arable	60	1	0	95	590
Arable	60	1	0	100	590
Arable	60	1	0.3	75	1927
Arable	60	1	0.3	85	2018

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Arable	60	1	0.3	95	2098
Arable	60	1	0.3	100	2118
Arable	60	1	0.45	75	2255
Arable	60	1	0.45	85	2356
Arable	60	1	0.45	95	2441
Arable	60	1	0.45	100	2457
Arable	60	1	0.6	75	2493
Arable	60	1	0.6	85	2593
Arable	60	1	0.6	95	2673
Arable	60	1	0.6	100	2682
Arable	120	0	0	100	1020
Arable	120	1	0	75	1020
Arable	120	1	0	85	1020
Arable	120	1	0	95	1020
Arable	120	1	0	100	1020
Arable	120	1	0.3	75	2177
Arable	120	1	0.3	85	2252
Arable	120	1	0.3	95	2318
Arable	120	1	0.3	100	2329
Arable	120	1	0.45	75	2438
Arable	120	1	0.45	85	2516
Arable	120	1	0.45	95	2579
Arable	120	1	0.45	100	2588
Arable	120	1	0.6	75	2608
Arable	120	1	0.6	85	2677
Arable	120	1	0.6	95	2718
Arable	120	1	0.6	100	2722
Dairy	35	0	0	100	775
Dairy	35	1	0	75	775
Dairy	35	1	0	85	775
Dairy	35	1	0	95	775
Dairy	35	1	0	100	775
Dairy	35	1	0.3	75	1542
Dairy	35	1	0.3	85	1582
Dairy	35	1	0.3	95	1726
Dairy	35	1	0.3	100	1767
Dairy	35	1	0.45	75	1717
Dairy	35	1	0.45	85	1822
Dairy	35	1	0.45	95	1950
Dairy	35	1	0.45	100	1994
Dairy	35	1	0.6	75	2068
Dairy	35	1	0.6	85	2112
Dairy	35	1	0.6	95	2151
Dairy	35	1	0.6	100	2161
Dairy	60	0	0	100	1034

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Dairy	60	1	0	75	1034
Dairy	60	1	0	85	1034
Dairy	60	1	0	95	1034
Dairy	60	1	0	100	1034
Dairy	60	1	0.3	75	1538
Dairy	60	1	0.3	85	1855
Dairy	60	1	0.3	95	2031
Dairy	60	1	0.3	100	2052
Dairy	60	1	0.45	75	1938
Dairy	60	1	0.45	85	2096
Dairy	60	1	0.45	95	2165
Dairy	60	1	0.45	100	2181
Dairy	60	1	0.6	75	2177
Dairy	60	1	0.6	85	2207
Dairy	60	1	0.6	95	2226
Dairy	60	1	0.6	100	2232
Dairy	120	0	0	100	1253
Dairy	120	1	0	75	1253
Dairy	120	1	0	85	1253
Dairy	120	1	0	95	1253
Dairy	120	1	0	100	1253
Dairy	120	1	0.3	75	1810
Dairy	120	1	0.3	85	1994
Dairy	120	1	0.3	95	2075
Dairy	120	1	0.3	100	2084
Dairy	120	1	0.45	75	2081
Dairy	120	1	0.45	85	2137
Dairy	120	1	0.45	95	2173
Dairy	120	1	0.45	100	2178
Dairy	120	1	0.6	75	2189
Dairy	120	1	0.6	85	2207
Dairy	120	1	0.6	95	2228
Dairy	120	1	0.6	100	2230
Horticulture: Vegetables	35	0	0	100	5711
Horticulture: Vegetables	35	1	0	75	5711
Horticulture: Vegetables	35	1	0	85	5711
Horticulture: Vegetables	35	1	0	95	5711
Horticulture: Vegetables	35	1	0	100	5711
Horticulture: Vegetables	35	1	0.3	75	12601
Horticulture:	35	1	0.3	85	13226

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Vegetables					
Horticulture: Vegetables	35	1	0.3	95	13820
Horticulture: Vegetables	35	1	0.3	100	13951
Horticulture: Vegetables	35	1	0.45	75	13998
Horticulture: Vegetables	35	1	0.45	85	14681
Horticulture: Vegetables	35	1	0.45	95	15326
Horticulture: Vegetables	35	1	0.45	100	15433
Horticulture: Vegetables	35	1	0.6	75	14882
Horticulture: Vegetables	35	1	0.6	85	15543
Horticulture: Vegetables	35	1	0.6	95	16199
Horticulture: Vegetables	35	1	0.6	100	16302
Horticulture: Vegetables	60	0	0	100	7352
Horticulture: Vegetables	60	1	0	75	7352
Horticulture: Vegetables	60	1	0	85	7352
Horticulture: Vegetables	60	1	0	95	7352
Horticulture: Vegetables	60	1	0	100	7352
Horticulture: Vegetables	60	1	0.3	75	13672
Horticulture: Vegetables	60	1	0.3	85	14250
Horticulture: Vegetables	60	1	0.3	95	14764
Horticulture: Vegetables	60	1	0.3	100	14870
Horticulture: Vegetables	60	1	0.45	75	14843
Horticulture: Vegetables	60	1	0.45	85	15416
Horticulture: Vegetables	60	1	0.45	95	15930
Horticulture: Vegetables	60	1	0.45	100	16014
Horticulture: Vegetables	60	1	0.6	75	15591
Horticulture: Vegetables	60	1	0.6	85	16078

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Horticulture: Vegetables	60	1	0.6	95	16545
Horticulture: Vegetables	60	1	0.6	100	16603
Horticulture: Vegetables	120	0	0	100	9577
Horticulture: Vegetables	120	1	0	75	9577
Horticulture: Vegetables	120	1	0	85	9577
Horticulture: Vegetables	120	1	0	95	9577
Horticulture: Vegetables	120	1	0	100	9577
Horticulture: Vegetables	120	1	0.3	75	14768
Horticulture: Vegetables	120	1	0.3	85	15218
Horticulture: Vegetables	120	1	0.3	95	15598
Horticulture: Vegetables	120	1	0.3	100	15683
Horticulture: Vegetables	120	1	0.45	75	15663
Horticulture: Vegetables	120	1	0.45	85	16066
Horticulture: Vegetables	120	1	0.45	95	16370
Horticulture: Vegetables	120	1	0.45	100	16420
Horticulture: Vegetables	120	1	0.6	75	16142
Horticulture: Vegetables	120	1	0.6	85	16431
Horticulture: Vegetables	120	1	0.6	95	16652
Horticulture: Vegetables	120	1	0.6	100	16669
Sheep and beef	35	0	0	100	884
Sheep and beef	35	1	0	75	884
Sheep and beef	35	1	0	85	884
Sheep and beef	35	1	0	95	884
Sheep and beef	35	1	0	100	884
Sheep and beef	35	1	0.3	75	1345
Sheep and beef	35	1	0.3	85	1364
Sheep and beef	35	1	0.3	95	1429
Sheep and beef	35	1	0.3	100	1447
Sheep and beef	35	1	0.45	75	1425
Sheep and beef	35	1	0.45	85	1471

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Sheep and beef	35	1	0.45	95	1524
Sheep and beef	35	1	0.45	100	1542
Sheep and beef	35	1	0.6	75	1572
Sheep and beef	35	1	0.6	85	1588
Sheep and beef	35	1	0.6	95	1604
Sheep and beef	35	1	0.6	100	1607
Sheep and beef	60	0	0	100	1025
Sheep and beef	60	1	0	75	1025
Sheep and beef	60	1	0	85	1025
Sheep and beef	60	1	0	95	1025
Sheep and beef	60	1	0	100	1025
Sheep and beef	60	1	0.3	75	1344
Sheep and beef	60	1	0.3	85	1485
Sheep and beef	60	1	0.3	95	1557
Sheep and beef	60	1	0.3	100	1565
Sheep and beef	60	1	0.45	75	1519
Sheep and beef	60	1	0.45	85	1582
Sheep and beef	60	1	0.45	95	1609
Sheep and beef	60	1	0.45	100	1615
Sheep and beef	60	1	0.6	75	1613
Sheep and beef	60	1	0.6	85	1624
Sheep and beef	60	1	0.6	95	1631
Sheep and beef	60	1	0.6	100	1634
Sheep and beef	120	0	0	100	1138
Sheep and beef	120	1	0	75	1138
Sheep and beef	120	1	0	85	1138
Sheep and beef	120	1	0	95	1138
Sheep and beef	120	1	0	100	1138
Sheep and beef	120	1	0.3	75	1466
Sheep and beef	120	1	0.3	85	1542
Sheep and beef	120	1	0.3	95	1574
Sheep and beef	120	1	0.3	100	1578
Sheep and beef	120	1	0.45	75	1577
Sheep and beef	120	1	0.45	85	1598
Sheep and beef	120	1	0.45	95	1612
Sheep and beef	120	1	0.45	100	1614
Sheep and beef	120	1	0.6	75	1618
Sheep and beef	120	1	0.6	85	1625
Sheep and beef	120	1	0.6	95	1632
Sheep and beef	120	1	0.6	100	1633

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SI-EastCoast-850

Land use	Soil PAW (mm)	Irrigable (1) / Not-Irrigable (0)	System Capacity (l/s/ha).	Supply Reliability (%)	Cash Operating Surplus ($/ha)
Arable	35	0	0	100	454
Arable	35	1	0	75	454
Arable	35	1	0	85	454
Arable	35	1	0	95	454
Arable	35	1	0	100	454
Arable	35	1	0.3	75	1749
Arable	35	1	0.3	85	1847
Arable	35	1	0.3	95	1934
Arable	35	1	0.3	100	1964
Arable	35	1	0.45	75	2093
Arable	35	1	0.45	85	2199
Arable	35	1	0.45	95	2293
Arable	35	1	0.45	100	2321
Arable	35	1	0.6	75	2342
Arable	35	1	0.6	85	2452
Arable	35	1	0.6	95	2546
Arable	35	1	0.6	100	2571
Arable	60	0	0	100	752
Arable	60	1	0	75	752
Arable	60	1	0	85	752
Arable	60	1	0	95	752
Arable	60	1	0	100	752
Arable	60	1	0.3	75	1978
Arable	60	1	0.3	85	2065
Arable	60	1	0.3	95	2138
Arable	60	1	0.3	100	2161
Arable	60	1	0.45	75	2280
Arable	60	1	0.45	85	2373
Arable	60	1	0.45	95	2447
Arable	60	1	0.45	100	2468
Arable	60	1	0.6	75	2494
Arable	60	1	0.6	85	2579
Arable	60	1	0.6	95	2644
Arable	60	1	0.6	100	2661
Arable	120	0	0	100	1189
Arable	120	1	0	75	1189
Arable	120	1	0	85	1189
Arable	120	1	0	95	1189
Arable	120	1	0	100	1189

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Arable	120	1	0.3	75	2218
Arable	120	1	0.3	85	2288
Arable	120	1	0.3	95	2345
Arable	120	1	0.3	100	2355
Arable	120	1	0.45	75	2451
Arable	120	1	0.45	85	2522
Arable	120	1	0.45	95	2570
Arable	120	1	0.45	100	2586
Arable	120	1	0.6	75	2594
Arable	120	1	0.6	85	2649
Arable	120	1	0.6	95	2678
Arable	120	1	0.6	100	2690
Dairy	35	0	0	100	746
Dairy	35	1	0	75	746
Dairy	35	1	0	85	746
Dairy	35	1	0	95	746
Dairy	35	1	0	100	746
Dairy	35	1	0.3	75	1600
Dairy	35	1	0.3	85	1675
Dairy	35	1	0.3	95	1854
Dairy	35	1	0.3	100	1976
Dairy	35	1	0.45	75	1990
Dairy	35	1	0.45	85	2101
Dairy	35	1	0.45	95	2200
Dairy	35	1	0.45	100	2234
Dairy	35	1	0.6	75	2118
Dairy	35	1	0.6	85	2234
Dairy	35	1	0.6	95	2281
Dairy	35	1	0.6	100	2299
Dairy	60	0	0	100	1042
Dairy	60	1	0	75	1042
Dairy	60	1	0	85	1042
Dairy	60	1	0	95	1042
Dairy	60	1	0	100	1042
Dairy	60	1	0.3	75	1851
Dairy	60	1	0.3	85	1951
Dairy	60	1	0.3	95	2085
Dairy	60	1	0.3	100	2123
Dairy	60	1	0.45	75	2148
Dairy	60	1	0.45	85	2284
Dairy	60	1	0.45	95	2329
Dairy	60	1	0.45	100	2364
Dairy	60	1	0.6	75	2249
Dairy	60	1	0.6	85	2329
Dairy	60	1	0.6	95	2373

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Dairy	60	1	0.6	100	2389
Dairy	120	0	0	100	1212
Dairy	120	1	0	75	1212
Dairy	120	1	0	85	1212
Dairy	120	1	0	95	1212
Dairy	120	1	0	100	1212
Dairy	120	1	0.3	75	1722
Dairy	120	1	0.3	85	1915
Dairy	120	1	0.3	95	2102
Dairy	120	1	0.3	100	2155
Dairy	120	1	0.45	75	2188
Dairy	120	1	0.45	85	2269
Dairy	120	1	0.45	95	2318
Dairy	120	1	0.45	100	2320
Dairy	120	1	0.6	75	2293
Dairy	120	1	0.6	85	2327
Dairy	120	1	0.6	95	2359
Dairy	120	1	0.6	100	2369
Horticulture: Vegetables	35	0	0	100	6636
Horticulture: Vegetables	35	1	0	75	6636
Horticulture: Vegetables	35	1	0	85	6636
Horticulture: Vegetables	35	1	0	95	6636
Horticulture: Vegetables	35	1	0	100	6636
Horticulture: Vegetables	35	1	0.3	75	12999
Horticulture: Vegetables	35	1	0.3	85	13593
Horticulture: Vegetables	35	1	0.3	95	14134
Horticulture: Vegetables	35	1	0.3	100	14309
Horticulture: Vegetables	35	1	0.45	75	14295
Horticulture: Vegetables	35	1	0.45	85	14923
Horticulture: Vegetables	35	1	0.45	95	15482
Horticulture: Vegetables	35	1	0.45	100	15641
Horticulture: Vegetables	35	1	0.6	75	15065
Horticulture: Vegetables	35	1	0.6	85	15667

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Horticulture: Vegetables	35	1	0.6	95	16227
Horticulture: Vegetables	35	1	0.6	100	16379
Horticulture: Vegetables	60	0	0	100	8334
Horticulture: Vegetables	60	1	0	75	8334
Horticulture: Vegetables	60	1	0	85	8334
Horticulture: Vegetables	60	1	0	95	8334
Horticulture: Vegetables	60	1	0	100	8334
Horticulture: Vegetables	60	1	0.3	75	14043
Horticulture: Vegetables	60	1	0.3	85	14567
Horticulture: Vegetables	60	1	0.3	95	15027
Horticulture: Vegetables	60	1	0.3	100	15184
Horticulture: Vegetables	60	1	0.45	75	15114
Horticulture: Vegetables	60	1	0.45	85	15623
Horticulture: Vegetables	60	1	0.45	95	16050
Horticulture: Vegetables	60	1	0.45	100	16184
Horticulture: Vegetables	60	1	0.6	75	15725
Horticulture: Vegetables	60	1	0.6	85	16133
Horticulture: Vegetables	60	1	0.6	95	16524
Horticulture: Vegetables	60	1	0.6	100	16639
Horticulture: Vegetables	120	0	0	100	10511
Horticulture: Vegetables	120	1	0	75	10511
Horticulture: Vegetables	120	1	0	85	10511
Horticulture: Vegetables	120	1	0	95	10511
Horticulture: Vegetables	120	1	0	100	10511
Horticulture: Vegetables	120	1	0.3	75	15110
Horticulture:	120	1	0.3	85	15506

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Vegetables					
Horticulture: Vegetables	120	1	0.3	95	15800
Horticulture: Vegetables	120	1	0.3	100	15865
Horticulture: Vegetables	120	1	0.45	75	15859
Horticulture: Vegetables	120	1	0.45	85	16180
Horticulture: Vegetables	120	1	0.45	95	16406
Horticulture: Vegetables	120	1	0.45	100	16512
Horticulture: Vegetables	120	1	0.6	75	16213
Horticulture: Vegetables	120	1	0.6	85	16442
Horticulture: Vegetables	120	1	0.6	95	16612
Horticulture: Vegetables	120	1	0.6	100	16622
Sheep and beef	35	0	0	100	926
Sheep and beef	35	1	0	75	926
Sheep and beef	35	1	0	85	926
Sheep and beef	35	1	0	95	926
Sheep and beef	35	1	0	100	926
Sheep and beef	35	1	0.3	75	1372
Sheep and beef	35	1	0.3	85	1407
Sheep and beef	35	1	0.3	95	1484
Sheep and beef	35	1	0.3	100	1535
Sheep and beef	35	1	0.45	75	1541
Sheep and beef	35	1	0.45	85	1584
Sheep and beef	35	1	0.45	95	1622
Sheep and beef	35	1	0.45	100	1635
Sheep and beef	35	1	0.6	75	1591
Sheep and beef	35	1	0.6	85	1635
Sheep and beef	35	1	0.6	95	1652
Sheep and beef	35	1	0.6	100	1658
Sheep and beef	60	0	0	100	1092
Sheep and beef	60	1	0	75	1092
Sheep and beef	60	1	0	85	1092
Sheep and beef	60	1	0	95	1092
Sheep and beef	60	1	0	100	1092
Sheep and beef	60	1	0.3	75	1483
Sheep and beef	60	1	0.3	85	1525
Sheep and beef	60	1	0.3	95	1578
Sheep and beef	60	1	0.3	100	1593

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Sheep and beef	60	1	0.45	75	1602
Sheep and beef	60	1	0.45	85	1653
Sheep and beef	60	1	0.45	95	1669
Sheep and beef	60	1	0.45	100	1681
Sheep and beef	60	1	0.6	75	1640
Sheep and beef	60	1	0.6	85	1669
Sheep and beef	60	1	0.6	95	1684
Sheep and beef	60	1	0.6	100	1690
Sheep and beef	120	0	0	100	1183
Sheep and beef	120	1	0	75	1183
Sheep and beef	120	1	0	85	1183
Sheep and beef	120	1	0	95	1183
Sheep and beef	120	1	0	100	1183
Sheep and beef	120	1	0.3	75	1427
Sheep and beef	120	1	0.3	85	1510
Sheep and beef	120	1	0.3	95	1585
Sheep and beef	120	1	0.3	100	1605
Sheep and beef	120	1	0.45	75	1618
Sheep and beef	120	1	0.45	85	1647
Sheep and beef	120	1	0.45	95	1665
Sheep and beef	120	1	0.45	100	1665
Sheep and beef	120	1	0.6	75	1656
Sheep and beef	120	1	0.6	85	1668
Sheep and beef	120	1	0.6	95	1679
Sheep and beef	120	1	0.6	100	1683

SI-InlandBasins

Land use	Soil PAW (mm)	Irrigable (1) / Not-Irrigable (0)	System Capacity (l/s/ha).	Supply Reliability (%)	Cash Operating Surplus ($/ha)
Dairy	35	0	0	100	189
Dairy	35	1	0	75	189
Dairy	35	1	0	85	189
Dairy	35	1	0	95	189
Dairy	35	1	0	100	189
Dairy	35	1	0.3	75	1603
Dairy	35	1	0.3	85	1799
Dairy	35	1	0.3	95	2095
Dairy	35	1	0.3	100	2385
Dairy	35	1	0.45	75	1974
Dairy	35	1	0.45	85	2250
Dairy	35	1	0.45	95	2548
Dairy	35	1	0.45	100	2700

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Dairy	35	1	0.6	75	2134
Dairy	35	1	0.6	85	2345
Dairy	35	1	0.6	95	2595
Dairy	35	1	0.6	100	2770
Dairy	60	0	0	100	419
Dairy	60	1	0	75	419
Dairy	60	1	0	85	419
Dairy	60	1	0	95	419
Dairy	60	1	0	100	419
Dairy	60	1	0.3	75	1845
Dairy	60	1	0.3	85	2088
Dairy	60	1	0.3	95	2414
Dairy	60	1	0.3	100	2597
Dairy	60	1	0.45	75	2227
Dairy	60	1	0.45	85	2467
Dairy	60	1	0.45	95	2726
Dairy	60	1	0.45	100	2852
Dairy	60	1	0.6	75	2403
Dairy	60	1	0.6	85	2585
Dairy	60	1	0.6	95	2745
Dairy	60	1	0.6	100	2862
Dairy	120	0	0	100	573
Dairy	120	1	0	75	573
Dairy	120	1	0	85	573
Dairy	120	1	0	95	573
Dairy	120	1	0	100	573
Dairy	120	1	0.3	75	2075
Dairy	120	1	0.3	85	2309
Dairy	120	1	0.3	95	2563
Dairy	120	1	0.3	100	2721
Dairy	120	1	0.45	75	2391
Dairy	120	1	0.45	85	2655
Dairy	120	1	0.45	95	2808
Dairy	120	1	0.45	100	2918
Dairy	120	1	0.6	75	2577
Dairy	120	1	0.6	85	2711
Dairy	120	1	0.6	95	2836
Dairy	120	1	0.6	100	2942
Horticulture:Grapes	35	0	0	100	13817
Horticulture:Grapes	35	1	0	75	13817
Horticulture:Grapes	35	1	0	85	13817
Horticulture:Grapes	35	1	0	95	13817

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Horticulture:Grapes	35	1	0	100	13817
Horticulture:Grapes	35	1	0.15	75	17069
Horticulture:Grapes	35	1	0.15	85	17544
Horticulture:Grapes	35	1	0.15	95	17817
Horticulture:Grapes	35	1	0.15	100	17829
Horticulture:Grapes	35	1	0.22	75	18167
Horticulture:Grapes	35	1	0.22	85	18647
Horticulture:Grapes	35	1	0.22	95	18822
Horticulture:Grapes	35	1	0.22	100	18824
Horticulture:Grapes	35	1	0.3	75	18519
Horticulture:Grapes	35	1	0.3	85	18835
Horticulture:Grapes	35	1	0.3	95	18901
Horticulture:Grapes	35	1	0.3	100	18901
Horticulture:Grapes	60	0	0	100	15872
Horticulture:Grapes	60	1	0	75	15872
Horticulture:Grapes	60	1	0	85	15872
Horticulture:Grapes	60	1	0	95	15872
Horticulture:Grapes	60	1	0	100	15872
Horticulture:Grapes	60	1	0.15	75	18056
Horticulture:Grapes	60	1	0.15	85	18301
Horticulture:Grapes	60	1	0.15	95	18401
Horticulture:Grapes	60	1	0.15	100	18408
Horticulture:Grapes	60	1	0.22	75	18667
Horticulture:Grapes	60	1	0.22	85	18860
Horticulture:Grapes	60	1	0.22	95	18892
Horticulture:Gr	60	1	0.22	100	18892

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apes					
Horticulture:Grapes	60	1	0.3	75	18801
Horticulture:Grapes	60	1	0.3	85	18897
Horticulture:Grapes	60	1	0.3	95	18904
Horticulture:Grapes	60	1	0.3	100	18904
Horticulture:Grapes	120	0	0	100	18031
Horticulture:Grapes	120	1	0	75	18031
Horticulture:Grapes	120	1	0	85	18031
Horticulture:Grapes	120	1	0	95	18031
Horticulture:Grapes	120	1	0	100	18031
Horticulture:Grapes	120	1	0.15	75	18754
Horticulture:Grapes	120	1	0.15	85	18785
Horticulture:Grapes	120	1	0.15	95	18792
Horticulture:Grapes	120	1	0.15	100	18885
Horticulture:Grapes	120	1	0.22	75	18890
Horticulture:Grapes	120	1	0.22	85	18899
Horticulture:Grapes	120	1	0.22	95	18901
Horticulture:Grapes	120	1	0.22	100	18901
Horticulture:Grapes	120	1	0.3	75	18897
Horticulture:Grapes	120	1	0.3	85	18901
Horticulture:Grapes	120	1	0.3	95	18904
Horticulture:Grapes	120	1	0.3	100	18904
Sheep and Beef	35	0	0	100	533
Sheep and Beef	35	1	0	75	533
Sheep and Beef	35	1	0	85	533
Sheep and Beef	35	1	0	95	533
Sheep and Beef	35	1	0	100	533
Sheep and Beef	35	1	0.3	75	1304
Sheep and Beef	35	1	0.3	85	1390

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Sheep and Beef	35	1	0.3	95	1511
Sheep and Beef	35	1	0.3	100	1618
Sheep and Beef	35	1	0.45	75	1463
Sheep and Beef	35	1	0.45	85	1570
Sheep and Beef	35	1	0.45	95	1674
Sheep and Beef	35	1	0.45	100	1722
Sheep and Beef	35	1	0.6	75	1526
Sheep and Beef	35	1	0.6	85	1604
Sheep and Beef	35	1	0.6	95	1689
Sheep and Beef	35	1	0.6	100	1744
Sheep and Beef	60	0	0	100	676
Sheep and Beef	60	1	0	75	676
Sheep and Beef	60	1	0	85	676
Sheep and Beef	60	1	0	95	676
Sheep and Beef	60	1	0	100	676
Sheep and Beef	60	1	0.3	75	1410
Sheep and Beef	60	1	0.3	85	1508
Sheep and Beef	60	1	0.3	95	1628
Sheep and Beef	60	1	0.3	100	1690
Sheep and Beef	60	1	0.45	75	1561
Sheep and Beef	60	1	0.45	85	1647
Sheep and Beef	60	1	0.45	95	1730
Sheep and Beef	60	1	0.45	100	1768
Sheep and Beef	60	1	0.6	75	1625
Sheep and Beef	60	1	0.6	85	1686
Sheep and Beef	60	1	0.6	95	1736
Sheep and Beef	60	1	0.6	100	1771
Sheep and Beef	120	0	0	100	768
Sheep and Beef	120	1	0	75	768
Sheep and Beef	120	1	0	85	768
Sheep and Beef	120	1	0	95	768
Sheep and Beef	120	1	0	100	768
Sheep and Beef	120	1	0.3	75	1503
Sheep and Beef	120	1	0.3	85	1591
Sheep and Beef	120	1	0.3	95	1679
Sheep and Beef	120	1	0.3	100	1729
Sheep and Beef	120	1	0.45	75	1620
Sheep and Beef	120	1	0.45	85	1708
Sheep and Beef	120	1	0.45	95	1755
Sheep and Beef	120	1	0.45	100	1787
Sheep and Beef	120	1	0.6	75	1683
Sheep and Beef	120	1	0.6	85	1726
Sheep and Beef	120	1	0.6	95	1763
Sheep and Beef	120	1	0.6	100	1794

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Appendix B: N Loss and Cash Operating Surplus Tables

The results of the population of the data on N loss and Cash Operating Surplus are shown in the following tables which report the results according to the Farm Model Region classification.

North Island-Lower Hill Country

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Sheep and Beef	35	0	0	25	180	GMP
Sheep and Beef	60	0	0	20	180	GMP
Sheep and Beef	120	0	0	18	180	GMP
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

North Island-Central

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Sheep and Beef	35	0	0	20	680	GMP
Sheep and Beef	60	0	0	16	680	GMP
Sheep and Beef	120	0	0	14	680	GMP
Sheep and Beef	35	1	0.6	26	1512	GMP
Sheep and Beef	35	1	0.6	24	1361	Mitigation 1
Sheep and Beef	35	1	0.6	25	1482	Mitigation 2
Sheep and Beef	60	1	0.6	24	1525	GMP
Sheep and Beef	60	1	0.6	22	1373	Mitigation 1
Sheep and Beef	60	1	0.6	24	1495	Mitigation 2
Sheep and Beef	120	1	0.6	22	1529	GMP
Sheep and Beef	120	1	0.6	20	1376	Mitigation 1
Sheep and Beef	120	1	0.6	21	1498	Mitigation 2
Dairy	35	0	0	48	1252	GMP
Dairy	35	0	0	45	1127	Mitigation 1
Dairy	35	0	0	40	1189	Mitigation 2

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Dairy	60	0	0	41	1252	GMP
Dairy	60	0	0	38	1127	Mitigation 1
Dairy	60	0	0	34	1189	Mitigation 2
Dairy	120	0	0	36	1252	GMP
Dairy	120	0	0	34	1127	Mitigation 1
Dairy	120	0	0	30	1189	Mitigation 2
Dairy	35	1	0.6	62	2098	GMP
Dairy	35	1	0.6	58	1888	Mitigation 1
Dairy	35	1	0.6	52	1993	Mitigation 2
Dairy	60	1	0.6	53	2132	GMP
Dairy	60	1	0.6	50	1919	Mitigation 1
Dairy	60	1	0.6	44	2025	Mitigation 2
Dairy	120	1	0.6	47	2141	GMP
Dairy	120	1	0.6	44	1927	Mitigation 1
Dairy	120	1	0.6	39	2034	Mitigation 2
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

North Island-South West Coast

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Sheep and Beef	35	0	0	18	1028	GMP
Sheep and Beef	60	0	0	14	1227	GMP
Sheep and Beef	120	0	0	12	1285	GMP
Sheep and Beef	35	1	0.6	28	1703	GMP
Sheep and Beef	35	1	0.6	25	1532	Mitigation 1
Sheep and Beef	35	1	0.6	27	1669	Mitigation 2
Sheep and Beef	60	1	0.6	22	1762	GMP
Sheep and Beef	60	1	0.6	20	1586	Mitigation 1
Sheep and Beef	60	1	0.6	22	1727	Mitigation 2
Sheep and Beef	120	1	0.6	20	1754	GMP
Sheep and Beef	120	1	0.6	18	1579	Mitigation 1
Sheep and Beef	120	1	0.6	20	1719	Mitigation 2
Dairy	35	0	0	46	1040	GMP
Dairy	35	0	0	43	936	Mitigation 1
Dairy	35	0	0	39	988	Mitigation 2
Dairy	60	0	0	39	1436	GMP
Dairy	60	0	0	37	1293	Mitigation 1
Dairy	60	0	0	33	1364	Mitigation 2
Dairy	120	0	0	34	1562	GMP
Dairy	120	0	0	32	1406	Mitigation 1
Dairy	120	0	0	29	1484	Mitigation 2

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Dairy	35	1	0.6	60	2428	GMP
Dairy	35	1	0.6	56	2185	Mitigation 1
Dairy	35	1	0.6	50	2306	Mitigation 2
Dairy	60	1	0.6	49	2612	GMP
Dairy	60	1	0.6	46	2350	Mitigation 1
Dairy	60	1	0.6	41	2481	Mitigation 2
Dairy	120	1	0.6	45	2585	GMP
Dairy	120	1	0.6	42	2327	Mitigation 1
Dairy	120	1	0.6	38	2456	Mitigation 2
Horticulture	35	0	0	39	6164	GMP
Horticulture	35	0	0	37	6041	Mitigation 1
Horticulture	35	0	0	34	5856	Mitigation 2
Horticulture	60	0	0	34	6164	GMP
Horticulture	60	0	0	32	6041	Mitigation 1
Horticulture	60	0	0	30	5856	Mitigation 2
Horticulture	120	0	0	32	6154	GMP
Horticulture	120	0	0	30	6031	Mitigation 1
Horticulture	120	0	0	28	5846	Mitigation 2
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

South Island-Inland Basins

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Sheep and Beef	35	0	0	2	37	GMP
Sheep and Beef	60	0	0	2	37	GMP
Sheep and Beef	120	0	0	1	37	GMP
Sheep and Beef	35	1	0.6	30	1721	GMP
Sheep and Beef	35	1	0.6	27	1549	Mitigation 1
Sheep and Beef	35	1	0.6	29	1686	Mitigation 2
Sheep and Beef	60	1	0.6	24	1750	GMP
Sheep and Beef	60	1	0.6	22	1575	Mitigation 1
Sheep and Beef	60	1	0.6	24	1715	Mitigation 2
Sheep and Beef	120	1	0.6	22	1743	GMP
Sheep and Beef	120	1	0.6	20	1569	Mitigation 1
Sheep and Beef	120	1	0.6	22	1708	Mitigation 2
Dairy	35	1	0.6	60	2481	GMP
Dairy	35	1	0.6	56	2233	Mitigation 1
Dairy	35	1	0.6	50	2357	Mitigation 2
Dairy	60	1	0.6	49	2570	GMP
Dairy	60	1	0.6	46	2313	Mitigation 1
Dairy	60	1	0.6	41	2442	Mitigation 2

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Dairy	120	1	0.6	45	2550	GMP
Dairy	120	1	0.6	42	2295	Mitigation 1
Dairy	120	1	0.6	38	2422	Mitigation 2
Viticulture	35	1	0.255	9	17829	GMP
Viticulture	60	1	0.255	9	18408	GMP
Viticulture	120	1	0.255	9	18885	GMP
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

South Island-Tasman

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Sheep and Beef	35	0	0	18	121	GMP
Sheep and Beef	60	0	0	14	121	GMP
Sheep and Beef	120	0	0	12	121	GMP
Dairy	35	0	0	46	1379	GMP
Dairy	35	0	0	43	1241	Mitigation 1
Dairy	35	0	0	39	1310	Mitigation 2
Dairy	60	0	0	39	1379	GMP
Dairy	60	0	0	37	1241	Mitigation 1
Dairy	60	0	0	33	1310	Mitigation 2
Dairy	120	0	0	34	1379	GMP
Dairy	120	0	0	32	1241	Mitigation 1
Dairy	120	0	0	29	1310	Mitigation 2
Dairy	35	1	0	60	746	GMP
Dairy	35	1	0	56	671	Mitigation 1
Dairy	35	1	0	50	709	Mitigation 2
Dairy	60	1	0	49	1042	GMP
Dairy	60	1	0	46	938	Mitigation 1
Dairy	60	1	0	41	990	Mitigation 2
Dairy	120	1	0	45	1212	GMP
Dairy	120	1	0	42	1091	Mitigation 1
Dairy	120	1	0	38	1151	Mitigation 2
Pipfruit	35	1	0.6	13	67642	GMP
Pipfruit	35	1	0.6	12	66289	Mitigation 1
Pipfruit	35	1	0.6	11	64260	Mitigation 2
Pipfruit	60	1	0.6	10	70391	GMP
Pipfruit	60	1	0.6	9	68983	Mitigation 1
Pipfruit	60	1	0.6	9	66871	Mitigation 2
Pipfruit	120	1	0.6	9	89864	GMP
Pipfruit	120	1	0.6	8	88066	Mitigation 1
Pipfruit	120	1	0.6	8	85371	Mitigation 2
Horticulture	35	1	0.6	39	16379	GMP
Horticulture	35	1	0.6	37	16052	Mitigation 1
Horticulture	35	1	0.6	34	15560	Mitigation 2
Horticulture	60	1	0.6	34	16639	GMP
Horticulture	60	1	0.6	32	16306	Mitigation 1
Horticulture	60	1	0.6	30	15807	Mitigation 2
Horticulture	120	1	0.6	32	16622	GMP
Horticulture	120	1	0.6	30	16289	Mitigation 1
Horticulture	120	1	0.6	28	15791	Mitigation 2

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Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

South Island-Inland Otago Southland

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Sheep and Beef	35	0	0	6	533	GMP
Sheep and Beef	60	0	0	5	676	GMP
Sheep and Beef	120	0	0	4	768	GMP
Sheep and Beef	35	1	0.6	45	1744	GMP
Sheep and Beef	35	1	0.6	41	1569	Mitigation 1
Sheep and Beef	35	1	0.6	44	1709	Mitigation 2
Sheep and Beef	60	1	0.6	24	1771	GMP
Sheep and Beef	60	1	0.6	22	1594	Mitigation 1
Sheep and Beef	60	1	0.6	24	1735	Mitigation 2
Sheep and Beef	120	1	0.6	22	1794	GMP
Sheep and Beef	120	1	0.6	20	1614	Mitigation 1
Sheep and Beef	120	1	0.6	22	1758	Mitigation 2
Dairy	35	1	0.6	71	2552	GMP
Dairy	35	1	0.6	67	2297	Mitigation 1
Dairy	35	1	0.6	60	2425	Mitigation 2
Dairy	60	1	0.6	52	2638	GMP
Dairy	60	1	0.6	49	2374	Mitigation 1
Dairy	60	1	0.6	44	2506	Mitigation 2
Dairy	120	1	0.6	50	2714	GMP
Dairy	120	1	0.6	47	2443	Mitigation 1
Dairy	120	1	0.6	42	2579	Mitigation 2
Arable	35	0	0	25	454	GMP
Arable	35	0	0	22	445	Mitigation 1
Arable	35	0	0	21	432	Mitigation 2
Arable	60	0	0	25	752	GMP
Arable	60	0	0	22	737	Mitigation 1
Arable	60	0	0	22	714	Mitigation 2
Arable	120	0	0	20	1189	GMP
Arable	120	0	0	25	1165	Mitigation 1
Arable	120	0	0	22	1129	Mitigation 2
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

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North Island-East Coast

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Sheep and beef	35	0	0	20	289	GMP
Sheep and beef	35	1	0.6	26	1789	GMP
Sheep and beef	35	1	0.6	24	1610	Mitigation 1
Sheep and beef	35	1	0.6	25	1753	Mitigation 2
Sheep and beef	60	0	0	18	289	GMP
Sheep and beef	60	1	0.6	24	1810	GMP
Sheep and beef	60	1	0.6	22	1629	Mitigation 1
Sheep and beef	60	1	0.6	24	1774	Mitigation 2
Sheep and beef	120	0	0	16	289	GMP
Sheep and beef	120	1	0.6	22	1804	GMP
Sheep and beef	120	1	0.6	20	1623	Mitigation 1
Sheep and beef	120	1	0.6	22	1768	Mitigation 2
Dairy	35	0	0	46	1316	GMP
Dairy	35	0	0	43	1184	Mitigation 1
Dairy	35	0	0	39	1250	Mitigation 2
Dairy	35	1	0.6	39	2697	GMP
Dairy	35	1	0.6	37	2427	Mitigation 1
Dairy	35	1	0.6	33	2562	Mitigation 2
Dairy	60	0	0	34	1316	GMP
Dairy	60	0	0	32	1184	Mitigation 1
Dairy	60	0	0	29	1250	Mitigation 2
Dairy	60	1	0.6	71	2771	GMP
Dairy	60	1	0.6	67	2494	Mitigation 1
Dairy	60	1	0.6	60	2632	Mitigation 2
Dairy	120	0	0	52	1316	GMP
Dairy	120	0	0	49	1184	Mitigation 1
Dairy	120	0	0	44	1250	Mitigation 2
Dairy	120	1	0.6	50	2748	GMP
Dairy	120	1	0.6	47	2474	Mitigation 1
Dairy	120	1	0.6	42	2611	Mitigation 2
Pipfruit	35	1	0.6	13	67642	GMP
Pipfruit	35	1	0.6	12	66289	Mitigation 1
Pipfruit	35	1	0.6	11	64260	Mitigation 2
Pipfruit	60	1	0.6	12	70391	GMP
Pipfruit	60	1	0.6	11	68983	Mitigation 1
Pipfruit	60	1	0.6	11	66871	Mitigation 2
Pipfruit	120	1	0.6	11	89864	GMP
Pipfruit	120	1	0.6	10	88066	Mitigation 1
Pipfruit	120	1	0.6	10	85371	Mitigation 2
Arable	35	1	0.6	25	2210	GMP
Arable	35	1	0.6	25	2166	Mitigation 1
Arable	35	1	0.6	22	2763	Mitigation 2
Arable	60	1	0.45	23	2133	GMP
Arable	60	1	0.45	25	2090	Mitigation 1
Arable	60	1	0.45	22	2666	Mitigation 2
Arable	120	1	0.45	20	2217	GMP
Arable	120	1	0.45	25	2173	Mitigation 1
Arable	120	1	0.45	22	2771	Mitigation 2
Horticulture	35	1	0.6	22	6636	GMP
Horticulture	35	1	0.6	21	16379	Mitigation 1
Horticulture	35	1	0.6	19	6304	Mitigation 2
Horticulture	60	1	0.6	19	16639	GMP
Horticulture	60	1	0.6	18	16306	Mitigation 1

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Horticulture	60	1	0.6	17	15807	Mitigation 2
Horticulture	120	1	0.45	16	16512	GMP
Horticulture	120	1	0.45	15	16181	Mitigation 1
Horticulture	120	1	0.45	14	15686	Mitigation 2
Viticulture	35	1	0.255	9	17829	GMP
Viticulture	60	1	0.255	9	18408	GMP
Viticulture	120	1	0.255	9	18885	GMP
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

South Island-Hill Country

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Sheep and Beef	35	0	0	4	37	GMP
Sheep and Beef	60	0	0	4	37	GMP
Sheep and Beef	120	0	0	4	37	GMP
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

South Island-East Coast-Marlborough

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Sheep and beef	35	0	0	4	512	GMP
Sheep and beef	35	1	0.6	50	1611	GMP
Sheep and beef	35	1	0.6	46	1450	Mitigation 1
Sheep and beef	35	1	0.6	49	1579	Mitigation 2
Sheep and beef	60	0	0	4	512	GMP
Sheep and beef	60	1	0.6	43	1638	GMP
Sheep and beef	60	1	0.6	39	1474	Mitigation 1
Sheep and beef	60	1	0.6	42	1605	Mitigation 2
Sheep and beef	120	0	0	4	512	GMP
Sheep and beef	120	1	0.6	40	1636	GMP
Sheep and beef	120	1	0.6	36	1473	Mitigation 1
Sheep and beef	120	1	0.6	39	1604	Mitigation 2
Dairy	35	1	0.6	71	2172	GMP
Dairy	35	1	0.6	67	1955	Mitigation 1
Dairy	35	1	0.6	60	2063	Mitigation 2
Dairy	60	1	0.6	52	2242	GMP
Dairy	60	1	0.6	49	2018	Mitigation 1
Dairy	60	1	0.6	44	2130	Mitigation 2
Dairy	120	1	0.6	50	2239	GMP
Dairy	120	1	0.6	47	2015	Mitigation 1
Dairy	120	1	0.6	42	2127	Mitigation 2
Arable	35	1	0.6	44	2402	GMP
Arable	35	1	0.6	25	2354	Mitigation 1
Arable	35	1	0.6	22	3002	Mitigation 2

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Arable	60	1	0.6	42	2507	GMP
Arable	60	1	0.6	25	2456	Mitigation 1
Arable	60	1	0.6	22	3133	Mitigation 2
Arable	120	1	0.45	40	2546	GMP
Arable	120	1	0.45	25	2496	Mitigation 1
Arable	120	1	0.45	22	3183	Mitigation 2
Horticulture	35	1	0.6	40	15358	GMP
Horticulture	35	1	0.6	38	15051	Mitigation 1
Horticulture	35	1	0.6	35	14590	Mitigation 2
Horticulture	60	1	0.6	38	15585	GMP
Horticulture	60	1	0.6	36	15273	Mitigation 1
Horticulture	60	1	0.6	33	14806	Mitigation 2
Horticulture	120	1	0.45	36	15629	GMP
Horticulture	120	1	0.45	34	15316	Mitigation 1
Horticulture	120	1	0.45	32	14847	Mitigation 2
Viticulture	35	1	0.255	9	17829	GMP
Viticulture	60	1	0.255	9	18408	GMP
Viticulture	120	1	0.255	9	18885	GMP
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

South Island-West Coast

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Sheep and Beef	35	0	0	18	483	GMP
Sheep and Beef	60	0	0	14	483	GMP
Sheep and Beef	120	0	0	12	483	GMP
Dairy	35	0	0	46	1379	GMP
Dairy	35	0	0	43	1241	Mitigation 1
Dairy	35	0	0	39	1310	Mitigation 2
Dairy	60	0	0	39	1379	GMP
Dairy	60	0	0	37	1241	Mitigation 1
Dairy	60	0	0	33	1310	Mitigation 2
Dairy	120	0	0	34	1379	GMP
Dairy	120	0	0	32	1241	Mitigation 1
Dairy	120	0	0	29	1310	Mitigation 2
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

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Canterbury-Upper Plains

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Dairy	35	0	0	67	849	GMP
Dairy	35	0	0	63	764	Mitigation 1
Dairy	35	0	0	56	807	Mitigation 2
Dairy	35	1	0.6	98	2299	GMP
Dairy	35	1	0.6	92	2069	Mitigation 1
Dairy	35	1	0.6	82	2184	Mitigation 2
Dairy	60	0	0	50	1164	GMP
Dairy	60	0	0	47	1048	Mitigation 1
Dairy	60	0	0	42	1106	Mitigation 2
Dairy	60	1	0.6	90	2389	GMP
Dairy	60	1	0.6	84	2150	Mitigation 1
Dairy	60	1	0.6	75	2270	Mitigation 2
Dairy	120	0	0	47	1345	GMP
Dairy	120	0	0	44	1211	Mitigation 1
Dairy	120	0	0	39	1278	Mitigation 2
Dairy	120	1	0.6	84	2369	GMP
Dairy	120	1	0.6	79	2132	Mitigation 1
Dairy	120	1	0.6	70	2250	Mitigation 2
Horticulture	35	0	0	35	6636	GMP
Horticulture	35	0	0	33	6503	Mitigation 1
Horticulture	35	0	0	31	6304	Mitigation 2
Horticulture	35	1	0.6	48	16379	GMP
Horticulture	35	1	0.6	45	16052	Mitigation 1
Horticulture	35	1	0.6	42	15560	Mitigation 2
Horticulture	60	0	0	33	8334	GMP
Horticulture	60	0	0	31	8168	Mitigation 1
Horticulture	60	0	0	29	7918	Mitigation 2
Horticulture	60	1	0.6	45	16639	GMP
Horticulture	60	1	0.6	42	16306	Mitigation 1
Horticulture	60	1	0.6	39	15807	Mitigation 2
Horticulture	120	0	0	30	10511	GMP
Horticulture	120	0	0	28	10301	Mitigation 1
Horticulture	120	0	0	26	9985	Mitigation 2
Horticulture	120	1	0.45	41	16512	GMP
Horticulture	120	1	0.45	38	16181	Mitigation 1
Horticulture	120	1	0.45	36	15686	Mitigation 2
Arable	35	0	0	41	454	GMP
Arable	35	0	0	25	445	Mitigation 1
Arable	35	0	0	22	568	Mitigation 2
Arable	35	1	0.6	60	2571	GMP
Arable	35	1	0.6	25	2520	Mitigation 1
Arable	35	1	0.6	22	3214	Mitigation 2
Arable	60	0	0	38	752	GMP
Arable	60	0	0	25	737	Mitigation 1
Arable	60	0	0	22	940	Mitigation 2
Arable	60	1	0.45	57	2468	GMP
Arable	60	1	0.45	25	2419	Mitigation 1
Arable	60	1	0.45	22	3086	Mitigation 2
Arable	120	0	0	35	1189	GMP
Arable	120	0	0	25	1165	Mitigation 1
Arable	120	0	0	22	1486	Mitigation 2
Arable	120	1	0.45	54	2586	GMP
Arable	120	1	0.45	25	2534	Mitigation 1

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Arable	120	1	0.45	22	3233	Mitigation 2
Sheep and beef	35	0	0	39	926	GMP
Sheep and beef	35	0	0	36	833	Mitigation 1
Sheep and beef	35	0	0	39	907	Mitigation 2
Sheep and beef	35	1	0.6	54	1658	GMP
Sheep and beef	35	1	0.6	50	1492	Mitigation 1
Sheep and beef	35	1	0.6	53	1625	Mitigation 2
Sheep and beef	60	0	0	36	1092	GMP
Sheep and beef	60	0	0	32	983	Mitigation 1
Sheep and beef	60	0	0	35	1070	Mitigation 2
Sheep and beef	60	1	0.6	58	1690	GMP
Sheep and beef	60	1	0.6	53	1521	Mitigation 1
Sheep and beef	60	1	0.6	57	1656	Mitigation 2
Sheep and beef	120	0	0	31	1183	GMP
Sheep and beef	120	0	0	28	1064	Mitigation 1
Sheep and beef	120	0	0	31	1159	Mitigation 2
Sheep and beef	120	1	0.6	54	1683	GMP
Sheep and beef	120	1	0.6	50	1514	Mitigation 1
Sheep and beef	120	1	0.6	53	1649	Mitigation 2
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

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Canterbury-Middle Plains

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Dairy	35	0	0	60	775	GMP
Dairy	35	0	0	57	1034	Mitigation 1
Dairy	35	0	0	51	1253	Mitigation 2
Dairy	35	1	0.6	89	2161	GMP
Dairy	35	1	0.6	83	1945	Mitigation 1
Dairy	35	1	0.6	74	2053	Mitigation 2
Dairy	60	0	0	45	1034	GMP
Dairy	60	0	0	43	931	Mitigation 1
Dairy	60	0	0	38	982	Mitigation 2
Dairy	60	1	0.6	72	2232	GMP
Dairy	60	1	0.6	68	2008	Mitigation 1
Dairy	60	1	0.6	60	2120	Mitigation 2
Dairy	120	0	0	42	1253	GMP
Dairy	120	0	0	40	1128	Mitigation 1
Dairy	120	0	0	36	1190	Mitigation 2
Dairy	120	1	0.6	65	2230	GMP
Dairy	120	1	0.6	61	2007	Mitigation 1
Dairy	120	1	0.6	55	2118	Mitigation 2
Horticulture	35	0	0	32	5711	GMP
Horticulture	35	0	0	30	5597	Mitigation 1
Horticulture	35	0	0	28	5425	Mitigation 2
Horticulture	35	1	0.6	43	16302	GMP
Horticulture	35	1	0.6	40	15976	Mitigation 1
Horticulture	35	1	0.6	38	15487	Mitigation 2
Horticulture	60	0	0	30	7352	GMP
Horticulture	60	0	0	28	7205	Mitigation 1
Horticulture	60	0	0	26	6984	Mitigation 2
Horticulture	60	1	0.6	41	16603	GMP
Horticulture	60	1	0.6	38	16271	Mitigation 1
Horticulture	60	1	0.6	36	15773	Mitigation 2
Horticulture	120	0	0	27	9577	GMP
Horticulture	120	0	0	25	9385	Mitigation 1
Horticulture	120	0	0	24	9098	Mitigation 2
Horticulture	120	1	0.45	37	16420	GMP
Horticulture	120	1	0.45	35	16091	Mitigation 1
Horticulture	120	1	0.45	32	15599	Mitigation 2
Arable	35	0	0	37	318	GMP
Arable	35	0	0	25	312	Mitigation 1
Arable	35	0	0	22	398	Mitigation 2
Arable	35	1	0.6	54	2584	GMP
Arable	35	1	0.6	25	2532	Mitigation 1
Arable	35	1	0.6	22	3230	Mitigation 2
Arable	60	0	0	34	590	GMP
Arable	60	0	0	25	578	Mitigation 1
Arable	60	0	0	22	738	Mitigation 2
Arable	60	1	0.45	52	2457	GMP
Arable	60	1	0.45	25	2408	Mitigation 1
Arable	60	1	0.45	22	3071	Mitigation 2
Arable	120	0	0	32	1020	GMP
Arable	120	0	0	25	1000	Mitigation 1
Arable	120	0	0	22	1275	Mitigation 2
Arable	120	1	0.45	49	2588	GMP
Arable	120	1	0.45	25	2536	Mitigation 1

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Arable	120	1	0.45	22	3235	Mitigation 2
Sheep and beef	35	0	0	36	884	GMP
Sheep and beef	35	0	0	32	796	Mitigation 1
Sheep and beef	35	0	0	35	867	Mitigation 2
Sheep and beef	35	1	0.6	49	1607	GMP
Sheep and beef	35	1	0.6	45	1447	Mitigation 1
Sheep and beef	35	1	0.6	48	1575	Mitigation 2
Sheep and beef	60	0	0	32	1025	GMP
Sheep and beef	60	0	0	29	923	Mitigation 1
Sheep and beef	60	0	0	32	1005	Mitigation 2
Sheep and beef	60	1	0.6	53	1634	GMP
Sheep and beef	60	1	0.6	48	1470	Mitigation 1
Sheep and beef	60	1	0.6	52	1601	Mitigation 2
Sheep and beef	120	0	0	28	1138	GMP
Sheep and beef	120	0	0	26	1024	Mitigation 1
Sheep and beef	120	0	0	28	1115	Mitigation 2
Sheep and beef	120	1	0.6	49	1633	GMP
Sheep and beef	120	1	0.6	45	1470	Mitigation 1
Sheep and beef	120	1	0.6	48	1600	Mitigation 2
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

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Canterbury-Lower Plains

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Dairy	35	0	0	49	464	GMP
Dairy	35	0	0	46	417	Mitigation 1
Dairy	35	0	0	41	441	Mitigation 2
Dairy	35	1	0.6	72	2172	GMP
Dairy	35	1	0.6	68	1955	Mitigation 1
Dairy	35	1	0.6	60	2063	Mitigation 2
Dairy	60	0	0	37	790	GMP
Dairy	60	0	0	35	711	Mitigation 1
Dairy	60	0	0	31	751	Mitigation 2
Dairy	60	1	0.6	66	2242	GMP
Dairy	60	1	0.6	62	2018	Mitigation 1
Dairy	60	1	0.6	55	2130	Mitigation 2
Dairy	120	0	0	34	952	GMP
Dairy	120	0	0	32	856	Mitigation 1
Dairy	120	0	0	29	904	Mitigation 2
Dairy	120	1	0.6	62	2239	GMP
Dairy	120	1	0.6	58	2015	Mitigation 1
Dairy	120	1	0.6	52	2127	Mitigation 2
Horticulture	35	0	0	26	3496	GMP
Horticulture	35	0	0	24	3427	Mitigation 1
Horticulture	35	0	0	23	3322	Mitigation 2
Horticulture	35	1	0.6	35	15358	GMP
Horticulture	35	1	0.6	33	15051	Mitigation 1
Horticulture	35	1	0.6	31	14590	Mitigation 2
Horticulture	60	0	0	24	5044	GMP
Horticulture	60	0	0	23	4943	Mitigation 1
Horticulture	60	0	0	21	4792	Mitigation 2
Horticulture	60	1	0.6	33	15585	GMP
Horticulture	60	1	0.6	31	15273	Mitigation 1
Horticulture	60	1	0.6	29	14806	Mitigation 2
Horticulture	120	0	0	22	7196	GMP
Horticulture	120	0	0	21	7052	Mitigation 1
Horticulture	120	0	0	19	6836	Mitigation 2
Horticulture	120	1	0.45	30	15629	GMP
Horticulture	120	1	0.45	28	15316	Mitigation 1
Horticulture	120	1	0.45	26	14847	Mitigation 2
Arable	35	0	0	30	-71	GMP
Arable	35	0	0	25	-70	Mitigation 1
Arable	35	0	0	22	-89	Mitigation 2
Arable	35	1	0.6	44	2402	GMP
Arable	35	1	0.6	25	2354	Mitigation 1
Arable	35	1	0.6	22	3002	Mitigation 2
Arable	60	0	0	28	183	GMP
Arable	60	0	0	25	179	Mitigation 1
Arable	60	0	0	22	229	Mitigation 2
Arable	60	1	0.45	42	2263	GMP
Arable	60	1	0.45	25	2218	Mitigation 1
Arable	60	1	0.45	22	2828	Mitigation 2
Arable	120	0	0	26	593	GMP
Arable	120	0	0	25	581	Mitigation 1
Arable	120	0	0	22	741	Mitigation 2
Arable	120	1	0.45	40	2405	GMP
Arable	120	1	0.45	25	2356	Mitigation 1

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Arable	120	1	0.45	22	3006	Mitigation 2
Sheep and beef	35	0	0	29	703	GMP
Sheep and beef	35	0	0	26	633	Mitigation 1
Sheep and beef	35	0	0	28	689	Mitigation 2
Sheep and beef	35	1	0.6	40	1611	GMP
Sheep and beef	35	1	0.6	36	1450	Mitigation 1
Sheep and beef	35	1	0.6	39	1579	Mitigation 2
Sheep and beef	60	0	0	26	893	GMP
Sheep and beef	60	0	0	24	804	Mitigation 1
Sheep and beef	60	0	0	26	875	Mitigation 2
Sheep and beef	60	1	0.6	43	1638	GMP
Sheep and beef	60	1	0.6	39	1474	Mitigation 1
Sheep and beef	60	1	0.6	42	1605	Mitigation 2
Sheep and beef	120	0	0	23	981	GMP
Sheep and beef	120	0	0	21	883	Mitigation 1
Sheep and beef	120	0	0	23	961	Mitigation 2
Sheep and beef	120	1	0.6	40	1636	GMP
Sheep and beef	120	1	0.6	36	1473	Mitigation 1
Sheep and beef	120	1	0.6	39	1604	Mitigation 2
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

South Island-Mountains

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Sheep and Beef	35	0	0	4	37	GMP
Sheep and Beef	60	0	0	4	37	GMP
Sheep and Beef	120	0	0	4	37	GMP
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

North Island-Bay of Plenty

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Sheep and Beef	35	0	0	18	1051	GMP
Sheep and Beef	60	0	0	16	1191	GMP
Sheep and Beef	120	0	0	14	1333	GMP
Dairy	35	0	0	48	1084	GMP
Dairy	35	0	0	45	975	Mitigation 1
Dairy	35	0	0	40	1030	Mitigation 2
Dairy	60	0	0	41	1363	GMP
Dairy	60	0	0	39	1227	Mitigation 1
Dairy	60	0	0	34	1295	Mitigation 2

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Dairy	120	0	0	36	1669	GMP
Dairy	120	0	0	34	1502	Mitigation 1
Dairy	120	0	0	30	1585	Mitigation 2
Horticulture	35	0	0	22	6164	GMP
Horticulture	35	0	0	21	6041	Mitigation 1
Horticulture	35	0	0	19	5856	Mitigation 2
Horticulture	60	0	0	19	6164	GMP
Horticulture	60	0	0	18	6041	Mitigation 1
Horticulture	60	0	0	17	5856	Mitigation 2
Horticulture	120	0	0	16	6164	GMP
Horticulture	120	0	0	15	6041	Mitigation 1
Horticulture	120	0	0	14	5856	Mitigation 2
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

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North Island- North West

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Sheep and Beef	35	0	0	18	406	GMP
Sheep and Beef	60	0	0	16	406	GMP
Sheep and Beef	120	0	0	14	406	GMP
Dairy	35	0	0	48	1316	GMP
Dairy	35	0	0	45	1184	Mitigation 1
Dairy	35	0	0	40	1250	Mitigation 2
Dairy	60	0	0	41	1316	GMP
Dairy	60	0	0	39	1184	Mitigation 1
Dairy	60	0	0	34	1250	Mitigation 2
Dairy	120	0	0	36	1316	GMP
Dairy	120	0	0	34	1184	Mitigation 1
Dairy	120	0	0	30	1250	Mitigation 2
Horticulture	35	0	0	22	6164	GMP
Horticulture	35	0	0	21	6041	Mitigation 1
Horticulture	35	0	0	19	5856	Mitigation 2
Horticulture	60	0	0	19	6164	GMP
Horticulture	60	0	0	18	6041	Mitigation 1
Horticulture	60	0	0	17	5856	Mitigation 2
Horticulture	120	0	0	16	6164	GMP
Horticulture	120	0	0	15	6041	Mitigation 1
Horticulture	120	0	0	14	5856	Mitigation 2
Horticulture	35	1	0.6	46	6164	GMP
Horticulture	35	1	0.6	43	6041	Mitigation 1
Horticulture	35	1	0.6	40	5856	Mitigation 2
Horticulture	60	1	0.6	39	6164	GMP
Horticulture	60	1	0.6	37	6041	Mitigation 1
Horticulture	60	1	0.6	34	5856	Mitigation 2
Horticulture	120	1	0.45	34	6164	GMP
Horticulture	120	1	0.45	32	6041	Mitigation 1
Horticulture	120	1	0.45	30	5856	Mitigation 2
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

North Island-Mountains

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Sheep and Beef	35	0	0	25	283	GMP
Sheep and Beef	60	0	0	20	283	GMP
Sheep and Beef	120	0	0	18	283	GMP
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

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South Island-South Coast

Land use	Soil PAW (mm)	Irrigated (1) /Dryland (0)	System Capacity (l/s/ha)	N loss (Kg/ha/yr)	Cash Operating Surplus ($/ha)	Scenario
Sheep and Beef	35	0	0	18	797	GMP
Sheep and Beef	35	0	0	16	717	Mitigation 1
Sheep and Beef	35	0	0	18	781	Mitigation 2
Sheep and Beef	60	0	0	14	797	GMP
Sheep and Beef	60	0	0	13	717	Mitigation 1
Sheep and Beef	60	0	0	14	781	Mitigation 2
Sheep and Beef	120	0	0	12	797	GMP
Sheep and Beef	120	0	0	11	717	Mitigation 1
Sheep and Beef	120	0	0	12	781	Mitigation 2
Dairy	35	0	0	46	1617	GMP
Dairy	35	0	0	43	1585	Mitigation 1
Dairy	35	0	0	39	1536	Mitigation 2
Dairy	60	0	0	39	1617	GMP
Dairy	60	0	0	37	1585	Mitigation 1
Dairy	60	0	0	33	1536	Mitigation 2
Dairy	120	0	0	34	1617	GMP
Dairy	120	0	0	32	1585	Mitigation 1
Dairy	120	0	0	29	1536	Mitigation 2
Forestry	35	0	0	3	600	
Forestry	60	0	0	3	600	
Forestry	120	0	0	3	600	

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NATIONAL ALLOCATION MODEL

Draft model and 1st tranche results

LWP
landwaterpeople

20-D-00014

Introduction

- MFE wishes to assess a range options for allocation of rights to take and discharge
- Model requires comprehensive national coverage, but sufficient detail to assess impacts of policies
- Analysis draws on a range of information sources, and is critically dependent on input data from Part B – economics of water use
- 3rd set of reporting in series following methodology and prototype reporting
- 1st reporting using full datasets and comprehensive modelling
- The work to now has focused on getting a model running – scenarios are examples only

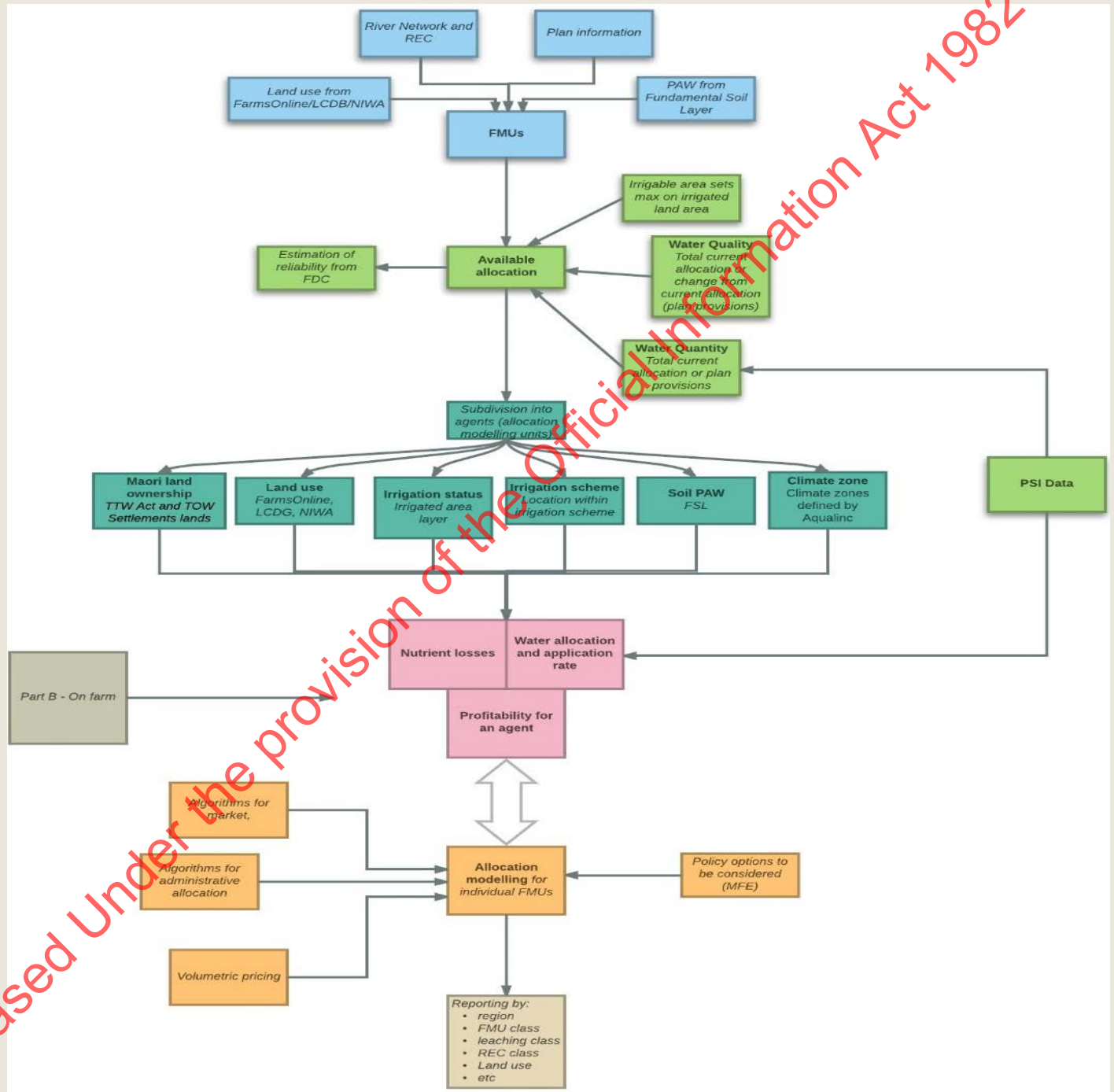
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Approach

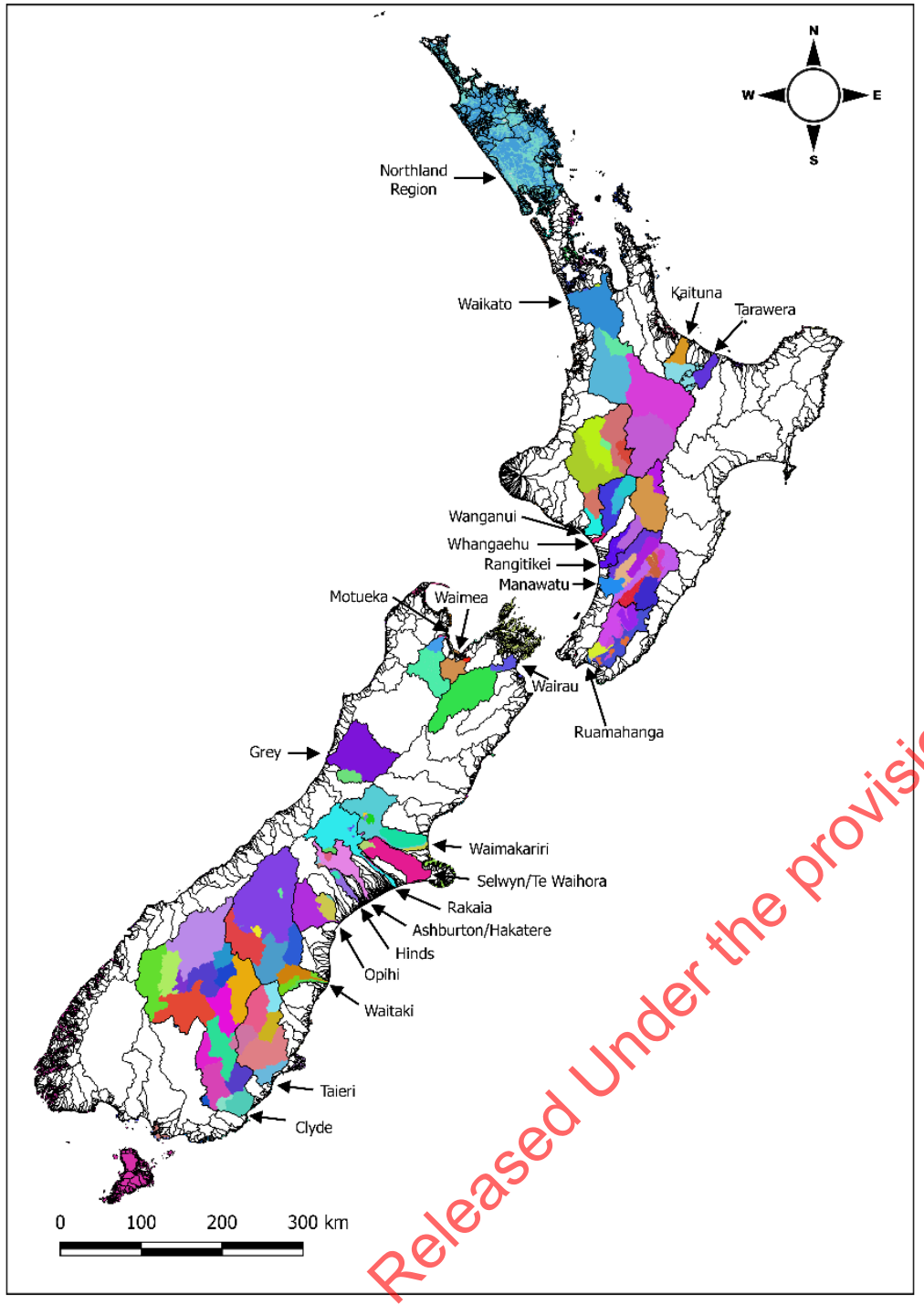
- Definition of FMUs
- Estimate available allocation, reliability
- Subdivision of the FMU into modelling agents
- Integration of profit function
- Modelling the economic outcome of allocation
- Provision of outputs.

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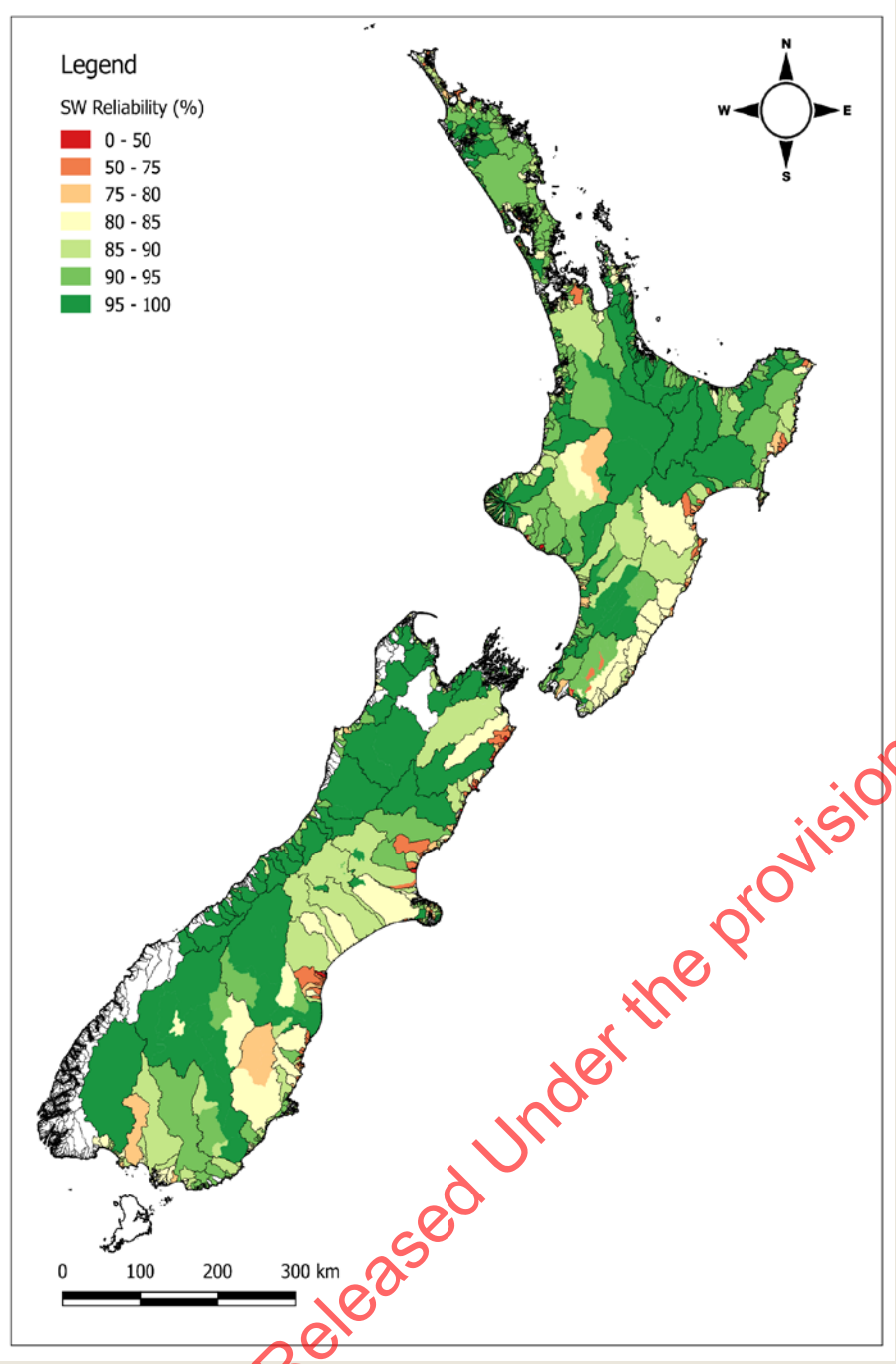
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Freshwater management units, specifically defined FMUs in colour

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Surface water reliability

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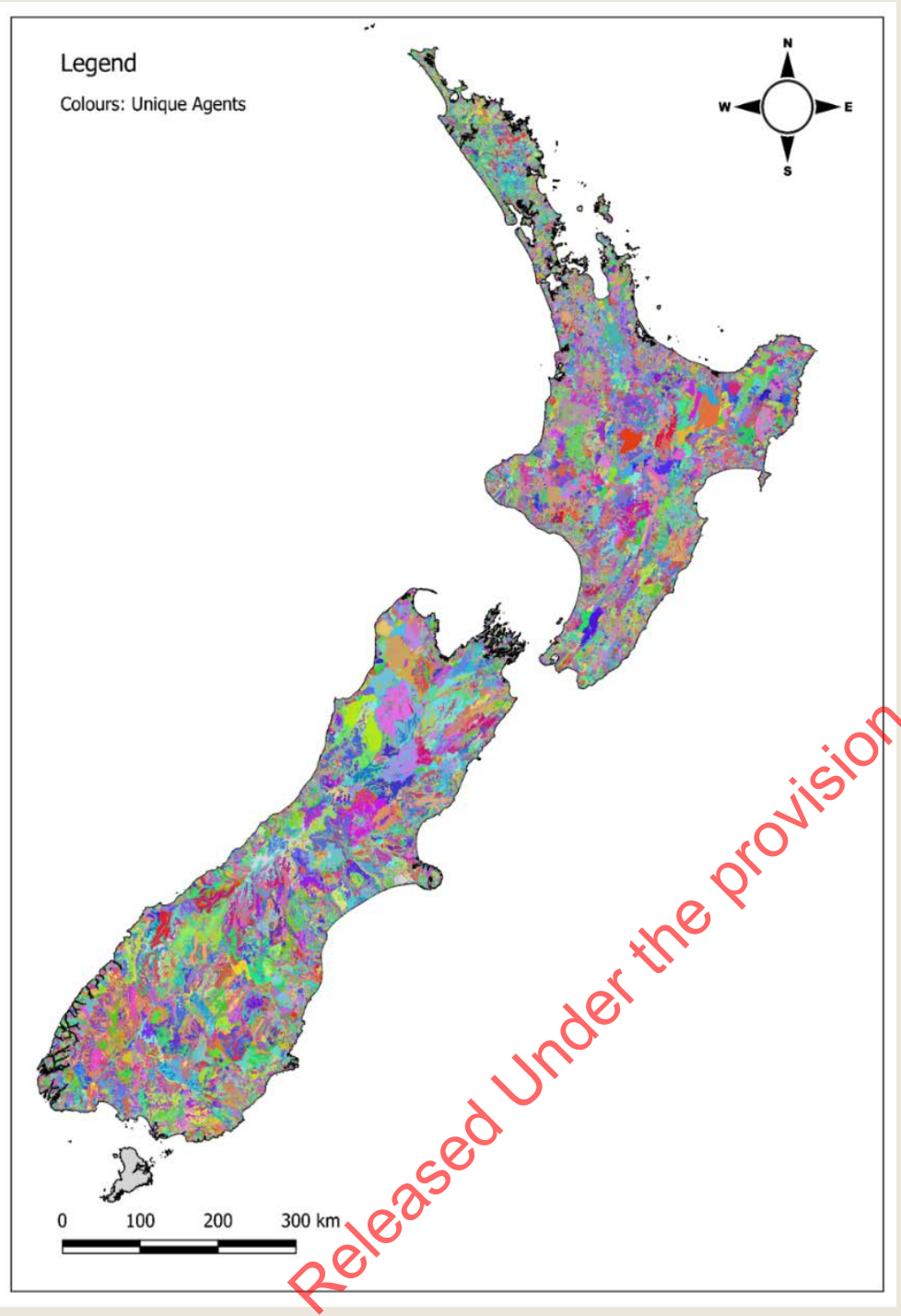
Defining agents

- Defining characteristics
  - *Current land use*
  - *Climate zone*
  - *Soil type*
  - *Irrigability of the land*
  - *Initial land use*
  - *Surface water and Groundwater FMUs*
  - *Regional Council Boundaries*
  - *Ownership by Māori entity*
  - *Location within irrigation scheme command area*
- 90,000 agents in current definition of model

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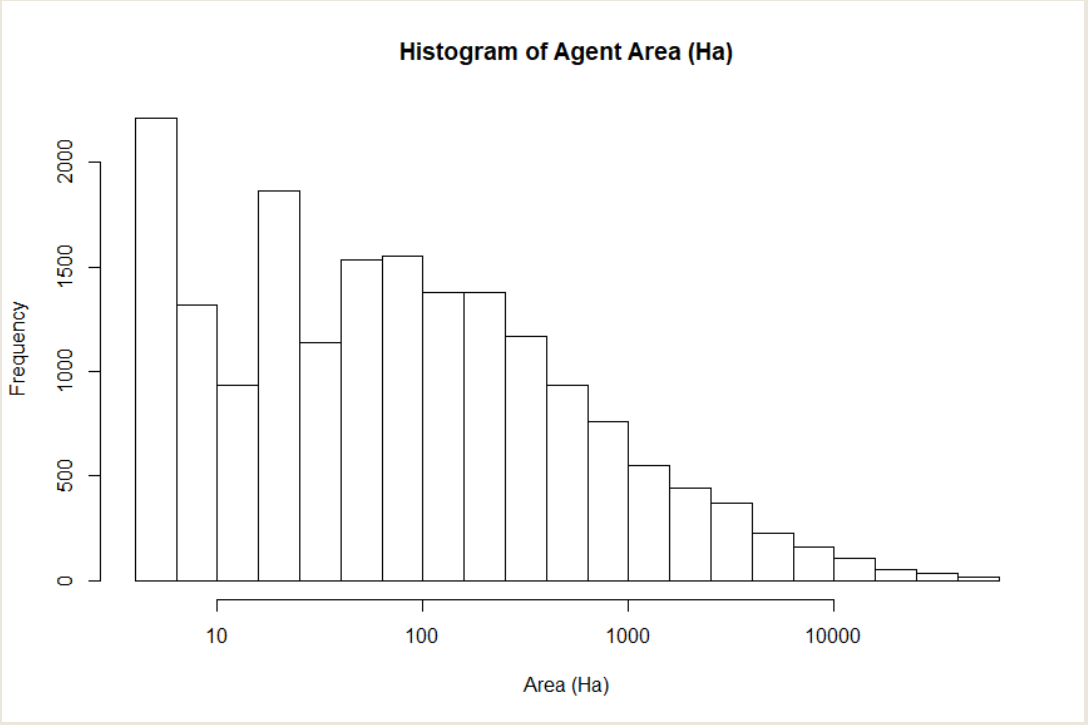
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Unique agents



Distribution of agent size

Active and non-zero agents only

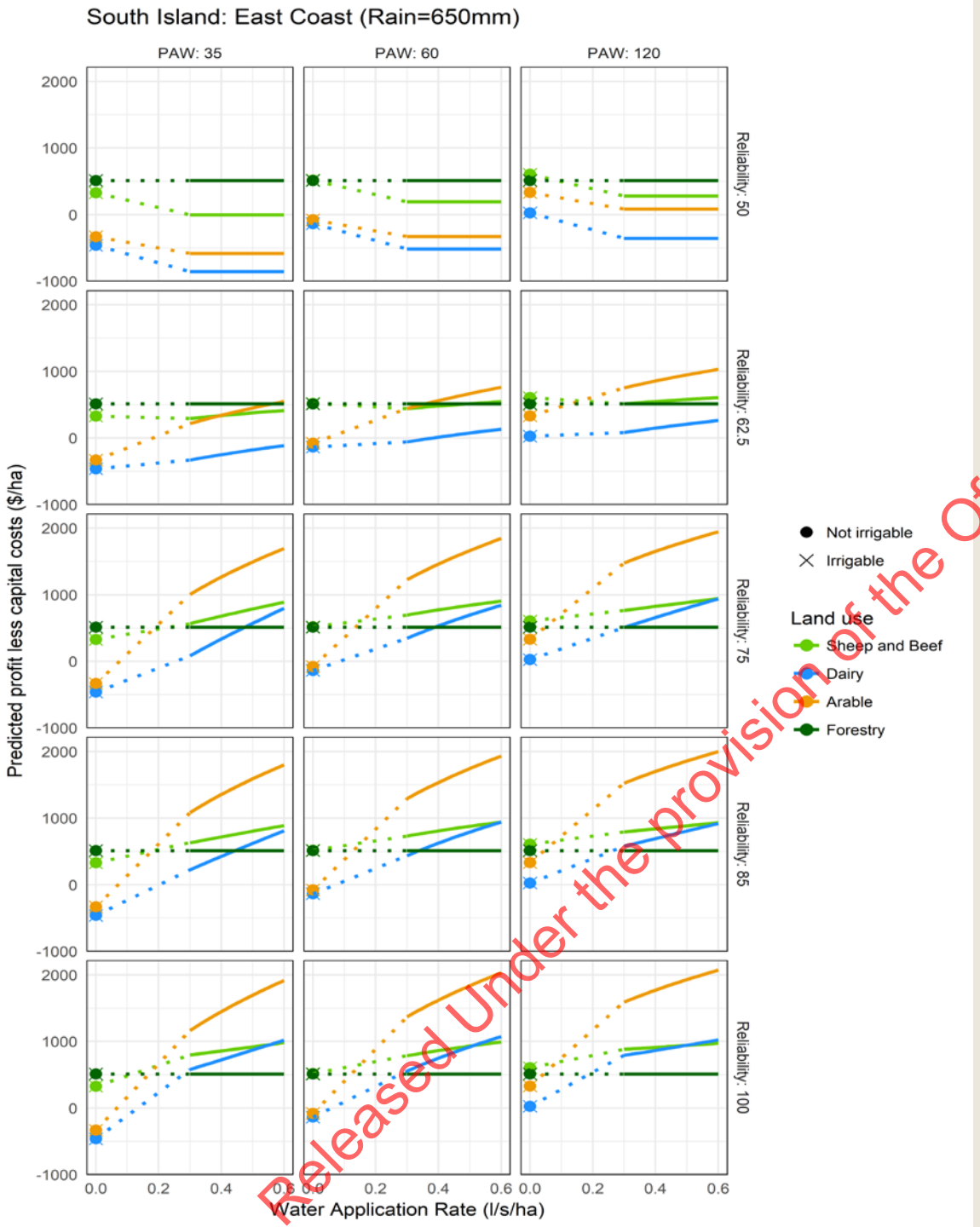


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Integrating profit functions

- Data from Part B project was turned into multidimensional continuous profit functions
- Capital costs were integrated so that differences in profitability weren't overestimated
- Constraints placed on increases in land use based on historic rates of change for dairy, horticulture and arable. No effective limits on forestry and sheep and beef to allow for balancing.

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Profit curves for South Island East Coast (excl. horticulture) showing variation in after capital profit with reliability and application rate

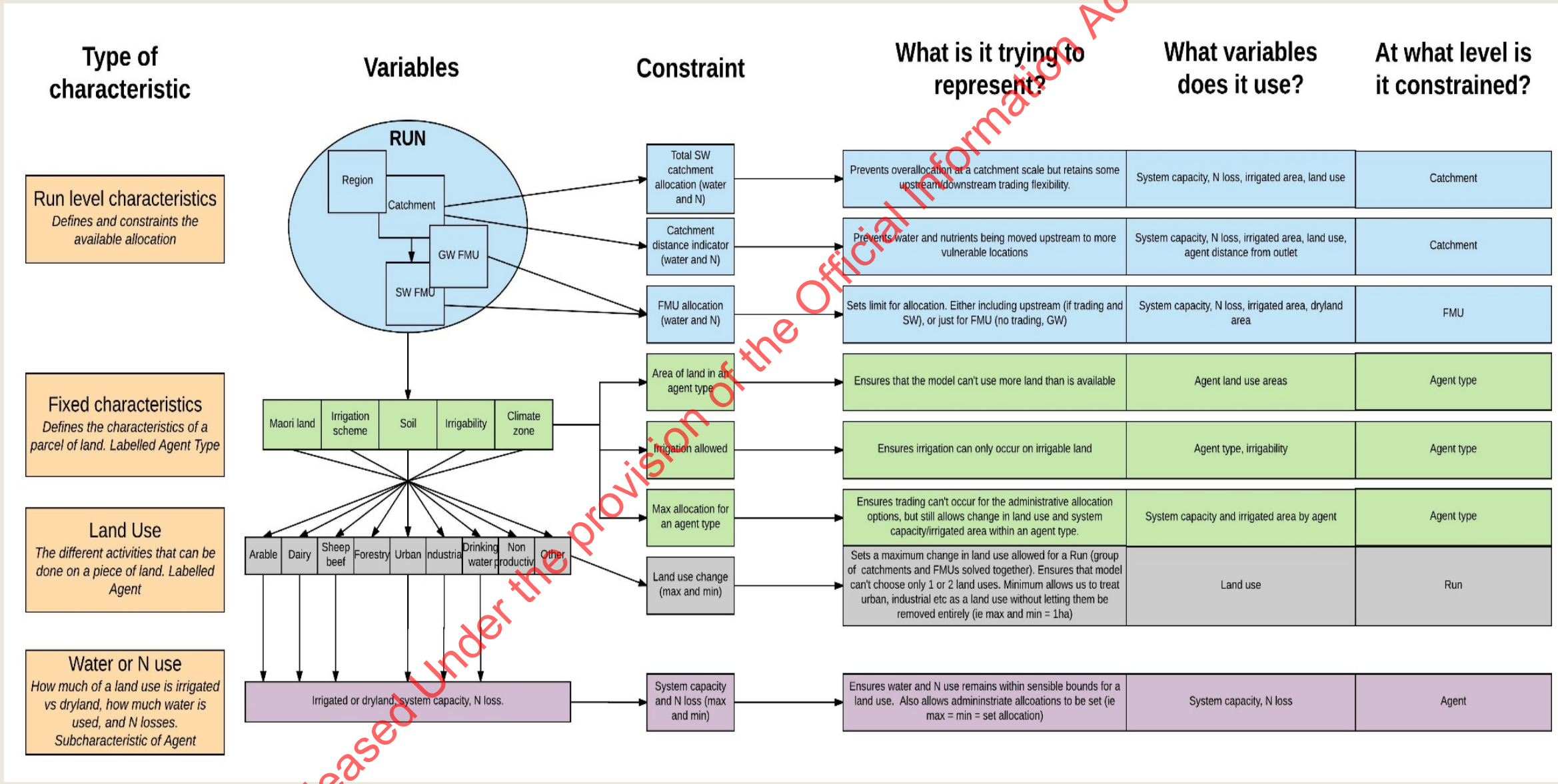
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Policy scenarios

- Scenarios tested
  - *Current Allocation Approach*
  - *Transfer market*
  - *Maori land development*
  - *Land based allocation*
  - *Volumetric pricing*
- Implemented in an optimisation module which chooses highest profit mix of land uses, water and nutrient use to match the scenario rules
- Scenario rules are implemented through constraints

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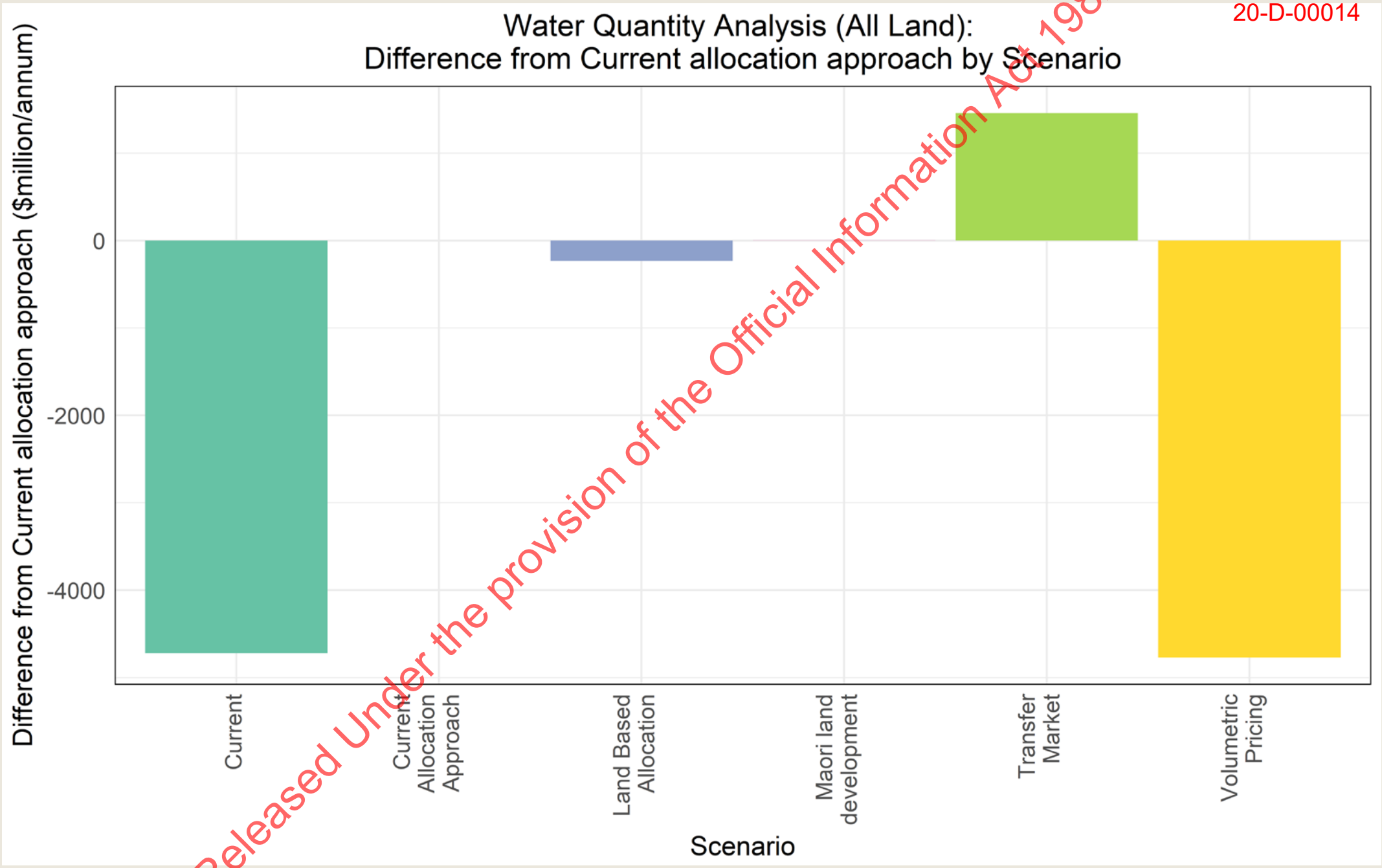
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Results

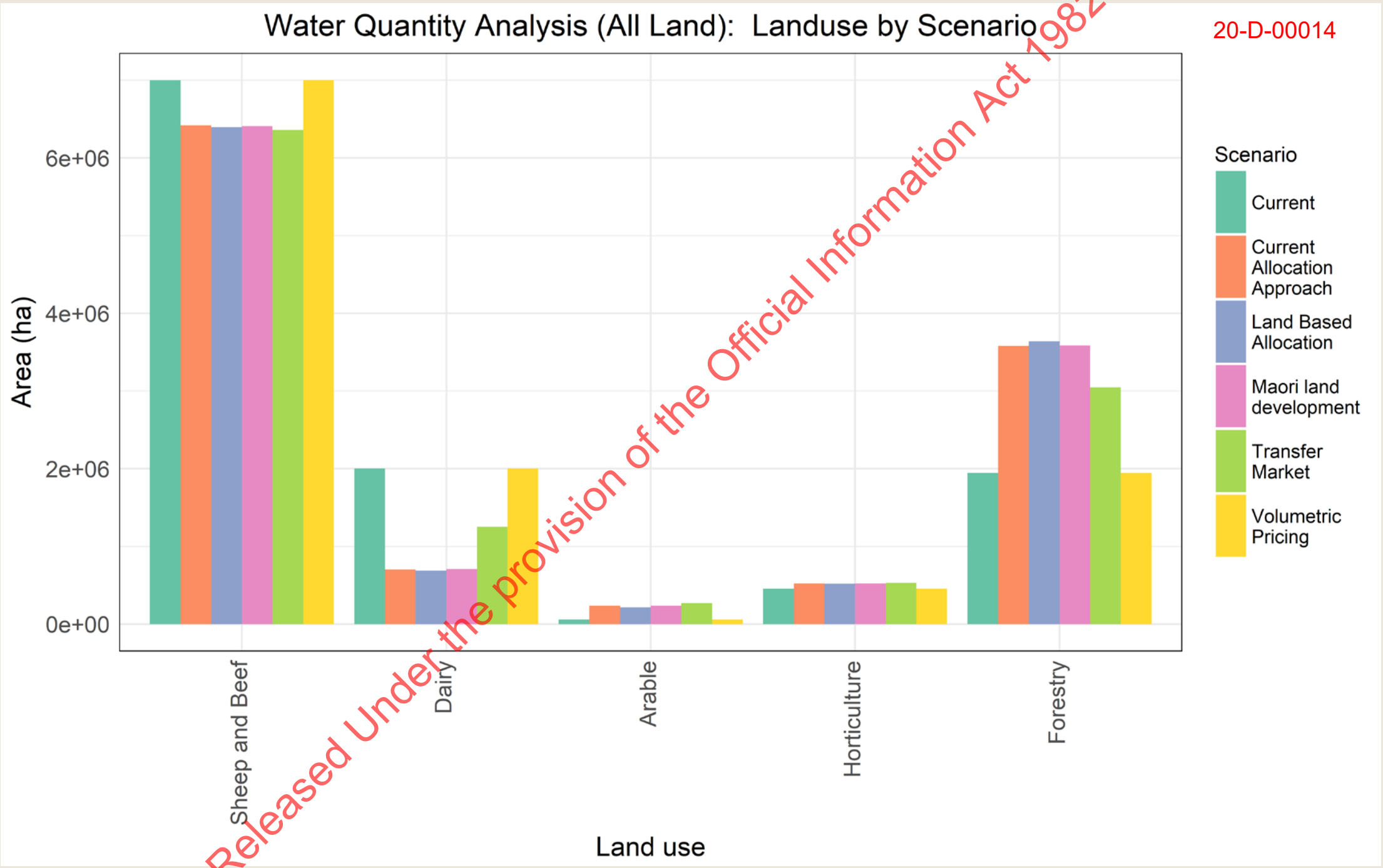
- Results are a comparison of what is achievable through different policy options
- They are NOT A PREDICTION of a future state
- Caveats around input data, ability to model policies, and ability to model individuals' responses
- Treat the results as experiments in what happens from different interventions

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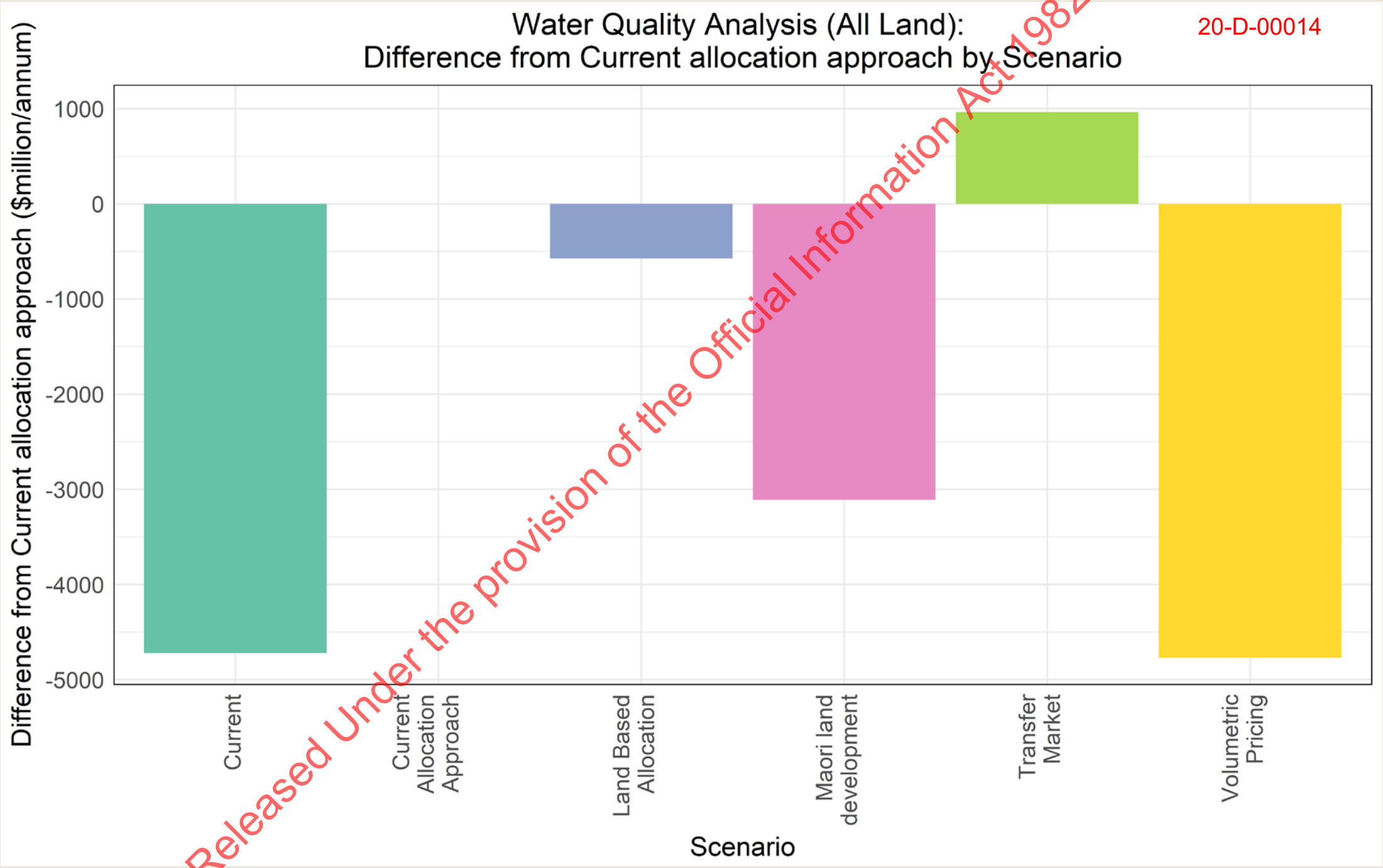
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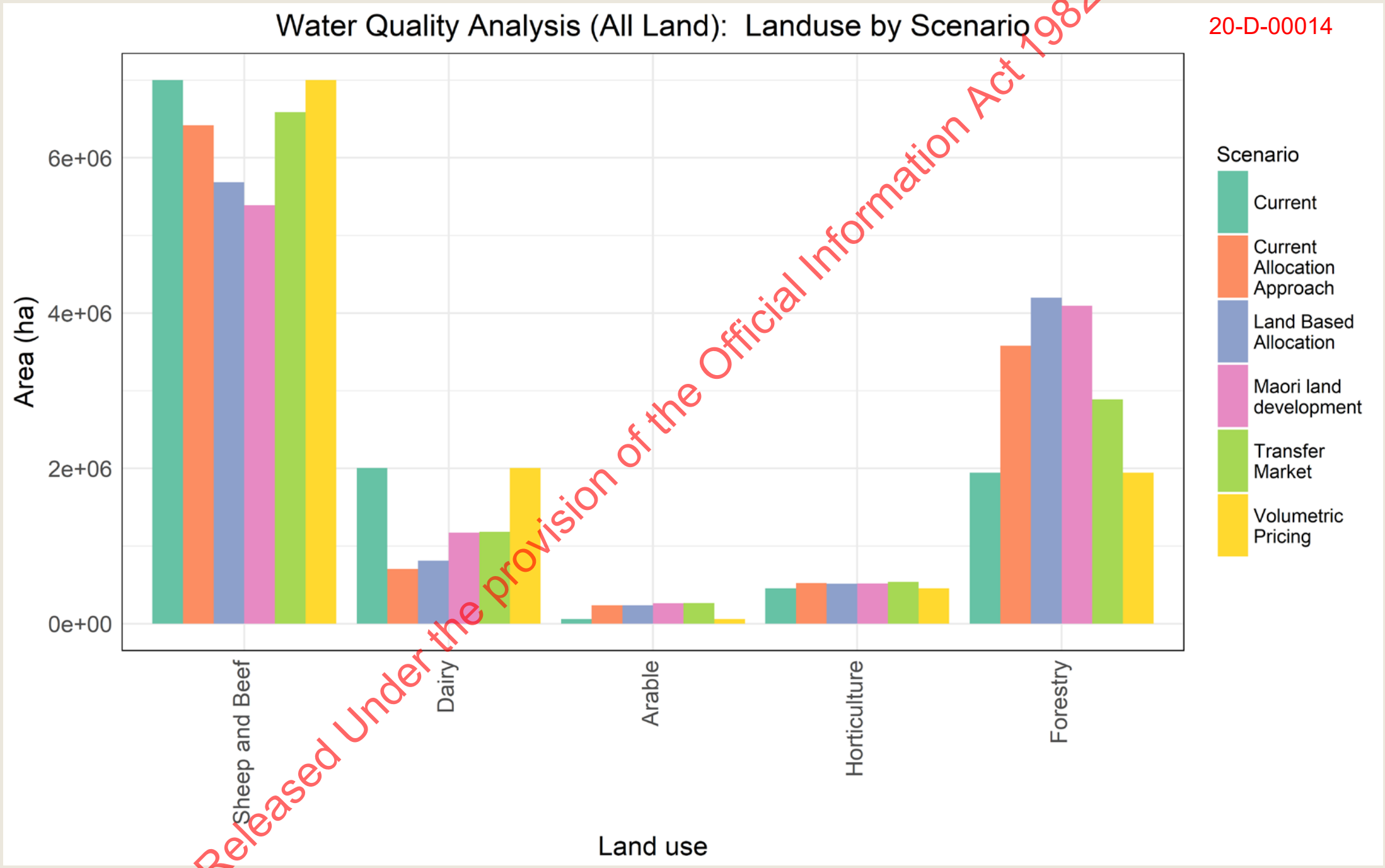
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Water Quantity Analysis (All Land): Landuse by Scenario
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Area (ha)
6e+06
4e+06
2e+06
0e+00
Sheep and Beef
Dairy
Arable
Horticulture
Forestry
Land use
Scenario
Current
Current Allocation Approach
Land Based Allocation
Maori land development
Transfer Market
Volumetric Pricing
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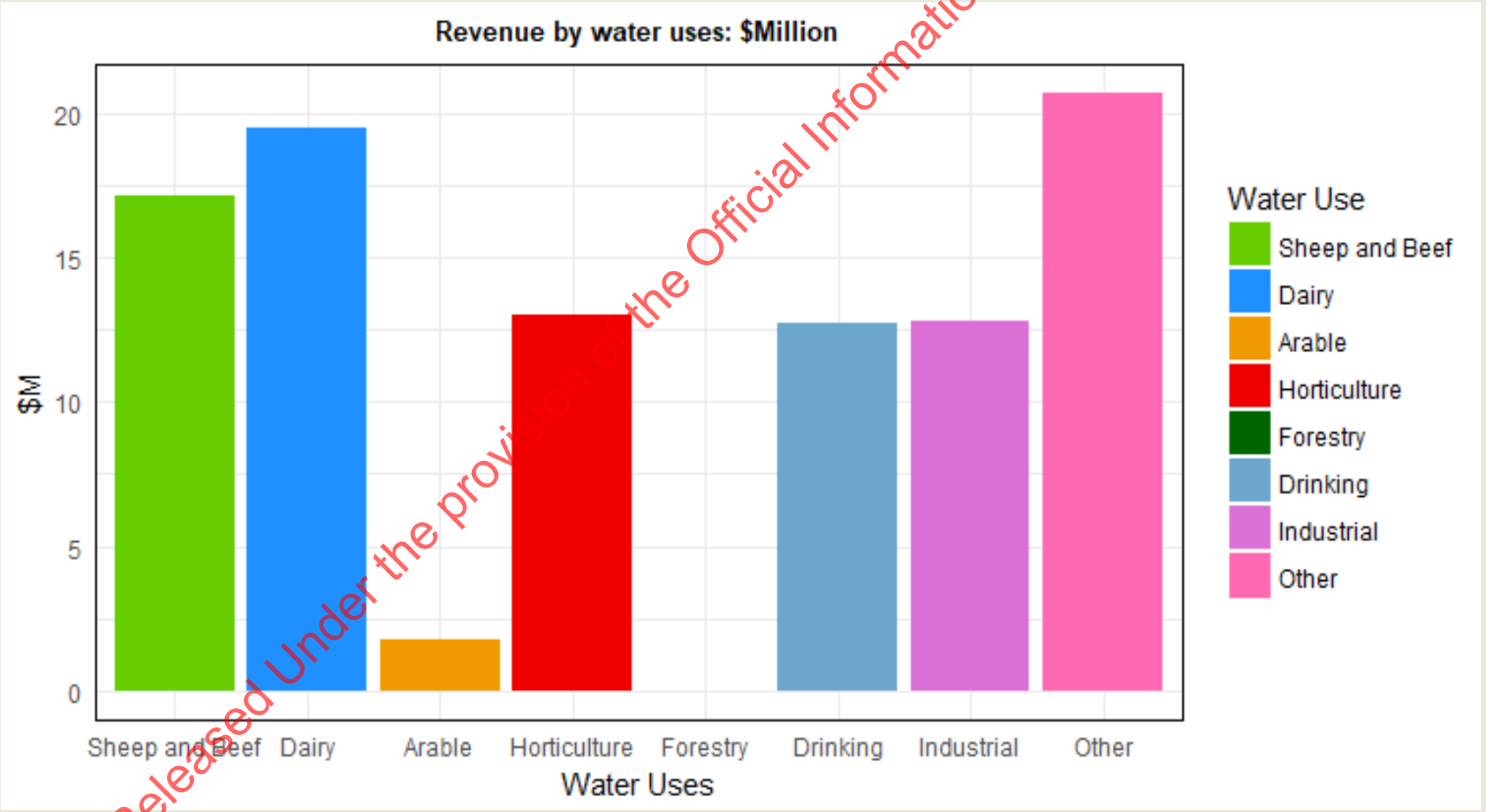


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Water Quality Analysis (All Land): Landuse by Scenario
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6e+06
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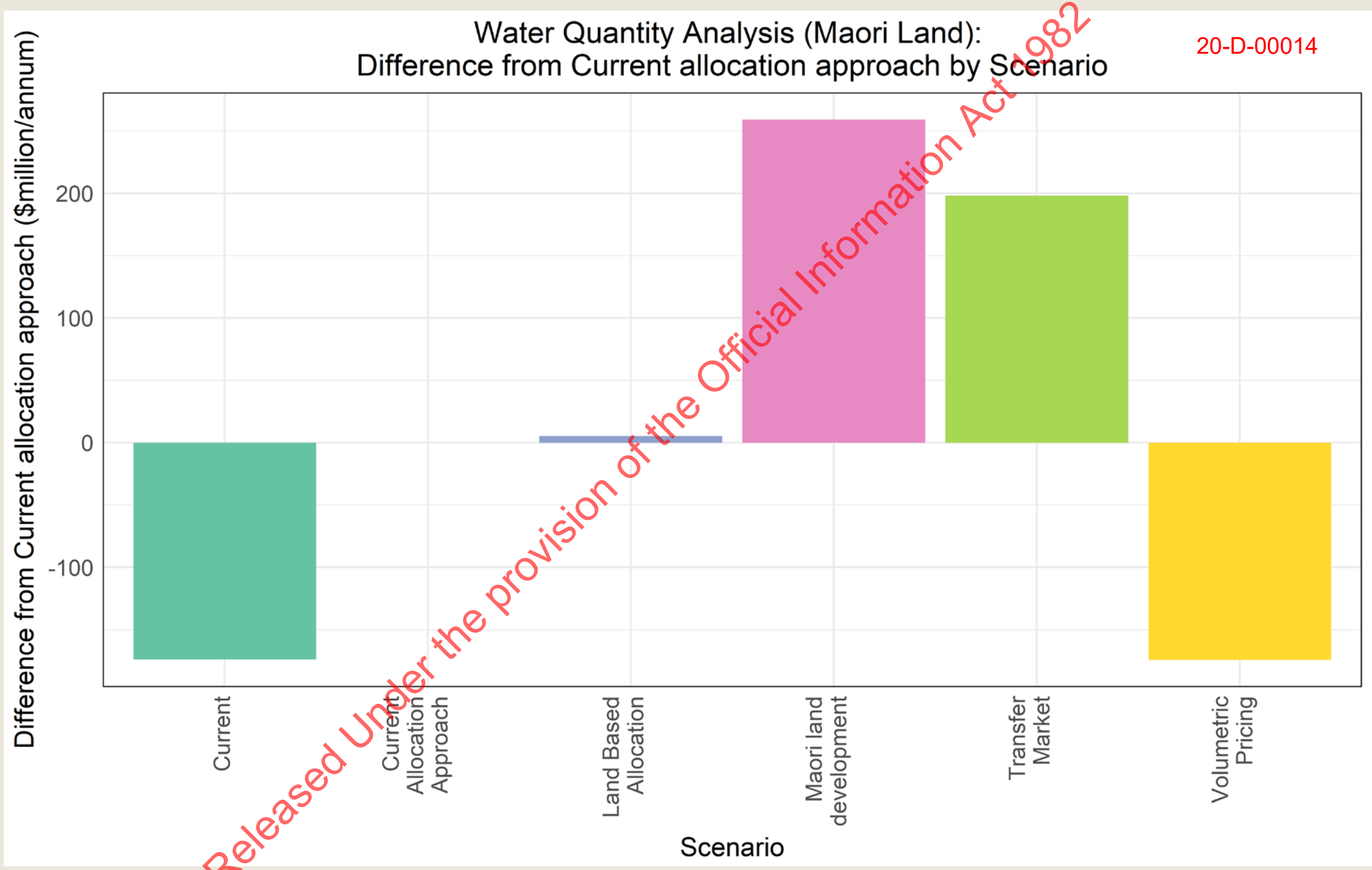
Volumetric Pricing

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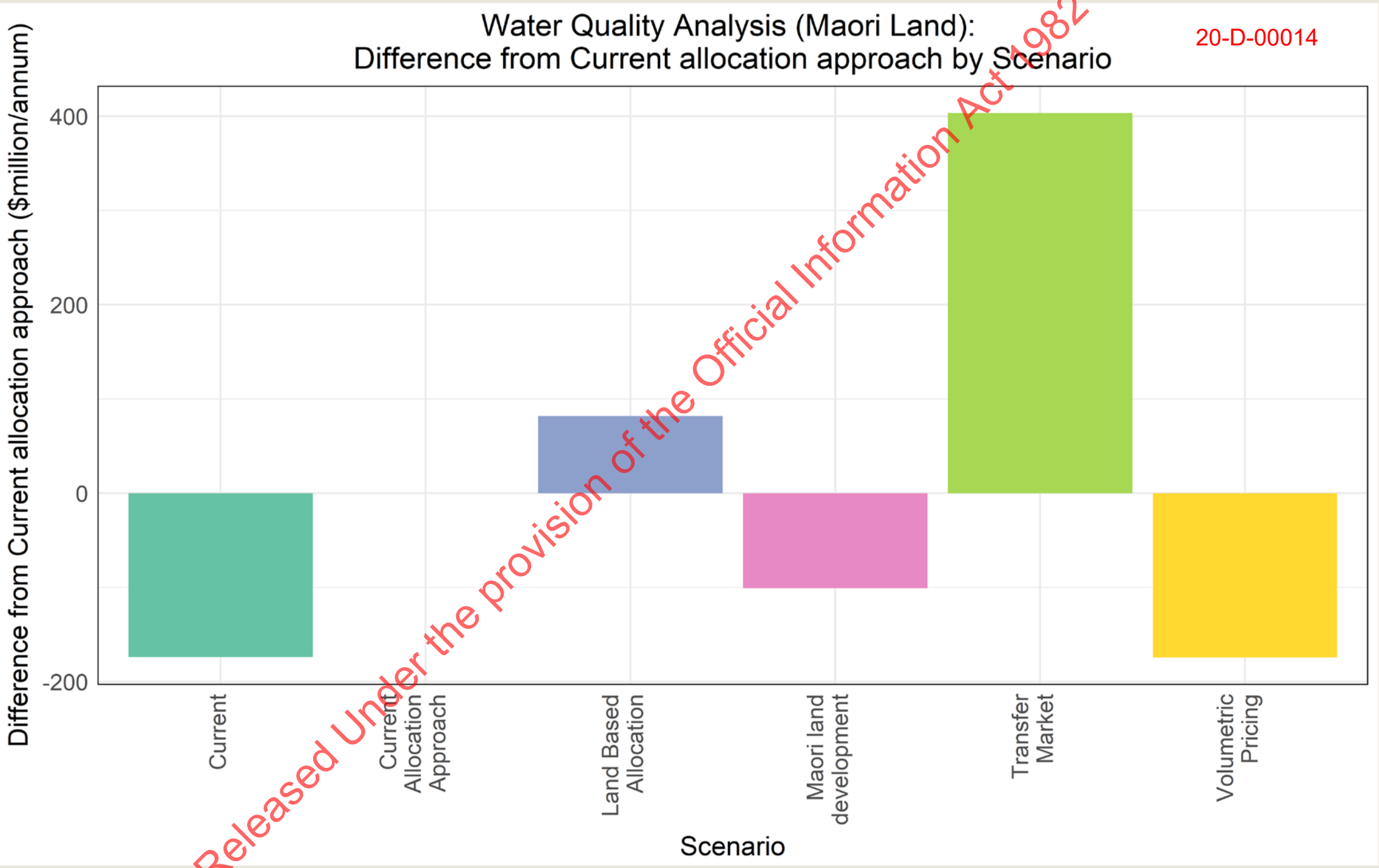
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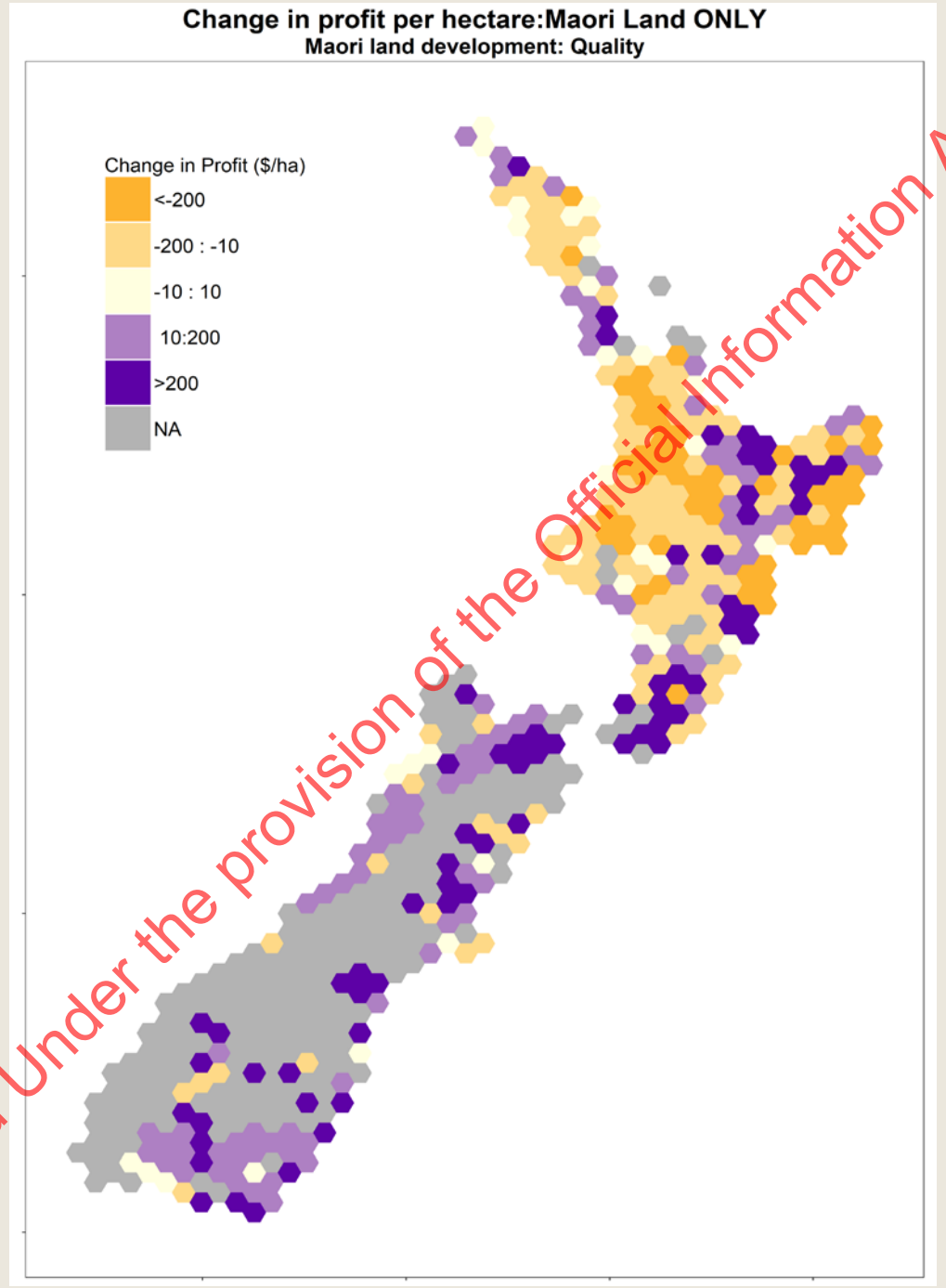
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Issues

- Overestimation of total profitability – associated with an overestimation in horticulture
- Profitability curves and capital costs
- Achievability of transfer market outcomes (and for other scenarios)
- Conjunctive allocation
- Land use change constraints
- Volumetric pricing and behavioural impacts

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Summary

- Model input data is comprehensive and very detailed for modelling at this scale
- Model solves successfully over all feasible catchments, and produces results that are consistent with the way the test scenarios are assumed to work
- Preliminary results suggest that there is considerable potential gain that can be achieved regardless of the allocation approach taken, with transfer markets demonstrating the greatest potential gains under the conditions tested.
- Allocation is very complex and potential exists for negative outcomes if policies are not carefully thought through. For example it is likely that water and nutrients need to be allocated together if resources are to be fully used.
- Will further refine model – use to experiment in the implications of individual and mixes of interventions.
- Interventions can be in the biophysical space (changes to minimum flows, flow regimes, reliability banding etc) or policies (resource rentals, allocation options, transfers, redistributions etc).
- Feedback on key issues of concern and methods of presentation would be greatly appreciated.

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National Allocation Model

Part 2

Appendices to Main report

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LWP Project:	MFE Allcoation

Quality Assurance Statement

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Version	**Reviewed By**	
	[Name]	[Signature]

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Introduction

This document contains the Appendices to the main report for the MFE National Allocation project. It provides additional technical information as well as supplementary figures and other outputs.

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Appendix A Details on Methods and Results

A1 Spatial Input Data: Agents Development

The fundamental unit of our analysis is the Agent. Agents are characterised as homogeneous areas in terms state conditions (i.e. soils, climate etc) and drivers (e.g. access to water allocation). Agents are defined by overlaying a number of national coverage spatial data sets, which are described in the following sections.

A1.1 Region

In New Zealand, the management of land and water is the responsibility of 11 Regional Councils and 4 Unitary councils. Boundaries for these regions were obtained from the Stats NZ website[1].

A1.2 Climate

Climate regions were developed based on climate zones described in NZMS (1983). As the climate definition for the agent is used to distinguish irrigation requirements, some further refinement was conducted based on expert knowledge to simplify or refine where necessary these zones (as described in the accompanying Aqualinc Report).

A1.3 Catchment

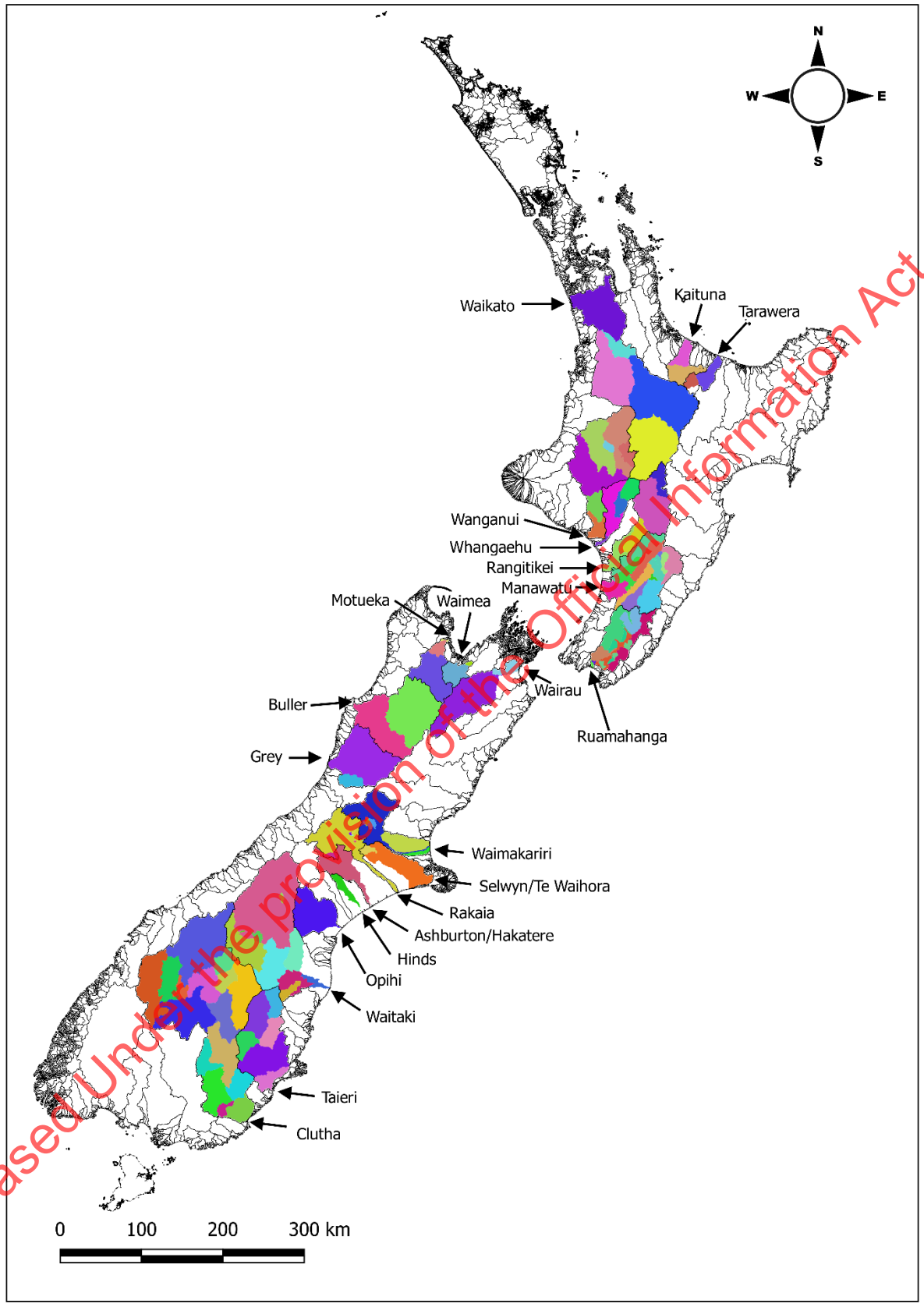
Sea draining catchments were defined based on the REC drainage network (Snelder and Biggs 2002). We have excluded any catchments with areas in agriculture <200ha, or horticulture<100ha. This is an arbitrary lower limit, but seeks to avoid the increasing errors and trading constraints associated with decreasing catchment size.

A1.4 Surface Water FMU

As a starting point, we have used the surface water FMUs compiled by Landcare Research Ltd (Daigneault et al. 2016). There were 19 major catchments that were subdivided into 2 of more surface water FMUs (excluding Northland, where most sea-draining catchments were subdivided into 2 FMUs). These sub-catchment FMUs are demonstrated in Figure 1.

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[1] (http://www.stats.govt.nz/browse_for_stats/maps_and_geography/geographic-areas/digital-boundary-files.aspx).



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Figure 1: Multi-FMU Catchments from Daigneault et al. 2016

A1.5 Groundwater FMU

Initial aquifer extents were estimated using a national aquifer map developed by GNS (Moreau and Bekele 2012). The associated report provides several caveats to accompany the dataset. There are differences in the delineation methodologies used in the different regions and in the detail provided. The southland region was represented as a single named aquifer in this dataset; given our knowledge of the region we felt that it was unlikely that free trading would be encouraged across all aquifers in the region. As such, initially, we replaced the GNS aquifers with groundwater zones from the proposed land and water regional plan.

A1.6 Maori land

MFE provided a GIS layer which defines land owned by iwi related entities. These were defined as land held under the Te Ture Whenua Māori Act 1993 and returned Treaty Settlement land. This layer is not definitive and omits some land which is owned outside the defined entity types. However it provides a basis from which to calculate impact on those entities as a result of different allocation approaches.

A1.7 Irrigability

We define a parcel of land's irrigability as the potential and likelihood of the given parcel to be irrigated. In general, irrigable land is identified as land with low slope and low altitude, and having sufficient soil water holding capacity. The specific methodology and rules applied to determine irrigability are described in AQUALINC REPORT??. This is not to say that irrigation cannot occur outside of these areas in practice, but for the purposes of this project it provides a reasonable extent on which to limit irrigation.

A1.8 Plant Available Water (PAW)

The Fundamental Soil Layer[2] (FSL) is used to provide soil information because of its national coverage and easy availability. The FSL contains a dataset that describes the Plant Available Water (PAW) for each soil type, which is the critical soil property required for the PART B modelling. The PAW dataset used in this modelling is available from the LRIS Portal[3].

The PART B modelling has defined four 600mm depth PAW classes: 0, 35 (>0 & <55), 60 (>55 & <80) and 120 (>80). These were derived from the FSL PAW_Max attribute, adjusted to account for a 600mm rooting depth (rather than 900mm). More detail about the justification for these ranges are provided within the Aqualinc accompanying report.

A1.9 Current Land use

Land use information is sourced from the NIWA dataset used for CLUES and other modelling. The dataset is a combination of the LCDB 4.1, FarmsOnline and some NIWA internal analysis to further subdivide sheep and beef types (see Appendix B) We have then simplified these categories into groups with expected similar economic outcomes.

A1.10 Irrigation Schemes

The presence of an irrigation scheme is an important consideration as: agents within an irrigation scheme will have a lower capital expenditure for irrigation water transfer; irrigation schemes will have reliabilities of supply that differ from the local run of river estimates; and

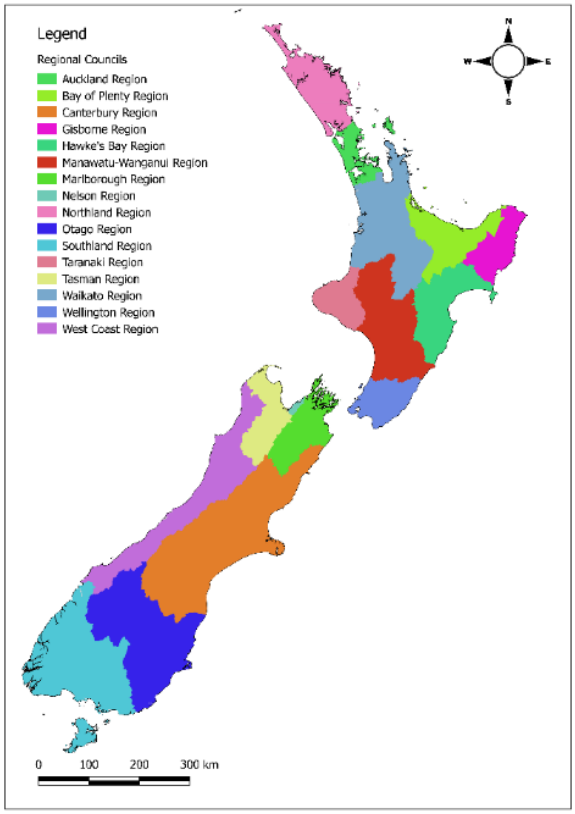
[2] https://soils.landcareresearch.co.nz/soil-data/fundamental-soil-layers
[3] https://lris.scinfo.org.nz/layer/100-fsl-profile-available-water/

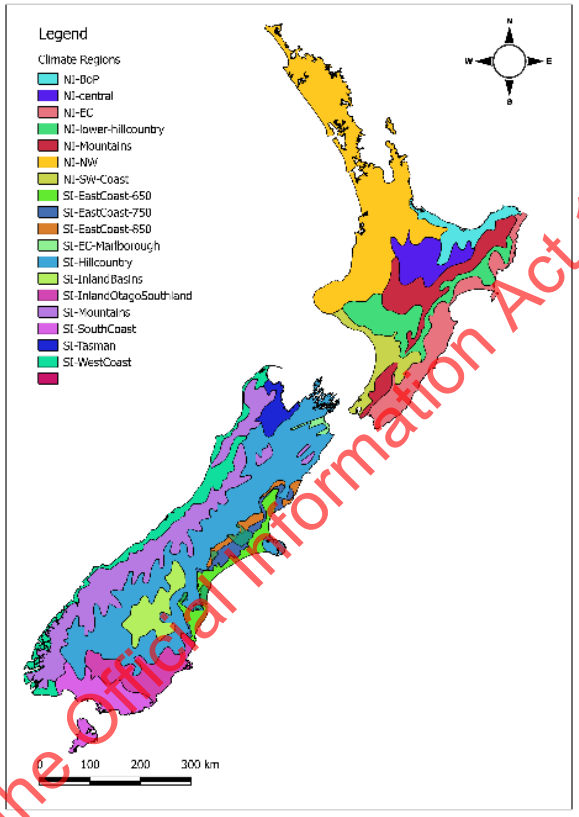
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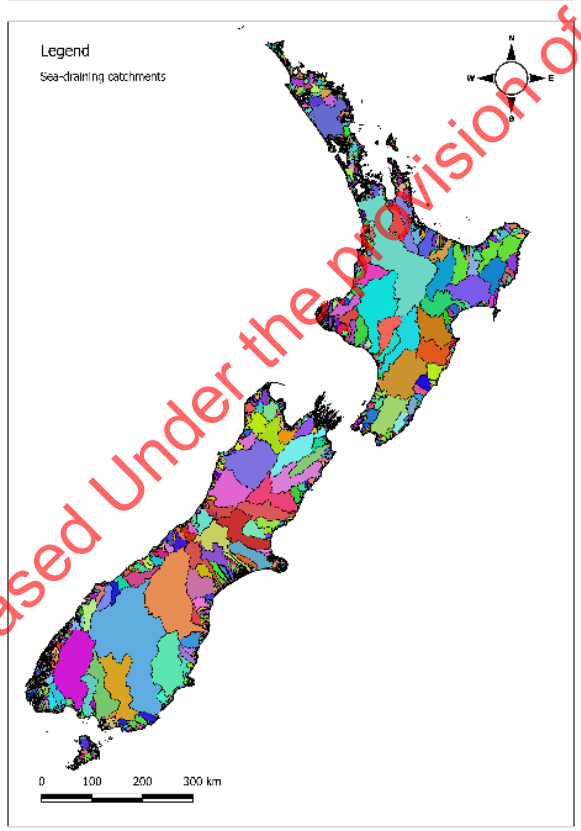
irrigation schemes in many places also represent areas where significant cross-catchment water transfer is occurring. A map of irrigation schemes used in this study was provided by P. Brown (pers. Comm.).

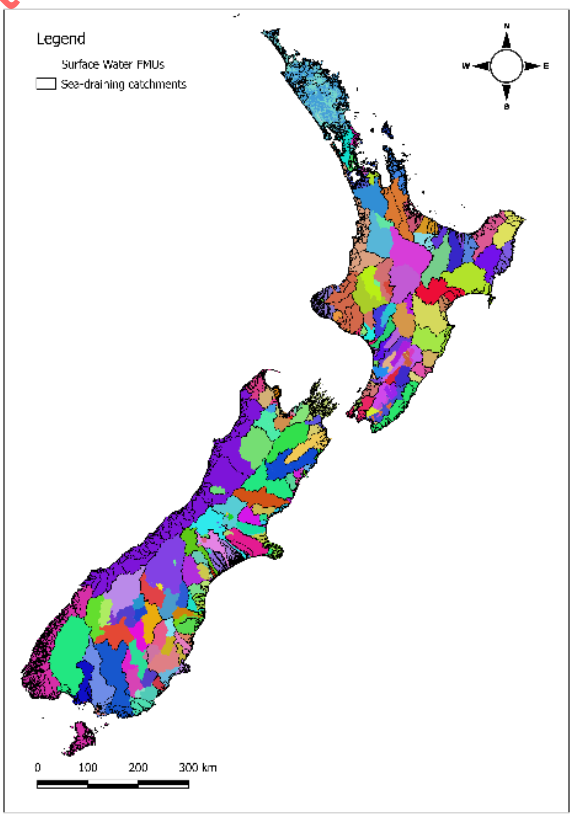
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Figure 2: Agent Base Maps

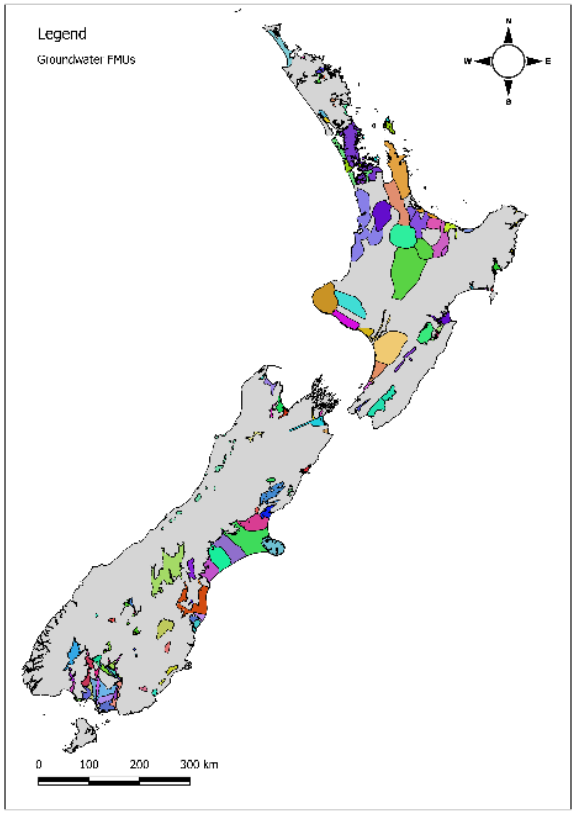


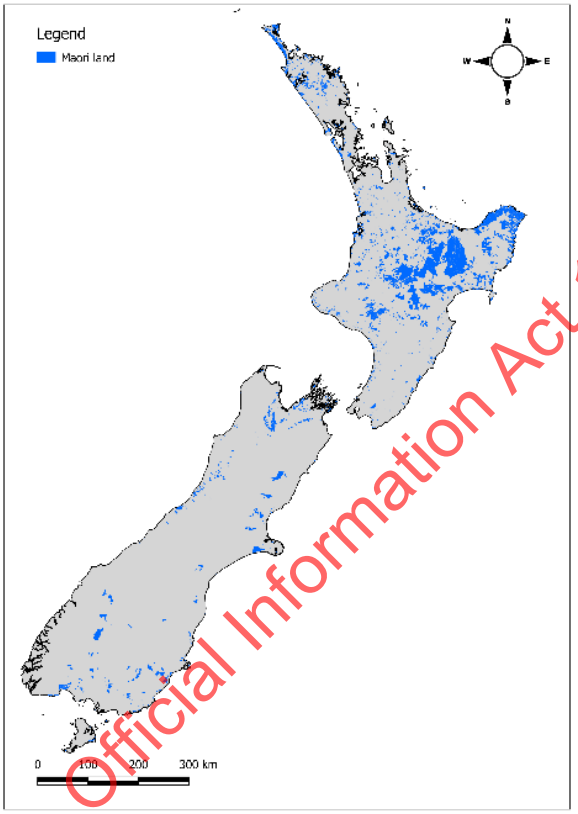


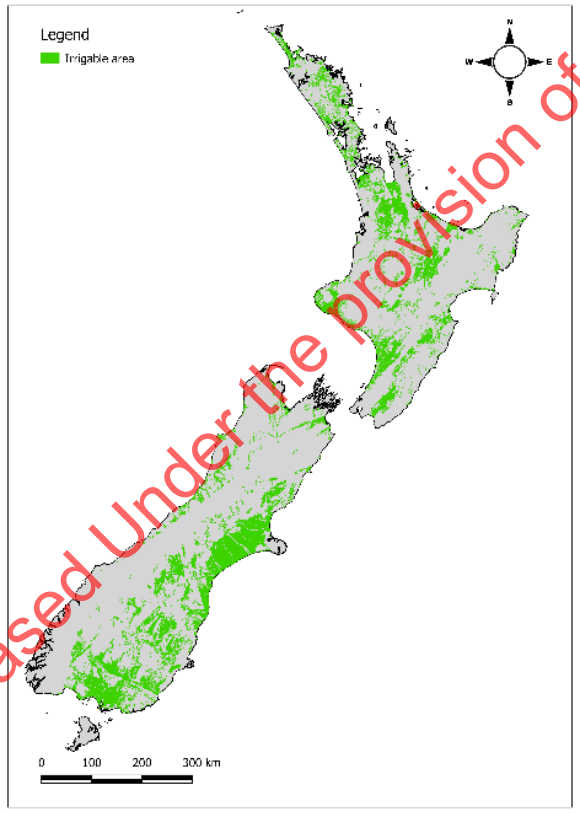


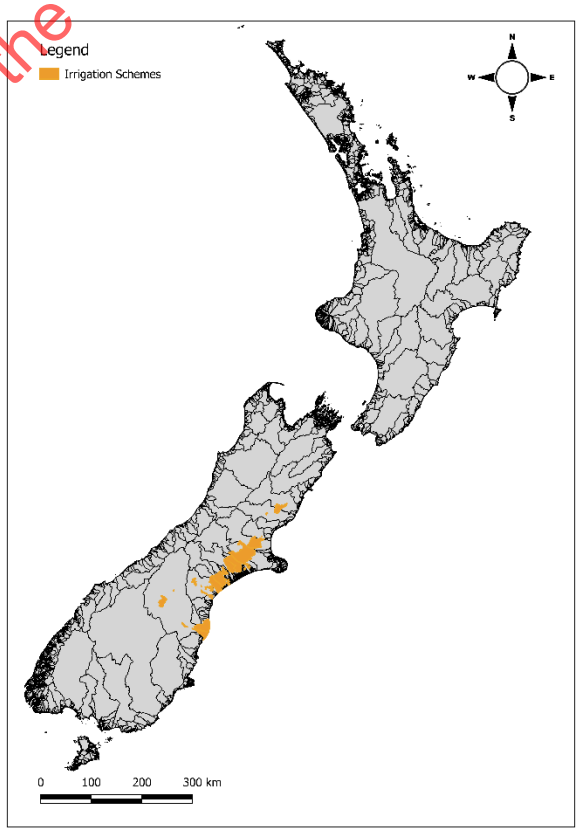


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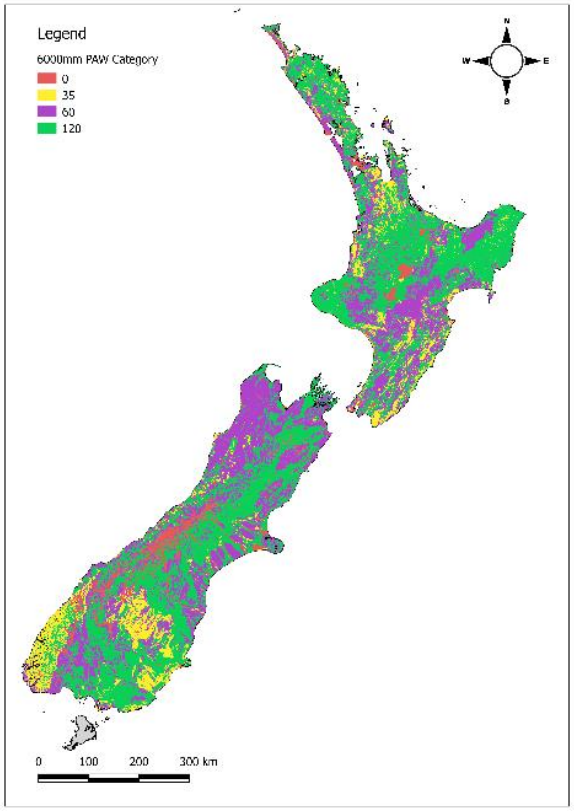


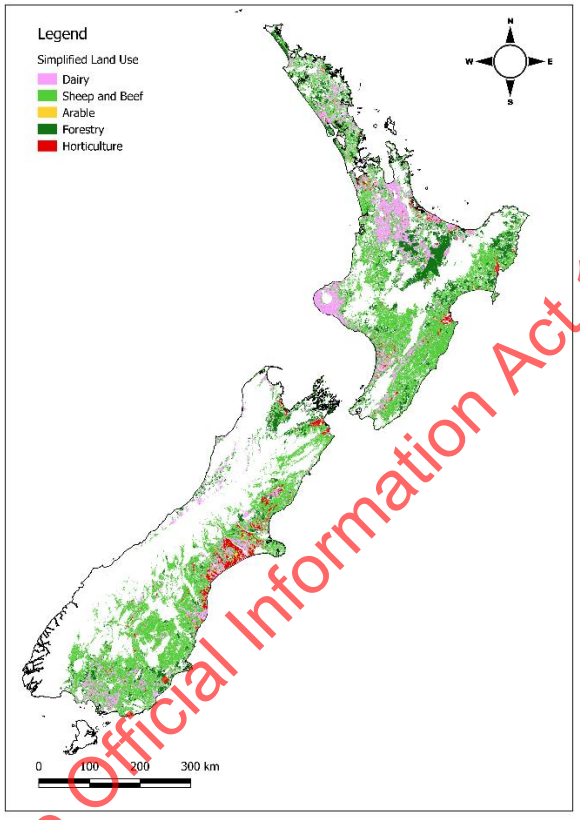






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A2 Combining agent characteristics

To make the spatial aggregation of the multiple agent characteristics tractable, we simplified each layer onto a uniform 200mx200m grid over the whole country. We then overlaid the 10 layers to define unique agents for the entire country.

Due to the nature of the different layers (both their sources and predefined limitations), in some places agents had one of the agent attributes undefined. Our initial approach was to exclude these areas from the analysis, as the expectation was that they would largely fall at the edges of regions/catchments/FMUs.

A3 Additional Input Data

A3.1 Resource Consents

The resource consents database used in this project is an early version of (Booker, Henderson, and Whitehead 2016) (NOTE: only small changes in the database have occurred subsequently and the up to date information can be incorporated in the subsequent analysis). This database provides a summary of nationwide resource consents, including metadata such as primary use and primary source of water. The location of these consents is shown in Figure 3 and the distribution by use and source is given in Table 1.

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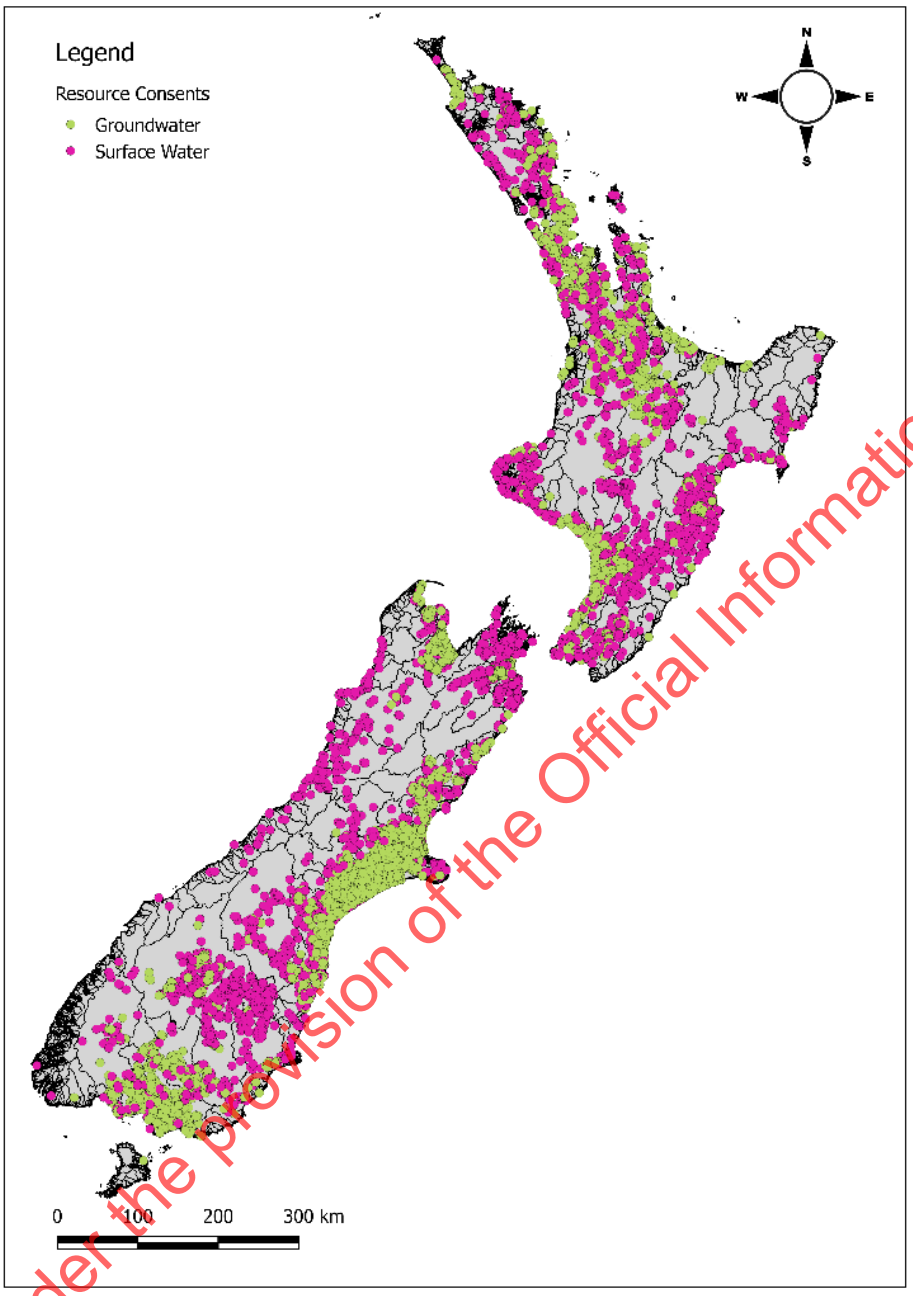


Figure 3 Location of groundwater and surface water consents

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Table 1: Summary of consents by water use and source

Primary Use	Primary Source	Maximum Rate (m^3s^{-1})	Maximum Annual Allocation (km^3)
Drinking	Groundwater	31	0.6
	Surface Water	26	0.7
	Subtotal	57	1.3
Hydro	Groundwater	0	0.0
	Surface Water	576	18.2
	Subtotal	576	18.2
Industrial	Groundwater	8	0.1
	Surface Water	75	1.1
	Subtotal	83	1.3
Irrigation	Groundwater	185	1.6
	Surface Water	226	3.4
	Subtotal	411	5.0
Other	Groundwater	21	0.2
	Surface Water	71	1.9
	Subtotal	92	2.1
Total:	Groundwater	244	2.6
Total:	Surface Water	975	25.3
	TOTAL	**1219**	**27.8**

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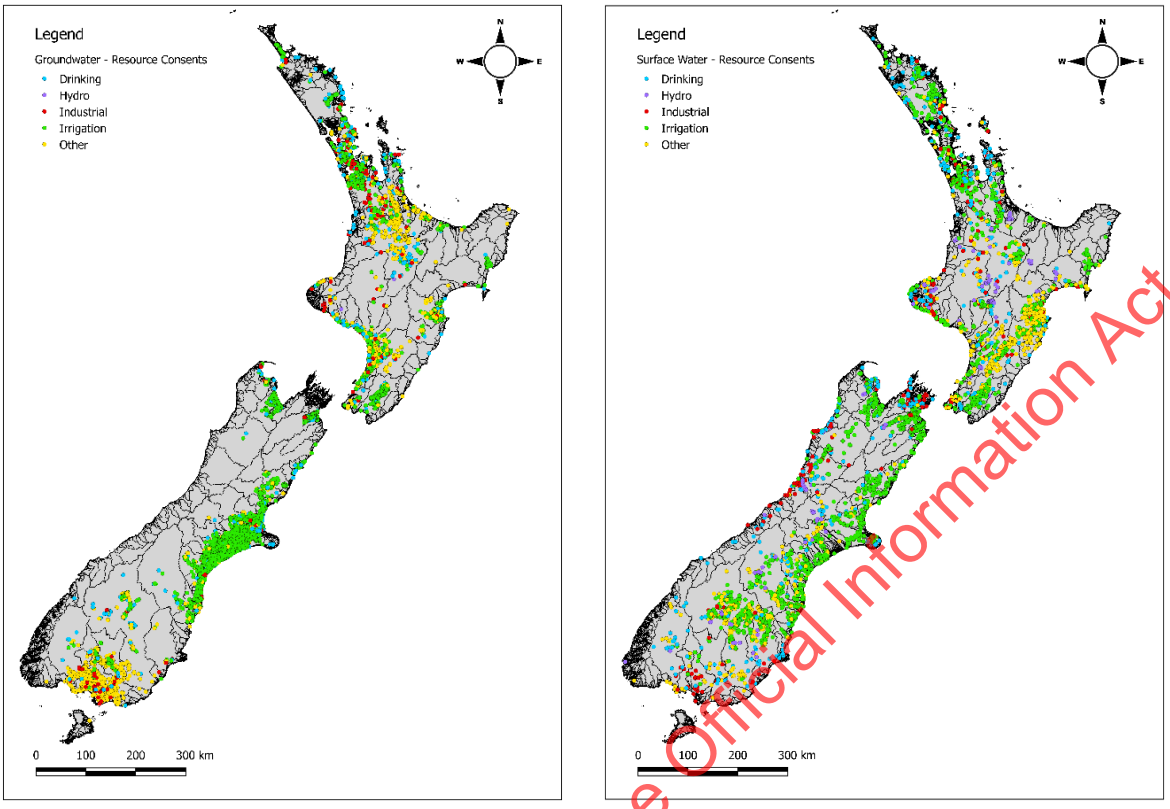


Figure 4 Breakdown of groundwater (a) and surface water (b) consents by water use

For this project we required further detail about irrigation water use, as such it was necessary to assign the irrigation water for the baseline across the four potential irrigated land uses: Dairy, Sheep and Beef, Horticulture and Arable. Each consent was assigned a land use by overlaying the consent locations with the land use map, and assigning either the land use coincident with the consent location, or the closest potentially irrigated land use. There are two key issues with this approach:

- the consent locations are not consistently located, and may be at the water source (i.e. in the centre of a river) rather than within the farm where the water is used, and
- it does not account for actual farm systems/boundaries which may have multiple irrigation uses.

Nevertheless, this provides the best possible assignment approach given the available datasets with national coverage.

A3.2 Irrigated Area

Actual irrigated areas were provided by MPI for this study. The mapping was conducted by Aqualinc Research Ltd as part of an ongoing contract, and is reported in [REF]. Although the dataset includes information about irrigation systems, we have only used irrigated area extent in our study. As of June 2017, irrigated area for eight regions was available as shown in Figure 5 and summarised in Table 2.

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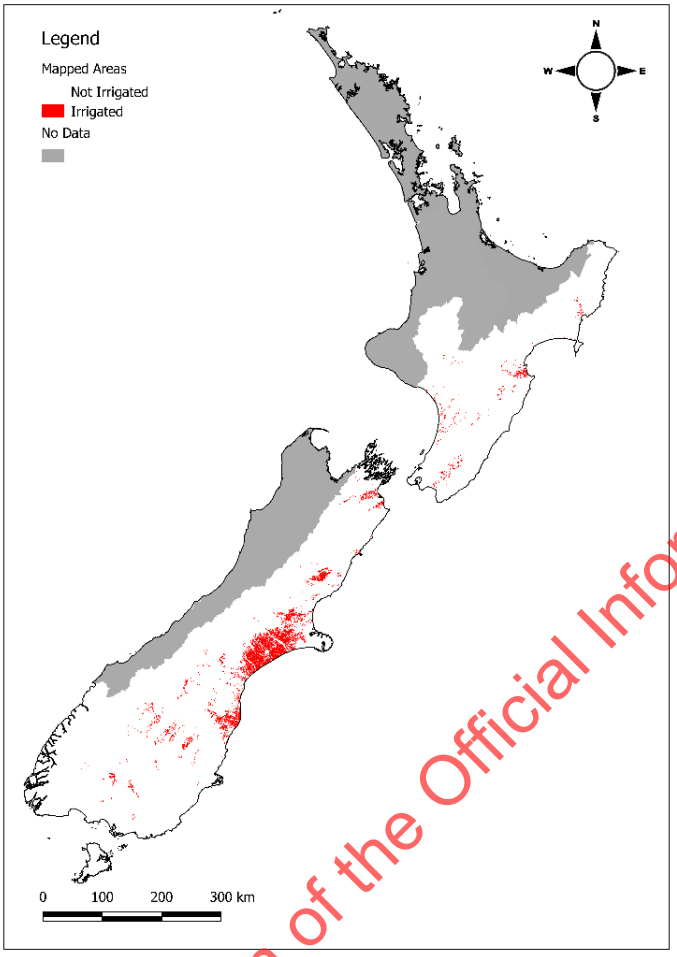


Figure 5: Map of Irrigated Area

Table 2: Summary of mapped irrigated areas

Region	Area Irrigated (km2)	% Region Irrigated	% of Irrigable area Irrigated
Gisborne Region	16	0.19	2.78
Hawke's Bay Region	70	0.50	3.88
Manawatu-Wanganui Region	58	0.26	1.49
Wellington Region	44	0.56	3.48
Canterbury Region	1240	2.84	9.64
Otago Region	228	0.73	3.43
Southland Region	46	0.16	0.69
Marlborough Region	77	0.80	9.95

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A4 Cleaning input layers

Due the different sources of the datasets, some layers that should theoretically be contiguous had minor deviations in their delineations. This was an obvious issue for layers that are largely related to hydrological catchments; these are: regional council boundaries, sea draining catchments and FMUs.

A systematic cleaning of the dataset was conducted to (where appropriate) align layers with sea draining catchment boundaries. The sea draining catchment boundaries were selected as the fixed alignment as these are derived from the REC network, which forms a fundamental part of the later analysis.

A4.1 Regional council boundaries

Deviations of regional council boundaries from the sea draining catchments were assumed to be delineation noise/error and were realigned in accordance with the sea-draining catchments, with the following exceptions (shown in the map below)

1. BOP/Gisborne boundary
2. Wairoa
3. Clarence
4. Buller
5. Waitaki
6. Clutha

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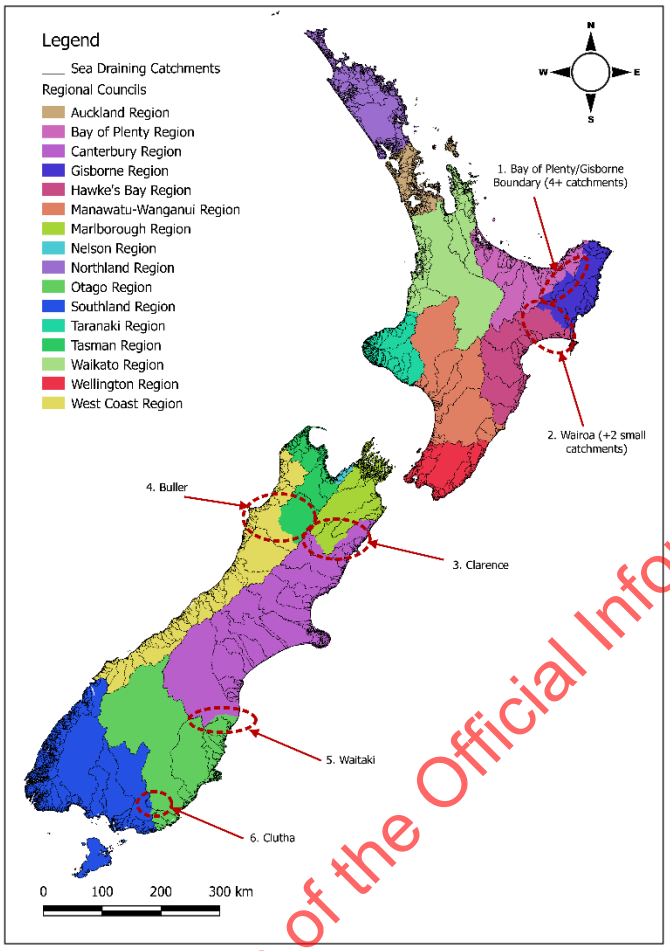


Figure 6 Comparison of regional council and catchment boundaries

For the remainder of the catchments, it was assumed that there was only one region per sea draining catchment. For catchments with more than one region, the dominant region (by area) was assigned to the catchment. In total, this led to a change in 649km^2.

A4.2 Irrigability

In regions where we also have actual mapped irrigated areas, we identified areas that are irrigated but not currently defined as irrigable, and added these irrigable area maps; this led to an increase of 381 km^2 of potential irrigable land. The percentage increase in irrigable area by region is demonstrated in the table below.

Region	% Irrigated Area not defined as Irrigable
Gisborne	3.3%
Hawke's Bay	8.0%
Manawatu-Wanganui	8.5%
Wellington	2.7%
Canterbury	3.6%

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Otago	12.4%
Southland	3.0%
Marlborough	8.7%

We also excluded areas from the irrigable area layer: where land use was classed as Urban and where PAW category was 0. This led to a reduction of 1338km^2.

A4.3 FMUs

It was assumed that all sea draining catchments had only a single SW FMU, except for the 19 catchments where clear development into sub-catchment FMUs was present. For the remaining sea draining catchments, the SW FMU was set to be contiguous with the catchment boundary. This deviates from the original SW FMU input file, where some SW FMUs contained multiple sea-draining catchments. Boundary errors for the 19 subdivided catchments were rectified through manual redefinition of the devious FMUs.

A5 Agent adjustments for solver compatibility

To make the optimiser problem tractable, we have made several assumptions to limit the types of solutions required, particularly in terms of the combinations of catchment(s), Surface Water FMUs and Groundwater FMUs. These assumptions are:

1. Surface water allocations and nutrients accumulate through a surface water network.
2. A sea draining catchment is the largest unit for surface water and nutrient accounting.
3. A sea draining catchment may be divided into several smaller FMUs. These FMUs must have some hydrological basis, to allow for sensible accumulations to be calculated
4. Groundwater zones are used solely for water quantity accounting/trading (nutrient allocations are based on surface water FMUs)
5. A single groundwater FMU may cross several surface water catchments.
6. A sea draining catchment with multiple FMUs may also have multiple groundwater FMUs that are contiguous with the surface water FMUs.

There are several configurations that are not compatible with these scenarios, including:

1. Surface water FMUs not defined based on surface water drainages (violates 1 and 3)
2. Cross-catchment transfers of water (violates 1)
3. Multiple groundwater FMUs across multiple Surface water catchments (violates 5 and/or 6)

Below we describe the approximations used to be able to represent these scenarios within the limitations of the optimiser.

A5.1 Non-hydrological surface water FMUs

The original surface water FMU definitions described in section A1.4 were in the main hydrologically defined, the exceptions being the Clutha River (Otago) and the Northland Region.

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In Northland, most sea-draining catchments had two SW FMUs (identifying steep and flat land) that were not hydrologically defined and therefore not compatible with the required FMU definition for this project. To overcome this, we have ignored this definition and simply assumed that the Northland region's FMUs are defined by the sea-draining catchments.

Some manual changes to the FMU boundaries in the Clutha (Otago) catchment were made to ensure compatibility with the assumptions of our model. The primary issue was the definition of FMUs where a large river was set as the boundary between FMUs. We aimed to preserve as far as possible the original FMUs and made many small changes to ensure hydrological integrity. These changes are demonstrated in the figures below.

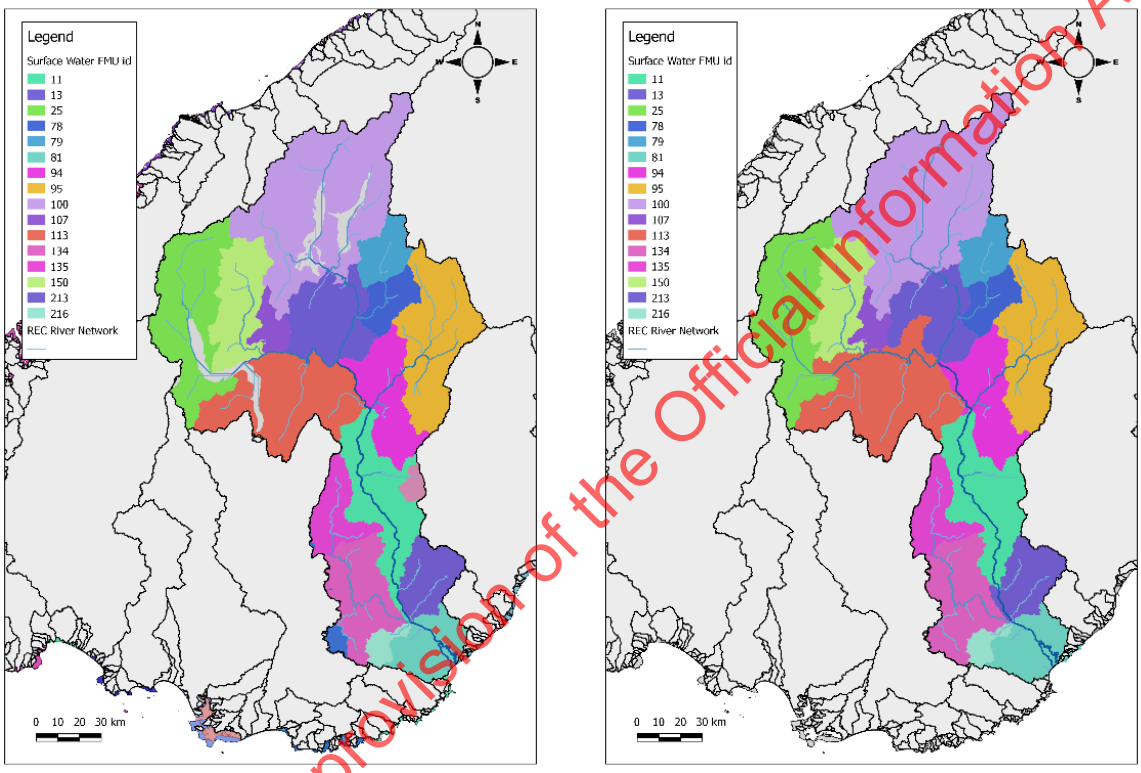


Figure 7: ORC Clutha FMU definition (Left) and Adjusted FMU definition used in this study (right)

A5.2 Cross-catchment transfers

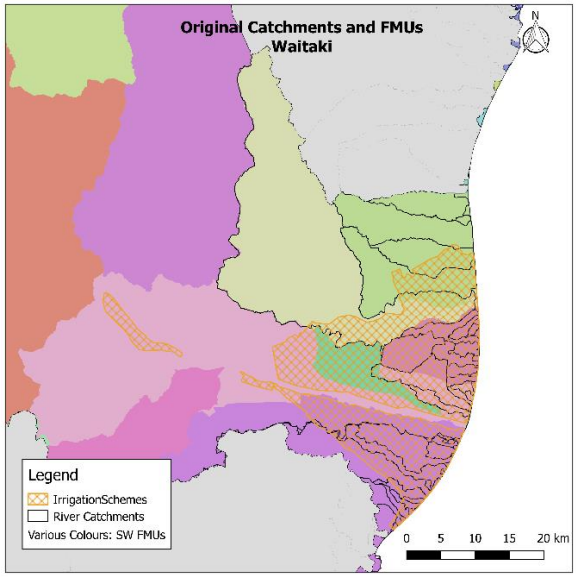
There are several locations within the country where significant cross-catchment transfer of surface water takes occur. These transfers may be associated with irrigation schemes or simply locations where significant water resources are located near catchment boundaries. We have only adjusted to account for situations where we expect cross-catchment transfers to be large; adjustments have been made in the following catchments:

- Waitaki
- Opihi
- RDR/Ashburton
- Selwyn
- Wairau Plains
- Awatere

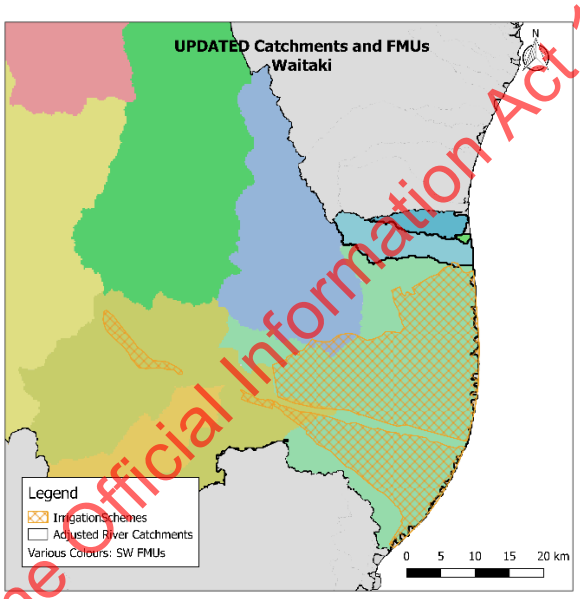
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Solutions employed to allow the model to trade water and accumulate takes and nutrients across catchments that share water involved amalgamating finely dissected SW catchments into FMU defined by a regional council, and/or any other sensible FMU boundary and treating these as “Catchments” in the optimiser. Irrigation infrastructure will be managed through a separate set of irrigation command areas in the agent characteristics.

A5.2.1 Waitaki

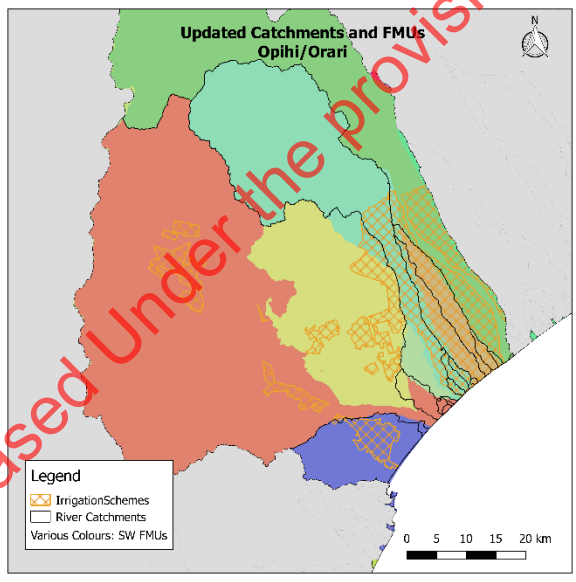


Original Catchments and FMUs

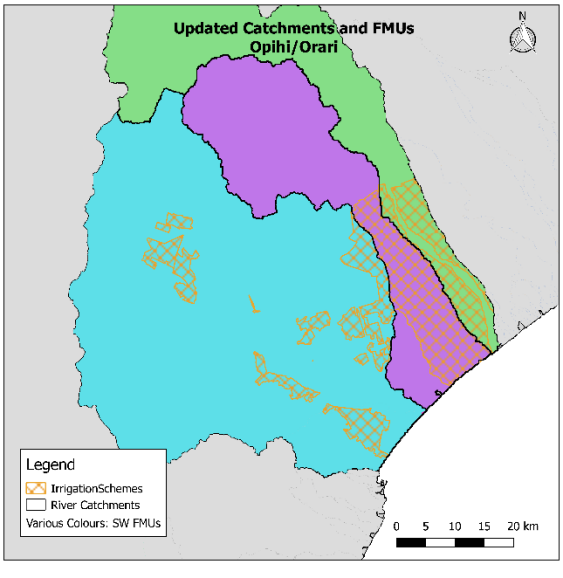


Updated Catchments and FMUs

A5.2.2 Opihi/Orari



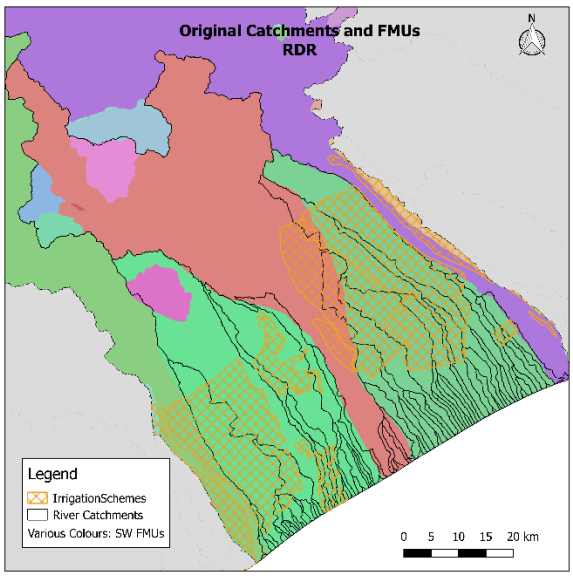
Original Catchments and FMUs



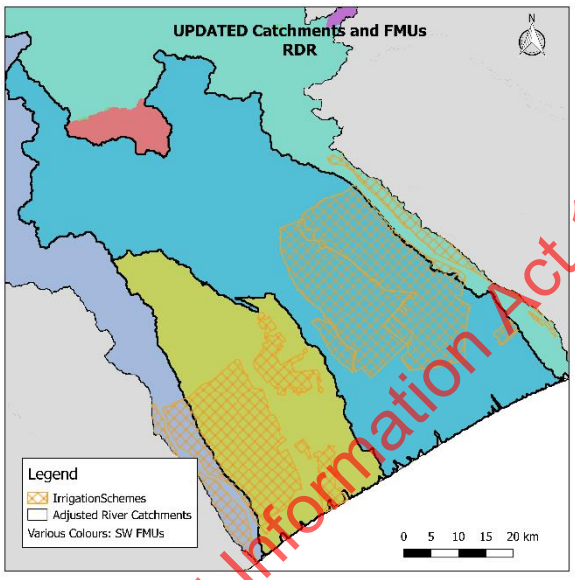
Updated Catchments and FMUs

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A5.2.3 RDR/Ashburton

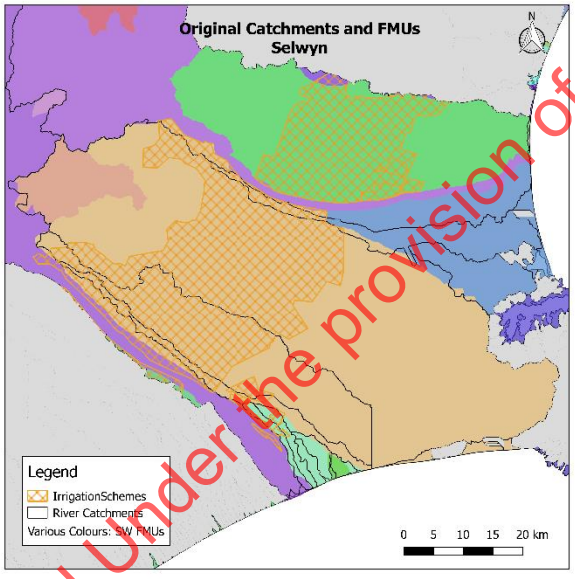


Original Catchments and FMUs

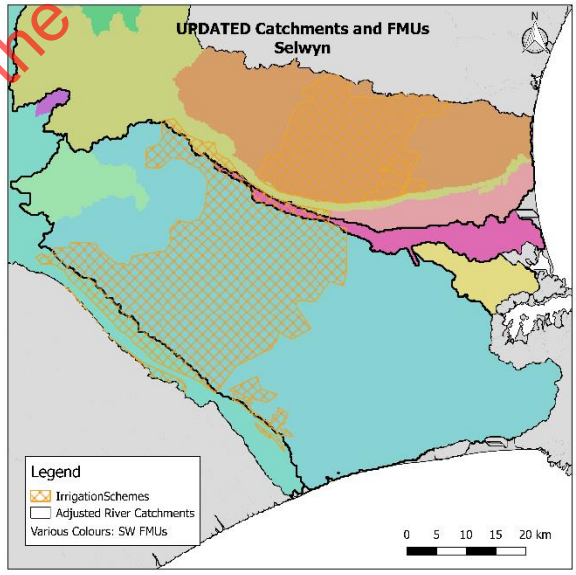


Updated Catchments and FMUs

A5.2.4 Selwyn



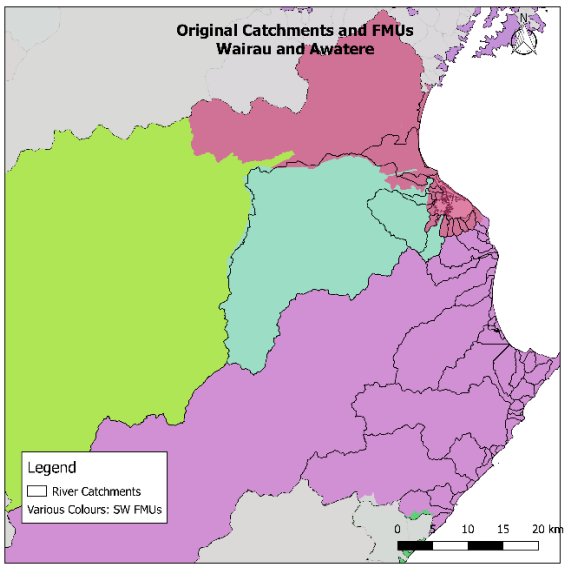
Original Catchments and FMUs



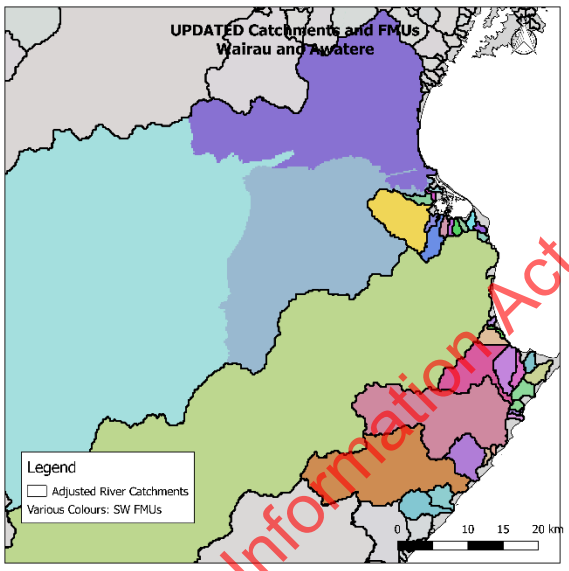
Updated Catchments and FMUs

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A5.2.5 Wairau and Awatere



Original Catchments and FMUs



Updated Catchments and FMUs

A5.3 Complex Groundwater/Surface water zones

For catchments where the surface water catchment and surface water FMU are contiguous, several options for representing the groundwater FMU exist:

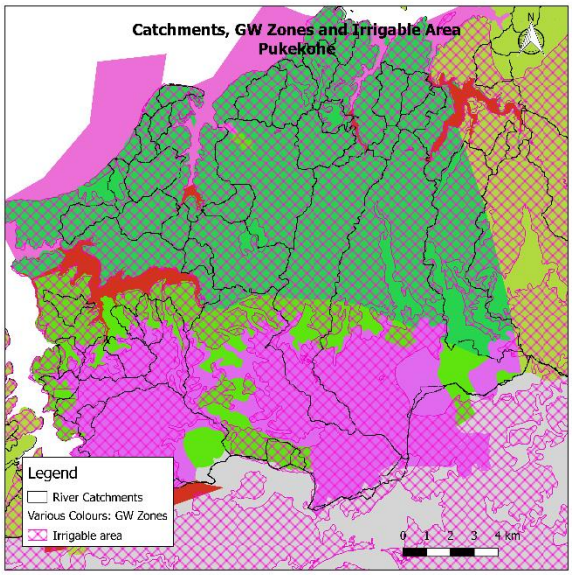
1. Have one groundwater FMU contiguous with the SW FMU
2. Have multiple groundwater FMUs within one sea-draining catchment
3. Have one groundwater FMU that spans multiple sea-draining catchments

GW FMUs exist to define areas where GW abstraction can be freely traded. GW can only be used within the GW FMU on land that is defined as irrigable. In most cases, the preference is to use the simplest solution (1). Selecting the appropriate solution was performed manually based on expert judgement, considering: the distribution of the groundwater takes for irrigation; the delineated groundwater zones/aquifers; and the relative contribution of groundwater to surface water for irrigation within the catchment.

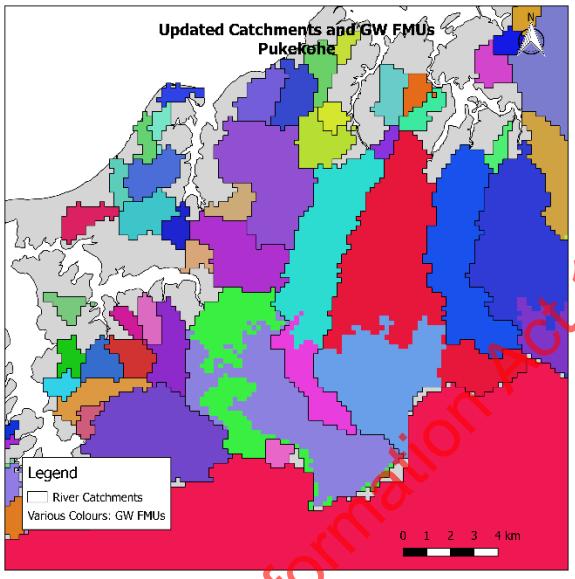
Some examples of the solutions implemented are demonstrated below

- A dominant aquifer across multiple catchments, but with large irrigable areas outside of the aquifer: Solution – maintain surface water FMUs and have 2 GW FMUs per catchment (e.g. Pukekohe)

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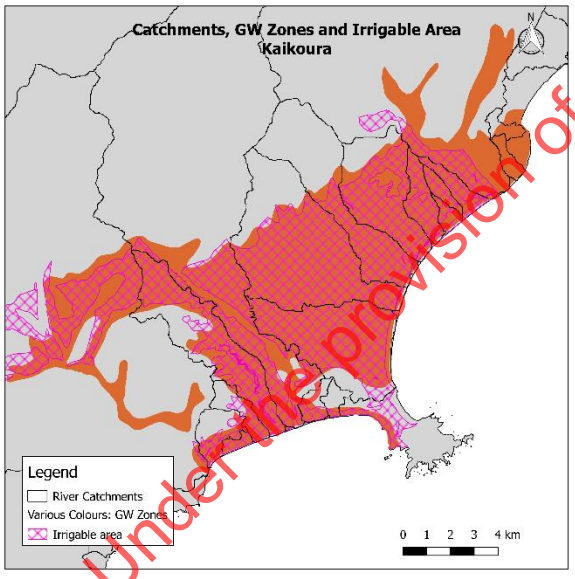


Original Catchments, Groundwater Zones and Irrigable Area

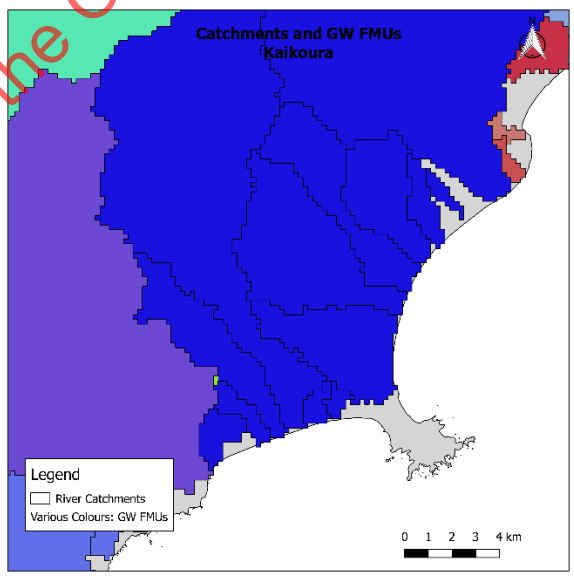


Updated Catchments and GW FMUs

- Coastal sea draining catchments with connected groundwater: solution, make one GW FMU for the group and optimise simultaneously (e.g. south Canterbury, Kaikoura). Note irrigable area is almost contiguous with delineated aquifers.



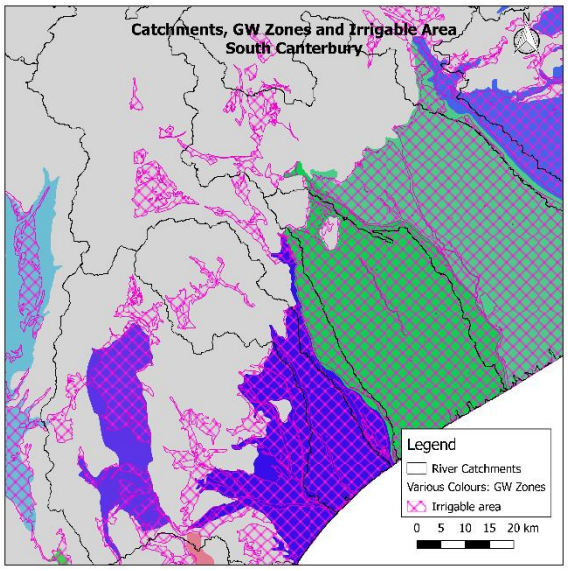
Original Catchments, Groundwater Zones and Irrigable Area



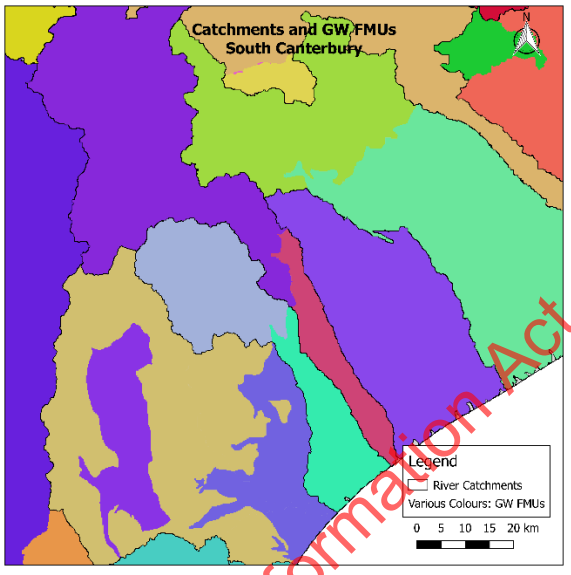
Updated Catchments and GW FMUs

- Only one aquifer, but with an extent much smaller than irrigable area of the surface water catchment: Solution: make two GW FMUs (the aquifer and “The rest”) (e.g. Ashburton, Rakaia, Opihi)

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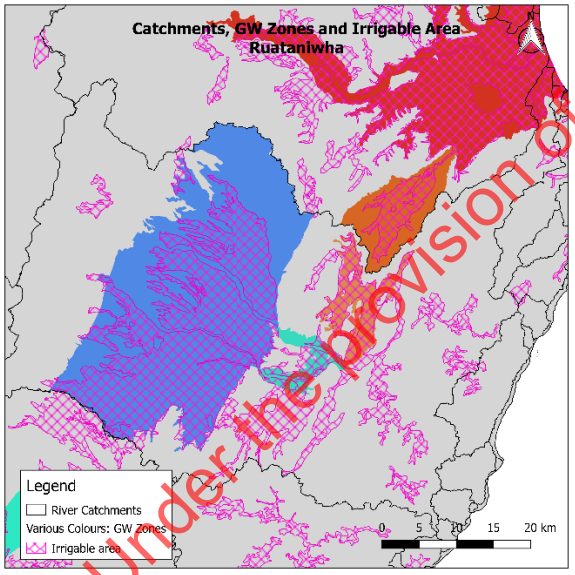


Original Catchments, Groundwater Zones and Irrigable Area

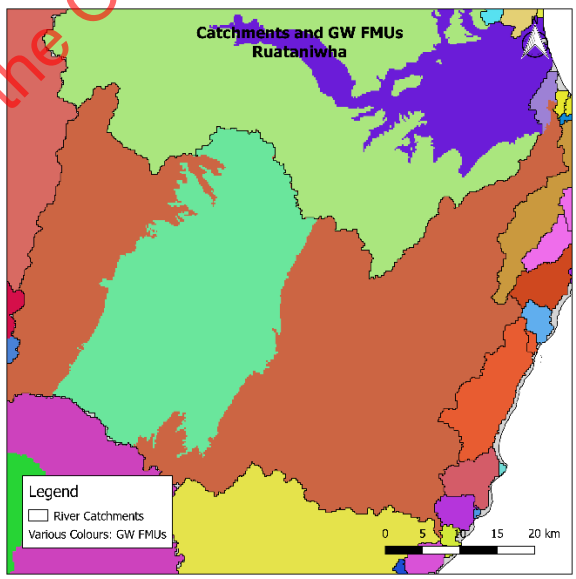


Updated Catchments and GW FMUs

- There are multiple aquifers across the catchment: Solution have multiple groundwater FMUs across the catchment, including a “non-aquifer” FMU (e.g. Southland catchments, Ruataniwha)



Original Catchments, Groundwater Zones and Irrigable Area



Updated Catchments and GW FMUs

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A6 Derived Agent Characteristics

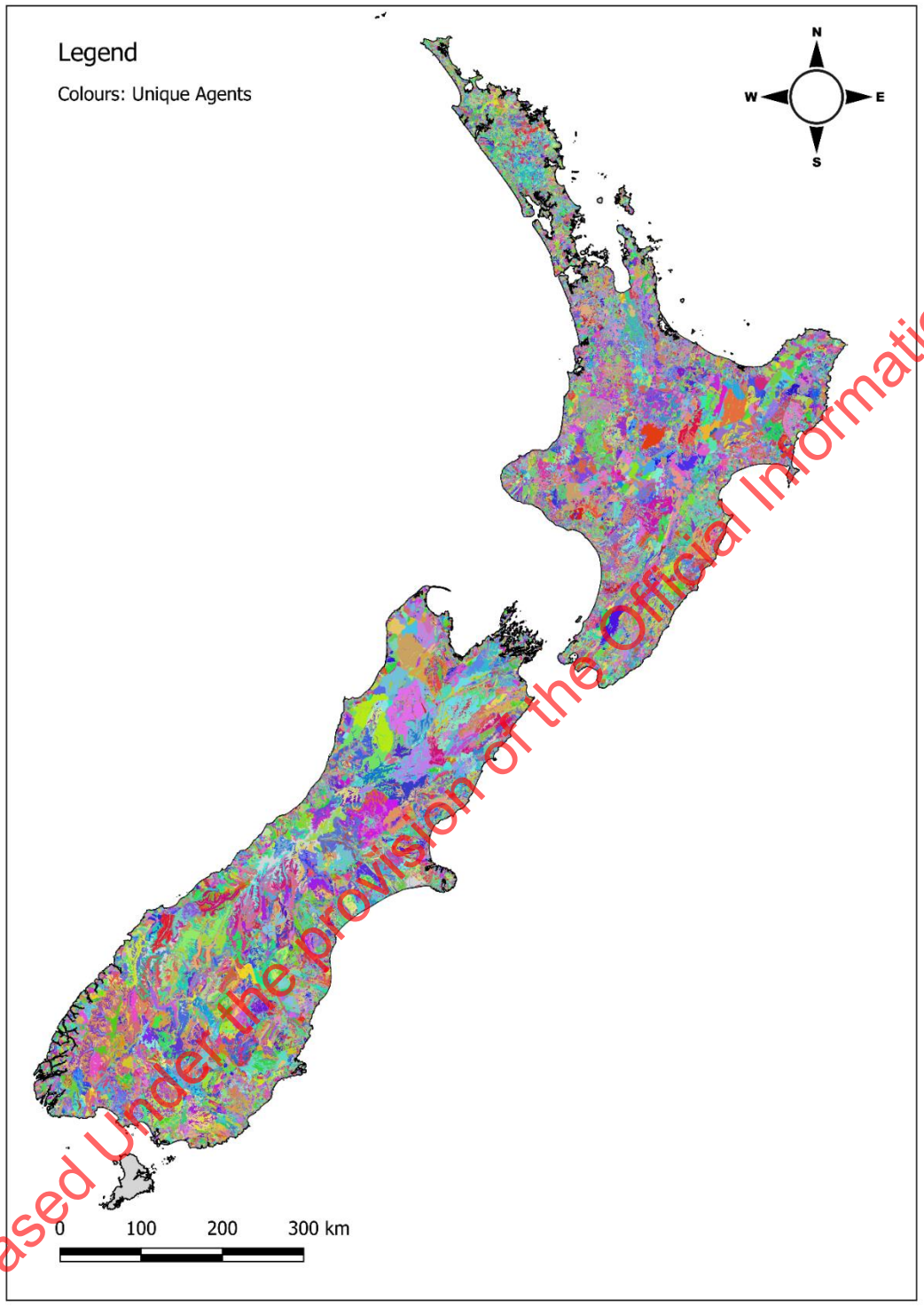


Figure 8: Map of all unique agents

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A6.1 Area

Once all agent attributes were combined using the 4ha NZ grid cell, cells with common agent attributes were combined to identify the Agents and Agent Types (note for the baseline, these two are the same). Based on this aggregation, total agent area was determined. Agents varied in size from 4ha to 278,924 ha, with a median area of 64ha. The distribution of the Agent areas is demonstrated in Figure 9.

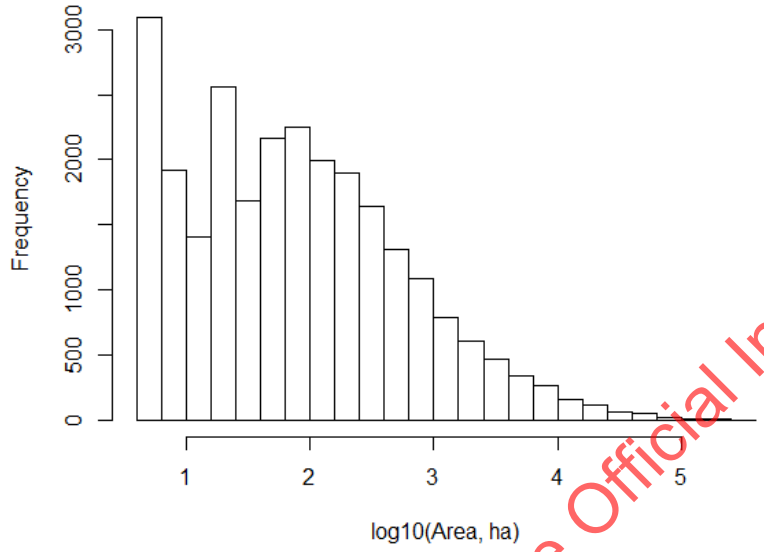


Figure 9: Distribution of Agent Areas

A6.2 Baseline Allocation

Where mapped irrigated area is available, baseline allocations are derived from this information. Elsewhere, the baseline allocation is derived from the local consents (Booker, Henderson, and Whitehead 2016). Non-irrigation water uses are sourced from consents information in both cases.

A6.2.1 Baseline allocations from irrigated area

In eight regions, we have actual irrigated area as well as consent information. In these regions, we have estimated water use (for irrigation) using actual irrigated area multiplied by the baseline system capacities provided by Aqualinc. The allocation is prorated between surface water and groundwater based on the ratio of groundwater:surface water consent volumes for each FMU. For non-irrigation water uses, we base the estimate on water use information from the consents database.

In four surface water FMUs, significant volumes of water are imported:

- Selwyn (CPW irrigation scheme; SOURCE: Waimakariri River)
- The two merged catchments between the Rangitata and Rakaia Rivers (see A5.2.3) (RDR; Imported SOURCE: Rangitata River)
- Orari (see A5.2.2) (South Rangitata Irrigation scheme; SOURCE: Rangitata River)

To determine the split of the baseline allocation derived from the irrigated area between surface water and groundwater, we have estimated the imported water contribution as the difference between the allocated water volume (from consents) and the estimated water use

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from irrigated area maps. As such the groundwater proportion is estimated as the consented groundwater volume divided by the total allocation (from irrigated area), the surface water proportion is one minus this value.

A6.2.2 Baseline allocation from consents

For locations where actual irrigated area information is not available, we have estimated current water use based on the consents database. We have used the maximum rate for all non-irrigation water takes and the smaller of the maximum rate or the annual rate over the irrigation season, which is estimated as the annual rate scaled by1/0.65 to account for typical requirement of actual use of an instantaneous take rate.

Irrigation consents are assigned a land use, based on the nearest productive land use. Consents were then defined based on their FMU, sea draining catchment, and land use. The consented takes were then prorated across the agents with irrigable areas.

A6.3 Supply Reliability

To estimate the profit of land uses in a FMU it is necessary to have an estimate of the reliability of the water supply. The approach taken here is to estimate the bulk supply reliability for a FMU using regionalised flow duration curves developed by Booker and Woods (2014). This requires an input of minimum flow and allocation for that FMU, and outputs a bulk supply reliability estimate that defines the proportion of time that the allocation is available. Booker (pers.comm.) supplied flow duration curves for the prototype catchments covering the irrigation season (September – May) only.

We have used the proposed NES default minimum flows. For the baseline case, the minimum flow was set as 0.8*MALF for FMUs categorised as LARGE (mean flow >5m^3s^{-1}) and 0.9*MALF for the remaining FMUs. MALF estimates for all REC reaches were sourced from a publicly available dataset produced by NIWA for MFE4 (Booker 2010; Booker and Hicks 2013; Booker and Woods 2014).

All groundwater consents were assumed to have 100% supply reliability and to have zero impact on surface water availability. This assumption may be updated in the future should appropriate reliability information become available for groundwater FMUs. Surface water consent reliabilities were assumed to be uniform across an FMU. FMU consent supply reliability was approximated by the frequency at which flows equal or exceeded the minimum flow plus half of the total (surface water) allocation at the FMU outlet(s); this approximation assumes flow ramping. This allocation includes the local FMU allocation as well as any upstream allocations and is determined by the accumulated adjusted consents. Note, this does not account for any discrepancies between the consented takes and the assumed water use based on irrigated area.

In the case of FMUs with more than one outlet, an allocation weighted average reliability was used. In the case that there are irrigation schemes present, estimates of the irrigation scheme reliabilities (from Brown 2012 and Brown pers. comm.) are used to develop an irrigated area weighted average reliability for the FMU. Estimates of irrigation scheme reliabilities have low certainty as the definition of and methodology used to calculate reliability varies between sources. Nevertheless, this information is used, as it was considered an improvement on the alternative of using a blanket estimate across all schemes. In the case that schemes did not

[4] https://data.mfe.govt.nz/table/2536-natural-river-flow-statistics-predicted-for-all-river-reaches/data/

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have available estimates, a default reliability of 90% was used. It is also likely to include the effect of any storage incorporated in the scheme. A map showing the irrigation scheme reliabilities used in this study is shown in Figure 10.

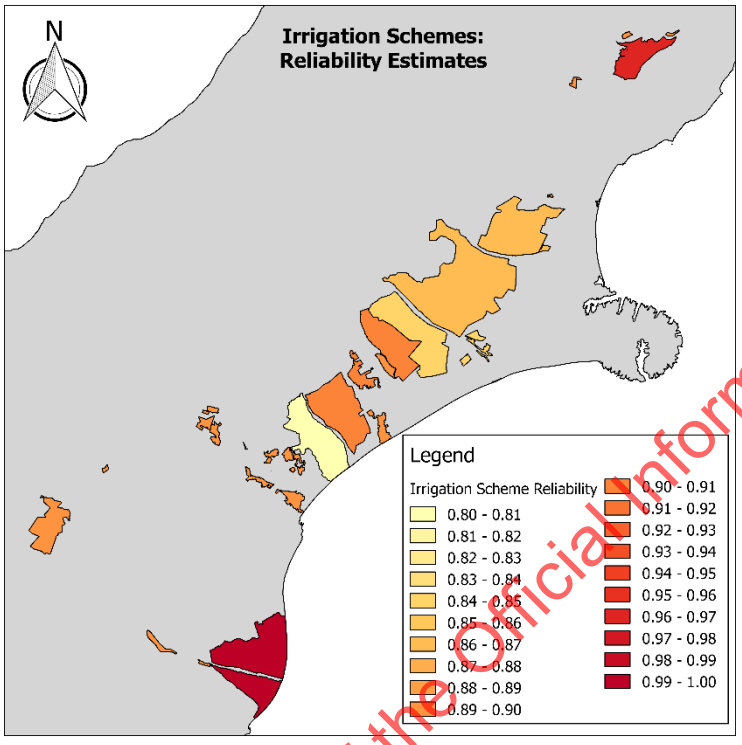


Figure 10: Estimated irrigation scheme bulk reliability

A6.3.1 Surface Water Reliability

The cumulative distribution of surface water allocation in relation to surface water reliability is shown in Figure 11 and the spatial distribution or reliability shown in Figure *12*.

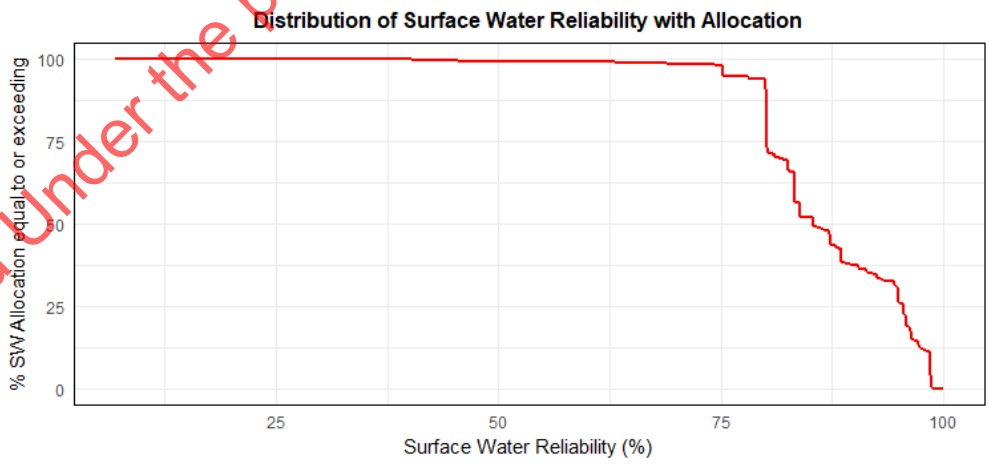


Figure 11: Distribution of Surface Water Reliability with Allocation

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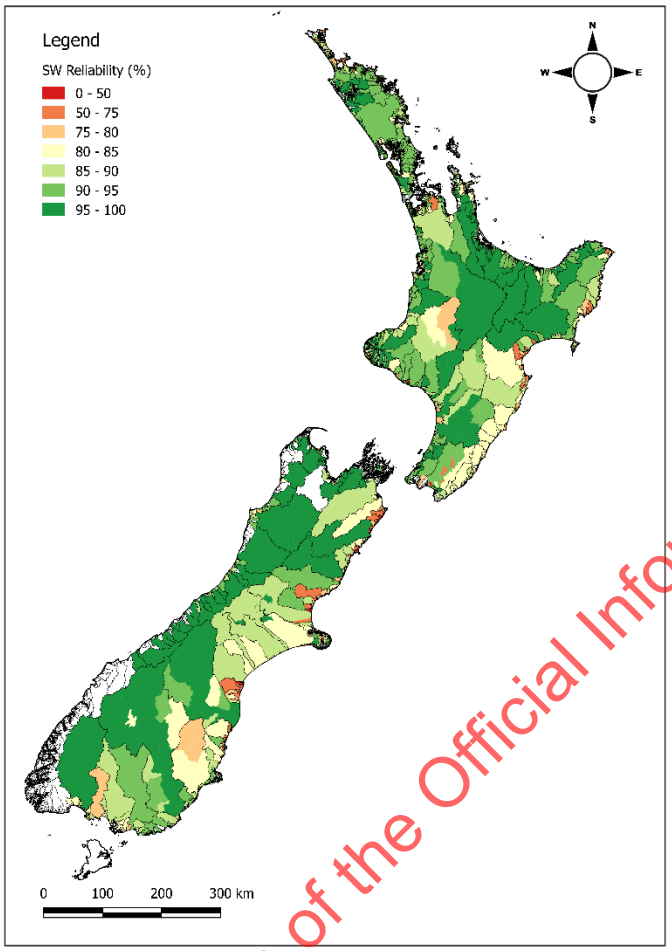


Figure 12: Map of estimated surface water reliability. In cases where there is no surface water allocation, the reliability shown is the frequency that MALF is equalled or exceeded.

A6.4 Irrigated Area

Irrigated area for each agent is either from mapped irrigated area, or, in regions with no mapped data, by converting consent maximum rates into areas using assumed application rates (varying by region and land use) as provided by Aqualinc. At this stage, any catchments that have agents with estimated agent irrigated area greater than agent area, have been excluded from the analysis until actual irrigated area can be used. This most notably excludes the Motueka River from the analysis. This error is most likely attributable to the incorrect assignment of land uses to consents.

Table 3 presents a comparison between the mapped irrigated areas and irrigated areas as estimated based on the consents database. A further breakdown of these areas by land use is provided in Appendix C.

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Table 3: Comparison of mapped irrigated area and irrigated area estimated by consents

Region	Mapped Area (ha)	Area Estimated by Consents (ha)
Gisborne	6,160	2,903
Hawke's Bay	26,856	27,759
Manawatu-Wanganui	20,036	19,230
Wellington	17,416	12,114
Canterbury	480,400	297,417
Otago	85,252	27,779
Southland	13,596	10,954
Marlborough	29,616	45,863

Differences between the mapped irrigated area and the areas estimated by the consents can be due to several reasons, including: differences between assumed and actual application rates and irrigation efficiencies; the use of storage; and incorrect assignment of consents to land uses. The causes for these differences are not explored as part of this investigation.

A6.5 Distance Indicator

The distance indicator is used to characterise the distribution of the allocation within the catchment. It provides a simple mechanism to restrict (on average) the movement of allocation upstream.

The REC database includes a characteristic of REC catchments that is the distance to the catchment outlet (Snelder and Biggs 2002). We rasterised the nationwide REC catchments onto the same 4ha grid cells as the agents, so that each grid cell could be assigned an REC reach number. The distance indicator is then calculated at the Agent Type level (i.e. all the fixed characteristics of the agent), as the mean of the REC distance to catchment outlet for all the grid cells within a given Agent Type. A map of the Agent Types coloured by distance indicators is shown in Figure 13.

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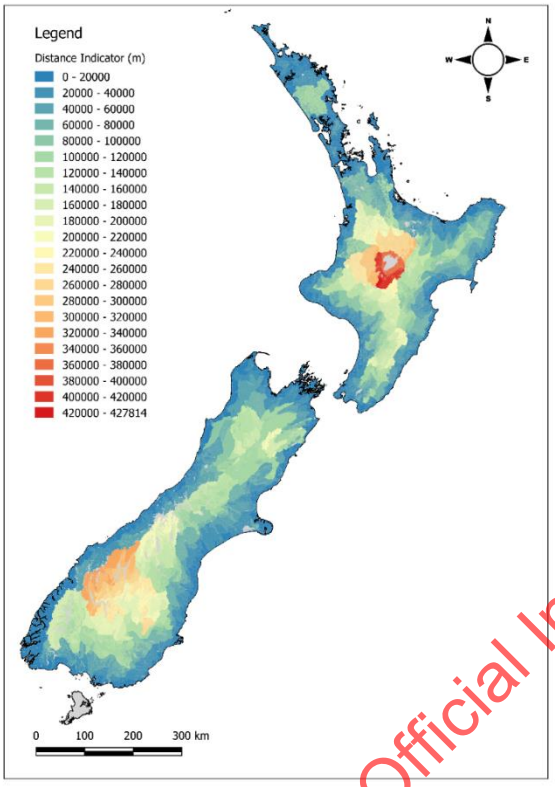


Figure 13: Map of distance indicator

Two catchment level average distance indicators are then calculated to constrain for each of the surface water allocation and the nutrient allocation. The average catchment distance is the allocation weighted Agent Type distance indicator.

This approach provides a simple mechanism to constrain transfers upstream. The approach should work particularly well in long, relatively linear stream networks. However, as the network becomes wider and more branched, the chance of effectively having trading between parallel streams (with the same distance to the sea, but no upstream connectivity) increases.

We can examine the efficacy of the constraint within the multiple FMU catchments by post processing outputs from the market simulations (which allow trading of surface water and nutrients between FMUs). We took the market optimised values for each FMU and accumulated them through the stream network and compared these values against the accumulated baseline allocations. These comparisons are shown in Figure 14. FMUs that are coloured shades of pink are places where the accumulated optimised allocation exceeds the allocation limits. For the nutrients, this is never exceeded the available allocation by more than 10% and only in 5 FMUs. For water quantity, two large overallocations occur within the Manawatu, but both cases appear to be trading water from a parallel catchment with a common drainage point.

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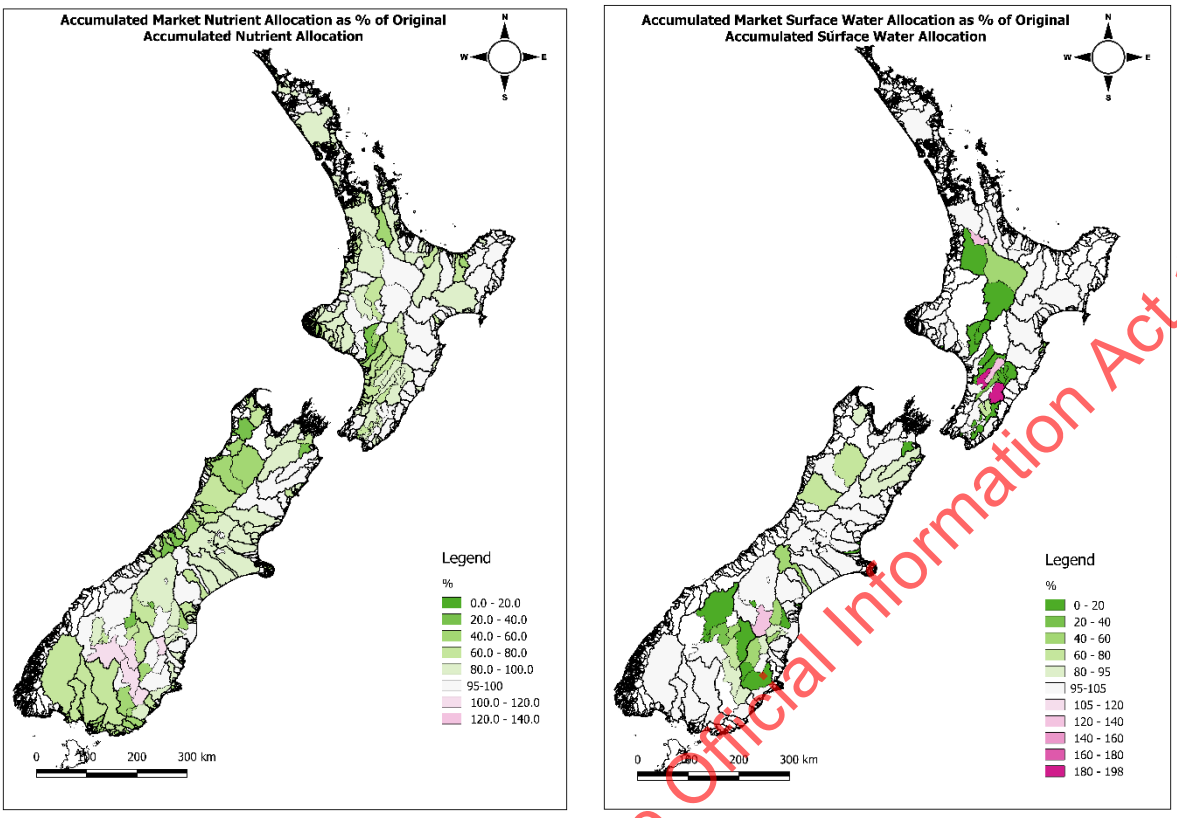


Figure 14: Accumulated market allocation as % of original accumulated allocation for (a) nutrients and (b) surface water

A7 Accumulations

In catchments with multiple surface water FMUs, we have calculated accumulated surface water allocations (both accumulated consented takes and allocations based on irrigated area) and accumulated nitrogen losses. In scenarios where downstream trading between FMUs of nutrients and surface water allocations are allowed, the accumulated allocations provide an upper feasible limit on the allocation. The accumulated surface water takes (from actual consents) are used to determine the reliabilities of the water supplies.

Administration points are locations in the river network either at the ocean outlet, or where there is a change in FMU. It is possible to have multiple administration points for a single FMU, depending on the extent of the FMU. For this study, the minimum administrative units considered are FMUs, and as such, we have calculated sums of surface water allocations and nutrient losses for each FMU.

Accumulations are performed by assigning summed FMU allocations (surface water and nitrogen) to the REC reaches associated with the FMU administration points. These takes are then accumulated through the REC network, and accumulated amounts are then extracted at each of the administration points, summing where multiple administrative points exist, to provide accumulated values for each FMU.

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A8 Profit Functions

A8.1 Water Quantity

Profit functions were developed for each unique combination of: Climate, PAW, Land Use, Irrigation scheme and Irrigability. The functions were fitted in three parts, with respect to reliability. As reliability is not updated as part of the optimization process, this does not cause any issues for the solver, which requires continuous and differentiable functional forms.

For each of the reliability bands a suitable functional relationship between reliability and system capacity was identified, taking into consideration a balance between the simplicity of the form, the goodness of fit and the potential for overparameterization. The goodness of fit for the 90 different combinations of Climate, PAW and Land use, ranged from R2=0.97 to R2=1. The fits are demonstrated in Appendix D. Final Cash operating surplus was calculated as the fitted values, minus capital costs (annualized over a ten-year period). The model equation is given by:

$$COS_1 = A_1 + A_2 S^{0.5} + A_3 (SR)^{1/3} + A_4 R + A_5 S^{0.5} R - C$$

Where:

COS_1	Cash operating surplus (ha^{-1} yr^{-1}) (Baseline with no nutrient mitigations)
$A_{(1:5)}$	Model coefficients (derived separately for each combination of Climate, PAW, Land Use, irrigation scheme, Irrigability and Reliability band
S	Application Rate ($ls^{-1}ha^{-1}$)
R	Adjusted Reliability (Reliability – 50%) (%)
C	Annualised Capital Costs ($ ha^{-1} yr^{-1})

Appendix E provides a summary of the fitted profit curves by region, allowing a comparison between the performance of different land uses.

A8.2 Water Quality

Variation of profit with water quality was only dependent on land use (see PART B project report). As most data sets only had two data points (one had three points), simple linear relationships were fit to describe the relationships between % reduction in nutrients loss and % reduction in profits. These relationships are demonstrated in Figure 15.

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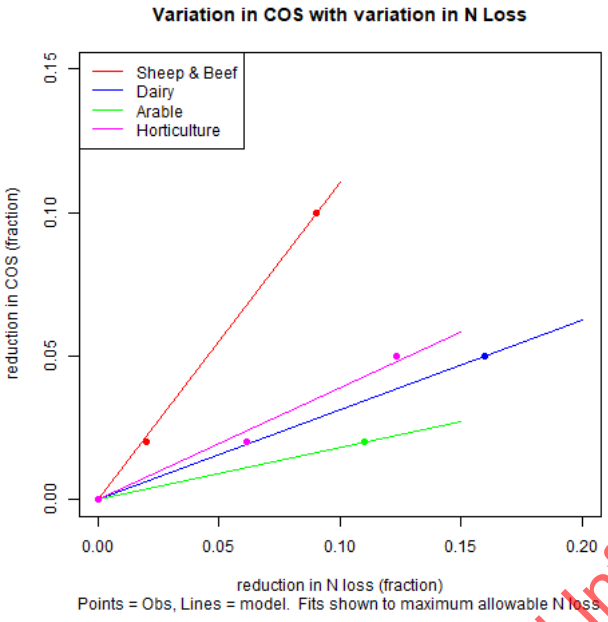


Figure 15: Variation in Cash operating surplus with variation in N loss by land use

The model equation is given by:

$$COS_2 = COS_1(1 - B_1 N_{red})$$

Where:

COS_2	Cash operating surplus ($ ha^{-1}yr^{-1}) (with nutrient mitigation[5])
B_1	Model coefficient (dependent on Land Use)
N_{red}	Nutrient reduction (fraction – i.e. reduce from 10 to 9 have N_{red}=0.1)

A9 Allocation Scenarios

The specific allocation scenarios are outlined in the main report. The table below is a technical note on the implementation of the scenarios within the R model environment.

[5] Nutrient mitigation is only allowed for the Quality scenarios.

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Table 4: Summary of Constraints: Technical note

						Current optimised	Market		Reduction and redistribution to Maori		LUC		Comment for coding
						An optimisation of current to allow comparison with other scenarios. No trading	Market with hydrological and market imperfection constraints		Reduce all non Maori, redistribute to Maori Land up to base rates. No trading ("red1" - see notes *2)		Remove all allocations and reallocate to assigned rates. No trading ("red2" - see nptes *3)		
Constraint name	**Level at which contstraint is summed**	**Constraint df**	**df col name**	**What is it constrained by?**	**UNITS**		**Quantity**	**Quality**	**Quantity**	**Quality**	**Quantity**	**Quality**	
Min_Agent_Area	**Agent**	df_agent	$land_LB	area	ha	0	same as cell to left as cell to left	same as cell to left as cell to left	same as cell to left as cell to left	same as cell to left as cell to left	same as cell to left as cell to left	same as cell to left as cell to left	
Max_Agent_Area	**Agent**	df_agent	$land_UB	area	ha	$AT_Area	same as cell to left as cell to left	same as cell to left as cell to left	same as cell to left as cell to left	same as cell to left as cell to left	same as cell to left as cell to left	same as cell to left as cell to left	
Min_Sys_Cap	**Agent**	df_agent	$Syscap_LB	System capacity	l/s/ha	SysCap	Sys_Cap_min	SysCap	SysCap*red1	SysCap	SysCap	SysCap	Limits trading within Agent types by preventing a reduction in system capacity and increasing elsewhere. Check whether non-irrigation takes are subject to reductions
Min_Nloss	**Agent**	df_agent	$Nloss_LB	N loss Rate	kgN/ha	CurrN_lossp ha	CurrN_lossp ha	CurrN_lossp ha*(1-Nlossmin_df$NlossminPerc|LU) (*1)	CurrN_lossp ha	CurrNLoss_pha*red1	CurrN_lossp ha	CurrN_lossp ha	
Max_Sys_Cap,	**Agent**	df_agent	$Syscap_UB	System capacity	l/s/ha	SysCap	Sys_Cap_max	SysCap	SysCap*red1	SysCap	SysCap	SysCap	
Max_Nloss	**Agent**	df_agent	$Nloss_UB	N loss Rate	kgN/ha	CurrN_lossp ha	CurrN_lossp ha	CurrN_lossp ha	CurrN_lossp ha	CurrNLoss_pha*red1	CurrN_lossp ha	CurrN_lossp ha	
SoilPAW_Climate_Tot	**Agent type**	df_agenttype	$AT_Area	Area	ha	sum(df_agent$Area|AgentTypeID)	same as cell to left	same as cell to left	same as cell to left	same as cell to left	same as cell to left	same as cell to left	
Agent_type_SW_max,	**Agent type**	df_agenttype	$AT_SW	SW allocation	l/s	sum(Alloc[Source==1] | Agent_type_id)	sum(Area[Source==1]*Max(Sys_Cap) | Agent_type_id)	same as cell to left	Maori ==0 =sum(Alloc[Source==1] | Agent_type_id)*red1 else (if Irri==1 and Source ==1) =sum(Alloc[Source==1]|Agent_Type_ID)+SW_maori (*5)*sum(Area|Agent_Type_ID)	sum(Alloc[Source==1] | Agent_type_id)	sum(Alloc[Source==1] | Agent_type_id)*red2_W	sum(Alloc[Source==1] | Agent_type_id)	Limits trading across Agent types but not trading within Agent types
Agent_type_GW_max,	**Agent type**	df_agenttype	$AT_GW	GW Allocaiton	l/s	sum(Alloc[Source==2] | Agent_type_id)	sum(Area[Source==2]*Sys_Cap_max | Agent_type_id)	same as cell to left	Maori ==0 =sum(Alloc[Source==2] | Agent_type_id)*red1 else (if Irri==1 and Source ==2) =sum(Alloc[Source==2]|Agent_Type_ID)+GW_maori (*6)*sum(Area|Agent_Type_ID)	sum(Alloc[Source==2] | Agent_type_id)	sum(Alloc[Source==2] | Agent_type_id)*red2_W	sum(Alloc[Source==2] | Agent_type_id)	
Agent_type_Ntot_max	**Agent type**	df_agenttype	$AT_N	N loss	kgN	sum(CurrN_lossp ha* Area| Agent_type_id)	sum(Area*max(CurrN_lossp ha|Agent_Type_id)|Agent_type_id)	same as cell to left	sum(CurrN_lossp ha* Area| Agent_type_id)	Maori ==0 =sum(CurrN_lossp ha* Area| Agent_type_id)red1 else (if Irri==1) =sum(CurrN_lossp ha* Area| Agent_type_id)+N_maori (*7)*sum(Area|Agent_Type_ID)	sum(CurrN_lossp ha* Area| Agent_type_id)	sum(CurrN_lossp ha* Area| Agent_type_id)*red2_N	
FMU_SWvol_max,	**FMU**	df_FMU_SW	$FMU_SW	SW Allocation	l/s	sum(Alloc[Source==1] | FMU_SW)	max(AccFMU_Quant_SW|FMU) (*4)	same as cell to left	sum(Alloc[Source==1] | FMU_SW)	same as cell to left	sum(Alloc[Source==1] | FMU_SW)	same as cell to left	
FMU_type_GWvol_max	**FMU**	df_FMU_GW	$FMU_GW	GW Allocation	l/s	sum(Alloc[Source==2] | FMU_GW)	same as cell to left	same as cell to left	same as cell to left	same as cell to left	sum(Alloc[Source==2] | FMU_GW)	same as cell to left	
FMU_Ntot_max	**FMU**	df_FMU_SW	$FMU_N	Total N loss for FMU	kgN	sum(CurrN_lossp ha*Area|FMU_SW)	max(AccFMU_N_lossp ha|FMU_SW)*sum(Area|FMU_SW) (*4)	same as cell to left	sum(CurrN_lossp ha*Area|FMU_SW)	same as cell to left	sum(CurrN_lossp ha*Area|FMU_SW)	same as cell to left	
Catch_Dist_Quant,	**Catchment**	df_catchment	$Catch_Dist_Quant	Weighted average catchment distance	km	sum(Alloc[Source==1]*Dist_ind[Source==1]|Catchment)/sum(Alloc[Source==1]|Catchment)	same as cell to left	same as cell to left	same as cell to left	same as cell to left	same as cell to left	same as cell to left	
Catch_Dist_Qual	**Catchment**	df_catchment	$Catch_Dist_Qual		km	sum(CurrN_lossp ha*Area*Dist_ind|Catchment)/sum(CurrN_lossp ha*Area|Catchment)	same as cell to left	same as cell to left	same as cell to left	same as cell to left	same as cell to left	same as cell to left	
Catchment_SWvol_max	**Catchment**	df_catchment	$Catch_SW	Total allocation for a SW catchment for A and B blocks	l/s	sum(Alloc[Source==1] | Catchment)	same as cell to left	same as cell to left	same as cell to left	same as cell to left	same as cell to left	same as cell to left	
LU_Run_Change_MAX	**Run**	df_LU	&dLU	Area of land use	%	from input file "Land use change long skinny format V3a.csv" based on dominant irrigable climate area	same as cell to left	same as cell to left	same as cell to left	same as cell to left	same as cell to left	same as cell to left	

Note - we are also setting bounds on areas of Agents from 0 to the maximum potential area. This is intending to be unconstraining.
Note - the industrial, urban etc water uses are now constrained by becoming Agent Types, which must have fixed areas. They are set up so that their system capacity doesn't change in any scenarios, although this can be altered.
Note - UserType = 1 is the productive land uses
Note - Source =1 is Surface water, Source = 2 is Groundwater

NOTES

*1 Will need to overirde the NlossminPerc for grapes to ZERO - this is landuse 4 in climate zones
*2 red1. Read in Land use to based reduction calculation on from "contstraints editable.csv" - constraint name: Red_Moari SEE BELOW FOR CALC
*3 red2. Read in Land use to based reduction calculation on from "contstraints editable.csv" - constraint name: Red_LUC_LU SEE BELOW FOR CALC
*4 whether you take the max, the mean or just the first value is unimportant - AccFMU values are just repeated for all agents within the FMU
*5 SW-Maori - red1% of sum of baseline SW allocation for Maori = 0 divided by sum of Area[Maori==1and Irri==1 and Source ==1)
*6 GW_Maori (l/s/ha) - red1% of sum of baseline GW allocation for Maori = 0 divided by sum of Area[Maori==1 and Irri==1 and Source ==2)

Calculating RED1
Determine water requirements for (irrigable) maori land in catchment to have prescribed land use (set at Dairy currently)
See if requirements can be accomodated by making all users reduce their syscap (limited to minimum sys caps)
If Yes to above - then allocate Maori land Area x sys_cap*red1 and other water users Alloc*red1
If there is not enough water, preferentially give water to the maori land to achieve desired land use at minimum allowable syscap.

Calculating RED2
Determine the water requirements if all land within the catchment was set to the desired land use
red2=water requirements/baseline allocation
allocate all land: Area*sys_cap[ludesired)*red2
See if requirements can be accomodated by making all users reduce their syscap (limited to minimum sys caps)
if yes, Sys_cap=Sys_cap[lu]*red2
if not, Sys_cap=min(Sys_cap[lu])

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A10 Model simulations

Following the preparation of the spatial datasets to form agents, an allocation of water (based on either consents or irrigated area) and an allocation of nutrients (based on lookup tables from Aqualinc) were assigned to model agents. Constraints were calculated for each policy scenario based on the details given within the body of the report and Table 4. Optimisations were performed for each model run (combinations of catchments and groundwater FMUs that required simultaneous solution, but generally sea-draining catchments) for all scenarios of interest.

Following the completion of all the simulation runs a series of tests and checks were completed to ensure that the assigned constraints were complied with and that sums of area and total allocation were consistent with baseline information.

The following sections provide some specific technical details about the model optimiser, which is described more generally within the main report.

A10.1 Scaling of Variables

The scaling of model variables is an extremely important consideration in almost all optimisation modelling. The scaling of variables can have adversely affect the number of iterations performed, the accuracy of the solution, and whether a solution can be found at all.

In all the example runs investigated, scaling of the profit parameters and nutrient loss variables and constraints provided improved run time, and in some cases a higher value of total profits, indicating an improvement in the determined optimal solution. The scaling factors of 10000 for each variable or constraint appeared to produce modest to rapid speedups in finding a solution.

Particular care must be taken to ensure that through the application of scaling factors, the output results are only altered by the chosen scaling factors. If the results alter in a way not proportional to the scaling factors, this is likely a sign of an error and some variables have either not been scaled, or incorrectly scaled.

Note that it is possible for the scaling factors to allow for a larger optimal value or total overall profit, in which case the parameters will not change with the scaling factors exactly. However, for a reasonably small change in the scaling factors there would likely be no improvement in the solution, so the objective value and relevant parameters/calculated values should only change in a manner consistent with the relevant scaling factors.

A10.2 Specification of starting values

The behaviour of the solver, its ability to find a solution and the value of the solution can be dependent on the start points which are selected. These correspond to the initial variable values for land, proportion of nutrient loss and system capacity. If altering the starting point produces a higher or lower value, it is indicative that the solver is effectively finding a local maximum as opposed to the global maximum.

One could only vary the starting values and take the highest value which results from this process. This could allow for the exploration of different local and possibly the global optimal solutions, but there would be no guarantee that the global maximum value has been discovered. It may also be useful to alter the starting values in the case where a solution could not be found due to reasons of poor convergence.

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A10.3 Notes on Constraints

Should any of the optimisation runs fail to solve, it may be worth looking at the relaxation of the either the distance indicator constraints and the land change max constraint. These could address a scenario where the model is requiring too many iterations to converge (likely due to non-linearities, or scaling) or the constraints are simply infeasible.

The key constraints to relax, or remove if failure to solve occurs:

- lu_run_change_max - Desirable. Look to relax/remove if failure to solve occurs
- catch_dist_quant - Desirable. Look to relax/remove if failure to solve occurs
- catch_dist_qual - Desirable for quality simulations. Look to relax/remove if failure to solve occurs

These constraints display the most complex and nonlinear behaviour. The remaining constraints are likely to be needed, and desirable to retain.

A10.4 Error Log:

The error log provides some high-level error messages should a component of the model fail.

- 'Error: could not import model inputs': this implies that the data could not be read in and processed correctly. It could be an issue with one of the column headers being mislabelled, inconsistent data or invalid data types.
- 'Error: model failed to initialise, continuing to next run': this implies that the model could not be constructed from the data. This may be a subtle issue with the data, perhaps missing values for constraints or profit function coefficients.
- 'Error: model failed to solve, there was an error in Ipopt': this indicates that a solution could not be found, and an error has occurred in the underlying solver.
- Error: error in producing the result output files: this indicates that the output files could not be constructed. This should only occur if there is an error in the solver, so not all of the required data will be returned and therefore the result and constraint files cannot be output.

If the model fails in the results output stage, no results or constraint files will be output, this should typically only occur due to an error in one of the previous stages.

In addition to this, there are three solver diagnostics which will be printed out at each run.

- Solver status – indicates if an error has occurred.
- Solution status – will indicate if a maximum has been found. (Can also print out unknown, but disregard this it will be a maximum)
- Termination condition – indicates the condition for which the solver has stopped running. Usually will be optimal, indicating an optimal solution has been found. Another common condition is maximum iterations reached – i.e. a solution could not be found before reaching the maximum number of iterations.

A10.5 Solver references, documentation, and webpages:

Ipopt + algorithm reference:

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A. Wächter and L. T. Biegler, On the Implementation of a Primal-Dual Interior Point Filter Line Search Algorithm for Large-Scale Nonlinear Programming, Mathematical Programming 106(1), pp. 25-57, 2006

Pyomo references:

Hart, William E., Jean-Paul Watson, and David L. Woodruff. "Pyomo: modelling and solving mathematical programs in Python." Mathematical Programming Computation 3, no. 3 (2011): 219-260.

Hart, William E., Carl D. Laird, Jean-Paul Watson, David L. Woodruff, Gabriel A. Hackebeil, Bethany L. Nicholson, and John D. Siirola. Pyomo – Optimization Modeling in Python. Second Edition. Vol. 67. Springer, 2017.

Metaheuristics paper

H.R. Maier, Z. Kapelan, J. Kasprzyk, J. Kollat, L.S. Matott, M.C. Cunha, G.C. Dandy, M.S. Gibbs, E. Keedwell, A. Marchi, A. Ostfeld, D. Savic, D.P. Solomatine, J.A. Vrugt, A.C. Zecchin, B.S. Minsker, E.J. Barbour, G. Kuczera, F. Pasha, A. Castelletti, M. Giuliani, P.M. Reed, Evolutionary algorithms and other metaheuristics in water resources: Current status, research challenges and future directions, In Environmental Modelling & Software, Volume 62, 2014, Pages 271-299

(http://www.sciencedirect.com/science/article/pii/S1364815214002679)

Ipopt (solver) documentation:
http://web.mit.edu/ipopt_v3.11.6/doc/documentation.pdf
https://projects.coin-or.org/Ipopt

Pyomo (optimisation modelling interface) documentation:
https://software.sandia.gov/downloads/pub/pyomo/PyomoOnlineDocs.html
http://www.pyomo.org/

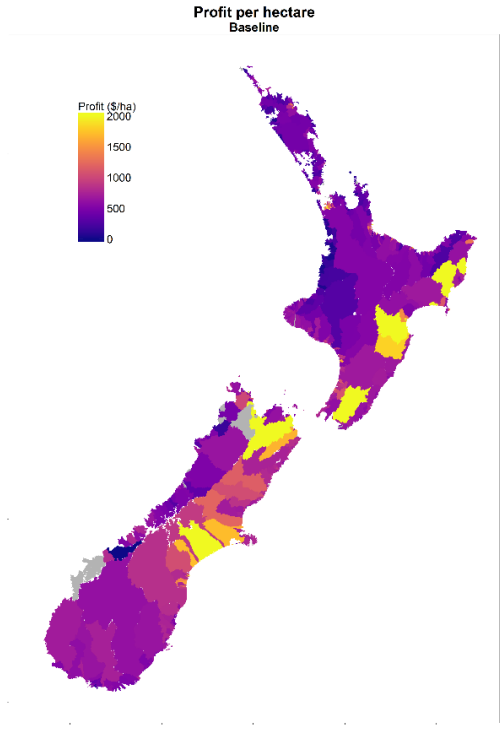
A11 Supplementary Results

The combined outputs amount to more than 800,000 rows of data with 40+ columns. The possibilities for exploring the results are numerous. One effective way of presenting the information is plotting spatially. We explored a variety of ways of presenting the outputs in map format. We considered both a range of spatial units (geographic and regular), as well as alternatives for classifications or continuous representations of the variables. A comparison of alternative hexagon grid sizes is provided in Appendix E.

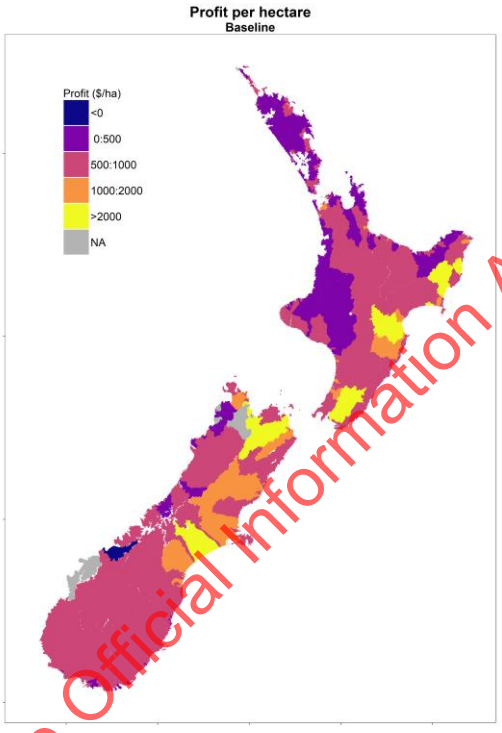
As an example, the exact same dataset (baseline profit per hectare) is plotted in Figure 16, using a Catchment or 25km hexagon spatial scale and with either a continuous or discrete colour scale. Both the continuous colour scale and the catchment spatial scale present a danger that interpretations might be made and conclusions reached that are beyond the degree of accuracy of the fundamental data. However, using a uniform grid and discrete scale requires some discretionary decisions to be made about appropriate spatial scales and colour scale break points – both of which can significantly impact on the immediate appearance of the data presented, and if not chosen subjectively could also lead to misinterpretations. The selection of an appropriate mapping schema will be largely dependent the information that is trying to be conveyed. Following discussions with MFE, it was decided that a 25km hexagon with a 25% inclusion threshold (i.e. a grid cell must be at least 25% filled to plotted) would be used as a regular grid to display the data. A further threshold that each hexagon should only

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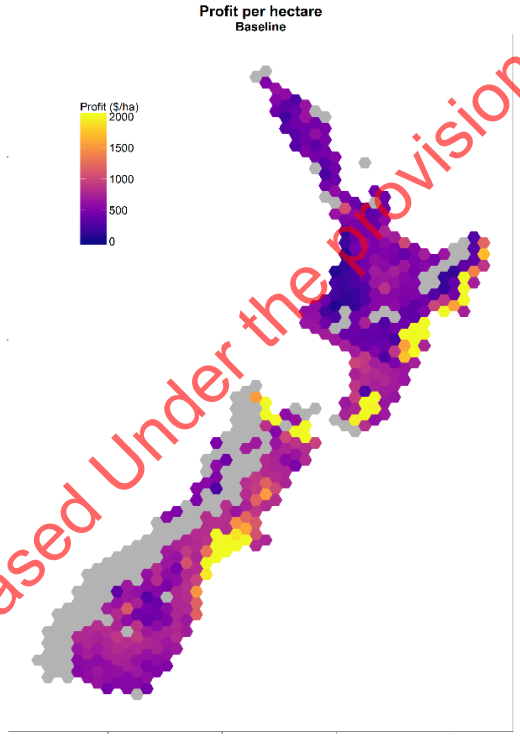
be plotted if it had more than 25% area of active agent cells was also included (although this was not applied for mapping Māori land scenarios.



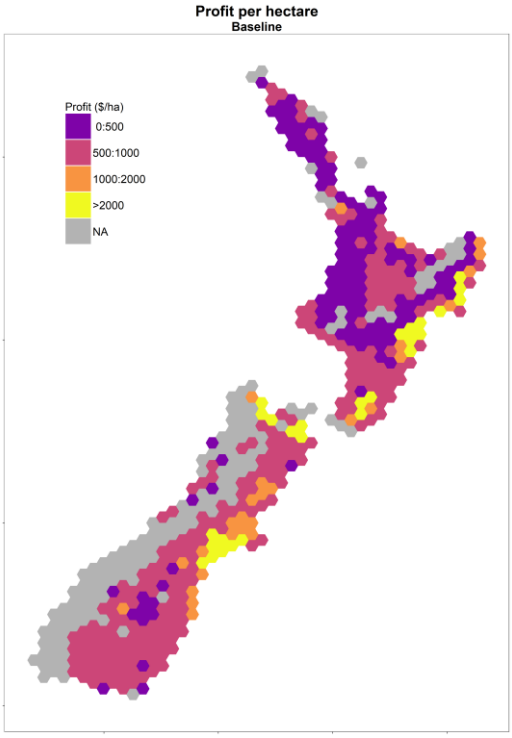
(a) Units: Catchment; Scale: Continuous



(b) Units: Catchment; Scale: Discrete



(c) Units: 25km Hex; Scale: Continuous



(d) Units: 25km Hex; Scale: Discrete

Figure 16: Comparison of spatial scale and colour scale alternatives

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A11.1 Mapped Variables

Results have been mapped for each scenario for the variables listed in Table 5, for both all land areas and for only Maori owned land, and are presented in the following sections.

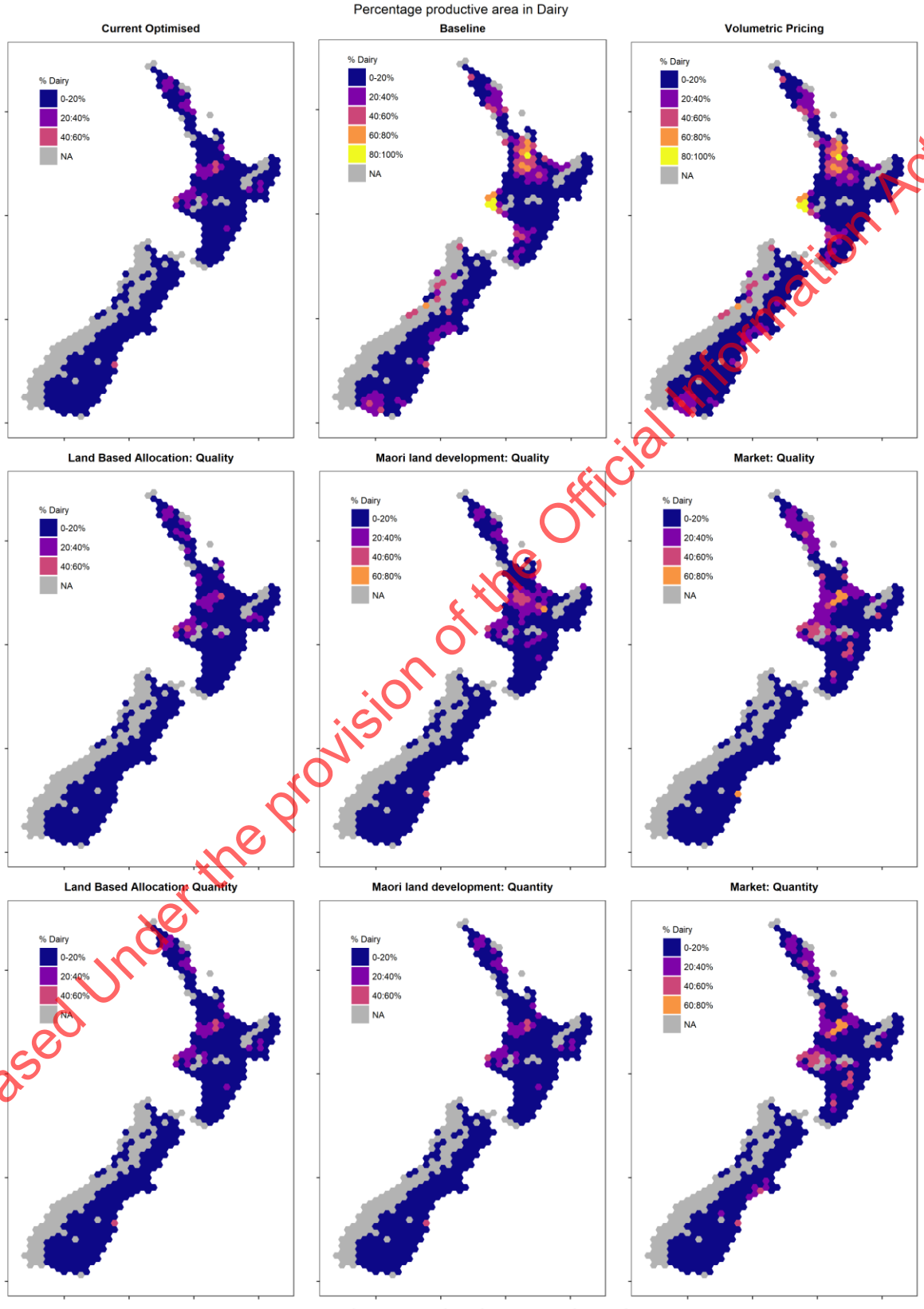
Table 5: Mapped Results variables

Variable Name	Description
% Dairy	Percentage productive area in Dairy
% Sheep and Beef	Percentage productive area in Sheep and Beef
% Horticulture	Percentage productive area in Horticulture
% Arable	Percentage productive area in Arable
% Forestry	Percentage productive area in Forestry
Weighted S.D. ($/ha)	Area weighted Standard deviation of agent profit/ha
Weighted S.D. of change in profit	Area weighted Standard deviation of change in profit/ha
Profit ($/ha)	Profit per hectare
Change in Profit ($/ha)	Change in profit per hectare
% Change in Profit	Percentage change in profit
Allocation (l/s/ha)	Water allocation
Change in allocation (l/s/ha)	Change in water allocation
% Change in Allocation	Percentage change in water allocation
N loss/ha	Nutrient loss per hectare
Change in Nloss/ha	Change in nutrient loss per hectare
% Change in Nloss	Percentage change in nutrient loss per hectare
Profit 80:20	Ratio of 80th to 20th profit percentiles
Change in Profit 80:20	Change in ratio of 80th to 20th profit percentiles
Change in % Diary	Change in percentage productive area in Dairy
% Change in Dairy	Percentage change in Dairy
Change in % Sheep and Beef	Change in percentage productive area in Sheep and Beef
% Change in Sheep and Beef	Percentage change in Sheep and Beef
Change in % Horticulture	Change in percentage productive area in Horticulture
% Change in Horticulture	Percentage change in Horticulture
Change in % Arable	Change in percentage productive area in Arable
% Change in Arable	Percentage change in Arable
Change in Forestry	Change in percentage productive area in Forestry
% Change in Forestry	Percentage change in Forestry

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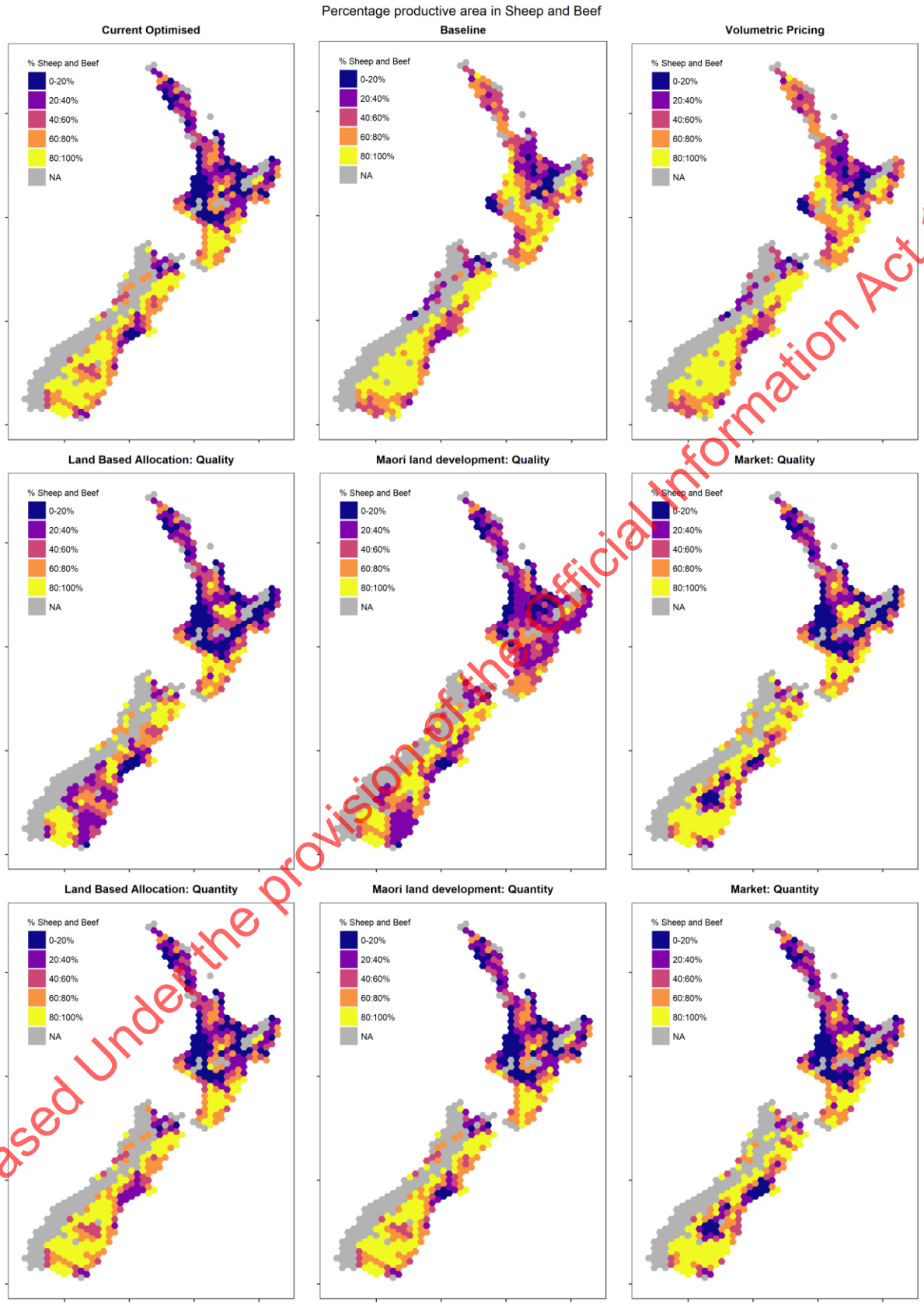
A11.2 Land Use Distribution

A11.2.1 All Land

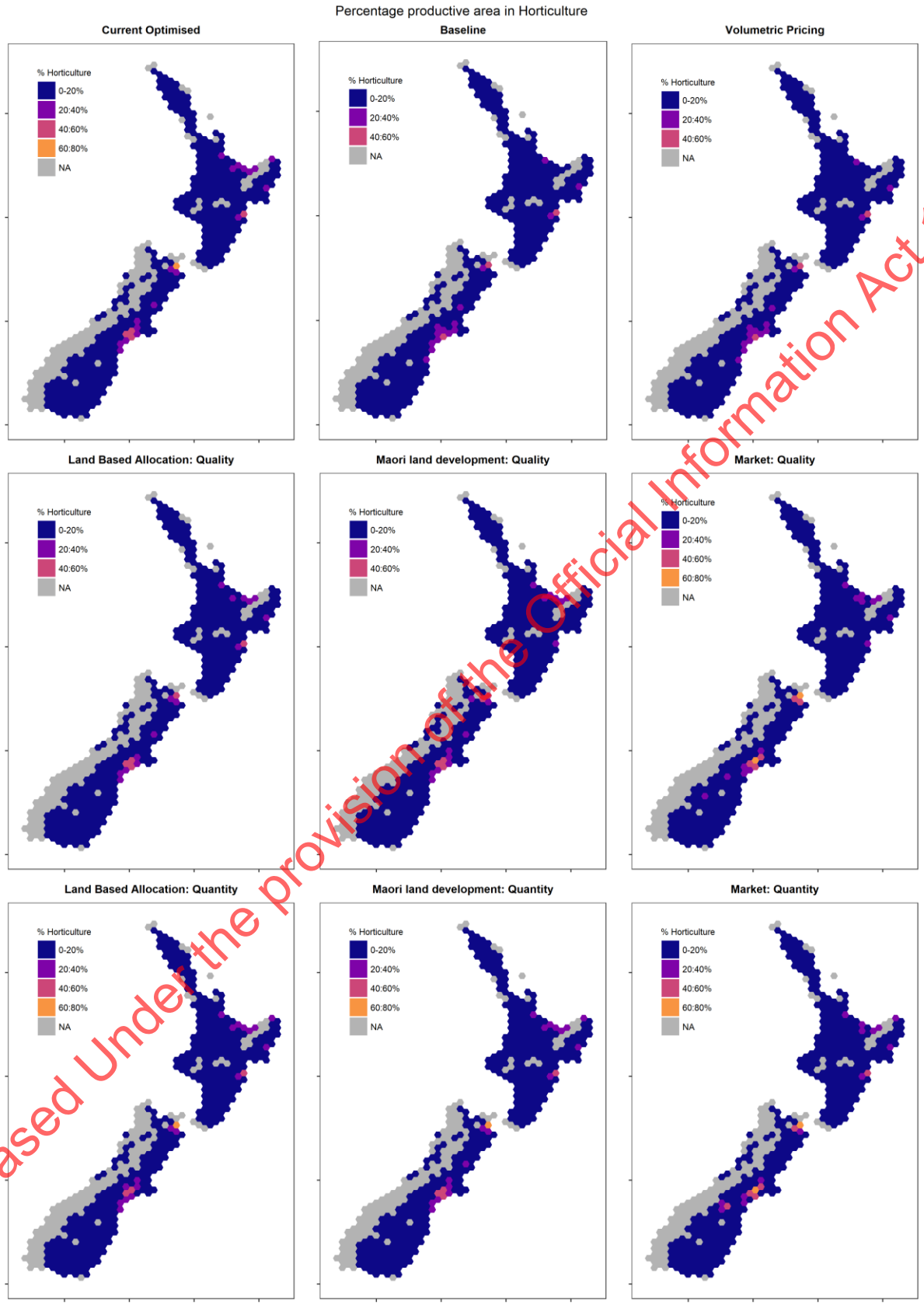


Data source: AllOutputs_0925_OnlyAGRagents_AgACcfix_AllSc2.csv

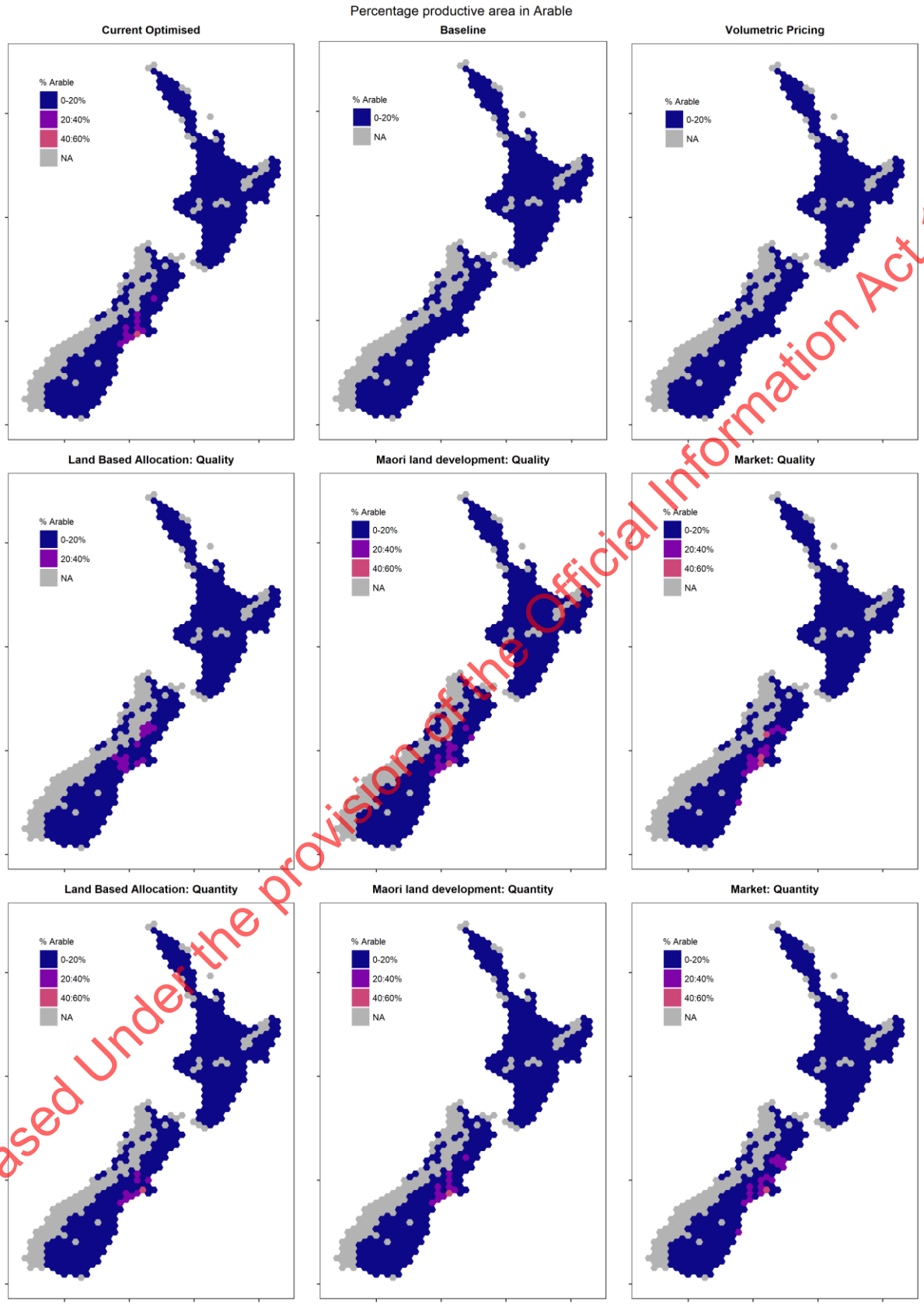
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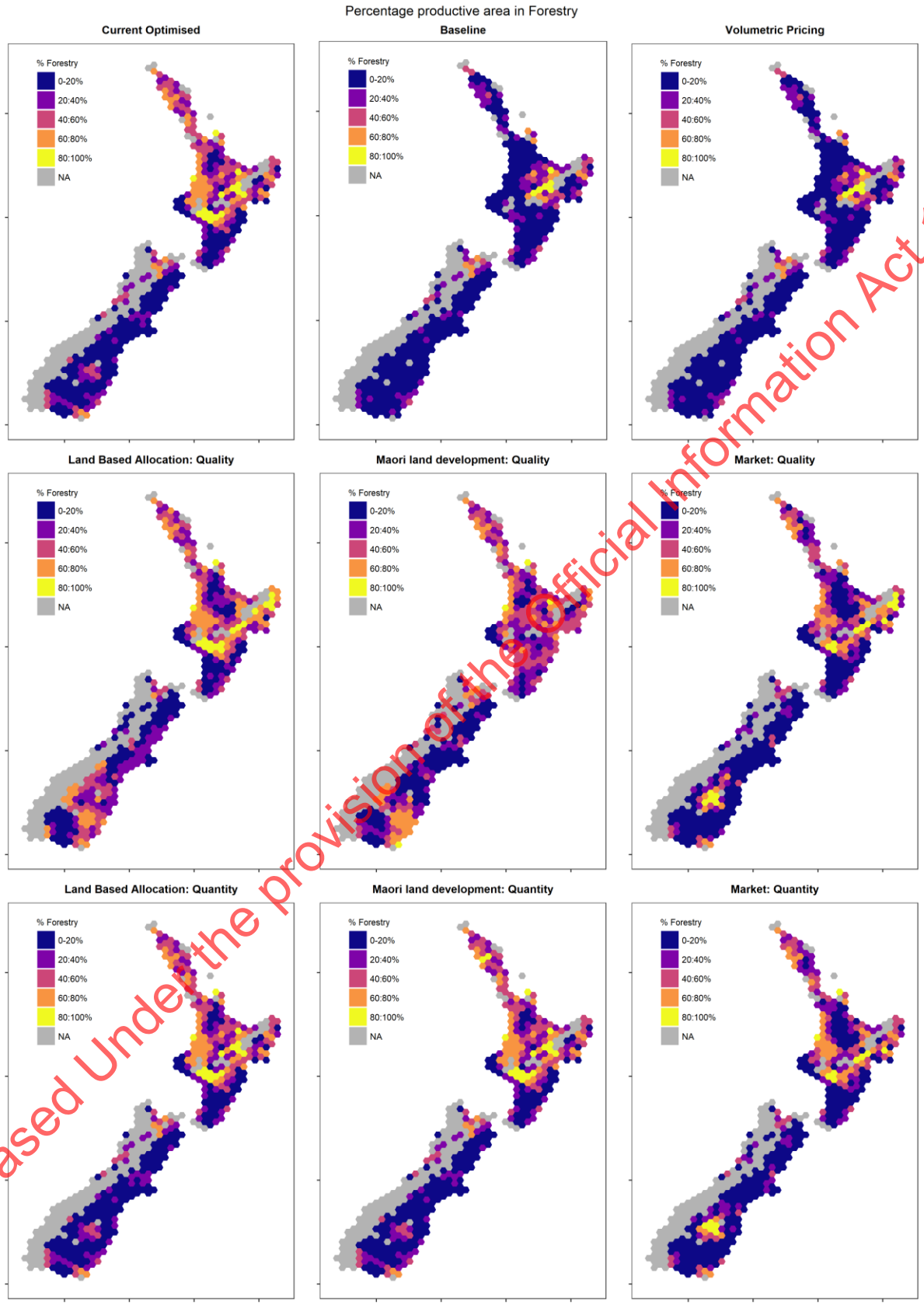
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Data source: AllOutputs_0925_OnlyAGRagents_AgACcfix_AllSc2.csv

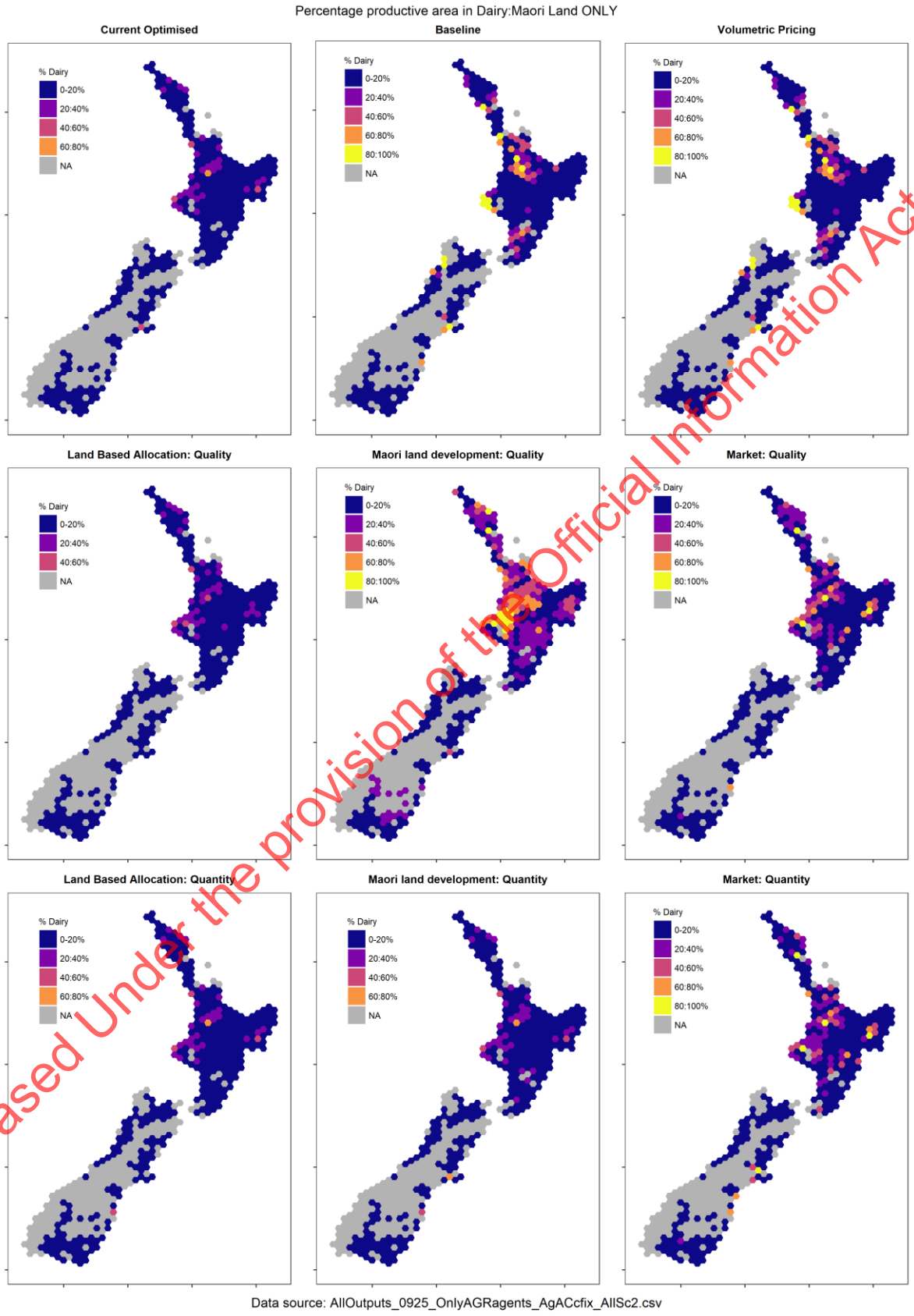
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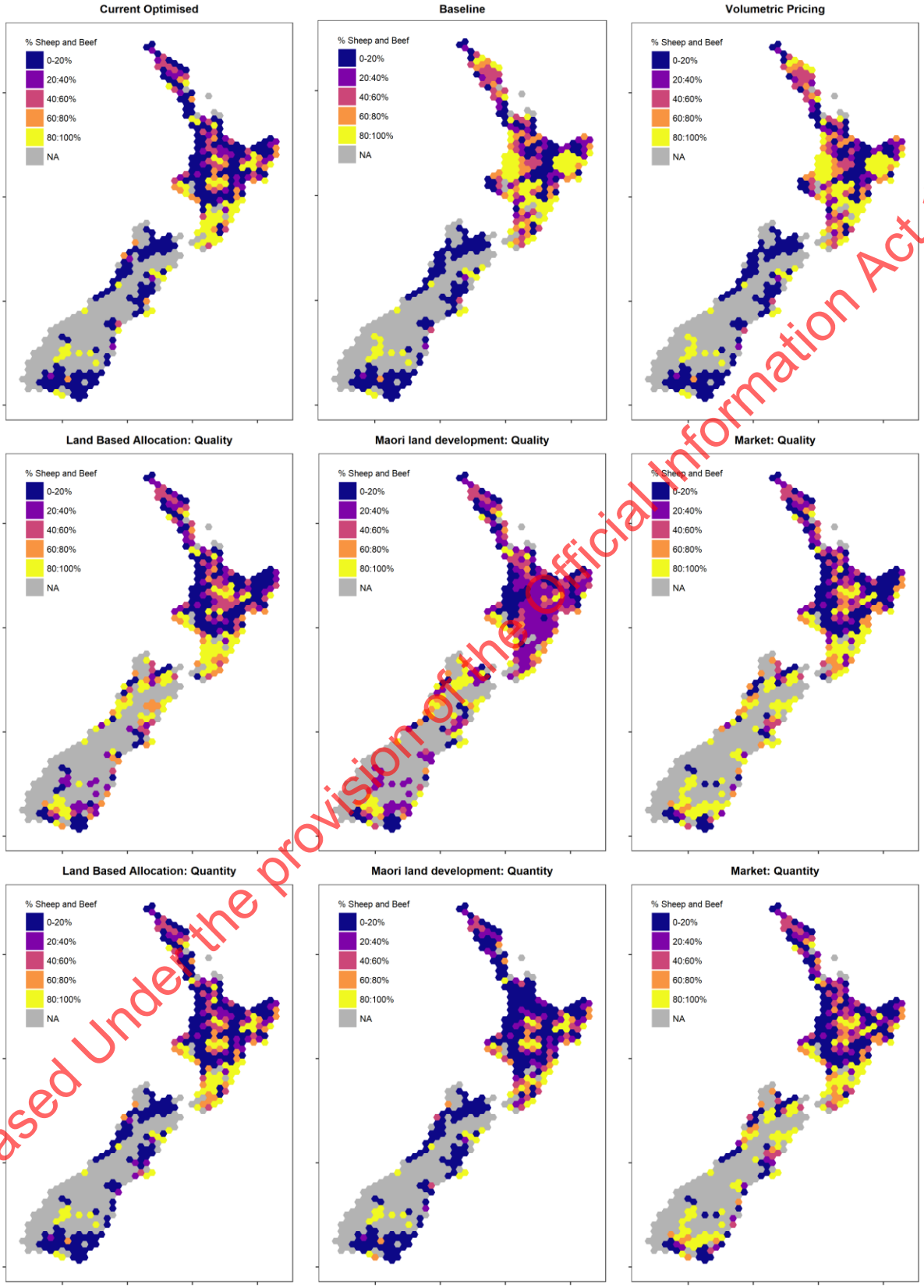
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A11.2.2 Maori Owned Land



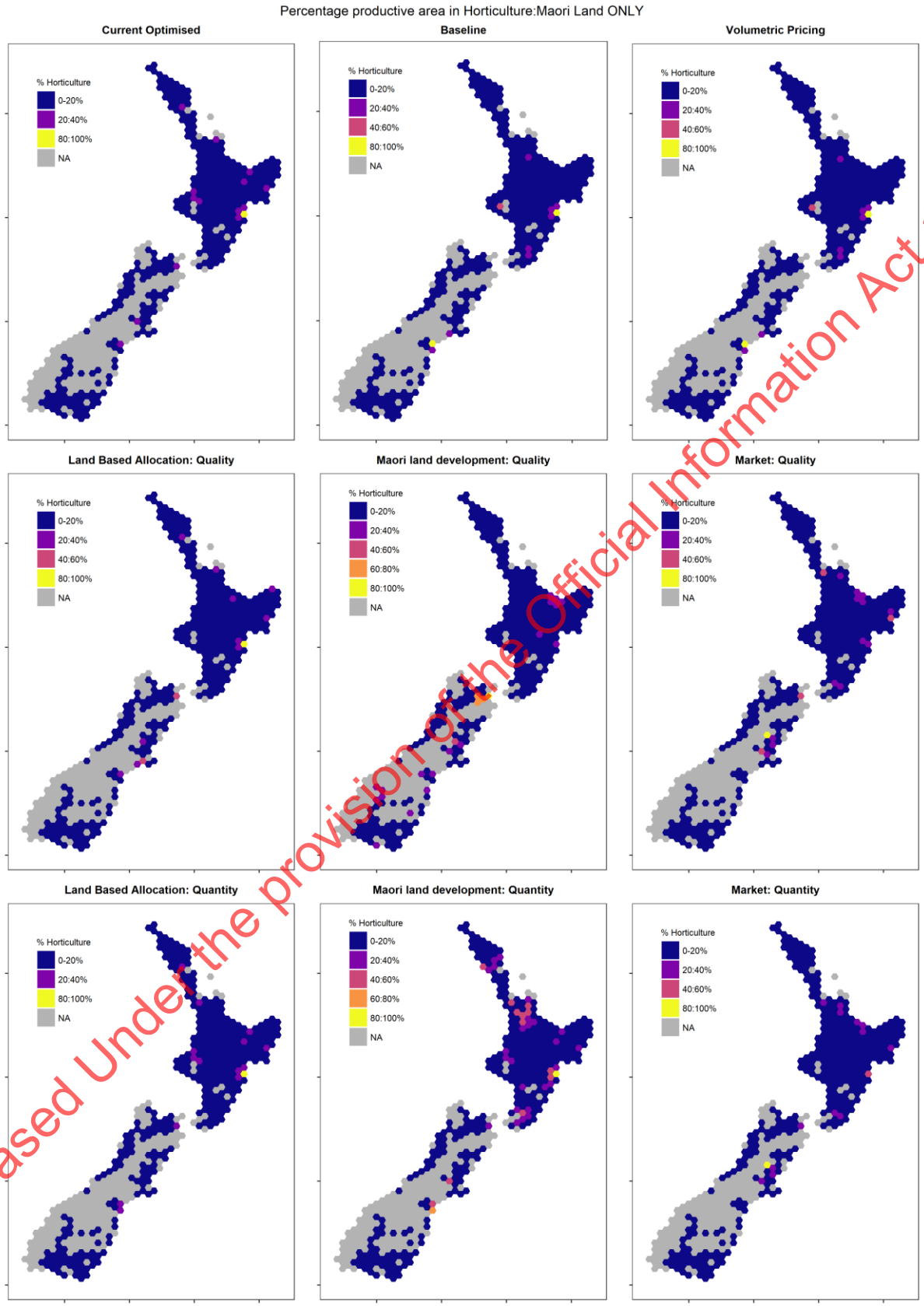
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Percentage productive area in Sheep and Beef:Maori Land ONLY

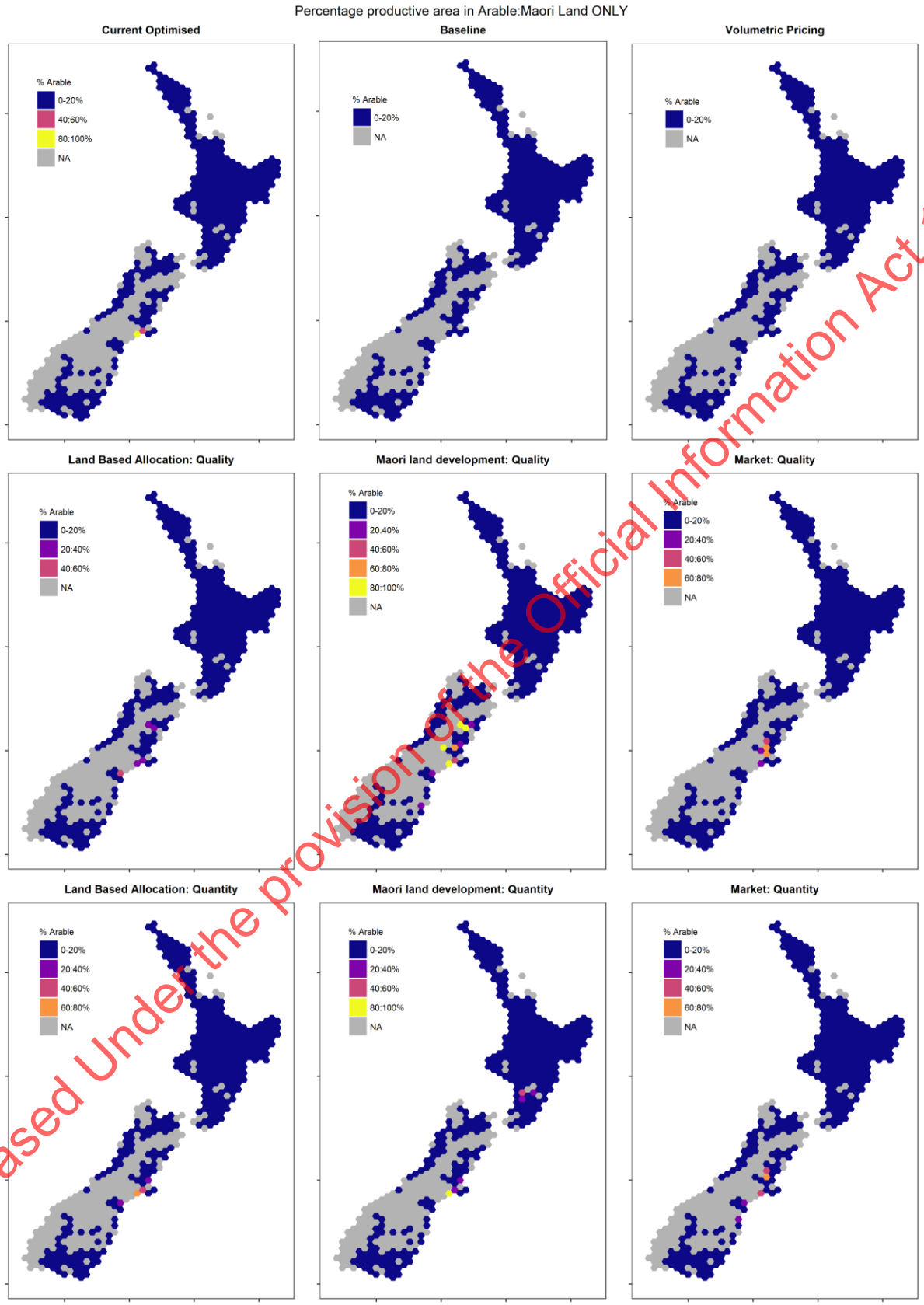


Data source: AllOutputs_0925_OnlyAGRagents_AgACcfix_AllSc2.csv

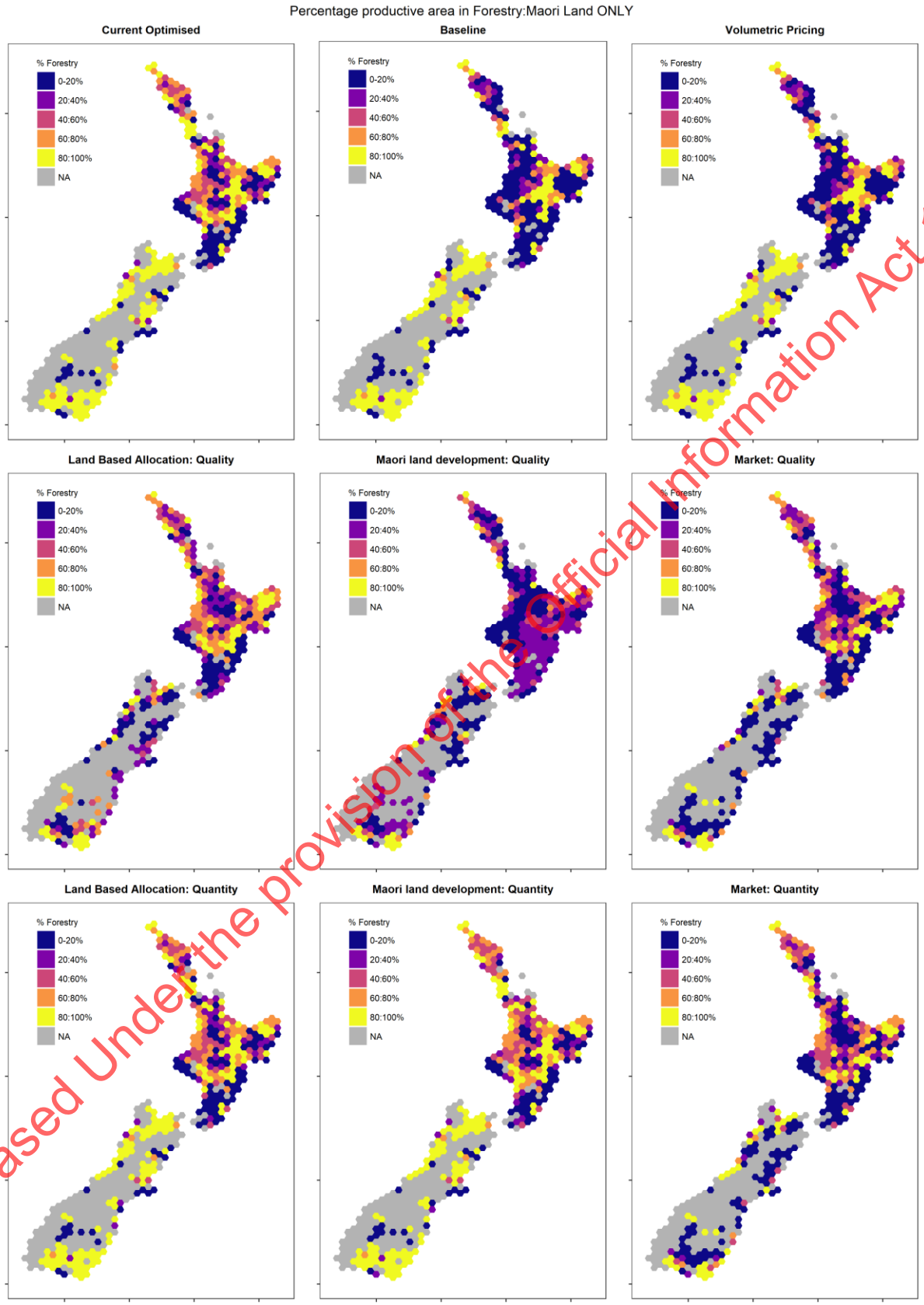
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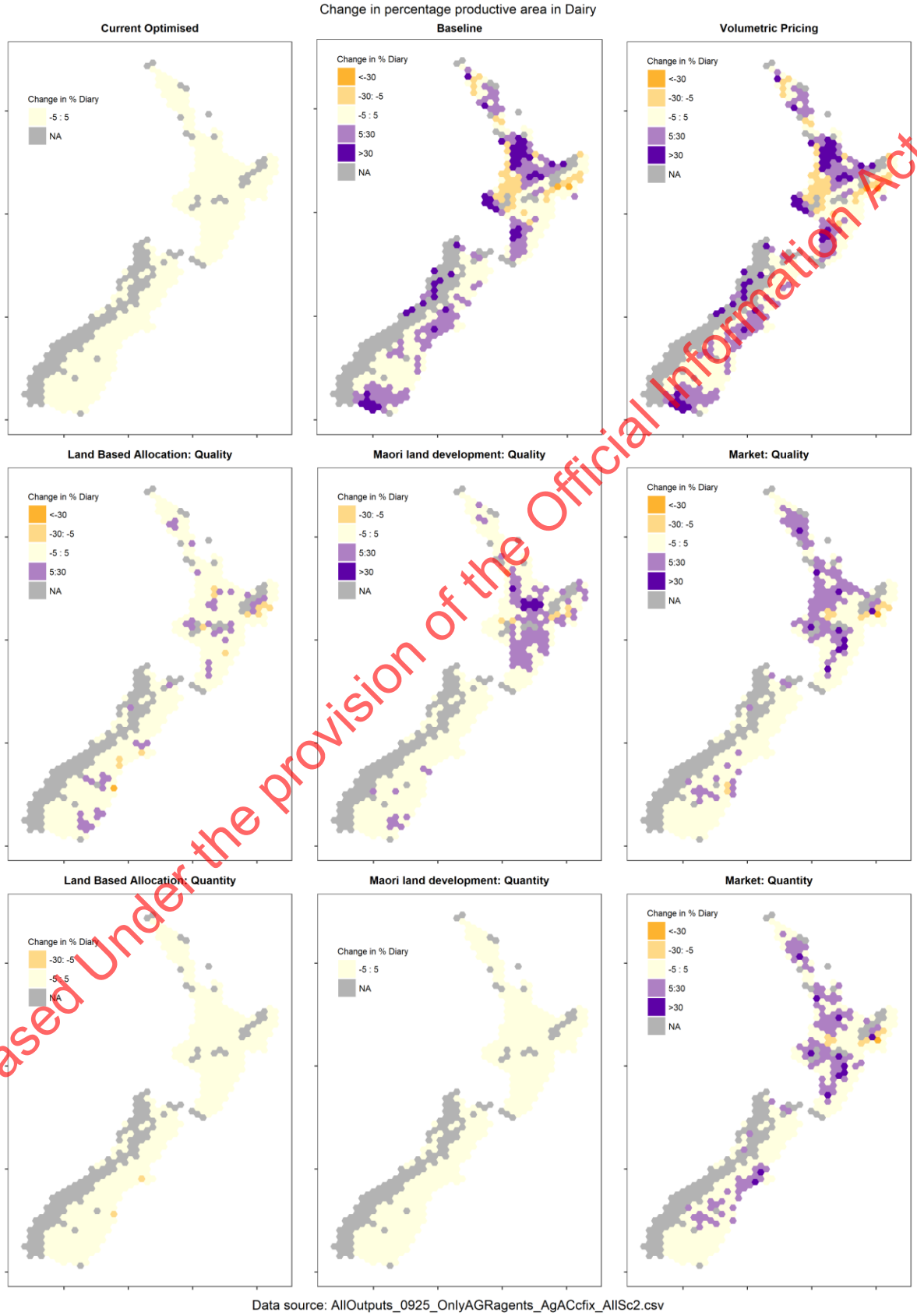
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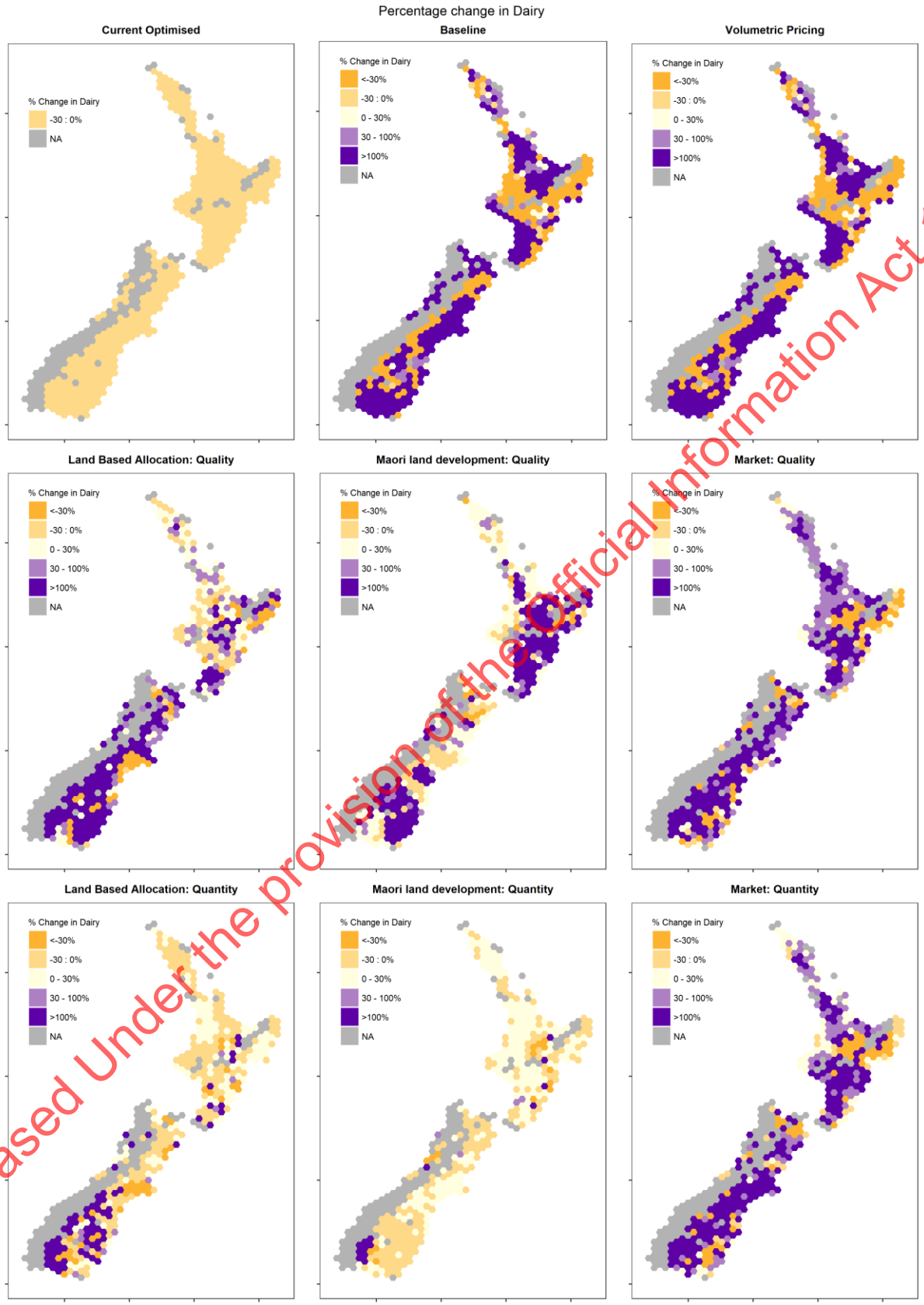
A11.3 Change in Land Use

A11.3.1 All Land

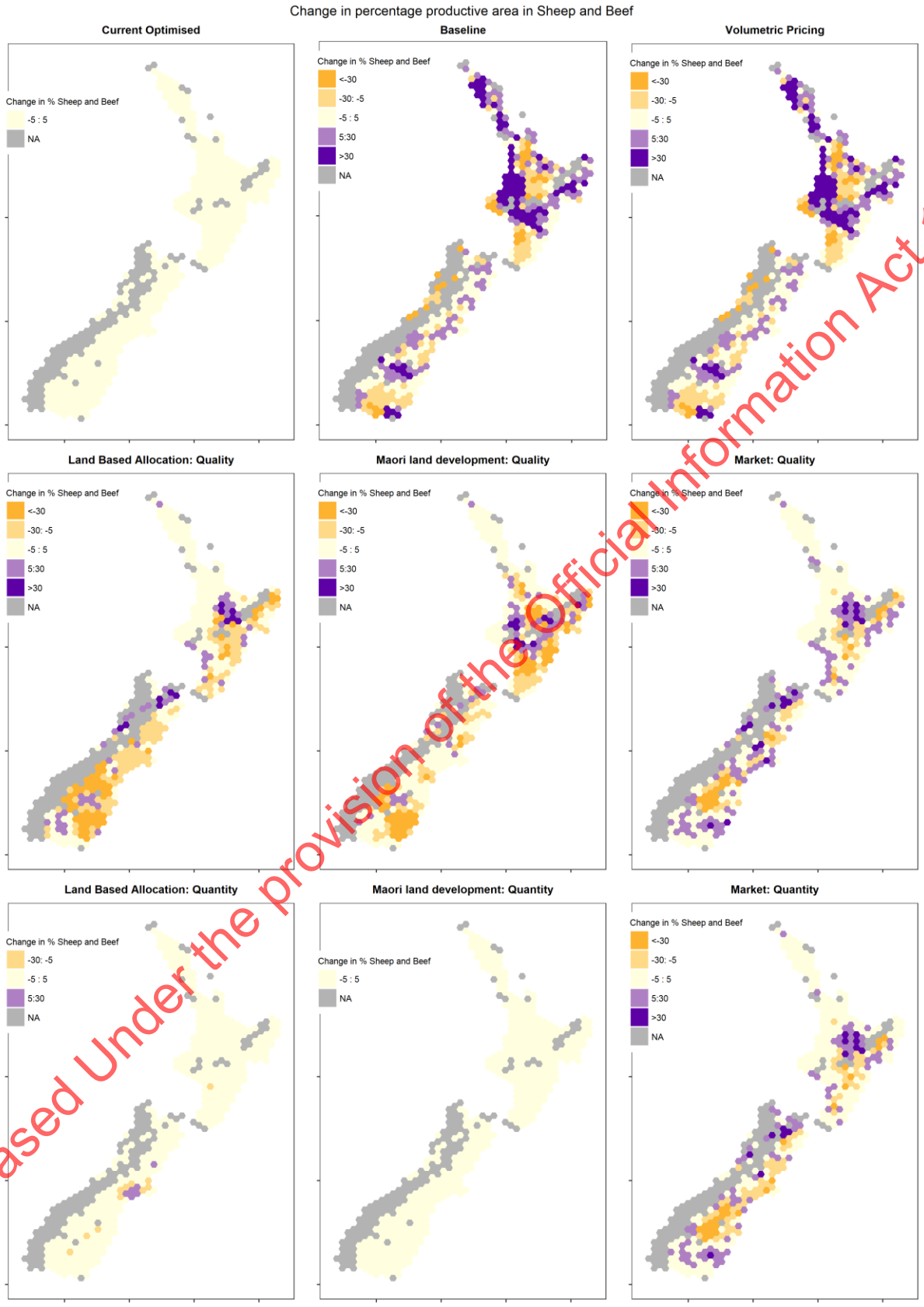


Data source: AllOutputs_0925_OnlyAGRagents_AgACcfix_AllSc2.csv

Released Under the provision of the Official Information Act 1982

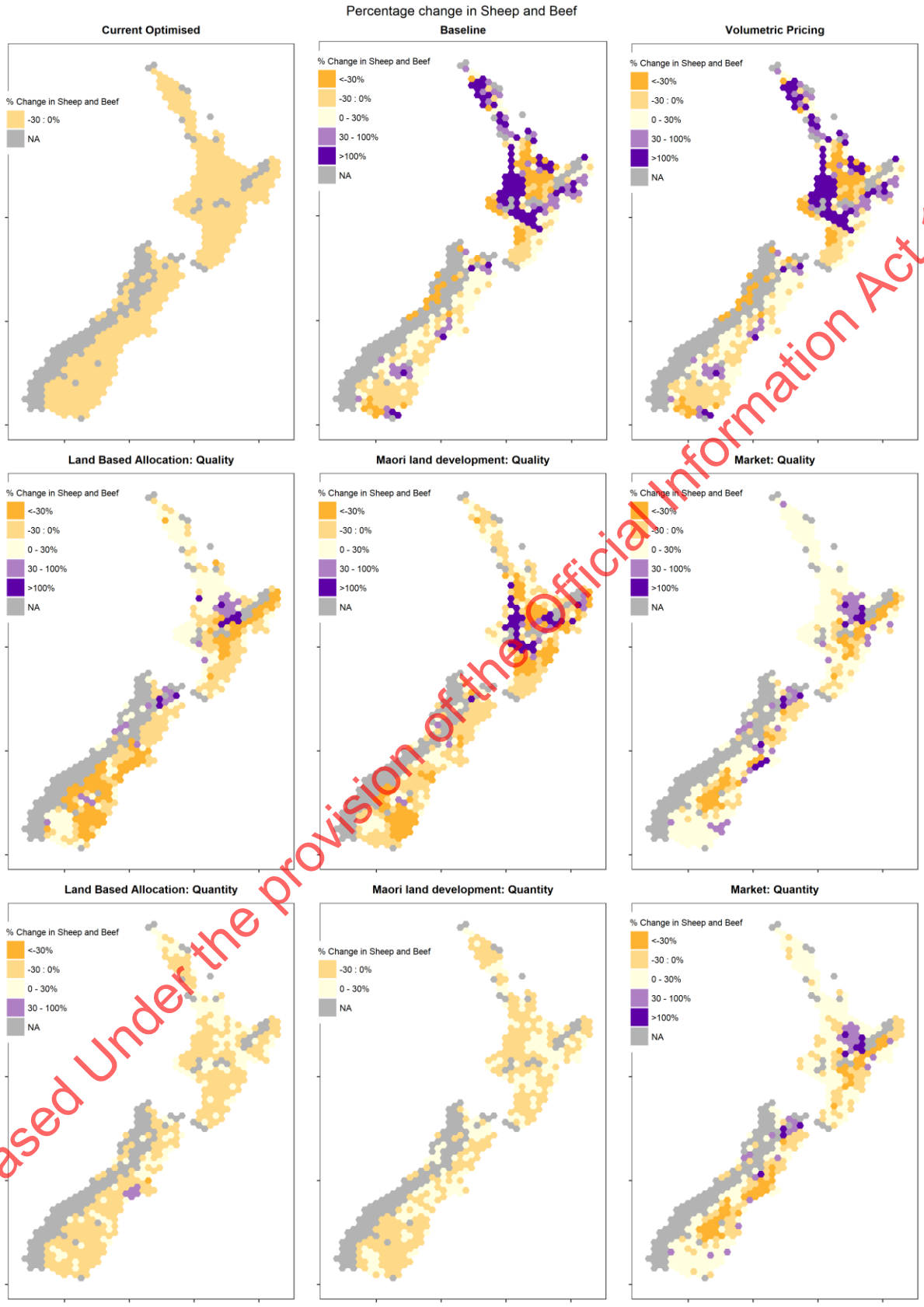


Released Under the provision of the Official Information Act 1982



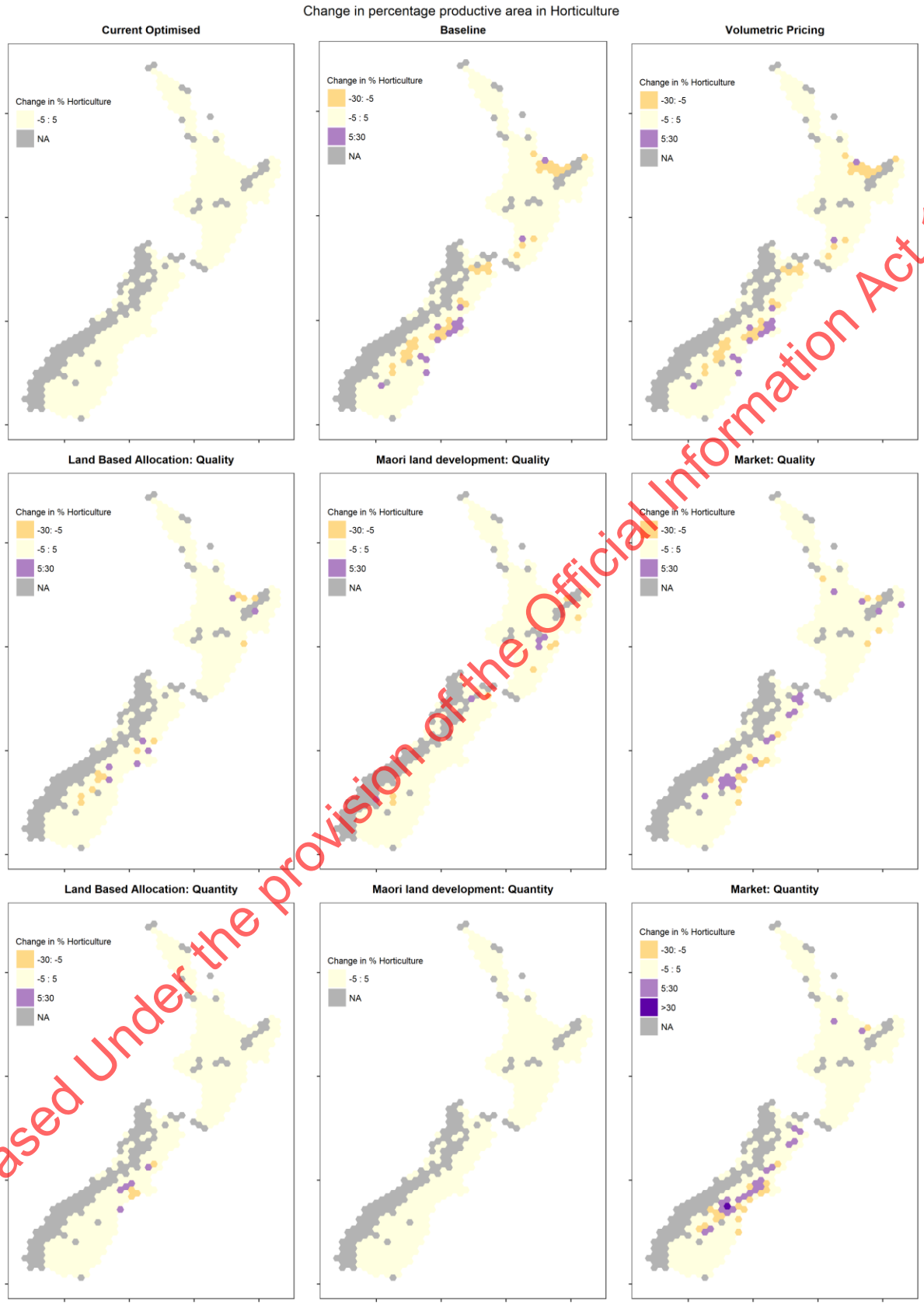
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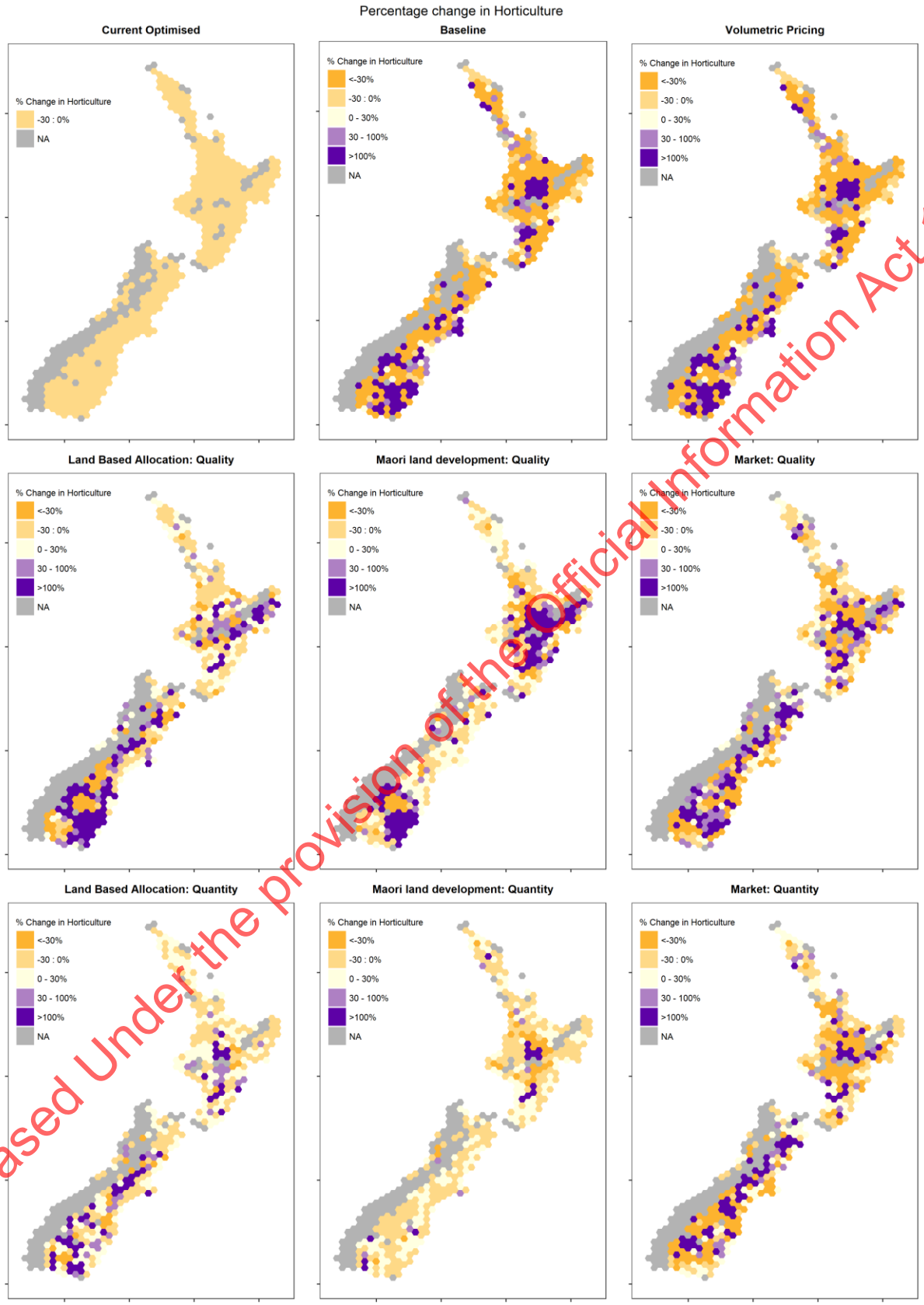


Data source: AllOutputs_0925_OnlyAGRagents_AgACcfix_AllSc2.csv

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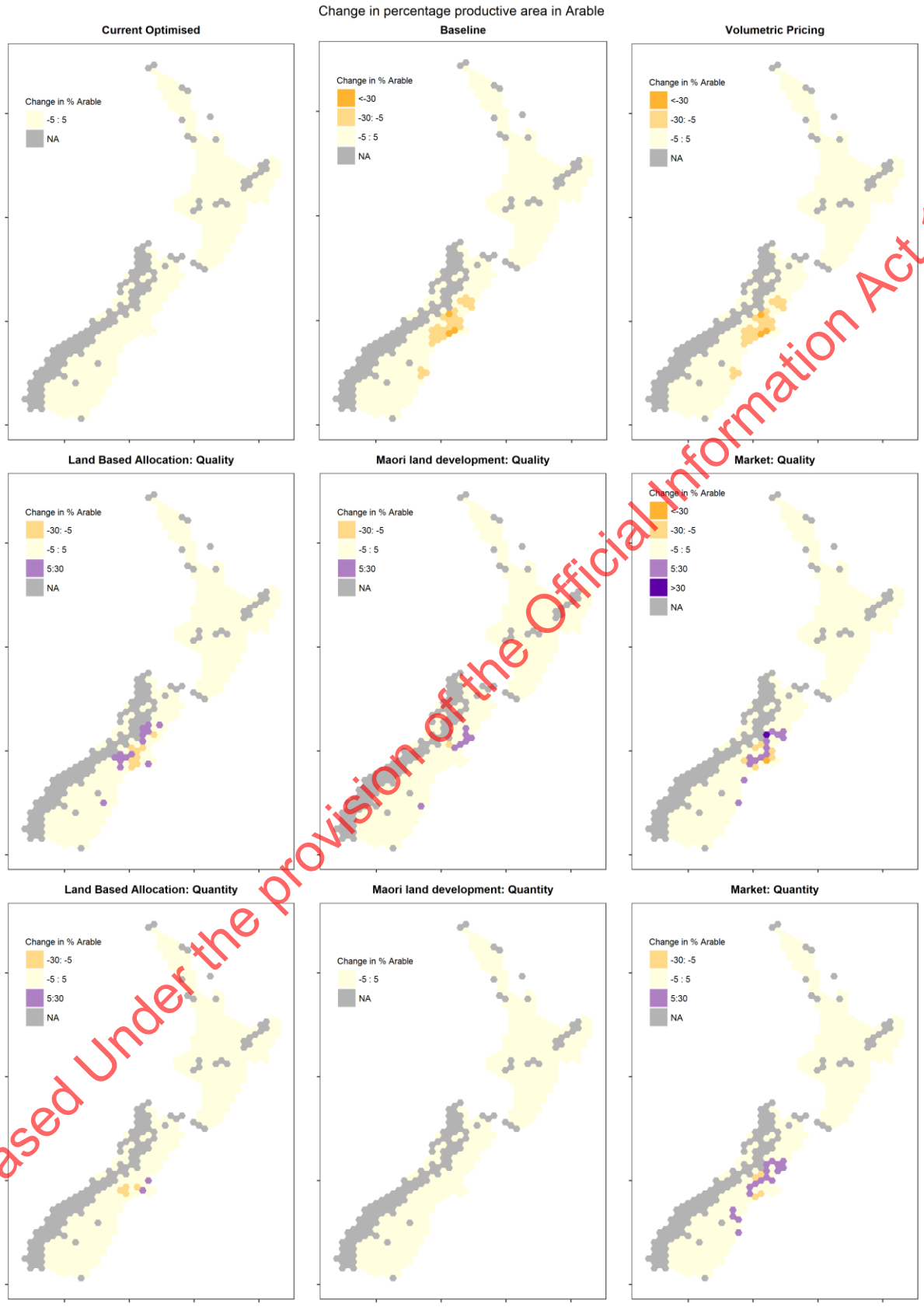


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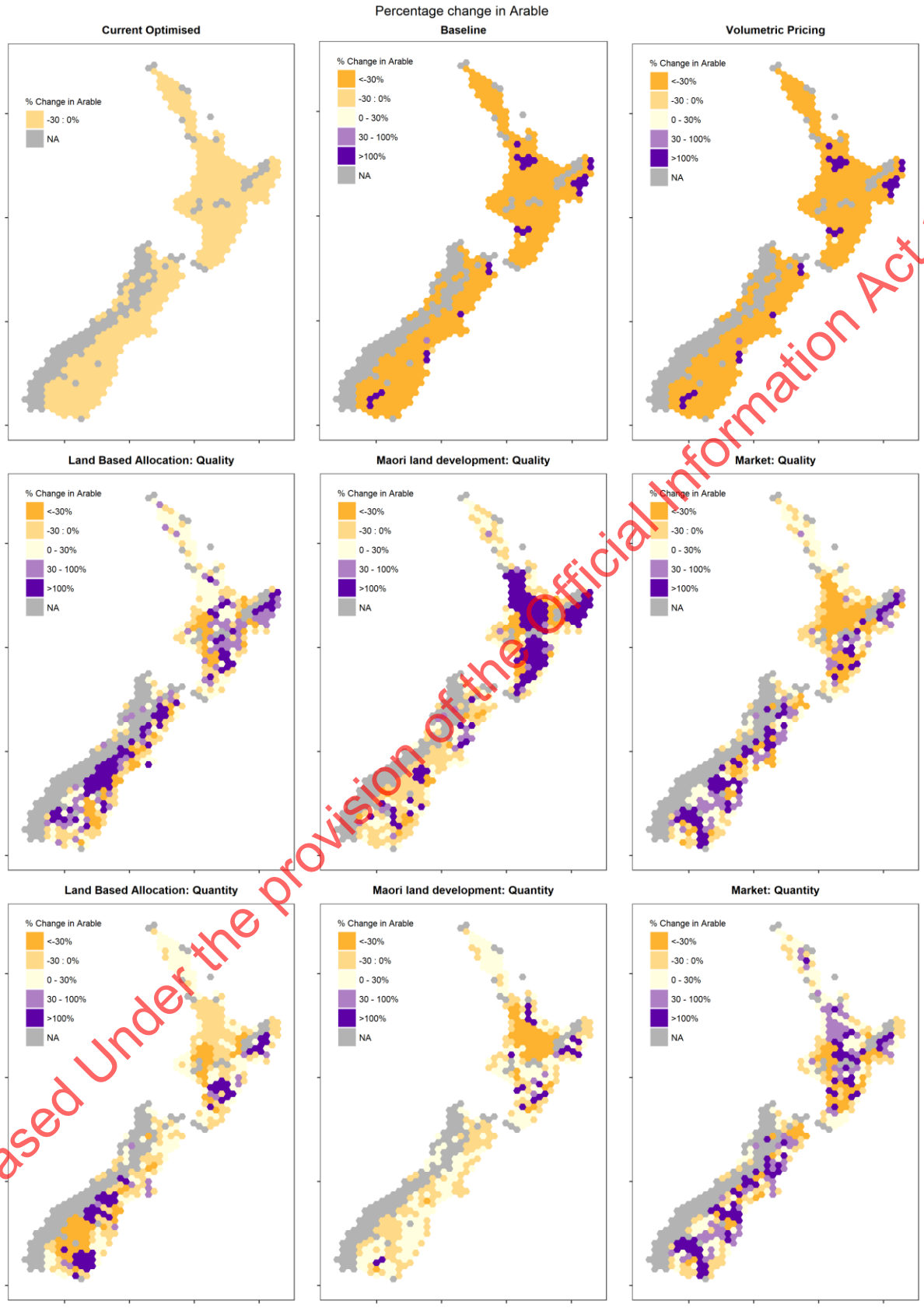
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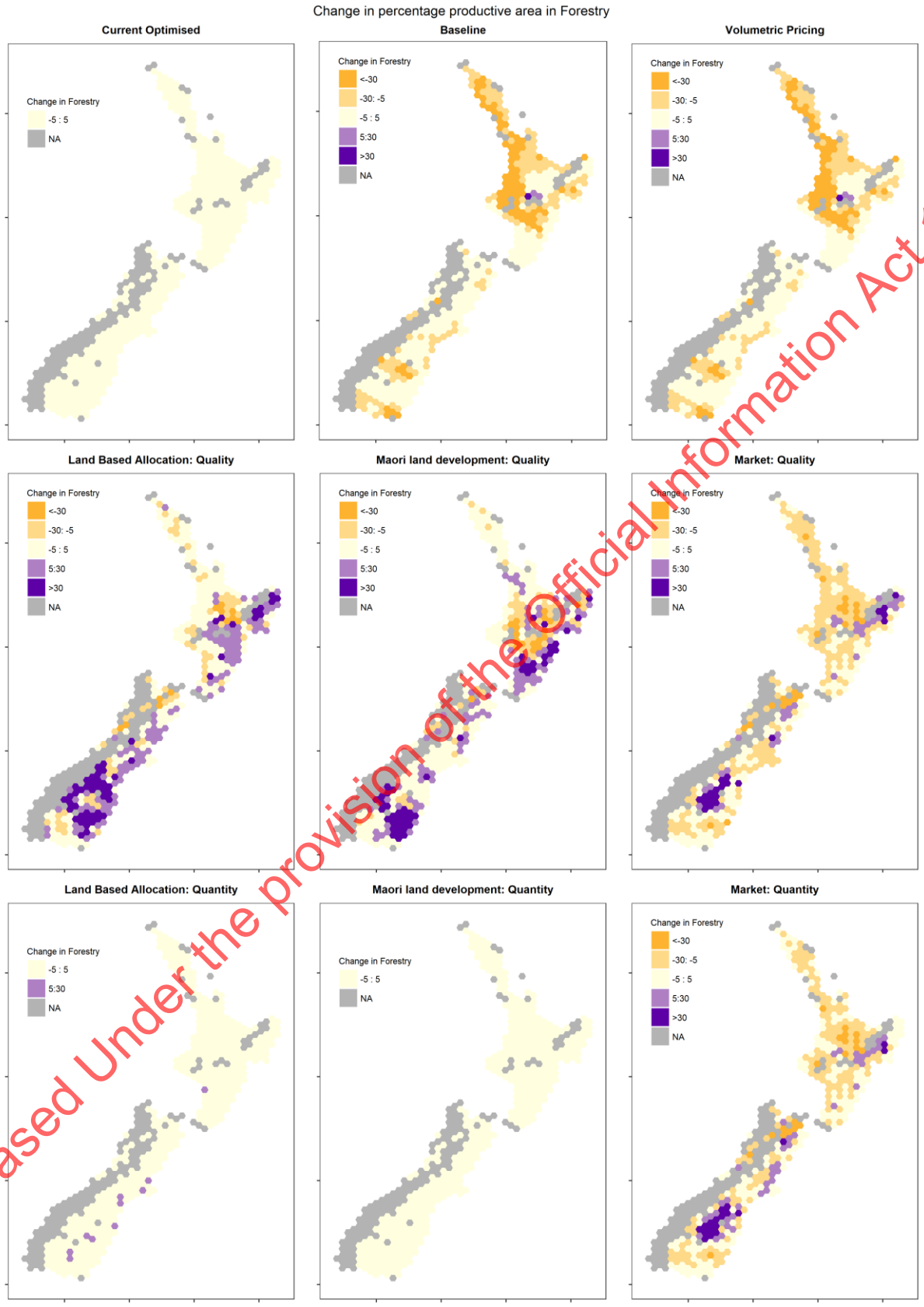
Released Under the provision of the Official Information Act 1982

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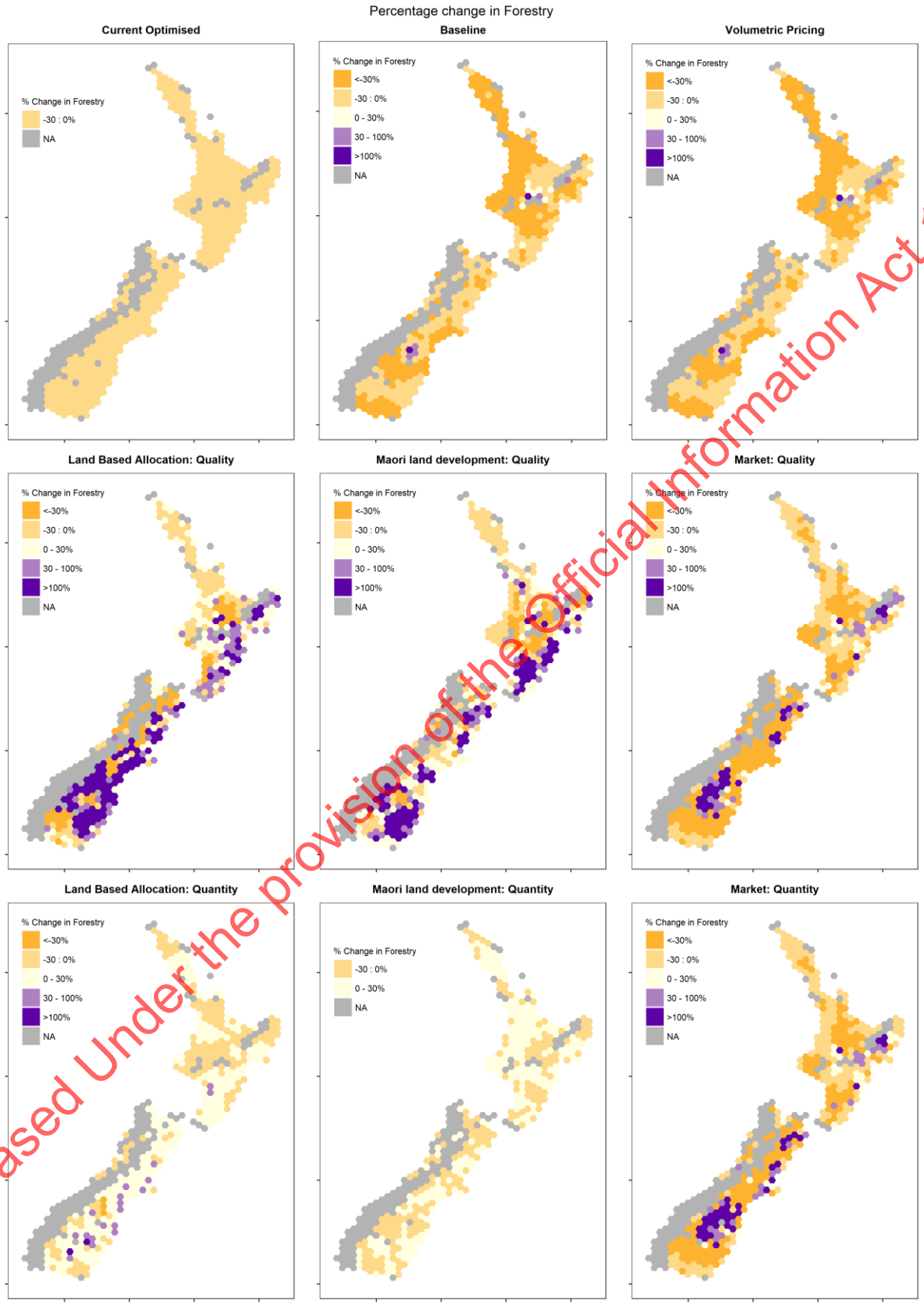
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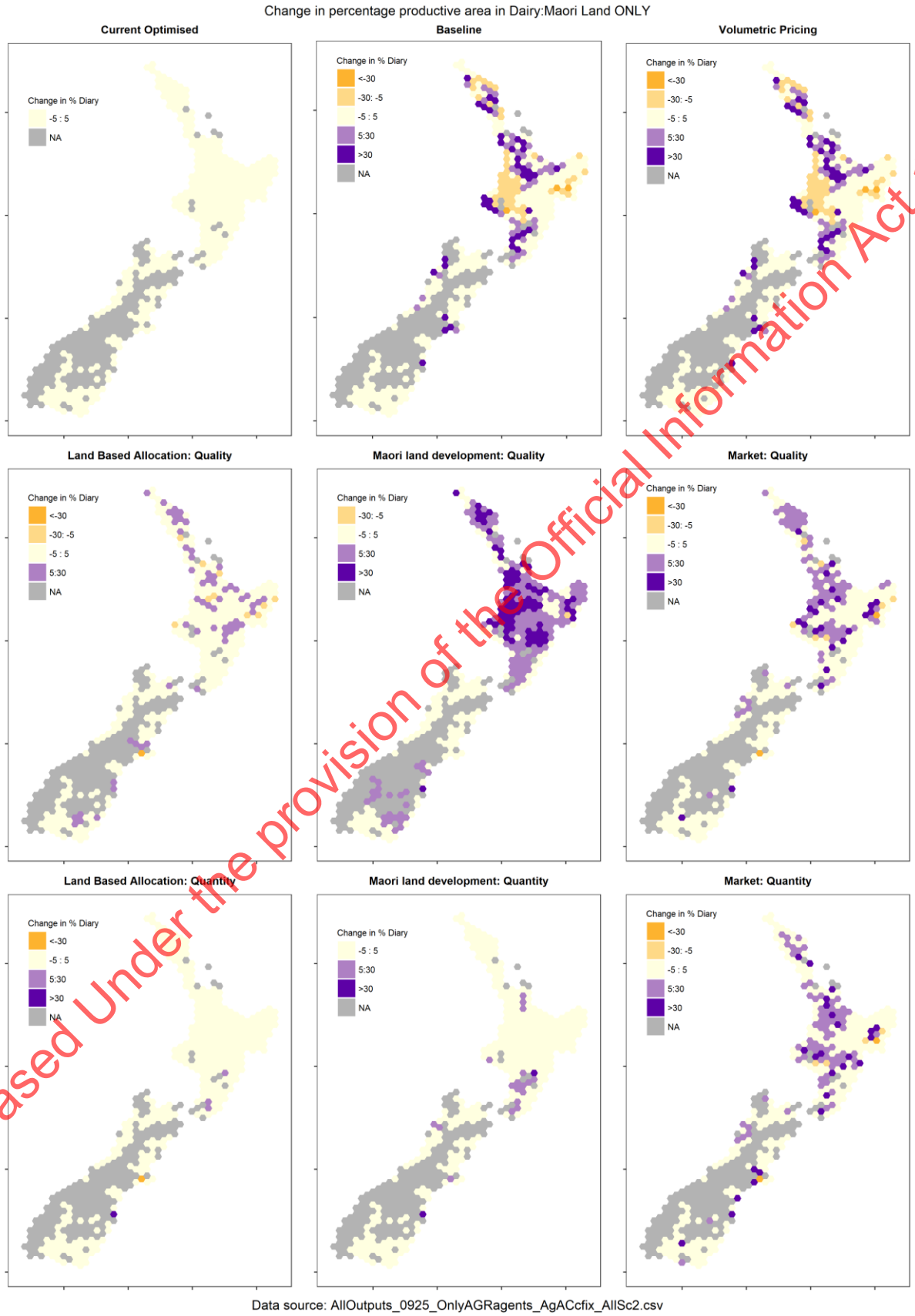
Released Under the provision of the Official Information Act 1982



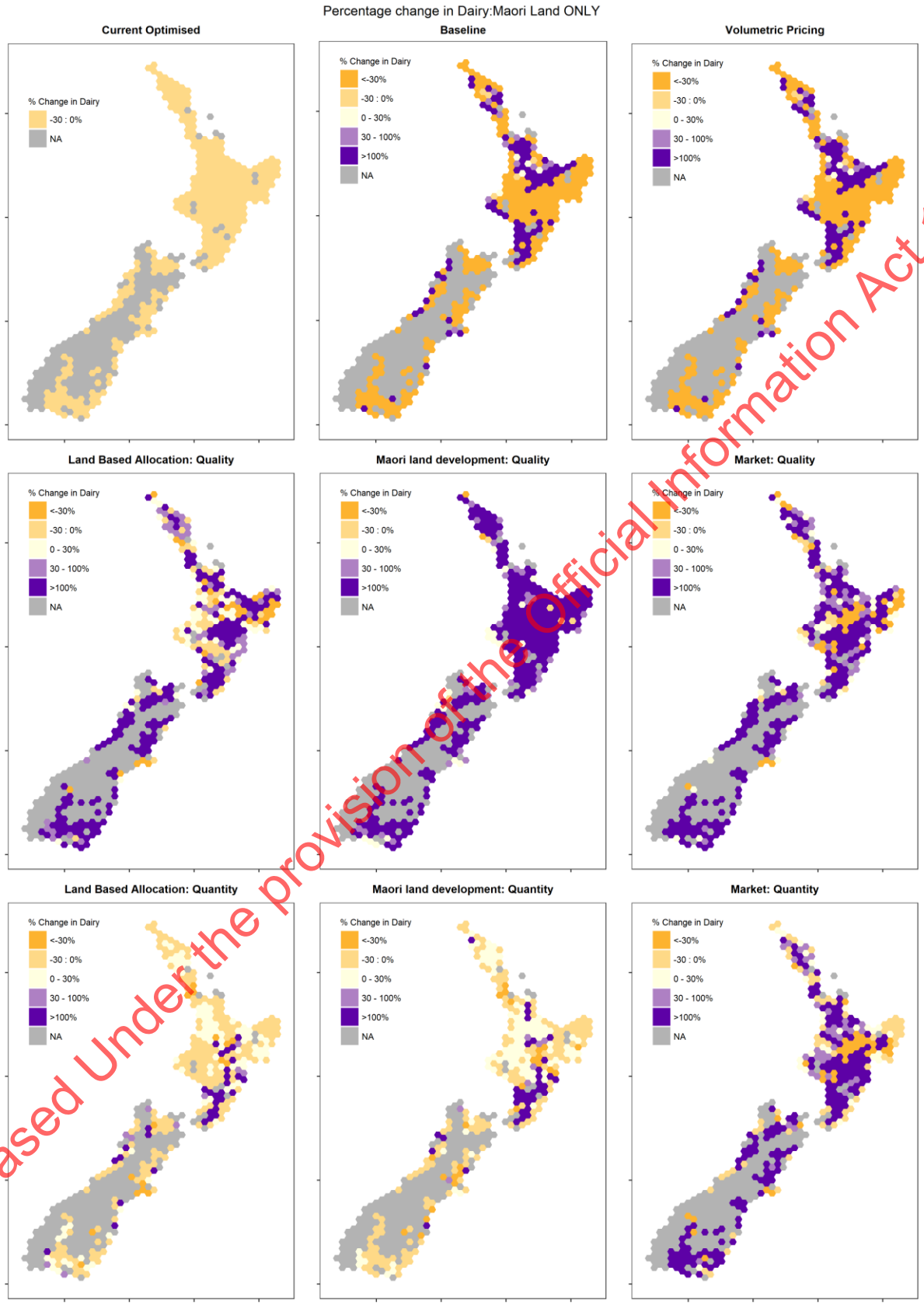
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A11.3.2 Maori Land



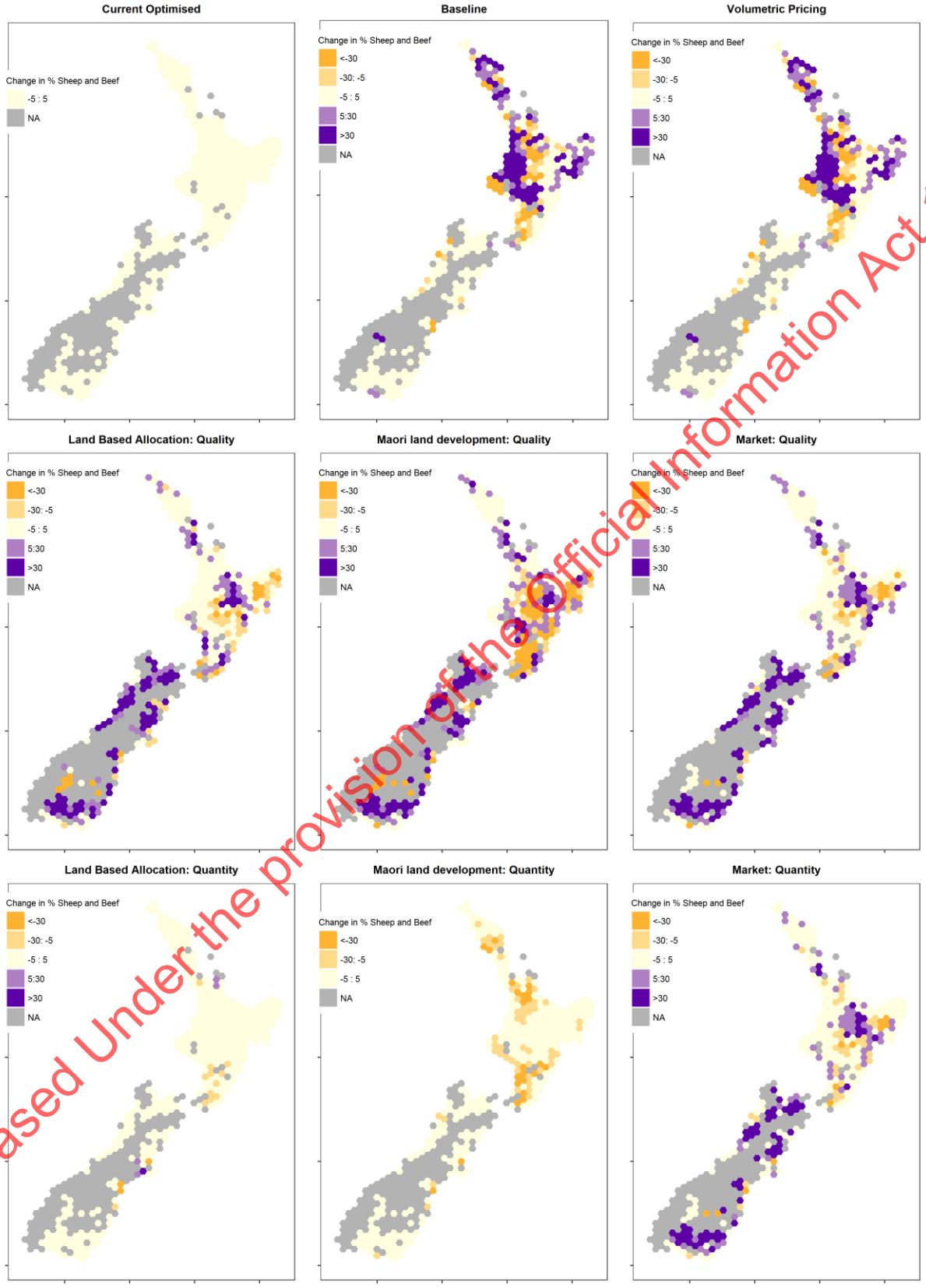
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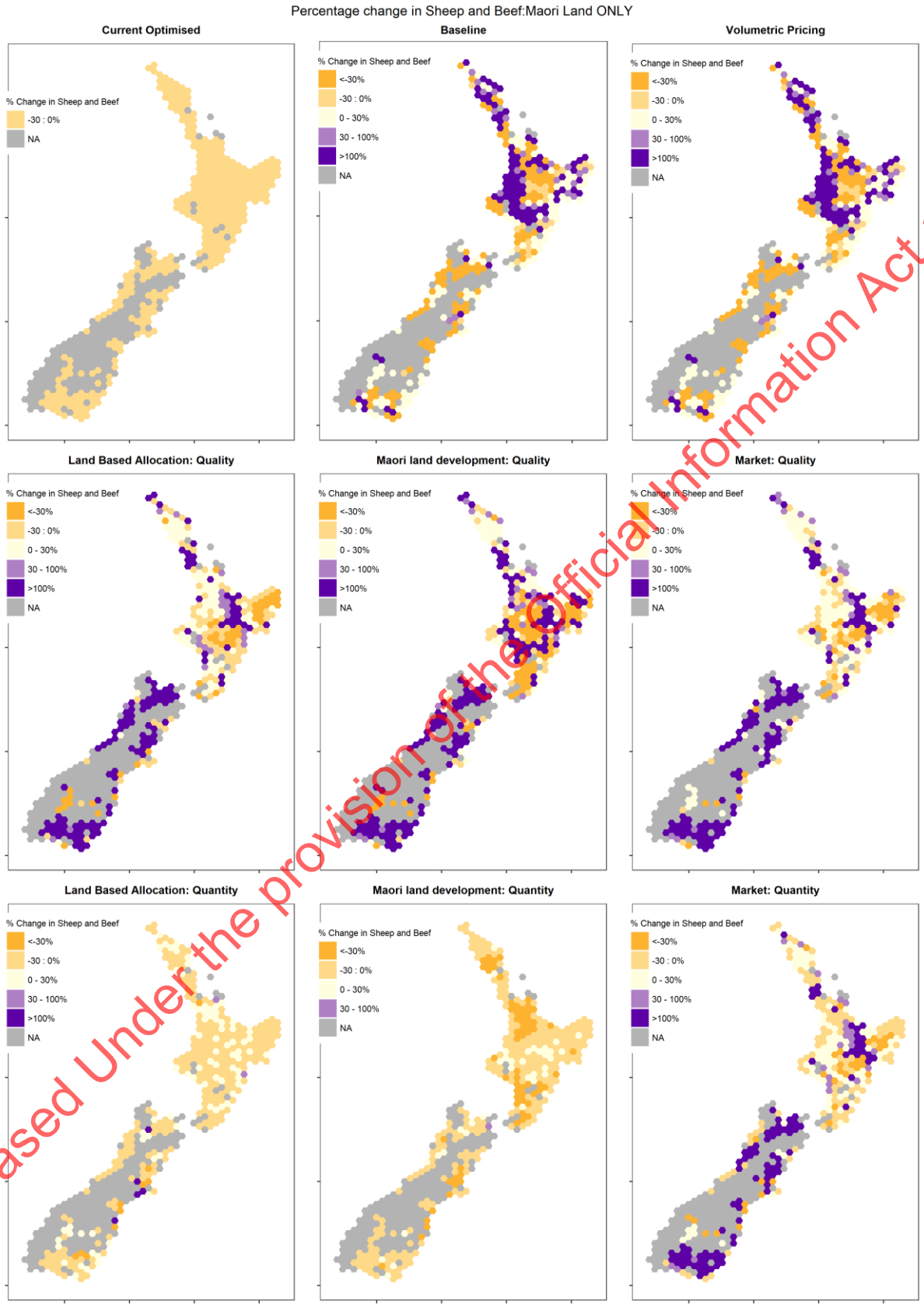
20-D-00014

Change in percentage productive area in Sheep and Beef:Maori Land ONLY

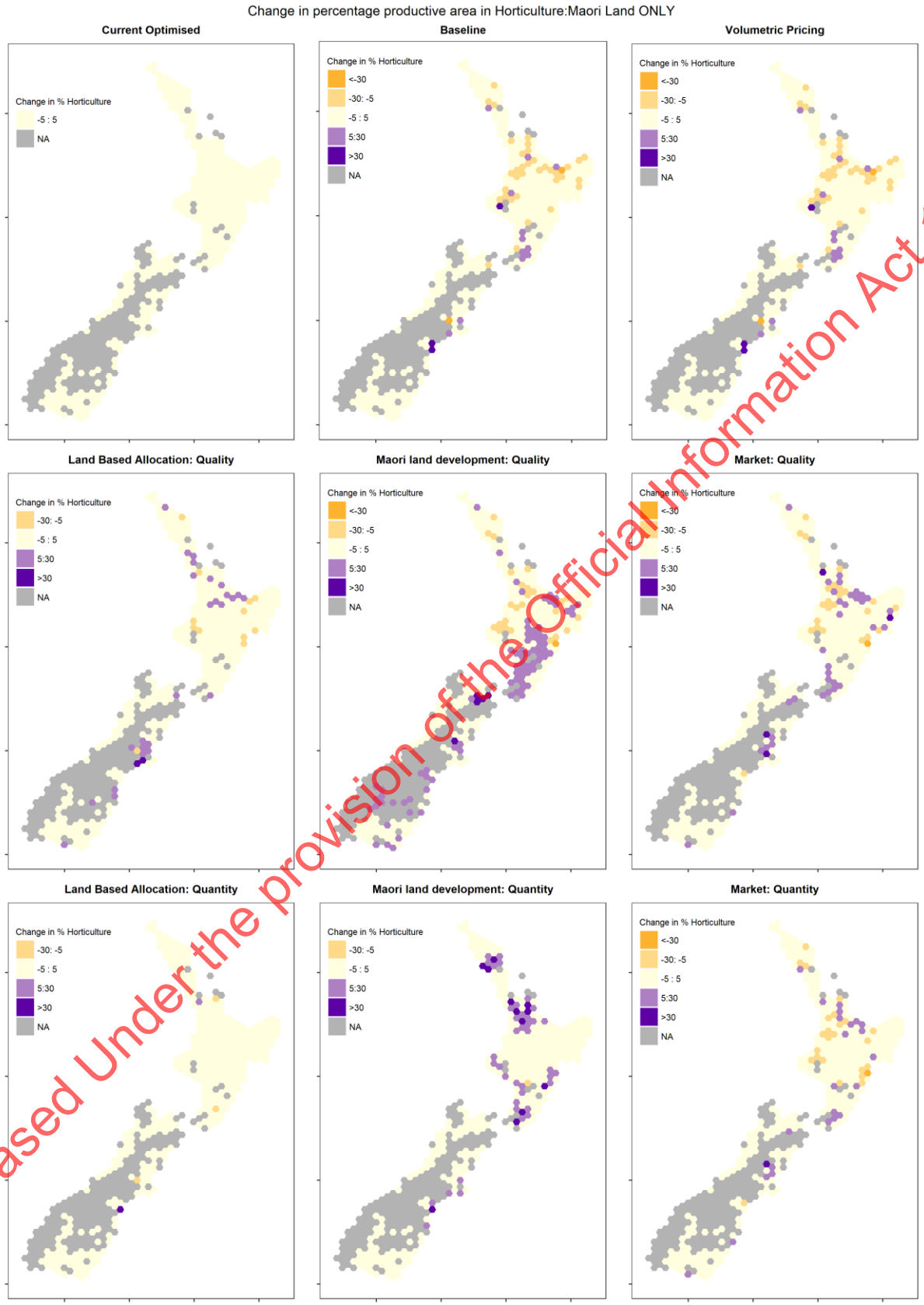


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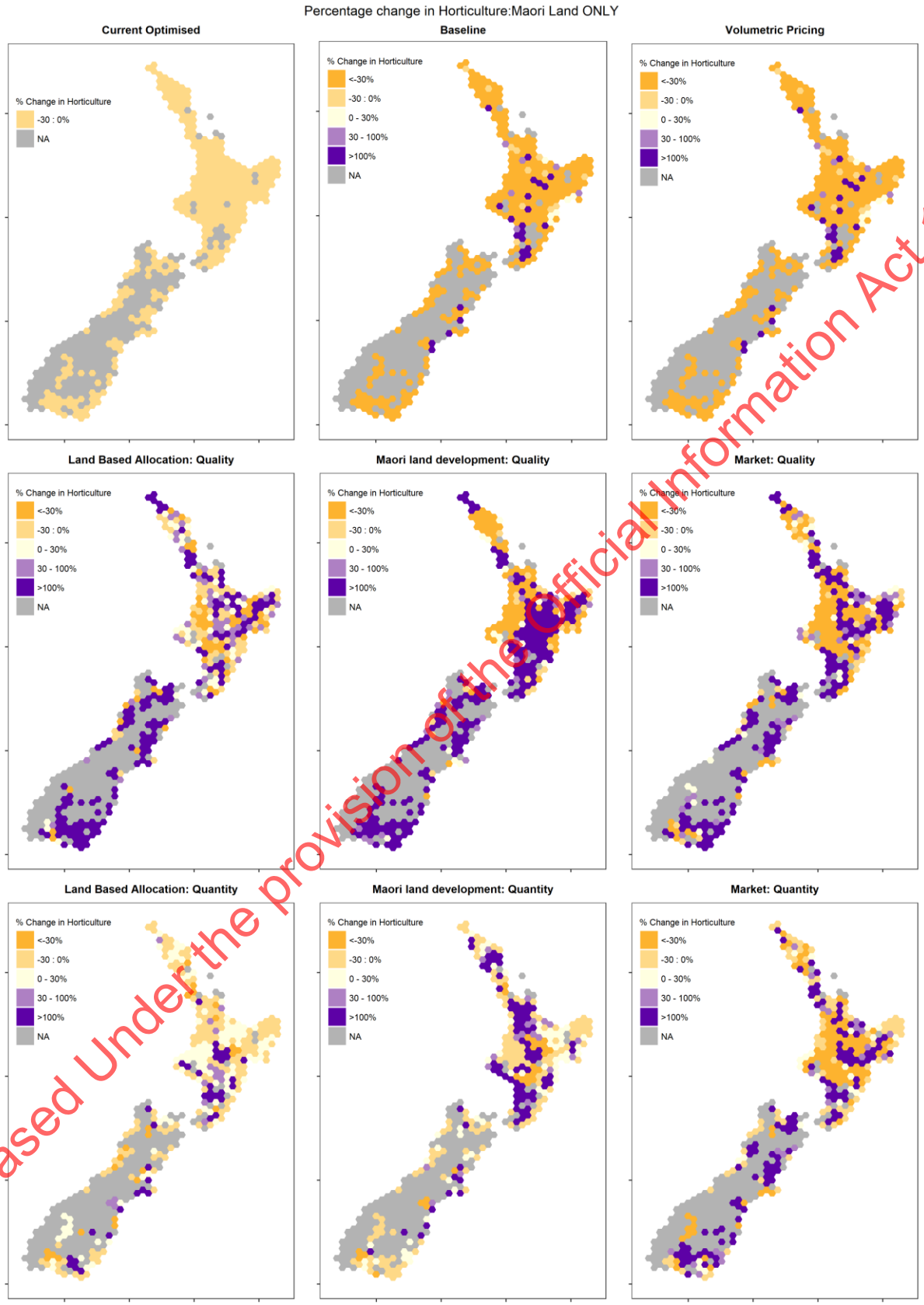
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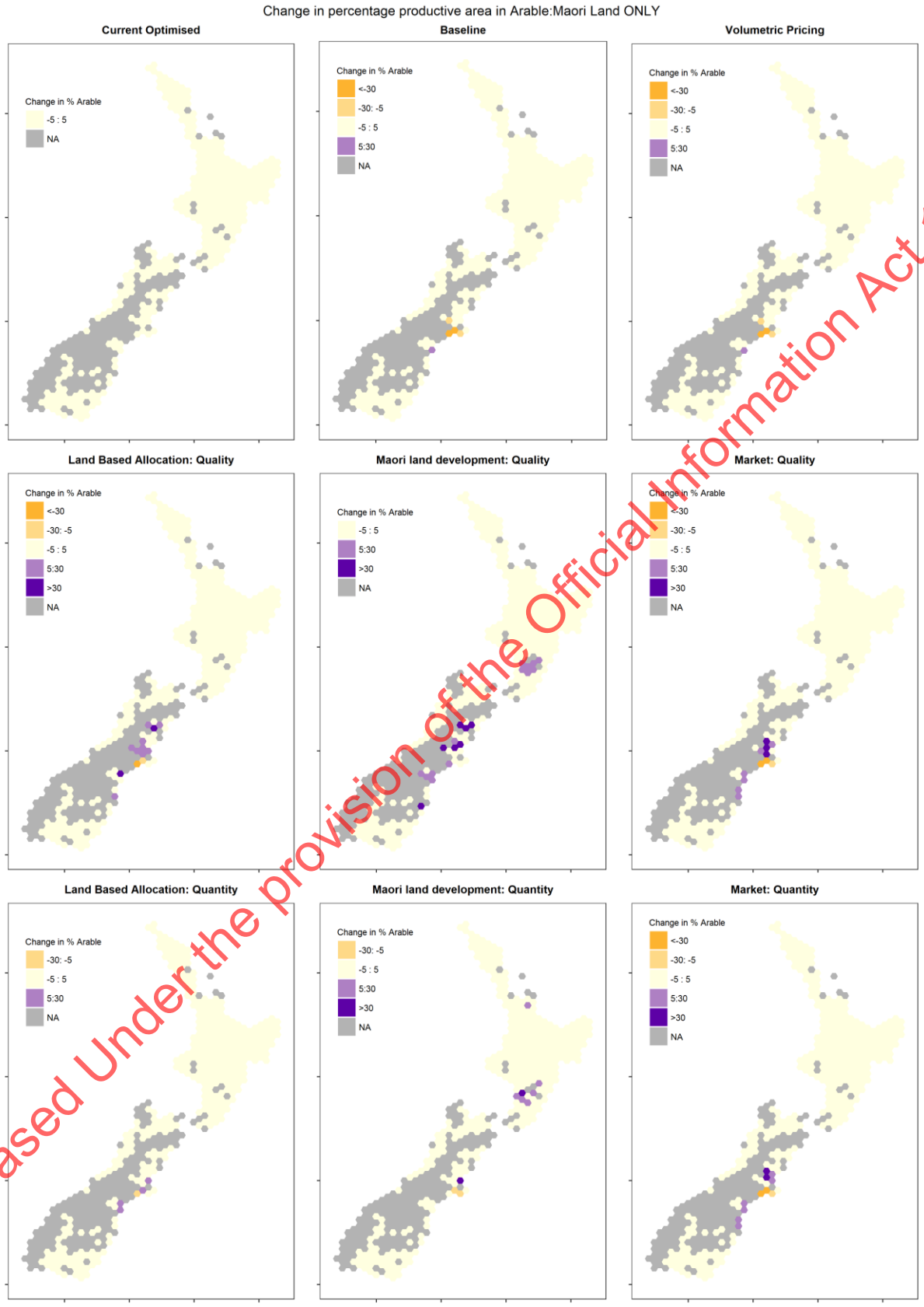


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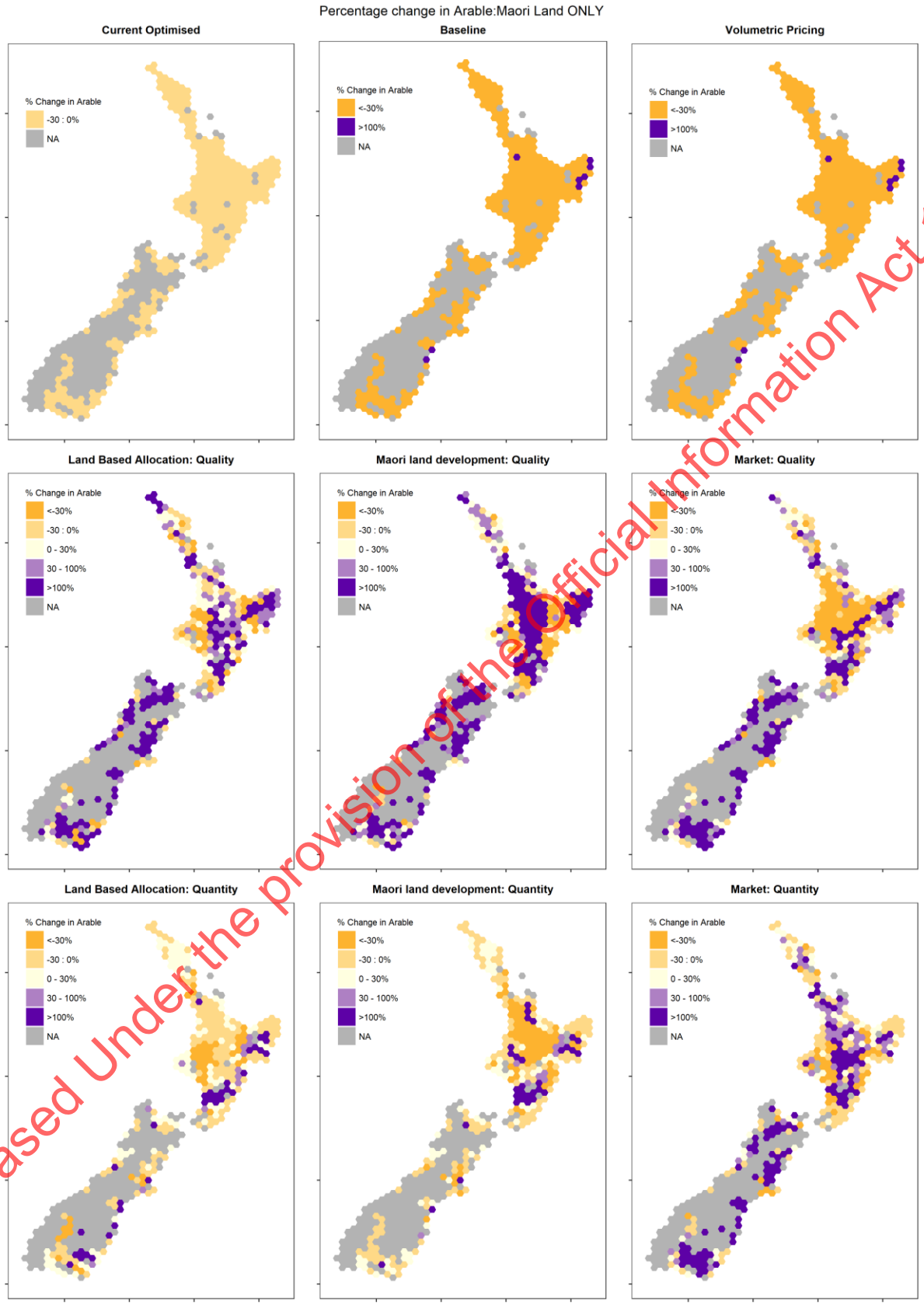
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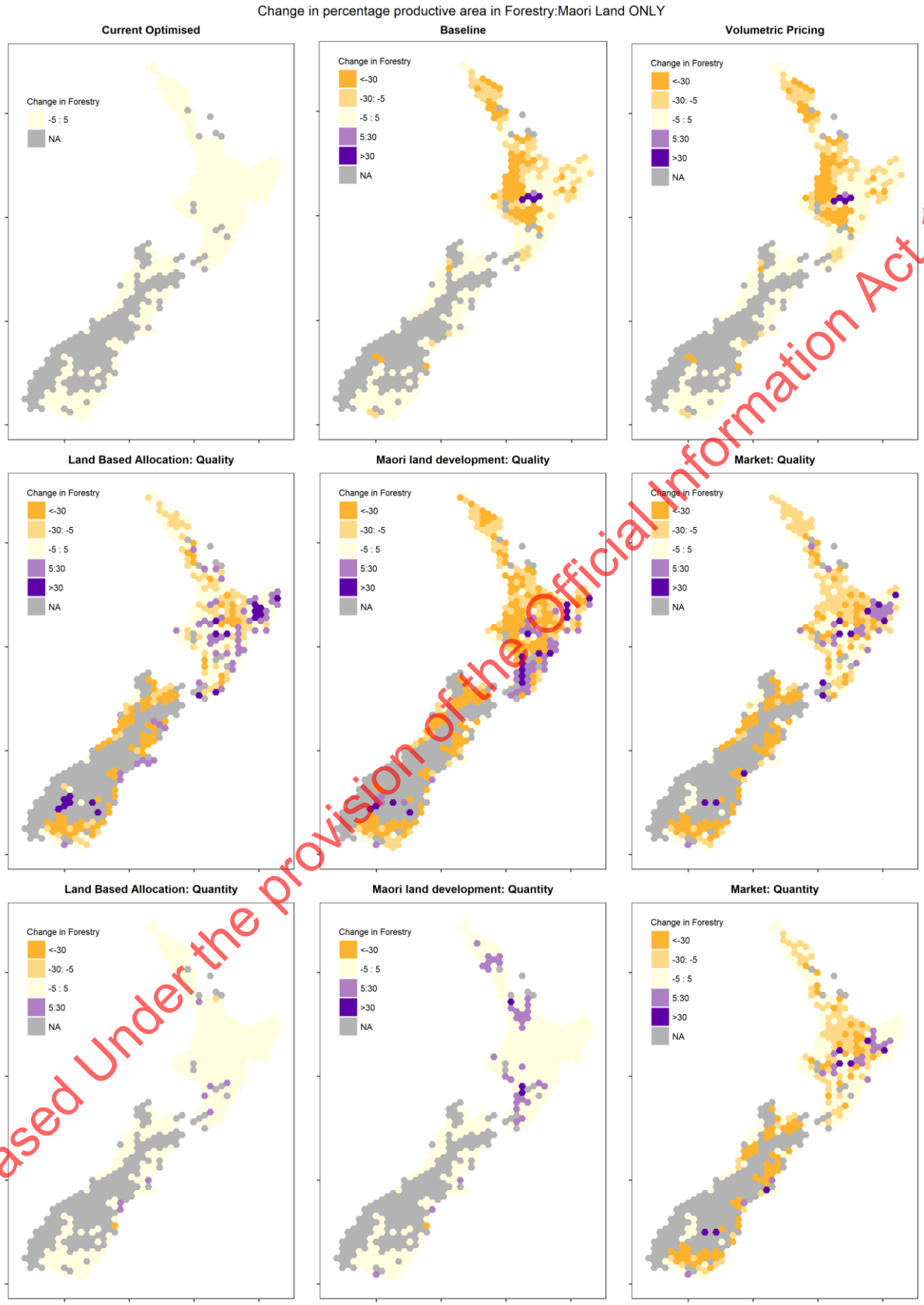


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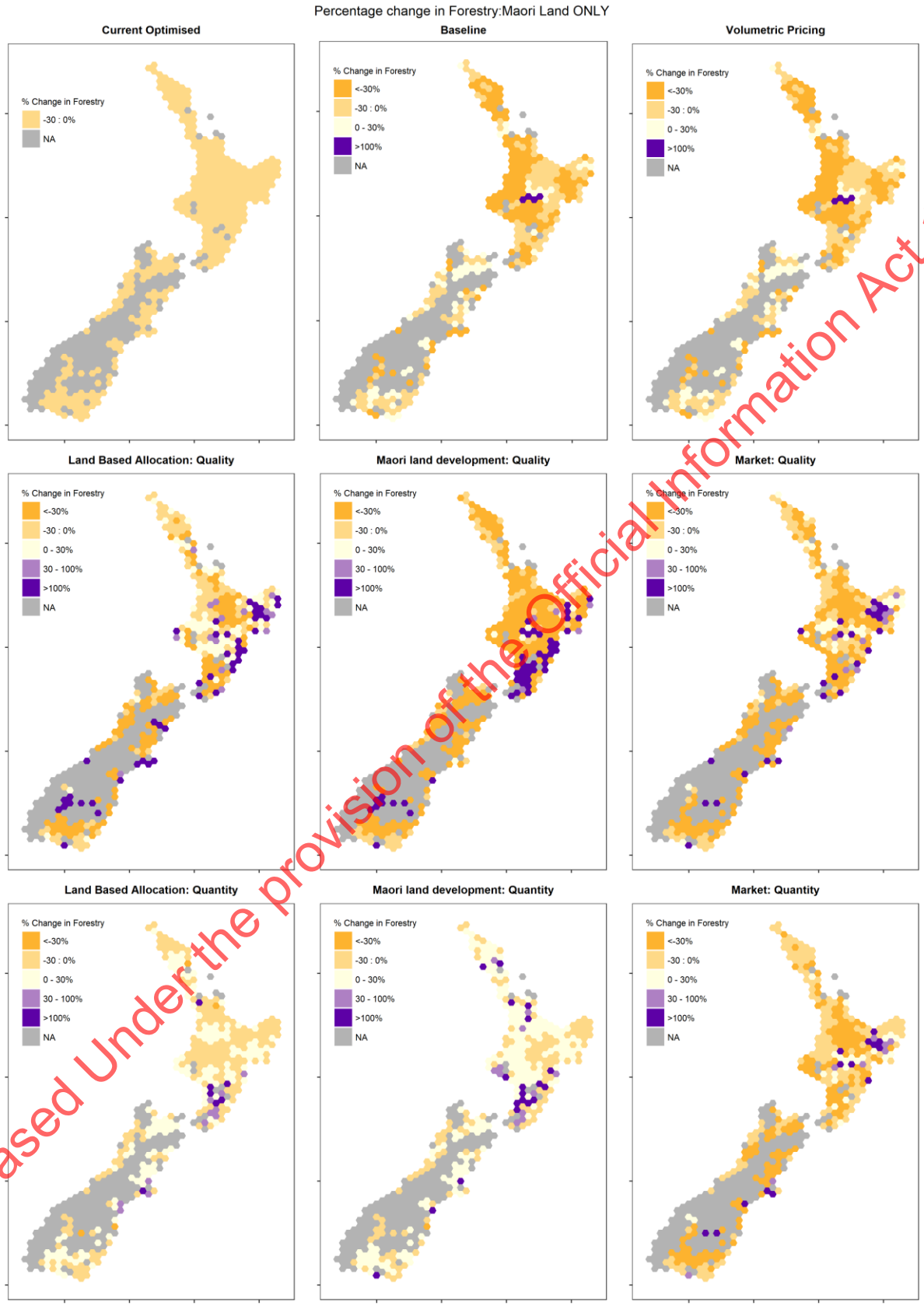
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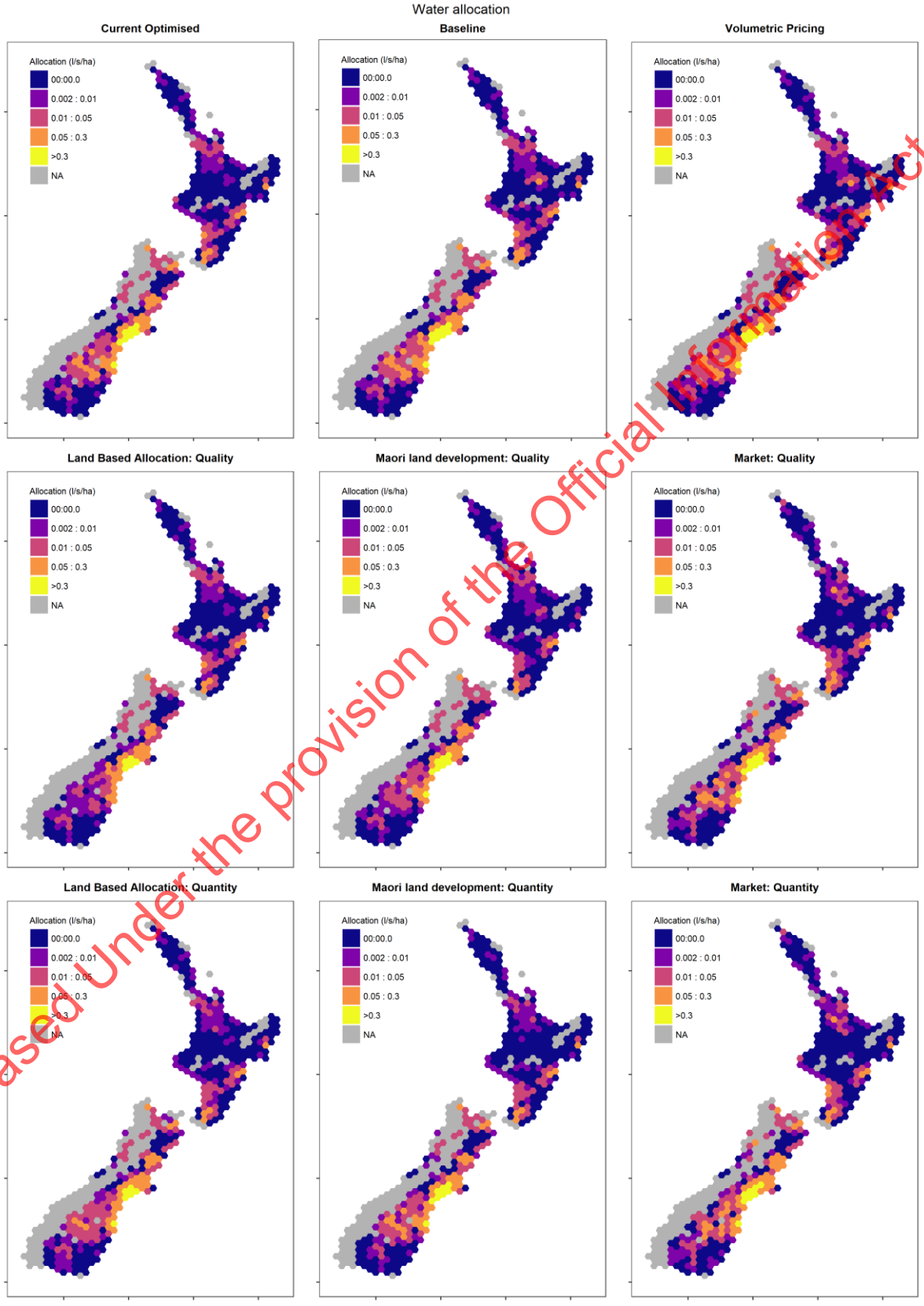
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A11.4 Water and Nutrient Allocation

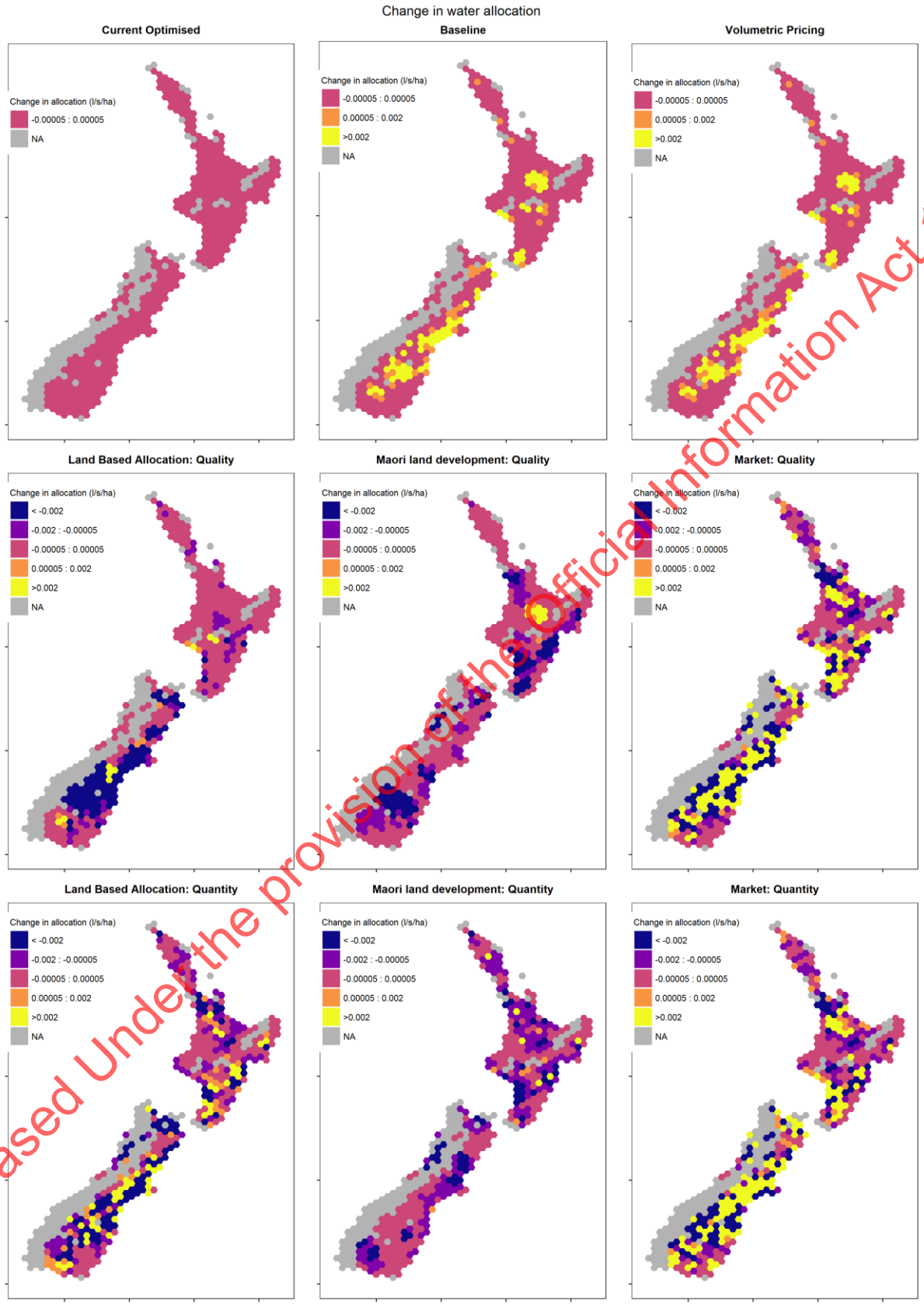
A11.4.1 All Land



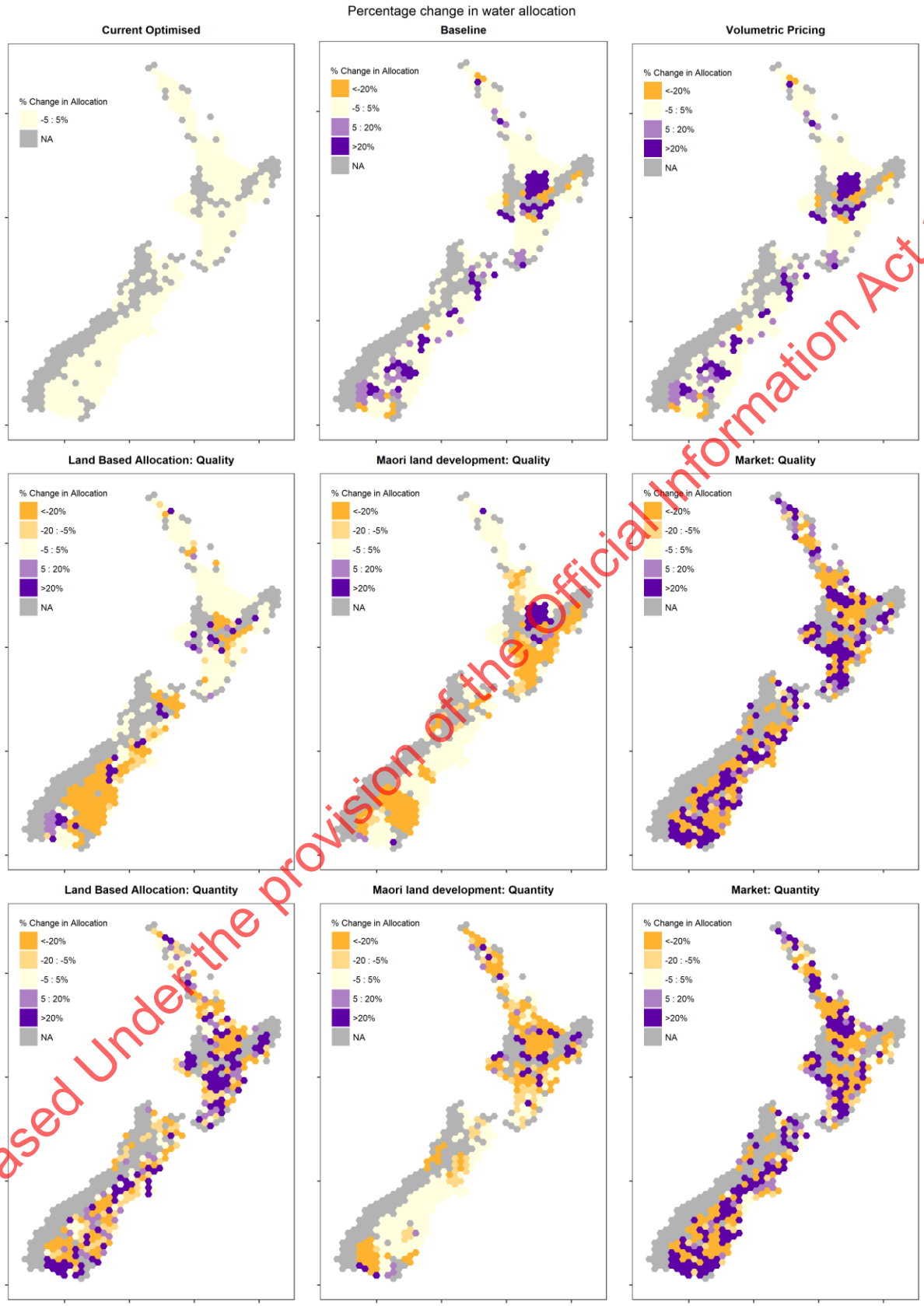
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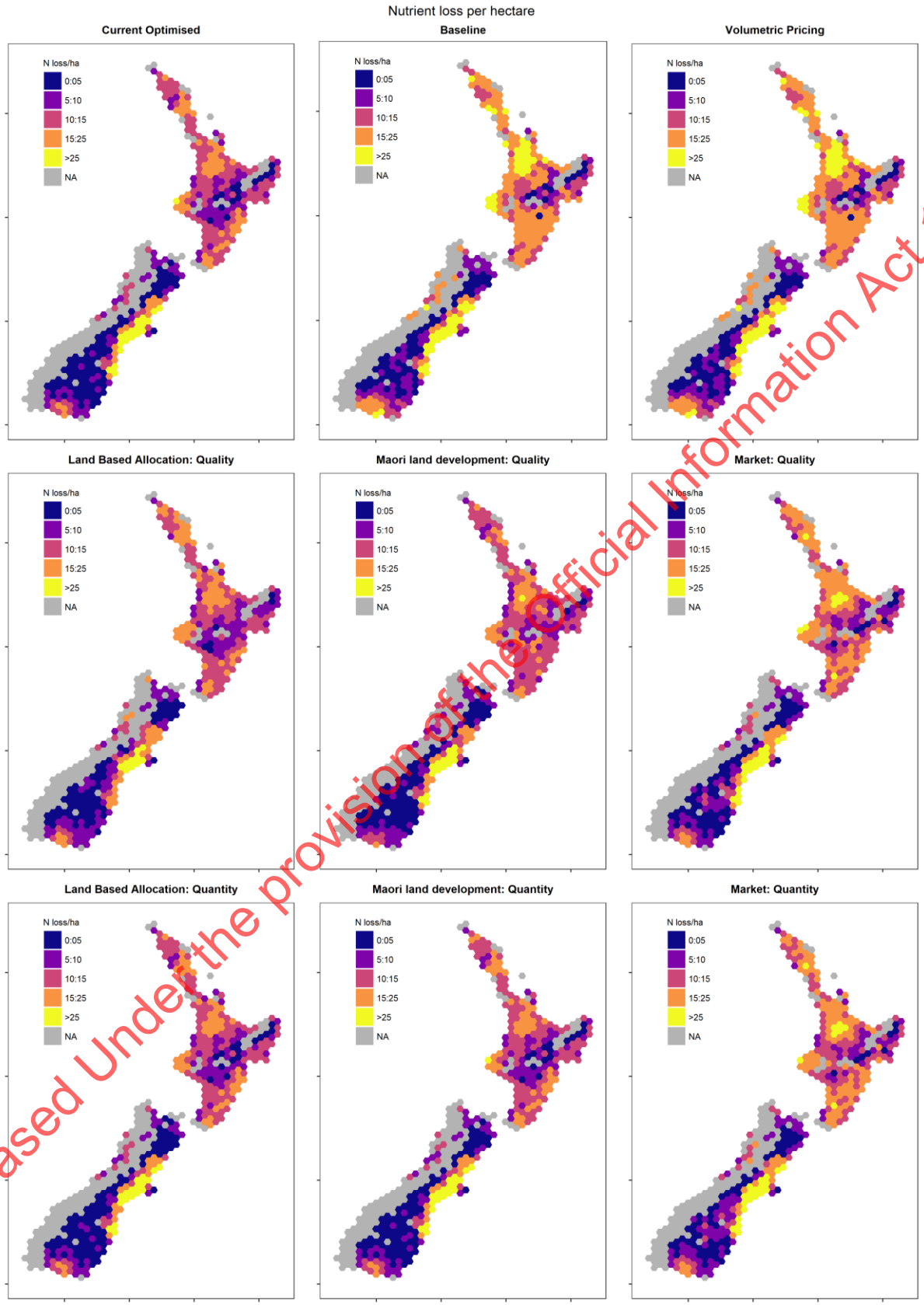


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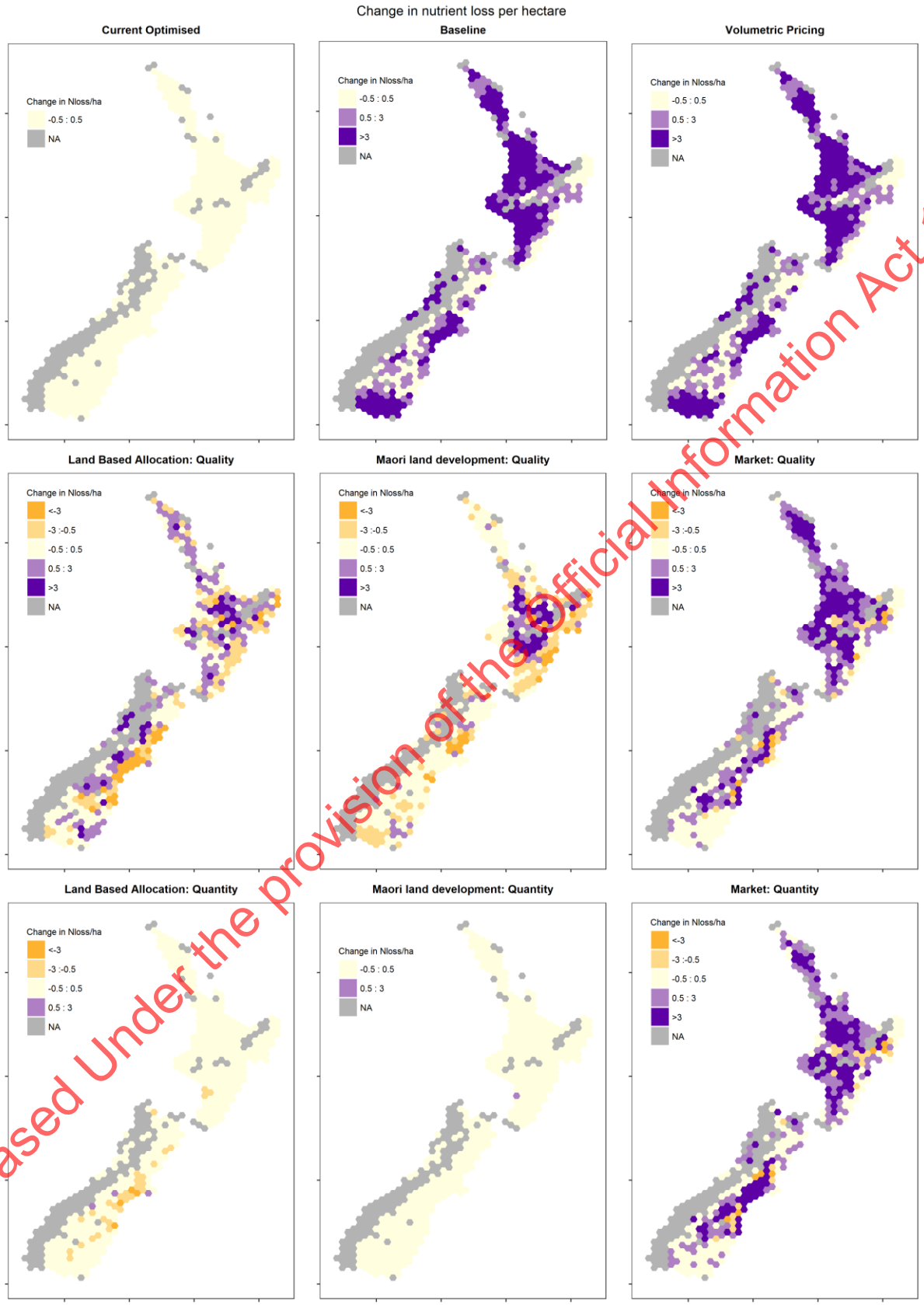


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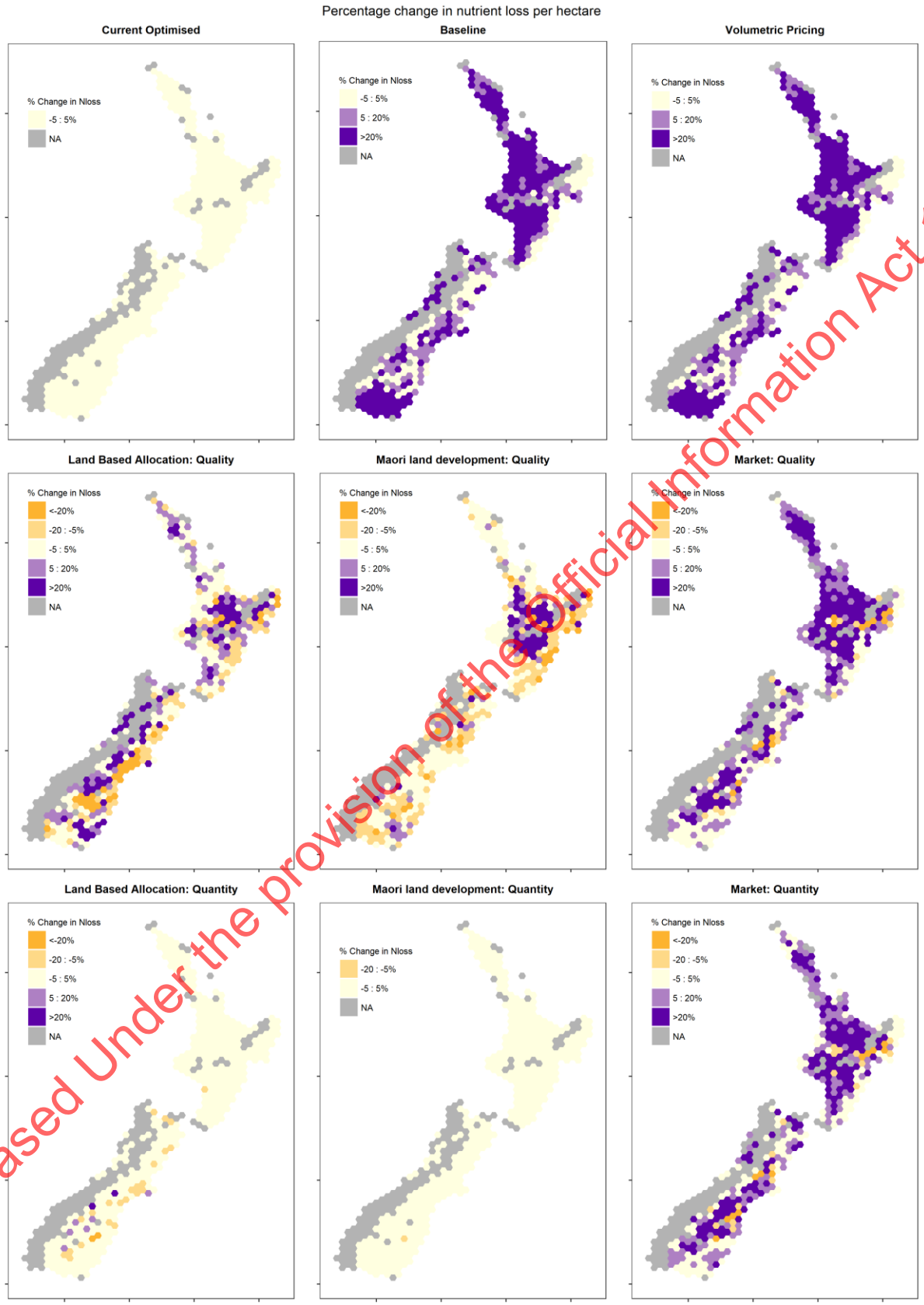


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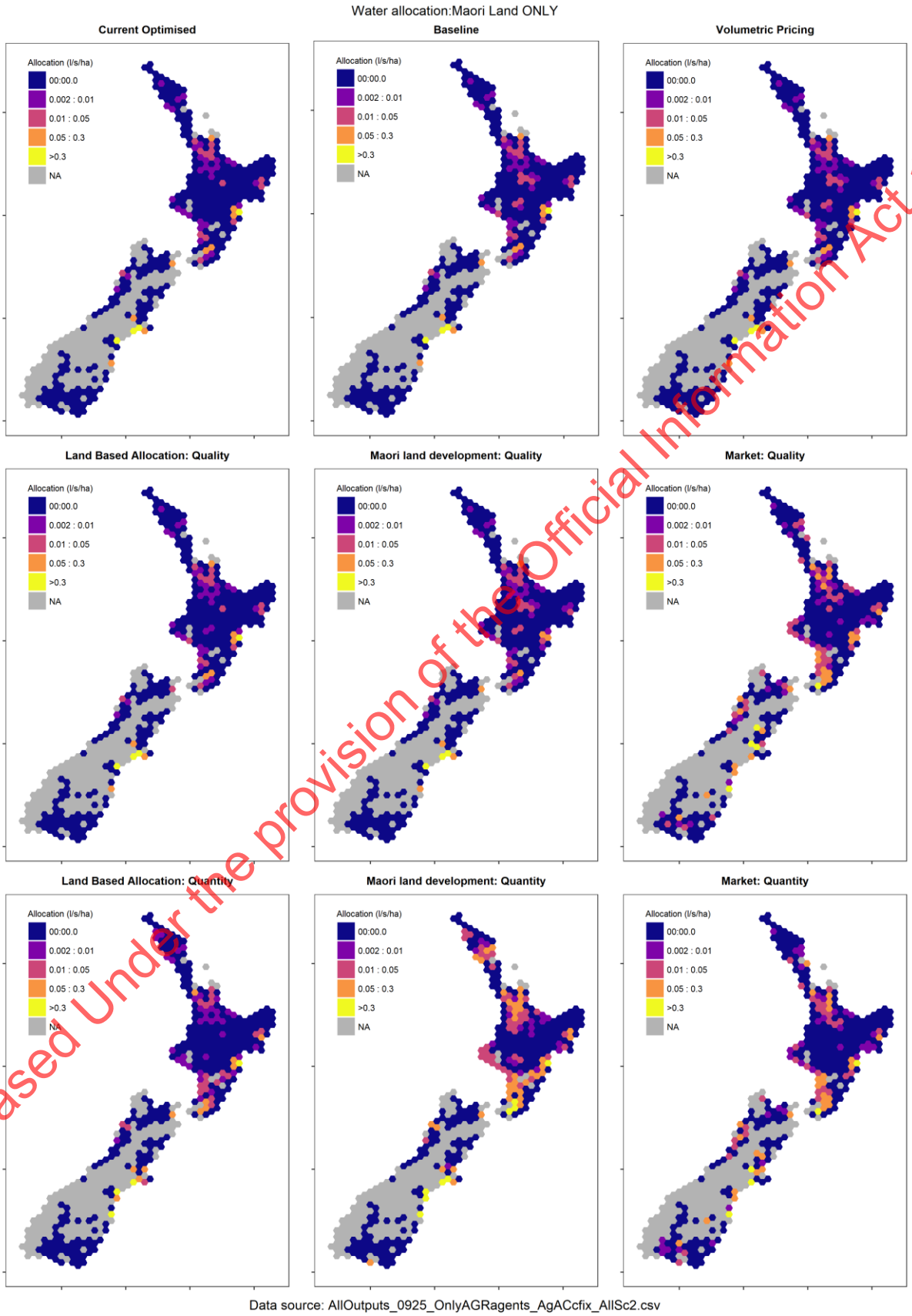
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Released Under the provision of the Official Information Act 1982



Released Under the provision of the Official Information Act 1982

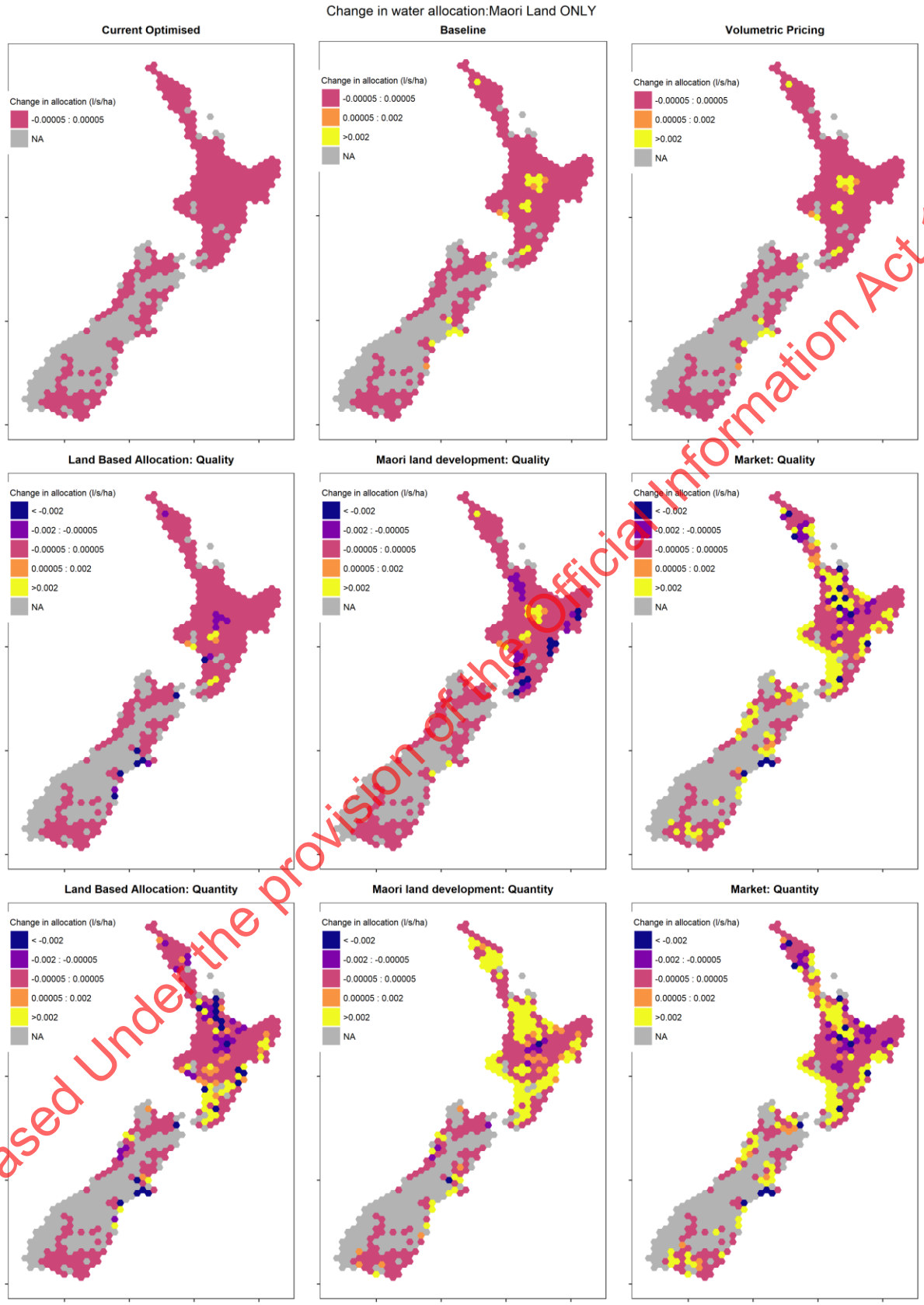
A11.4.2 Maori Land



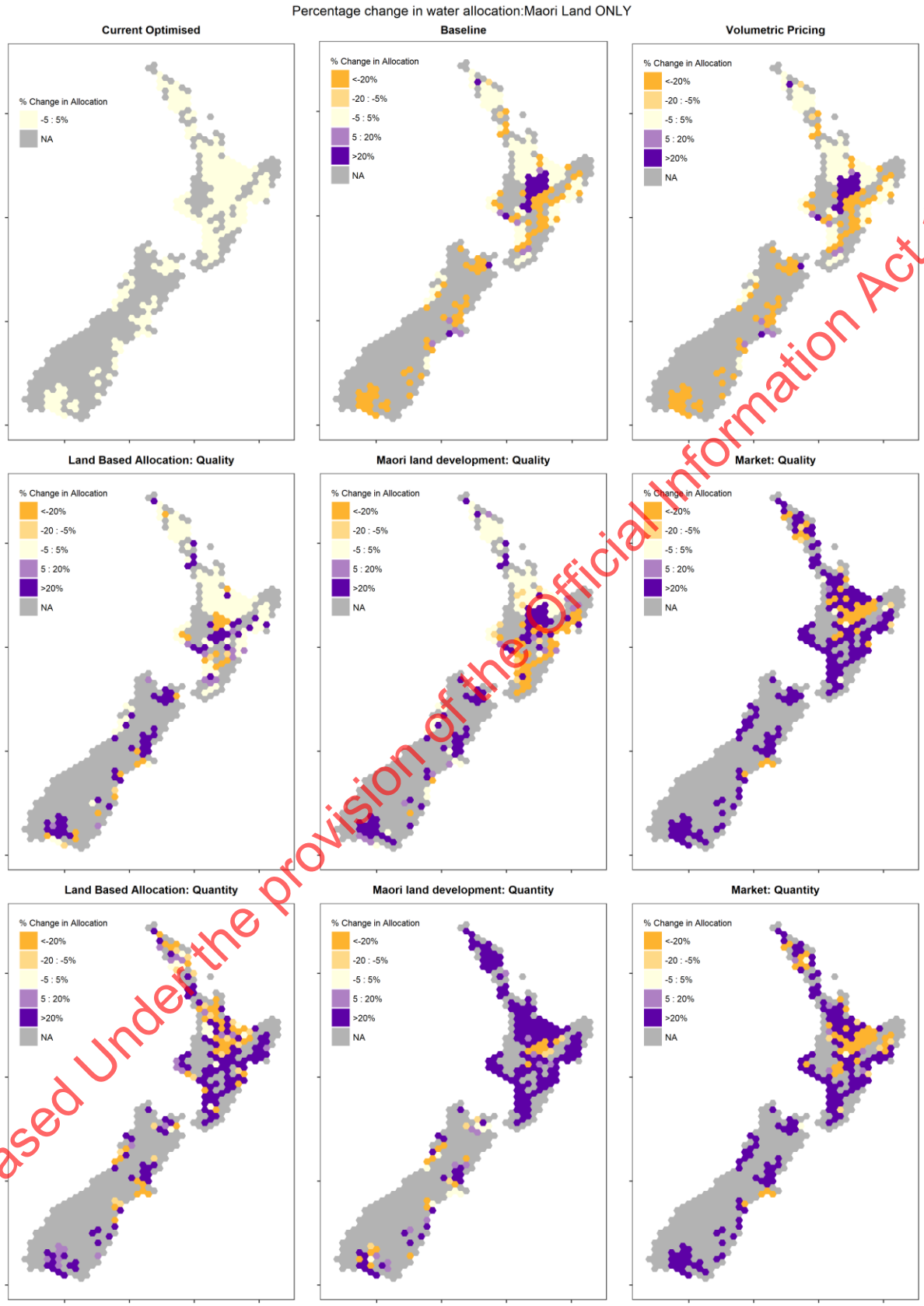
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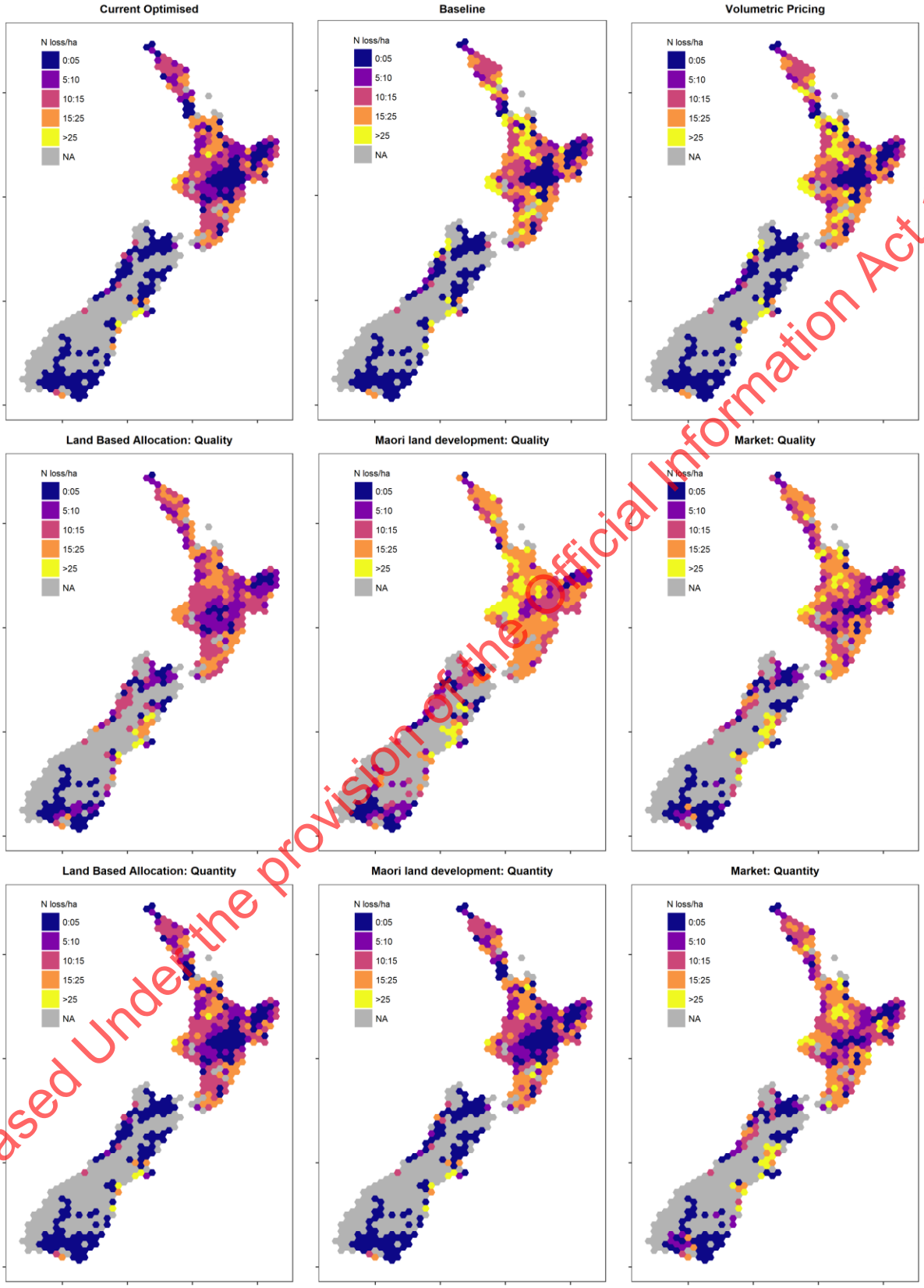


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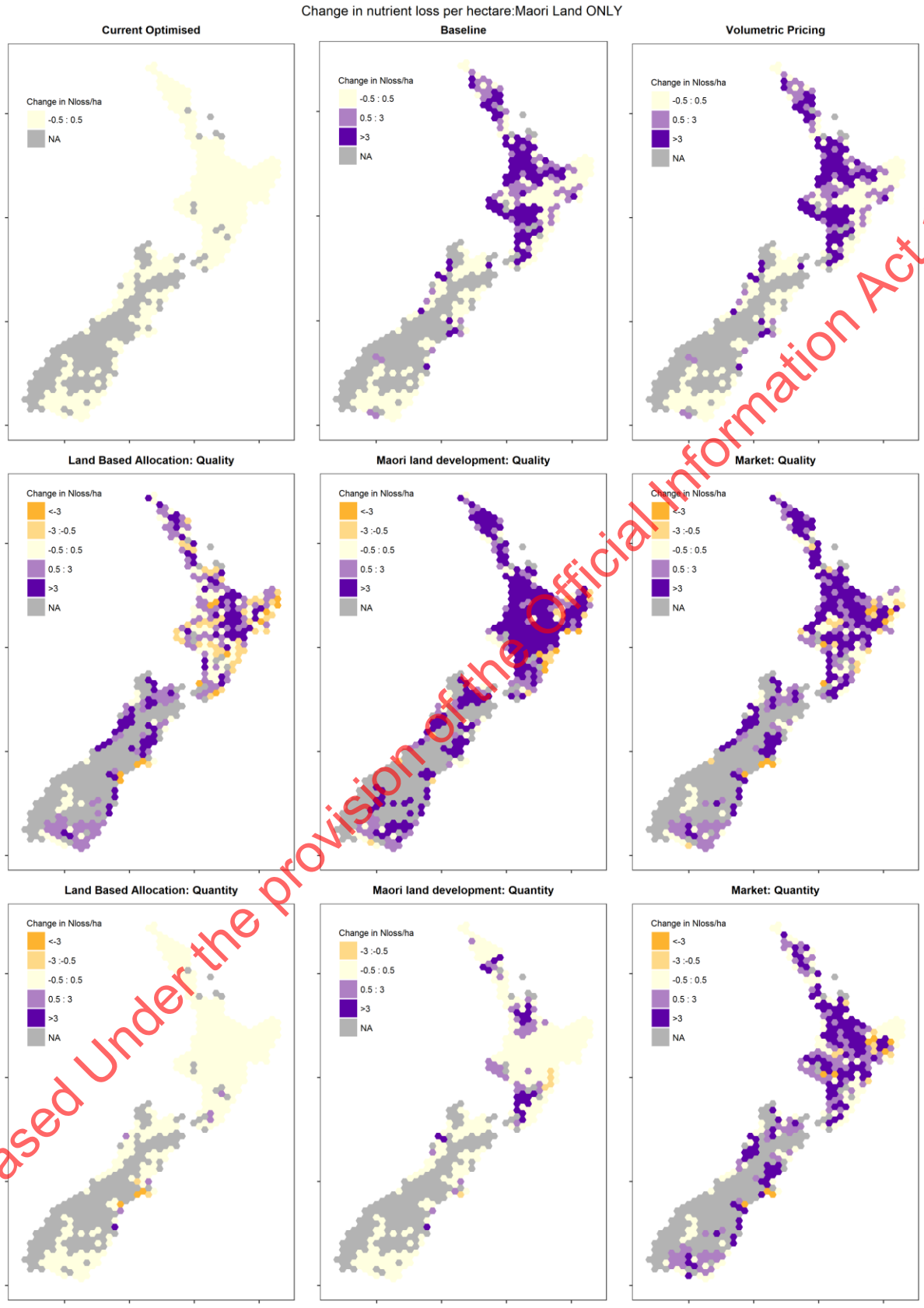
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Nutrient loss per hectare:Maori Land ONLY



Data source: AllOutputs_0925_OnlyAGRagents_AgACcfix_AllSc2.csv

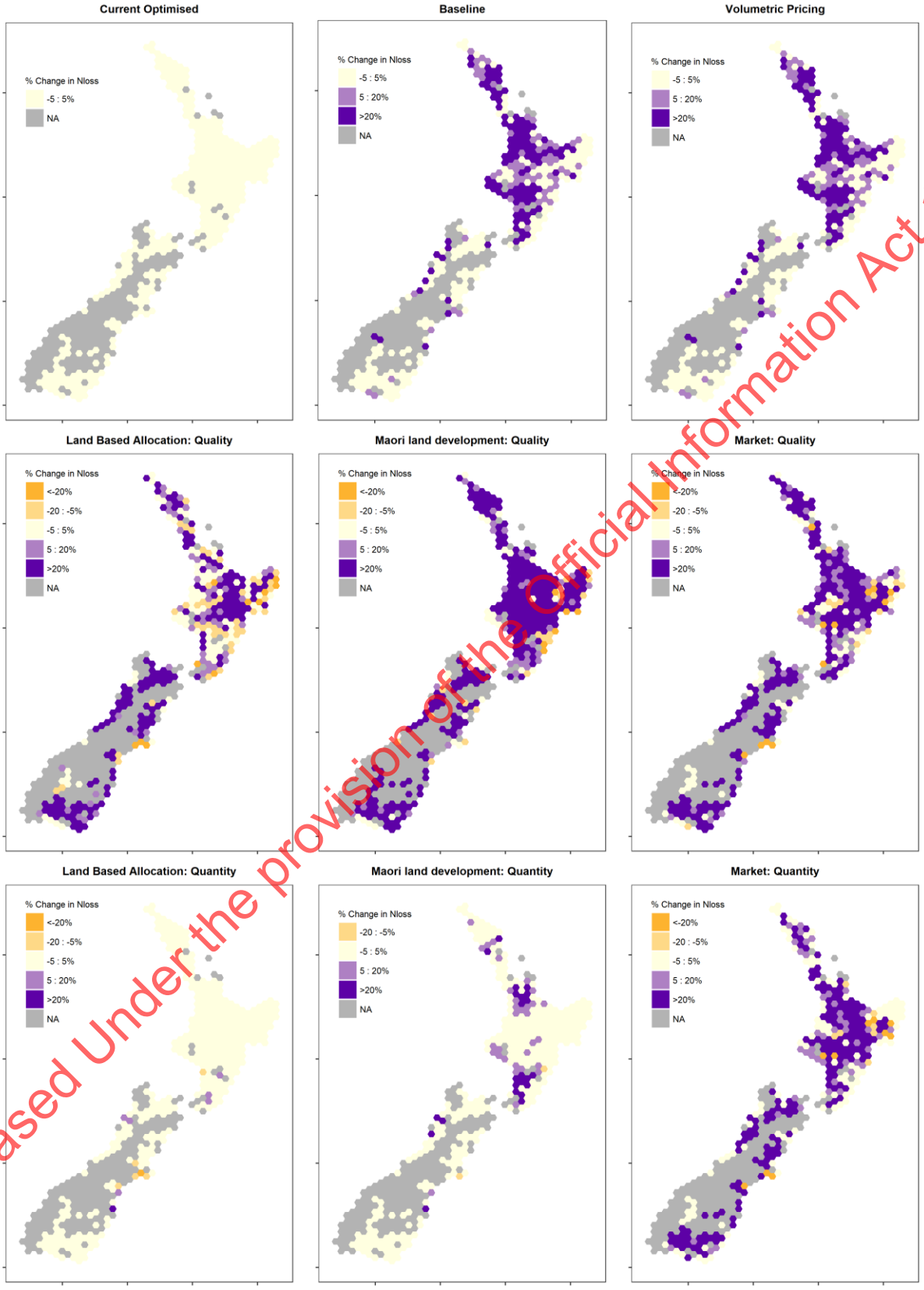
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20-D-00014

Percentage change in nutrient loss per hectare:Maori Land ONLY

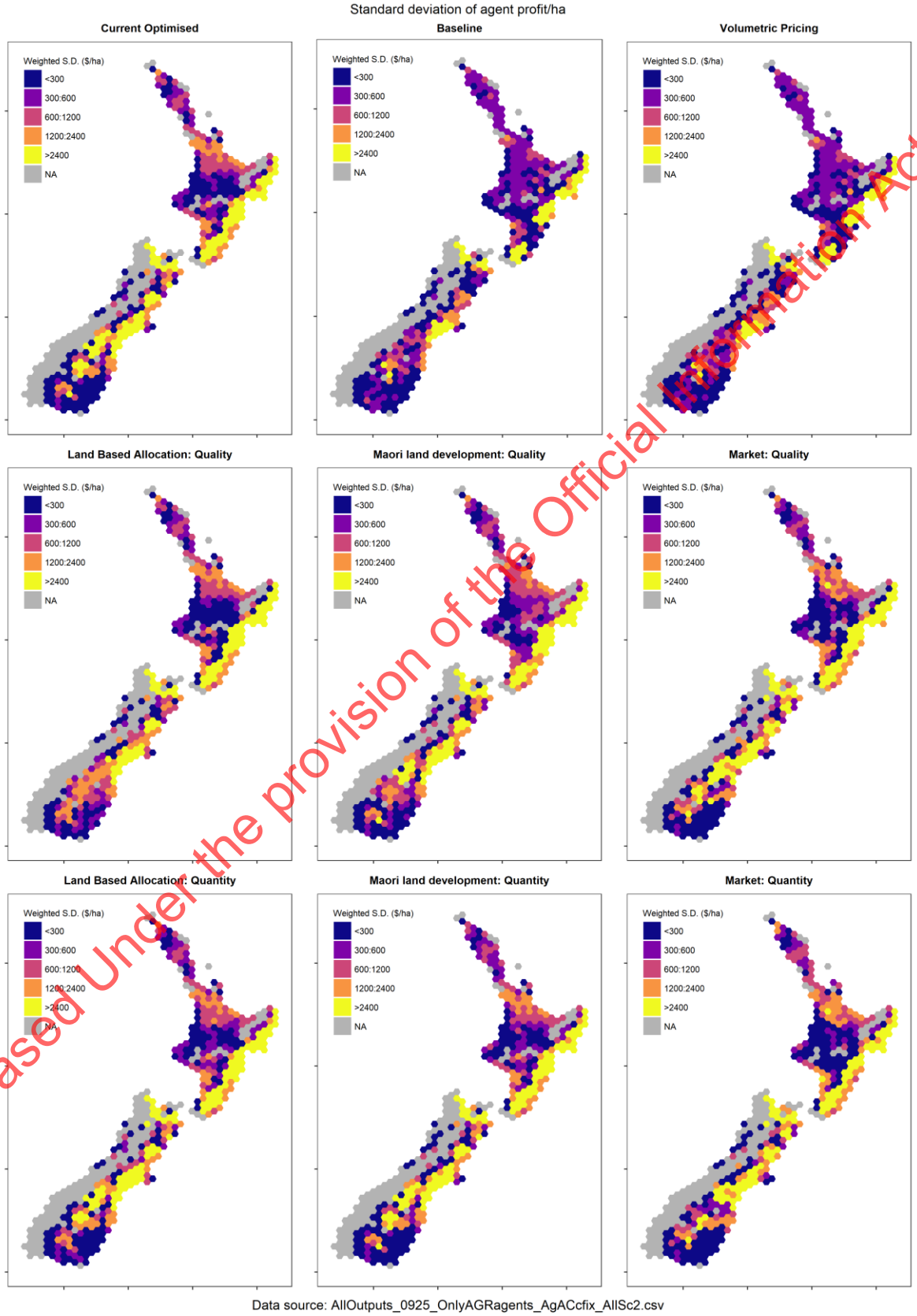


Data source: AllOutputs_0925_OnlyAGRagents_AgACcfix_AllSc2.csv

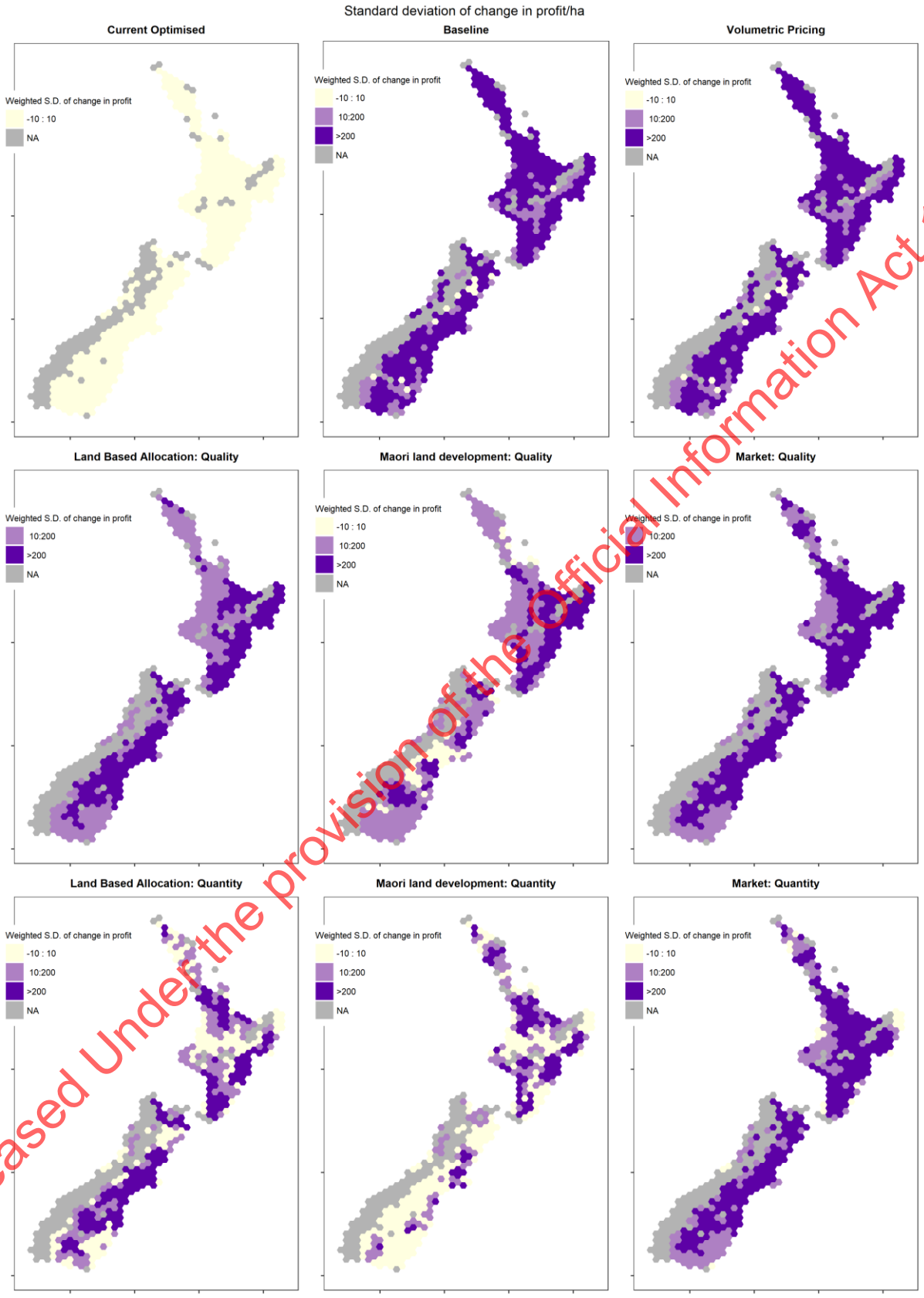
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A11.5 Profits

A11.5.1 All Land



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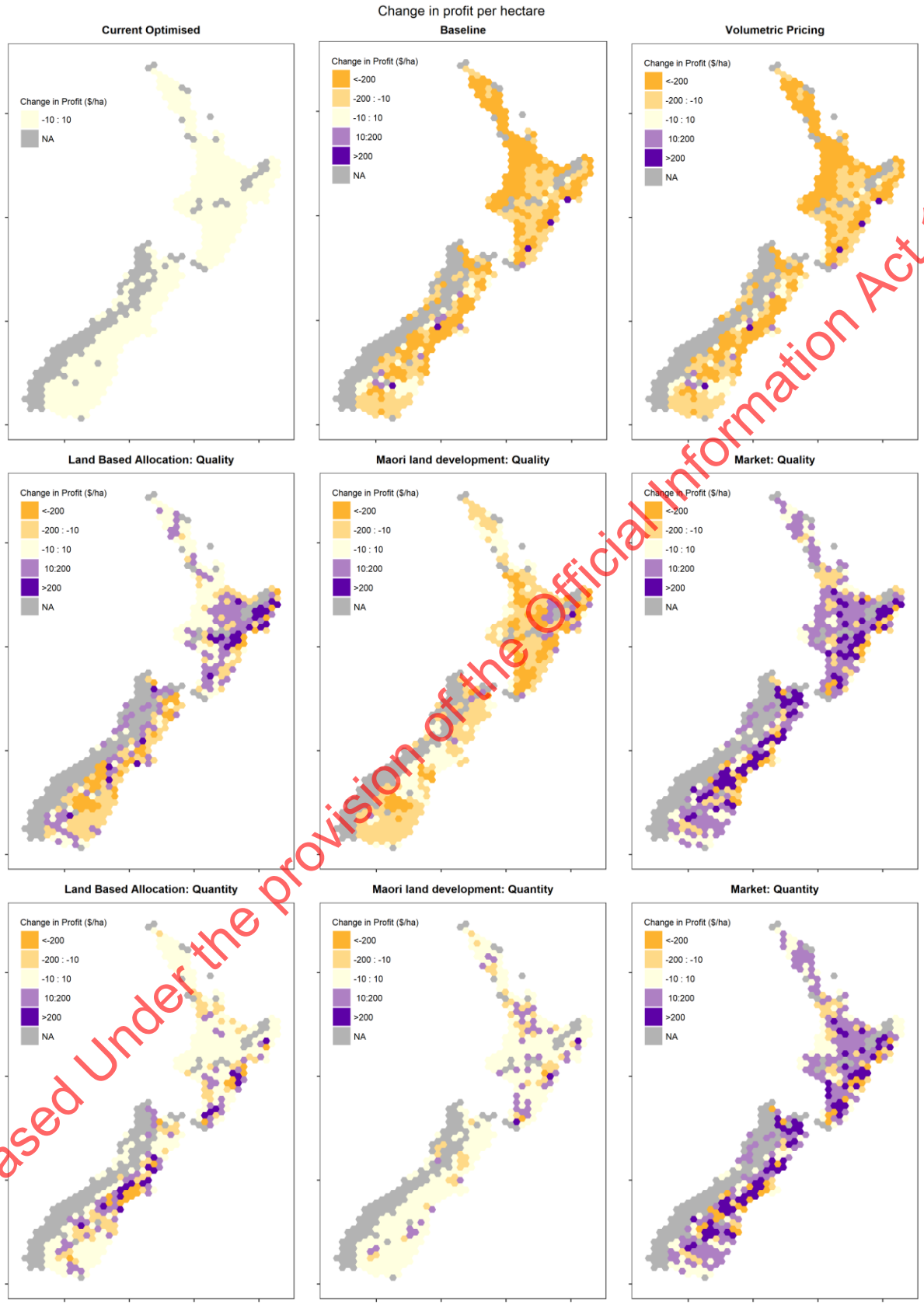
20-D-00014



Data source: AllOutputs_0925_OnlyAGRagents_AgACcfix_AllSc2.csv

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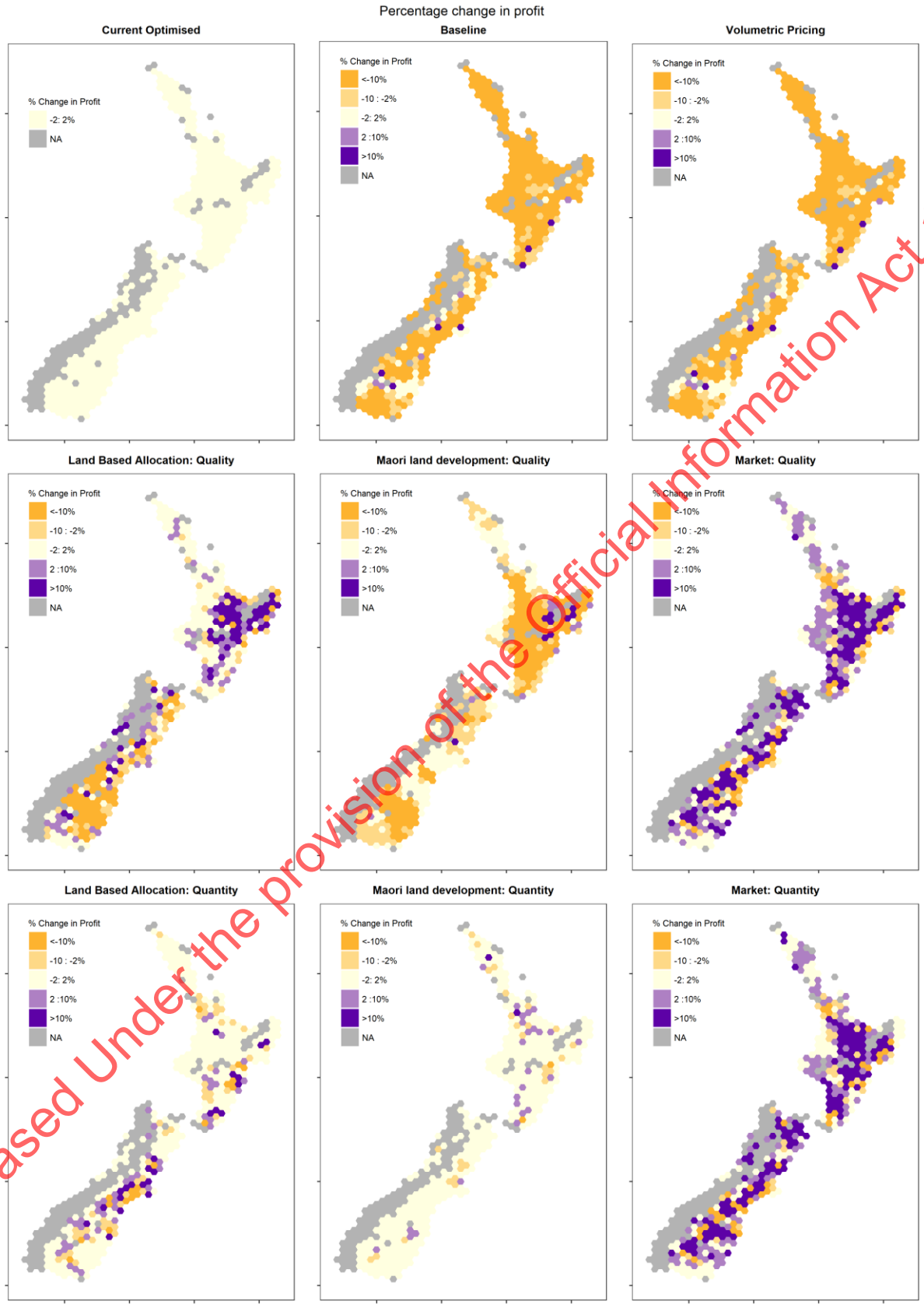
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Data source: AllOutputs_0925_OnlyAGRagents_AgACcfix_AllSc2.csv

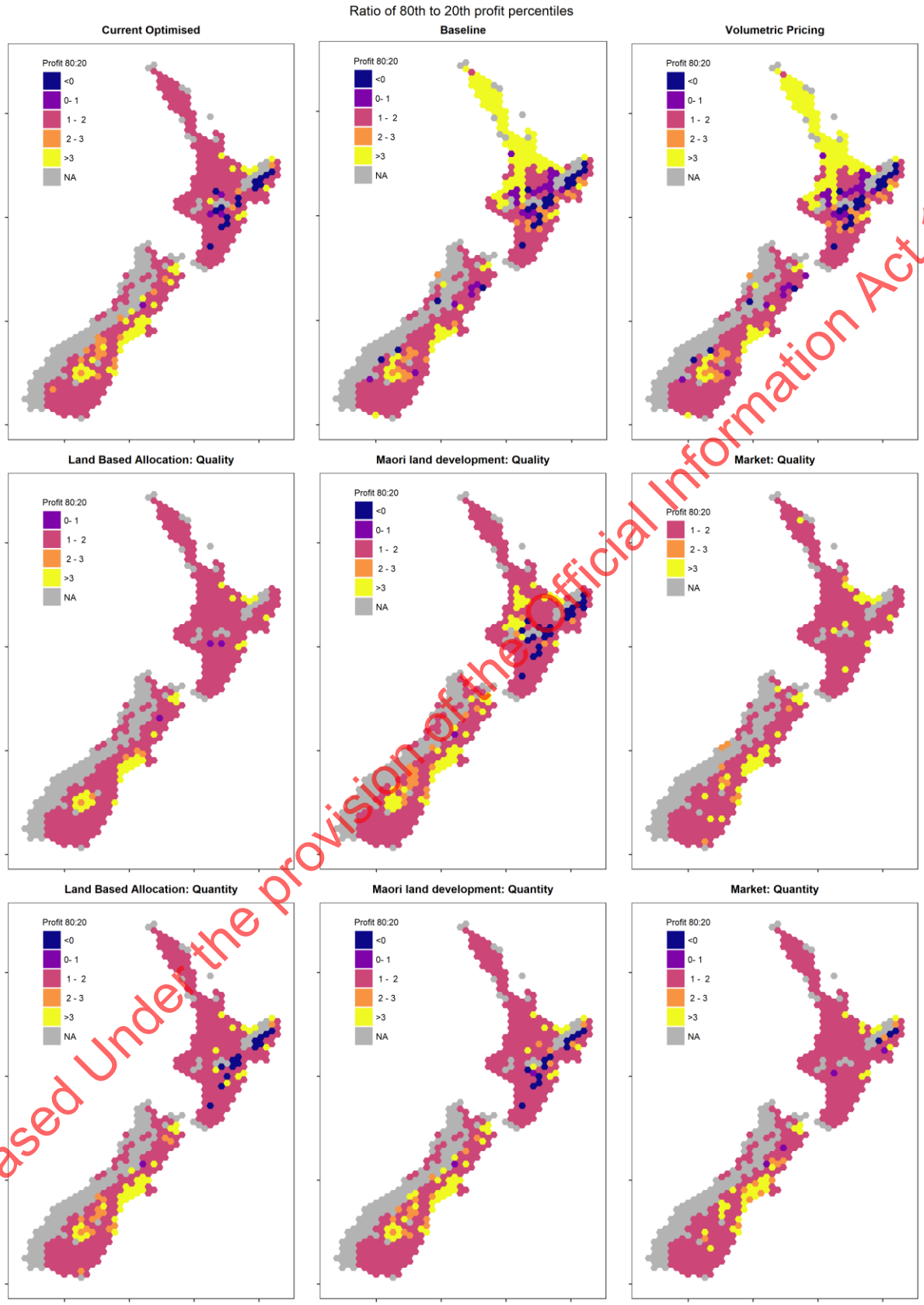
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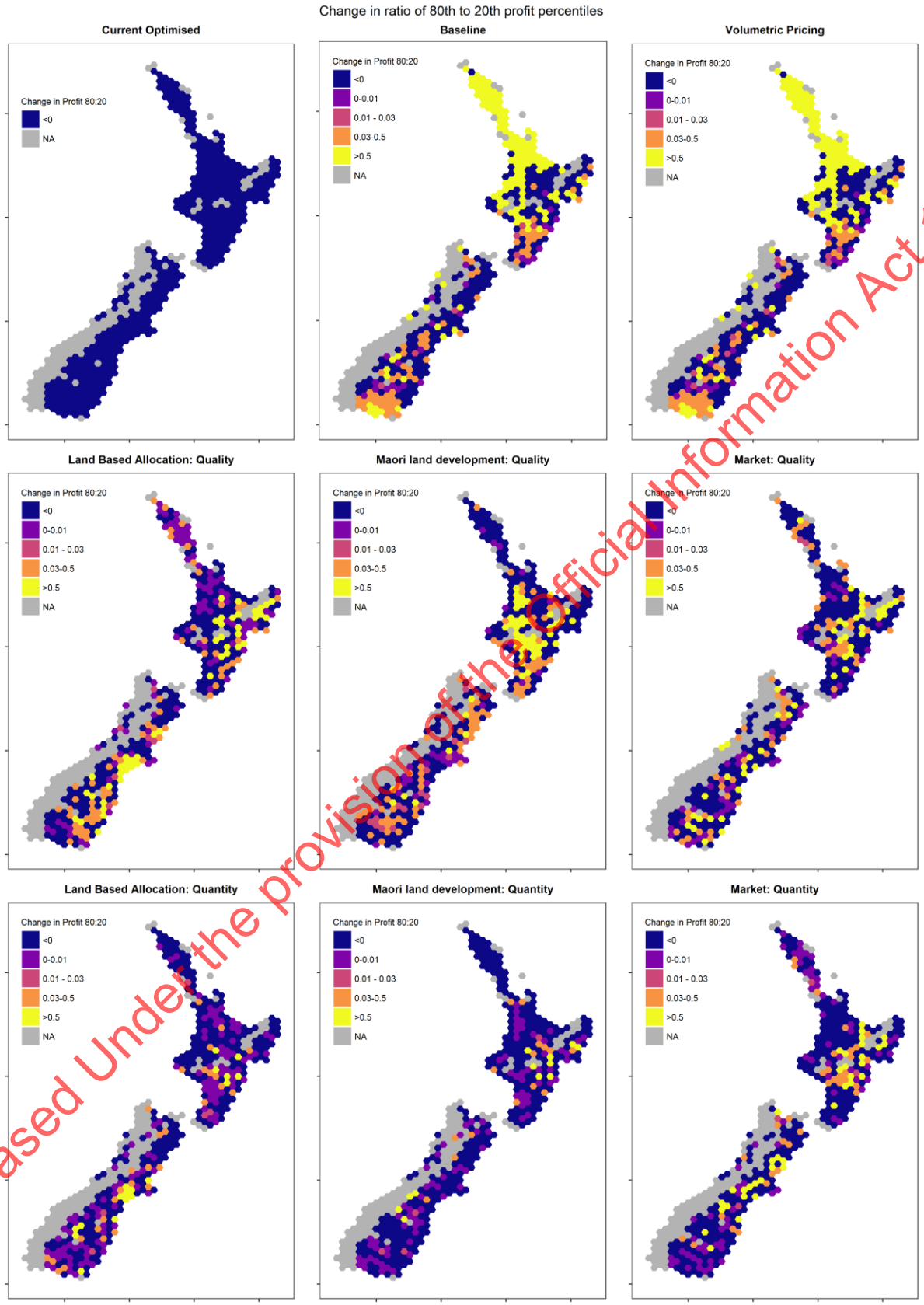
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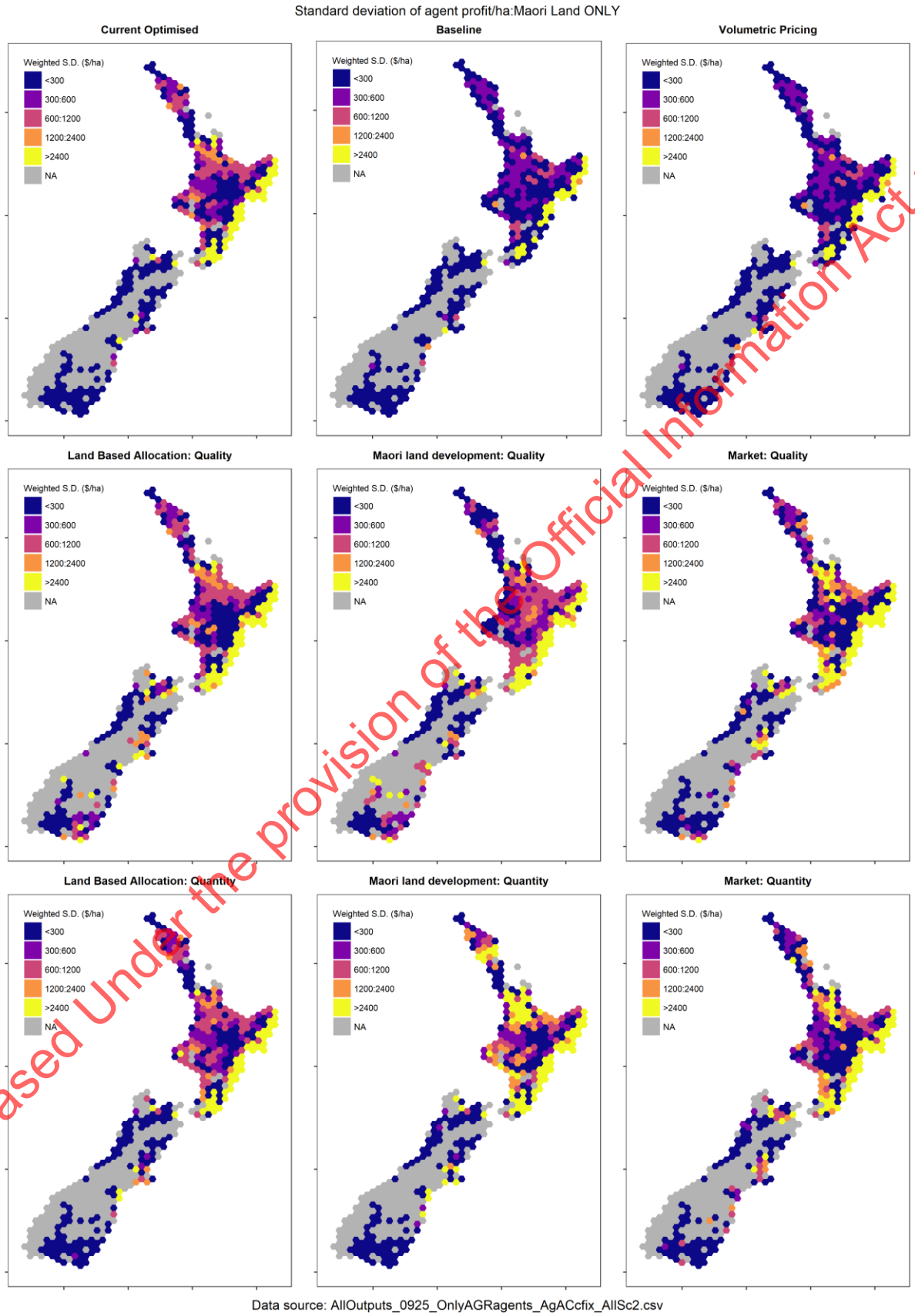
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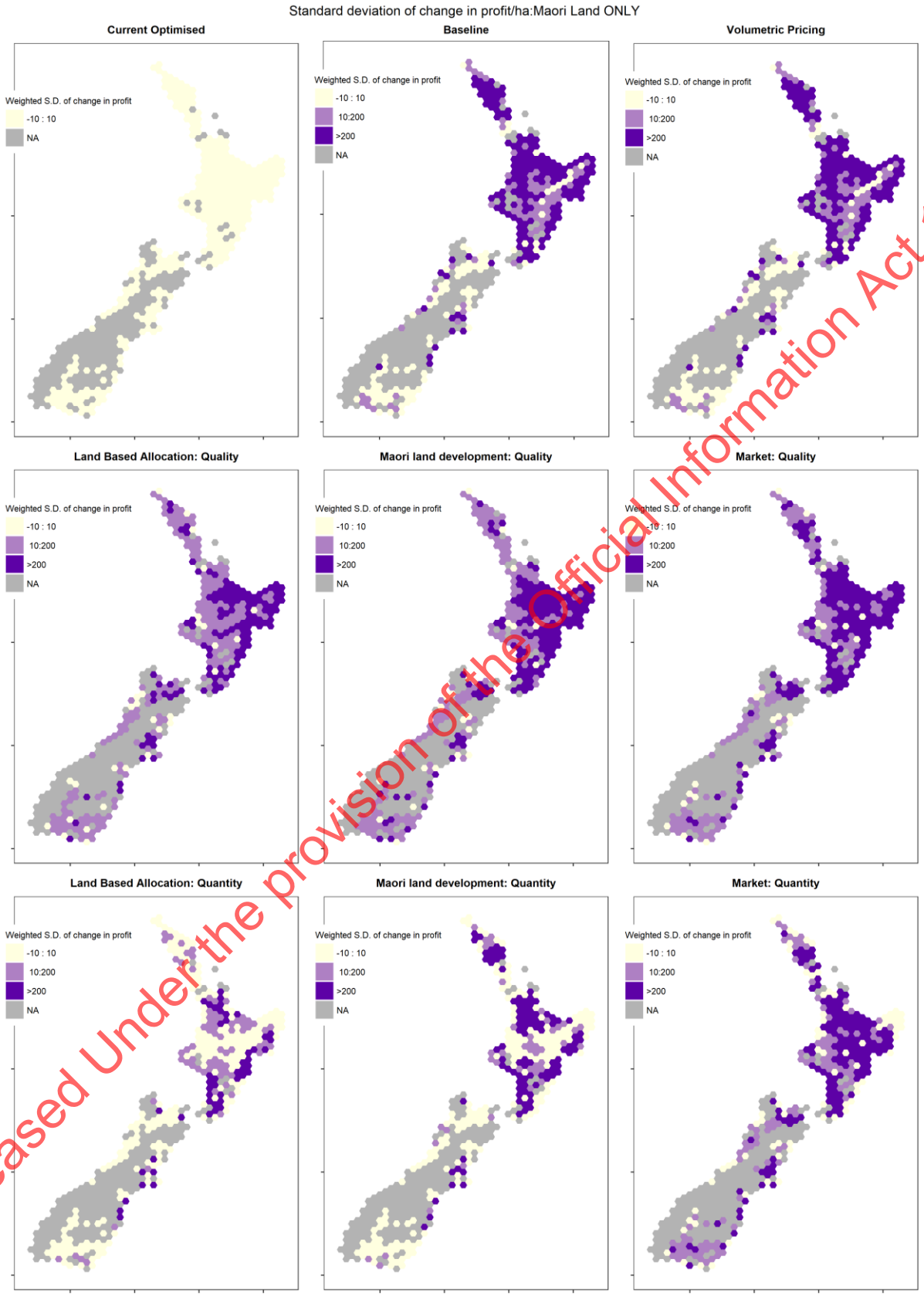
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A11.5.2 Maori Land

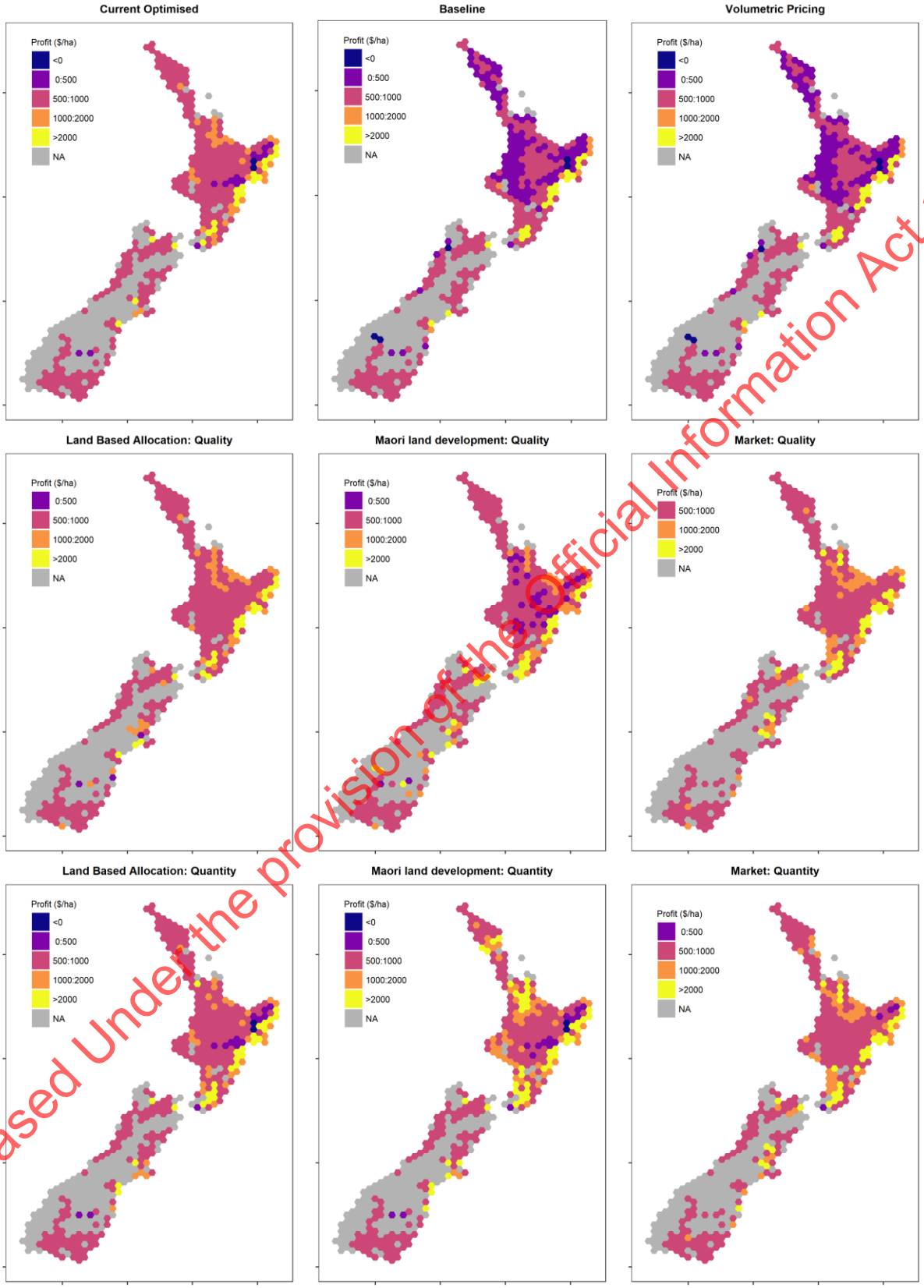


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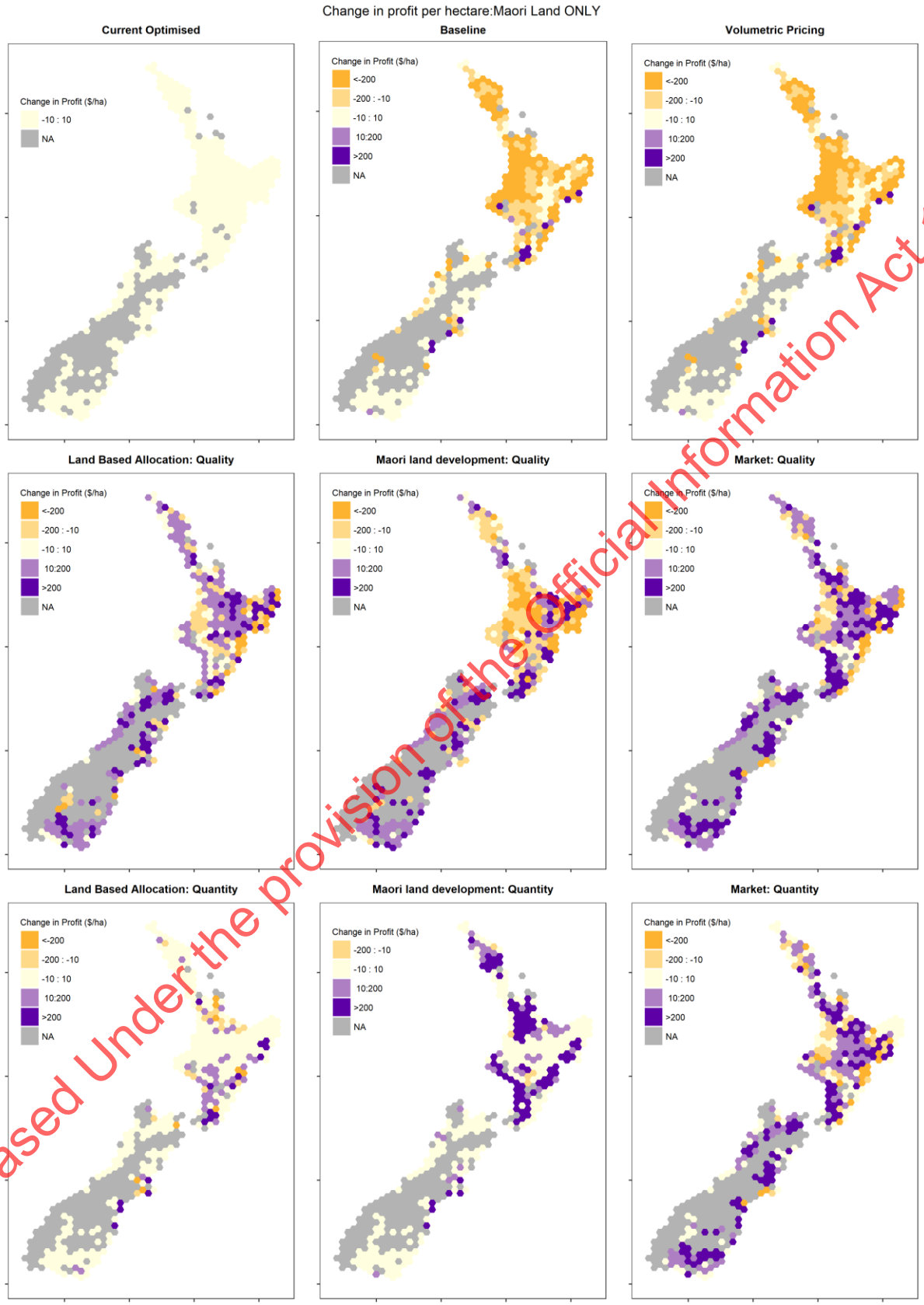
Profit per hectare:Maori Land ONLY



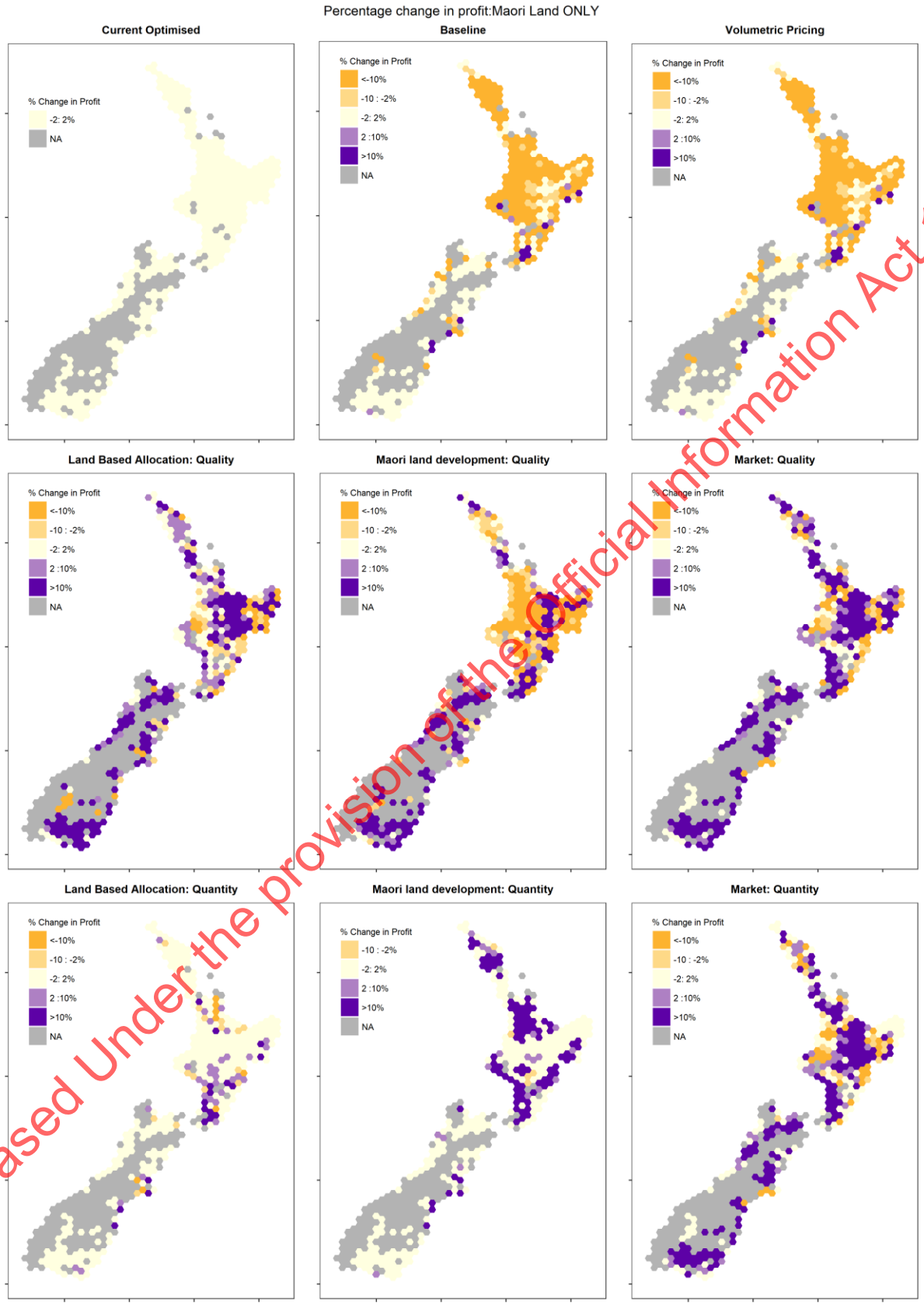
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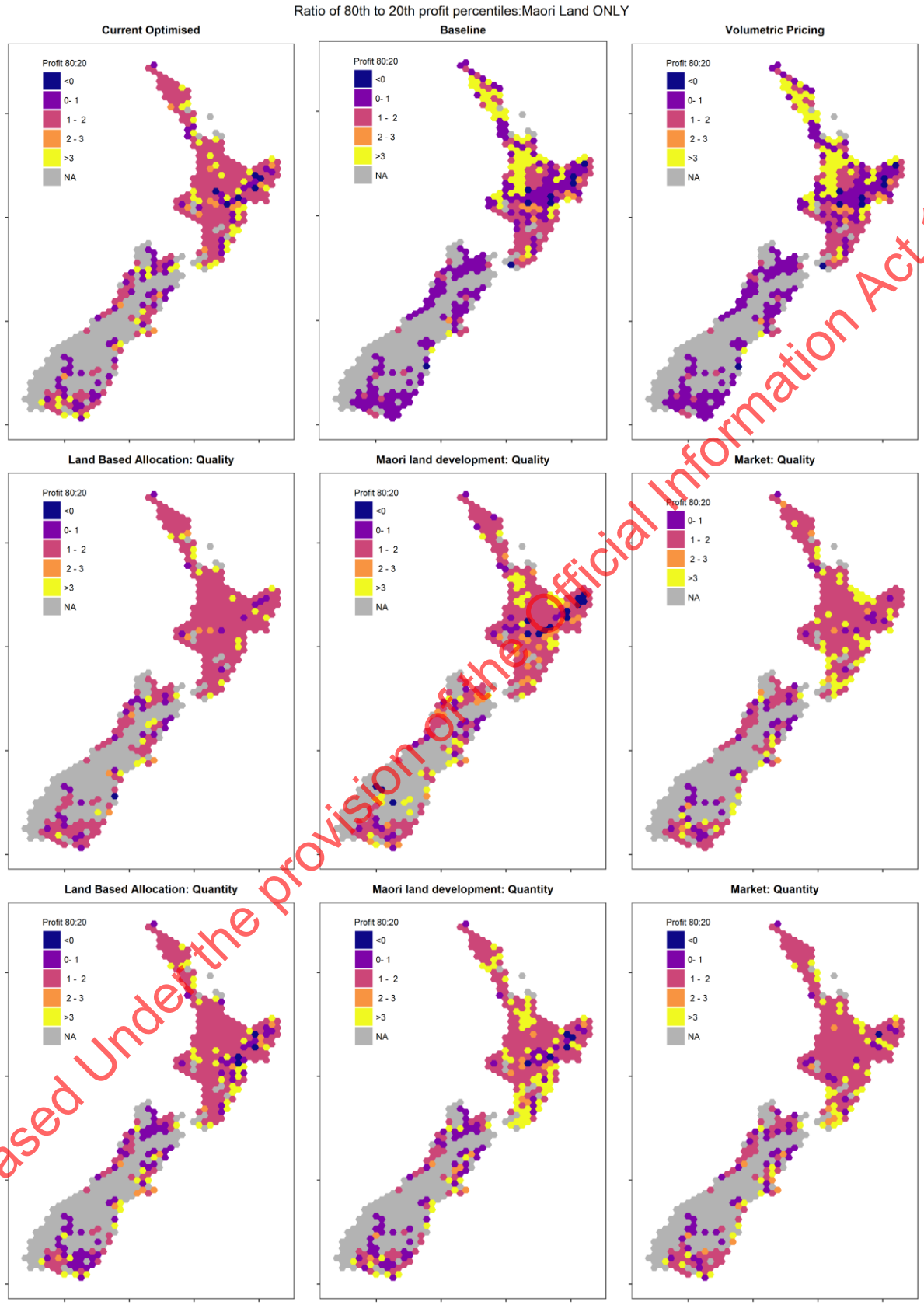
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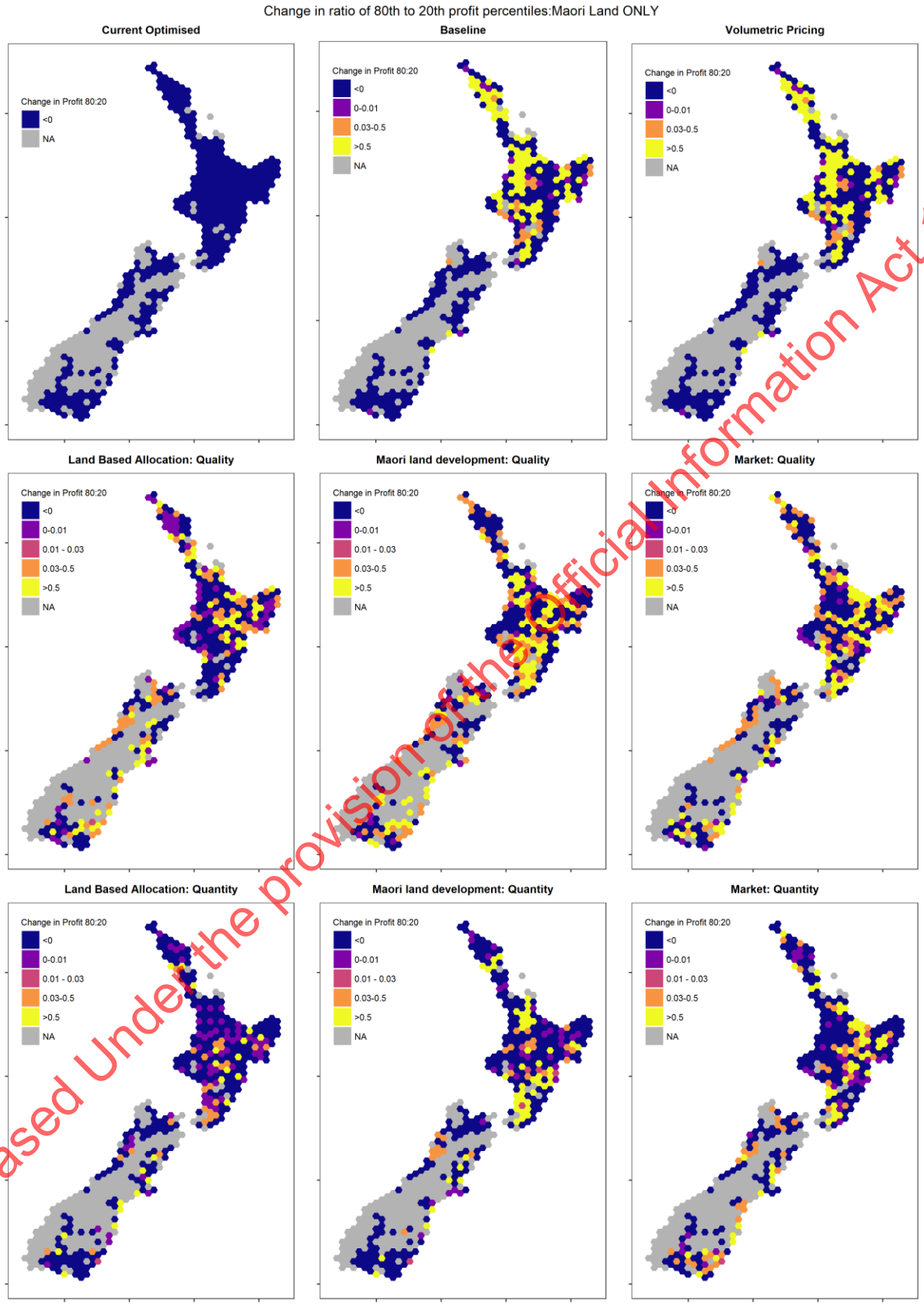


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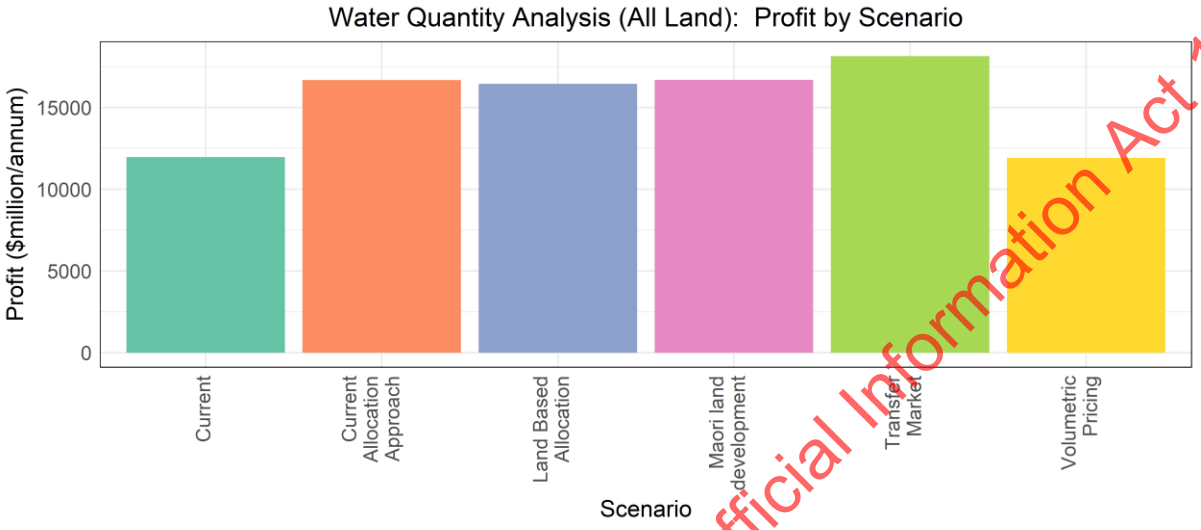


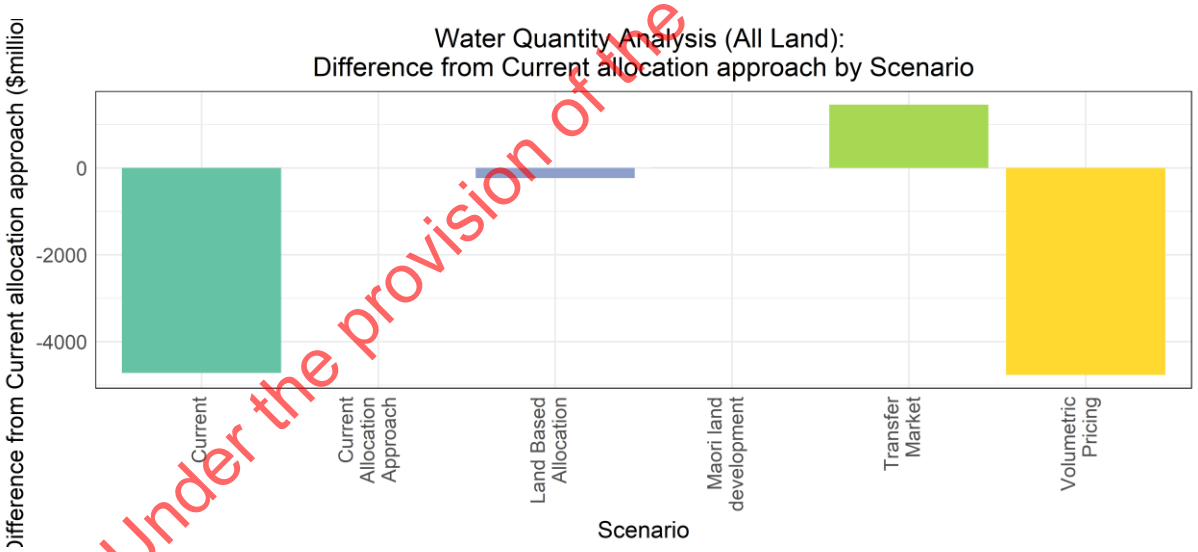
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A11.6 Quantity Summaries

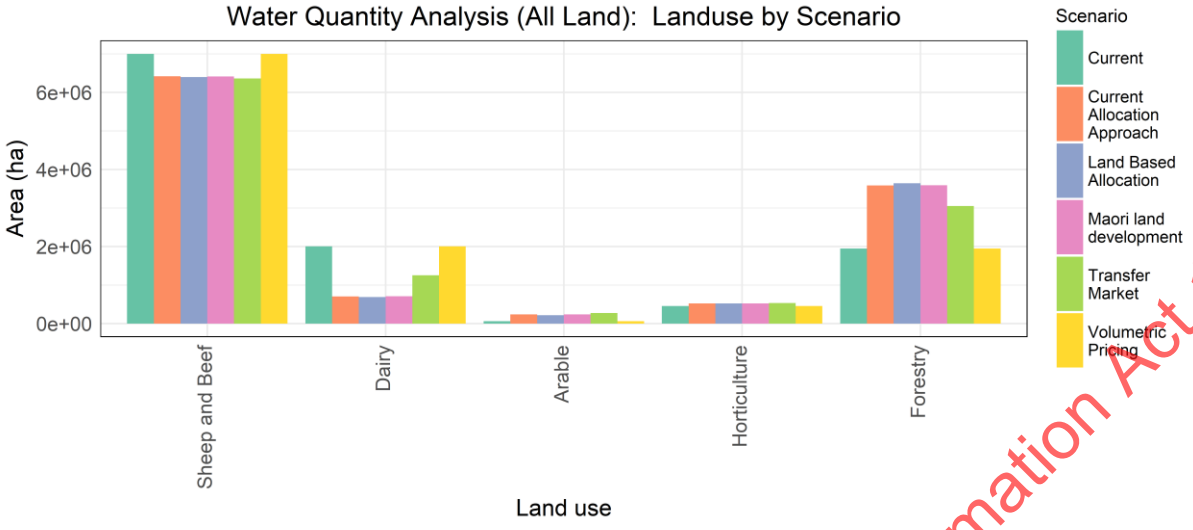
The following sections provide supplementary plots summarising the model outputs for the quantity optimisation scenarios, for both all land, as well as specifically for Māori owned land.

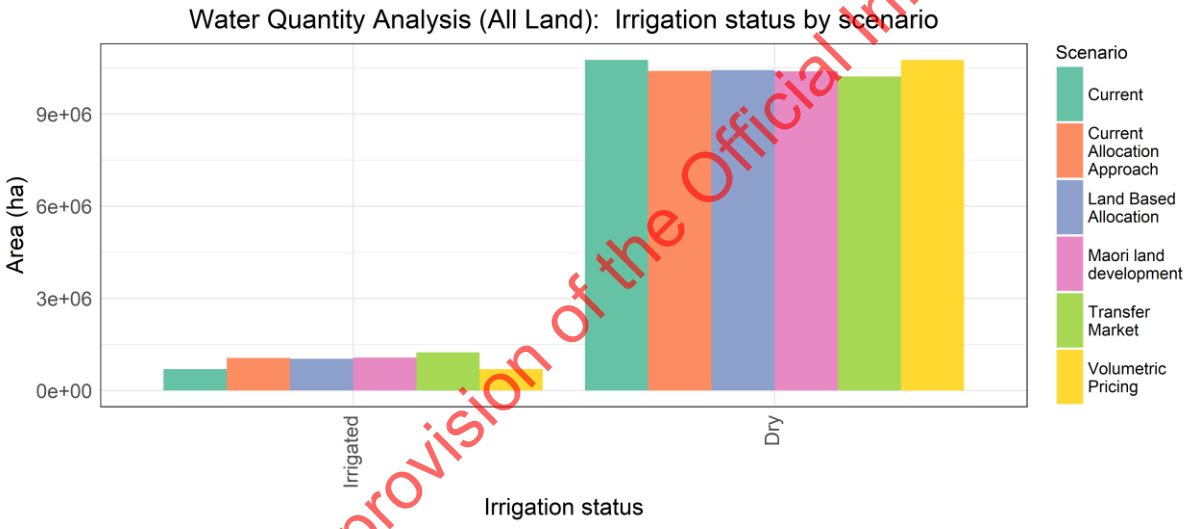
A11.6.1 All Land

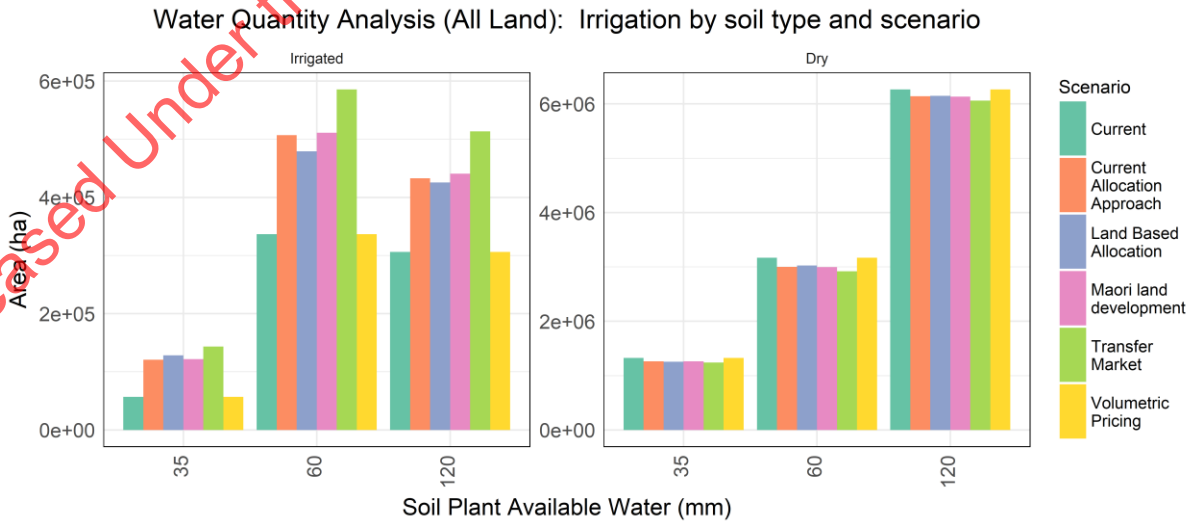




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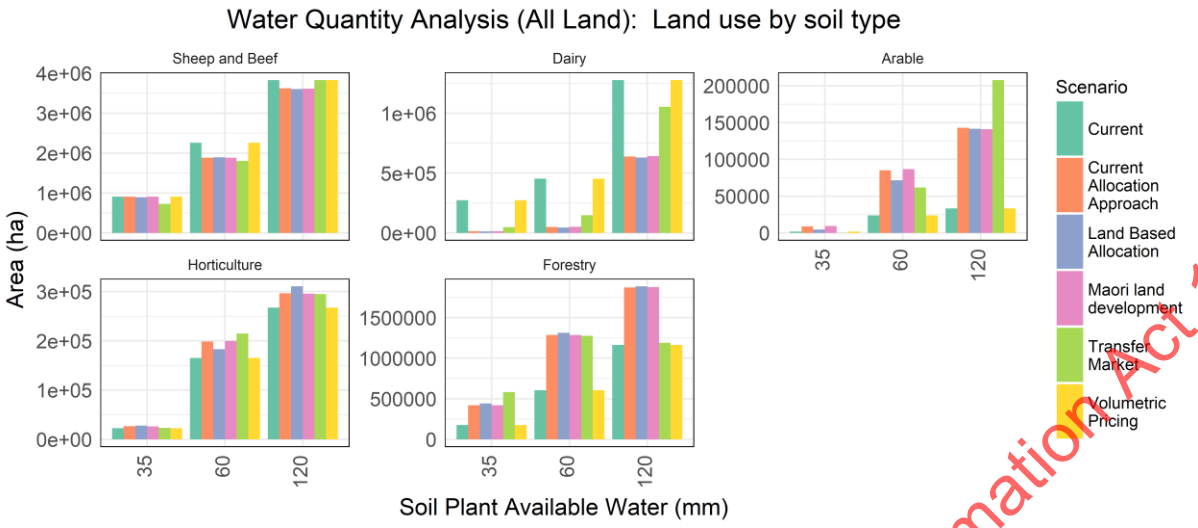


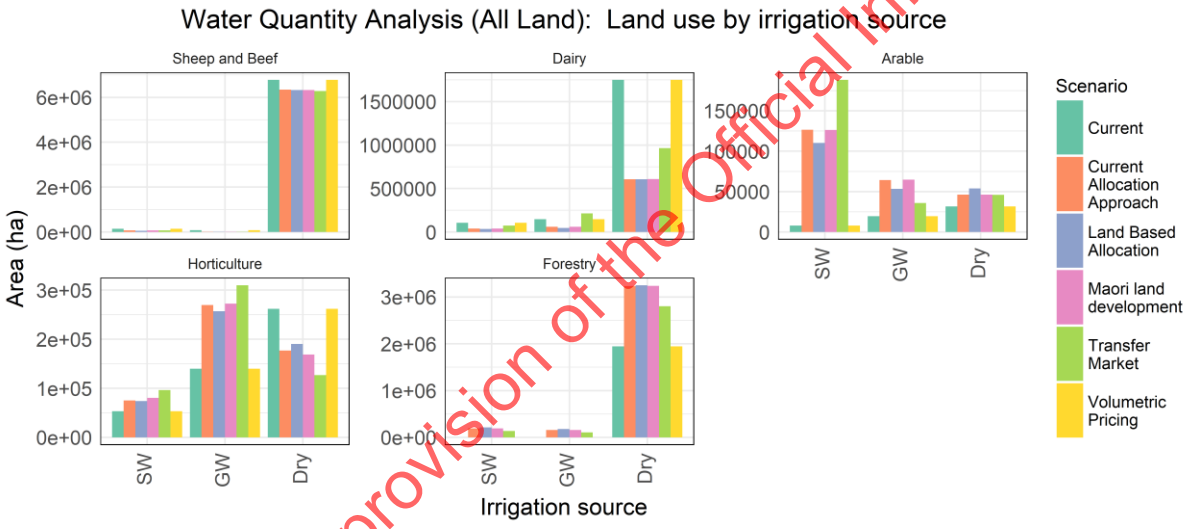


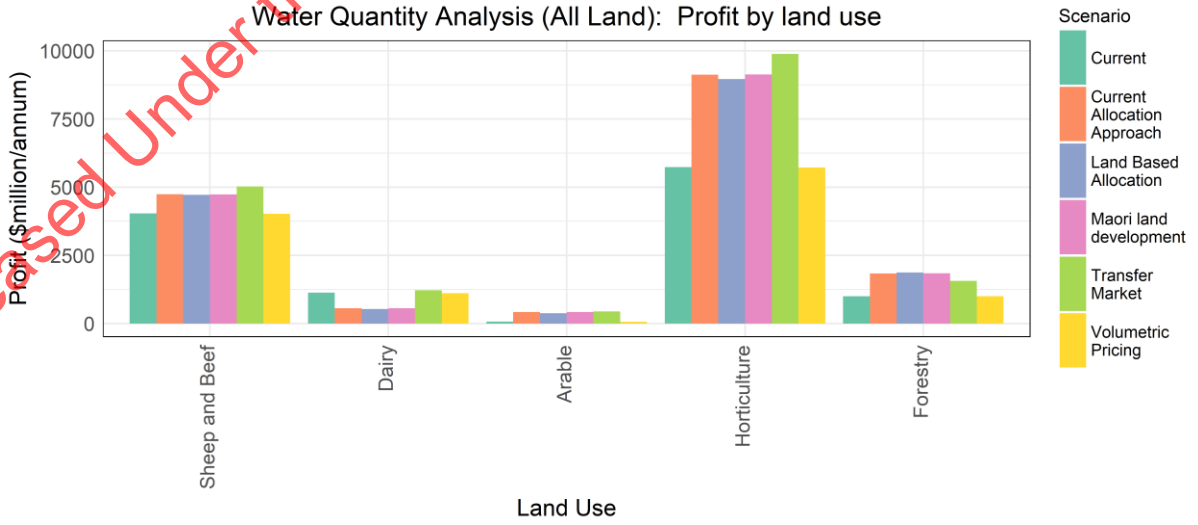


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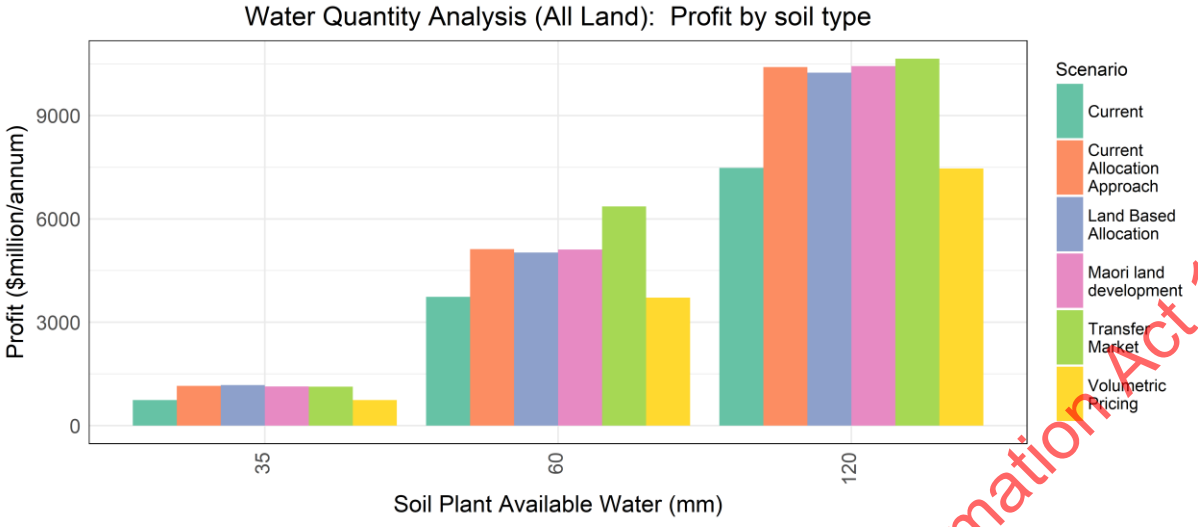
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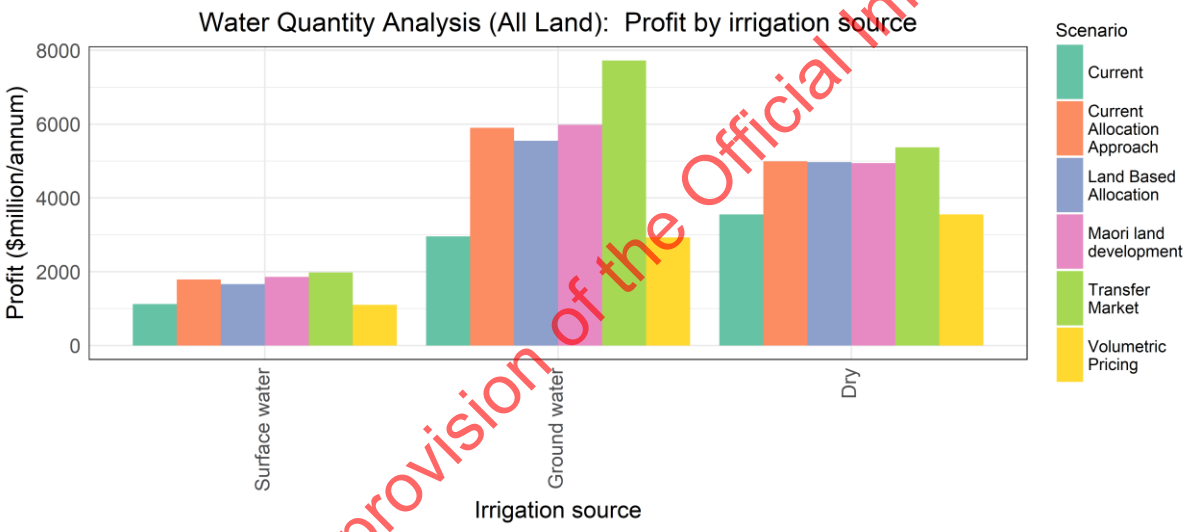


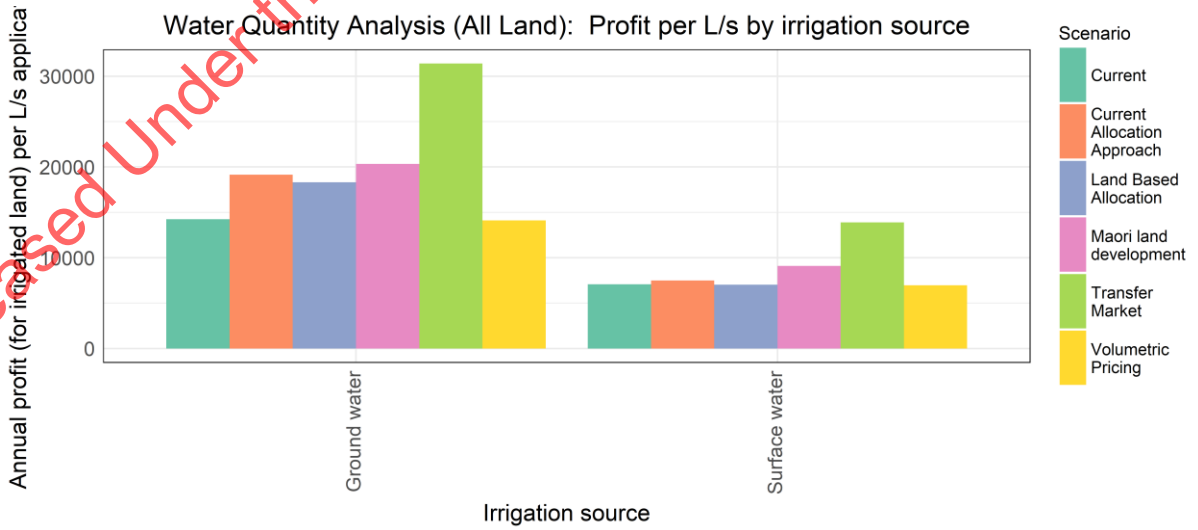




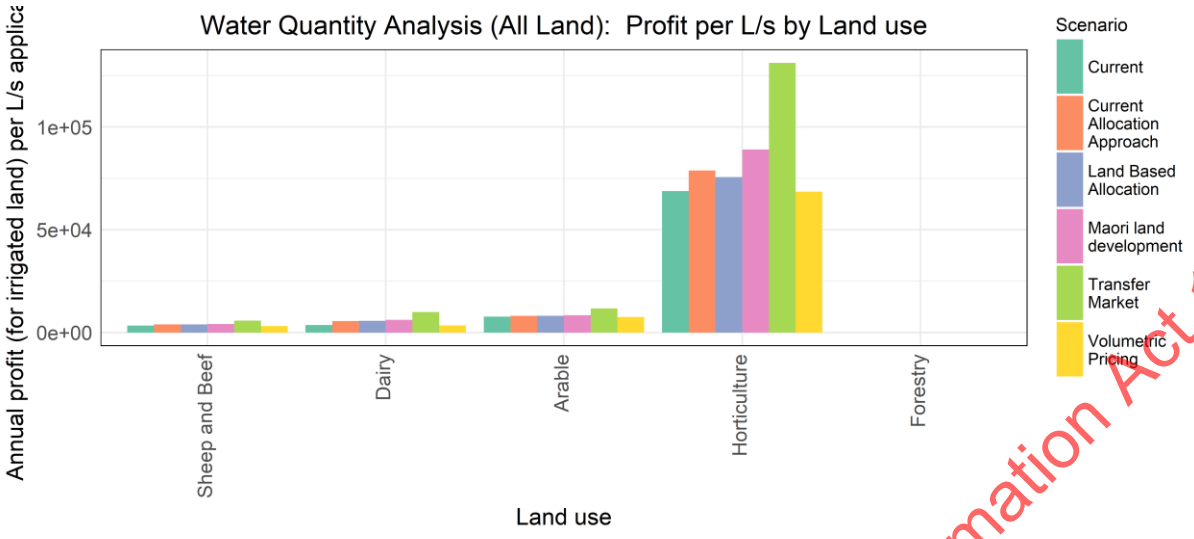
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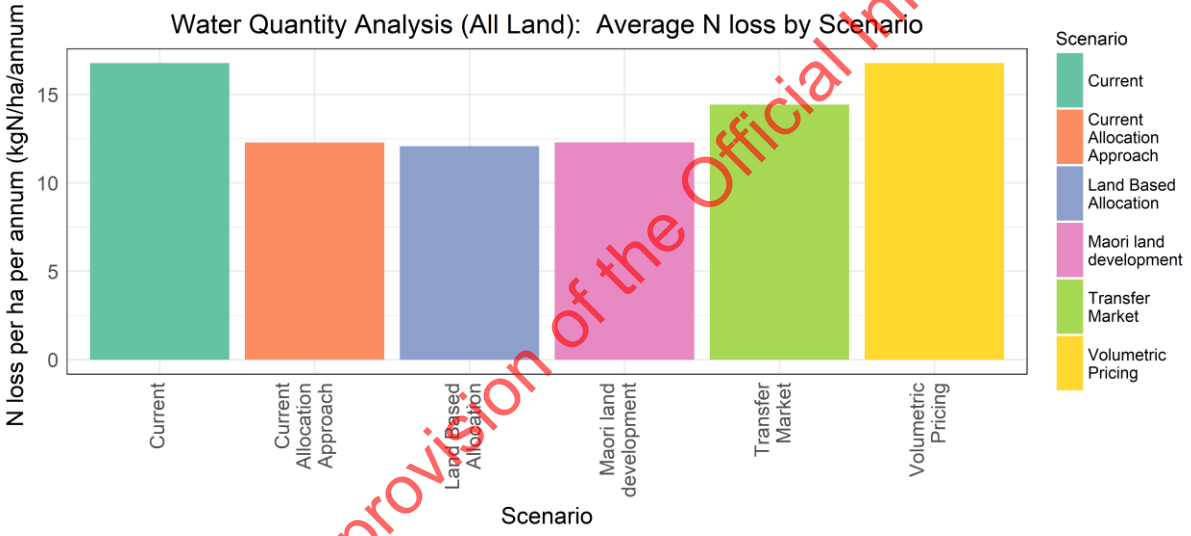


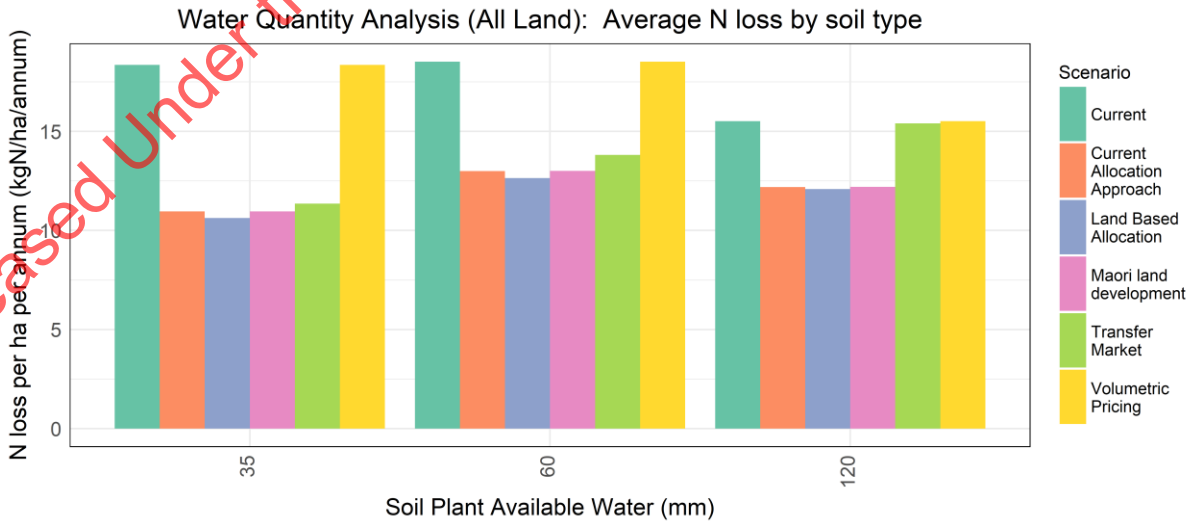




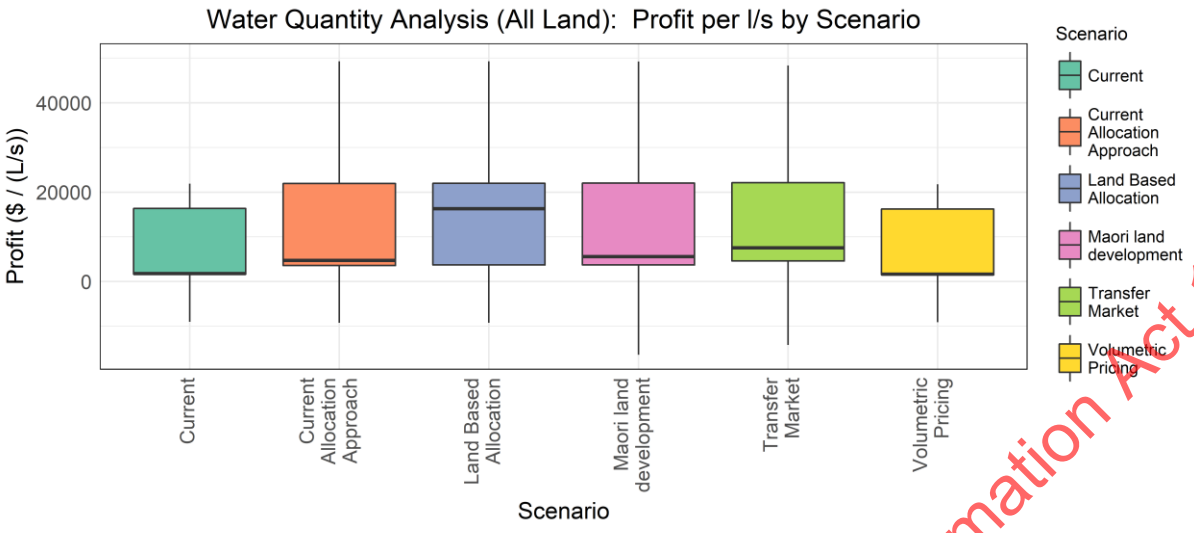
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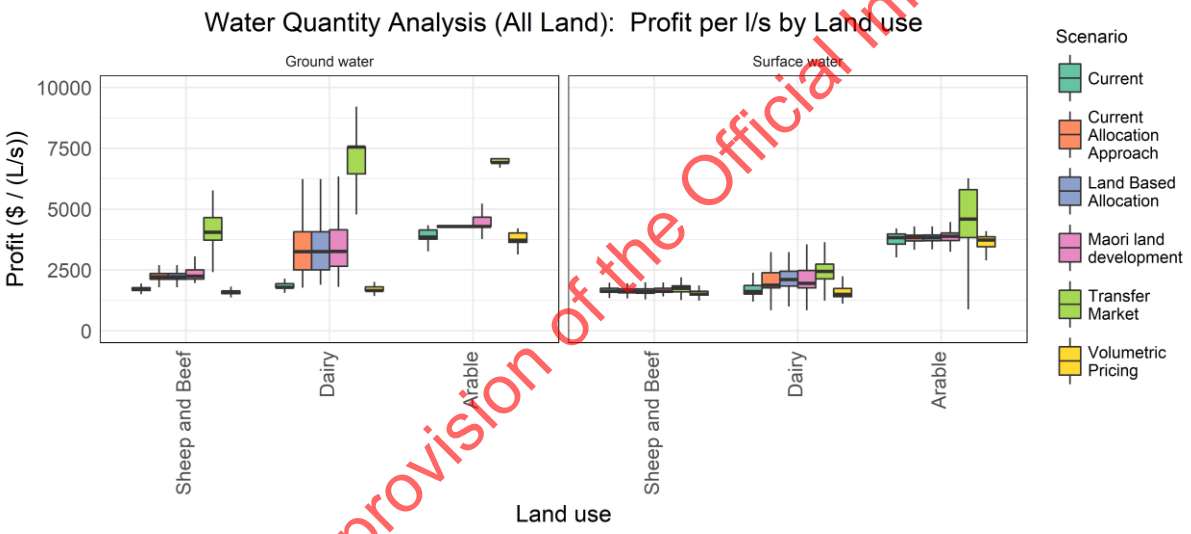


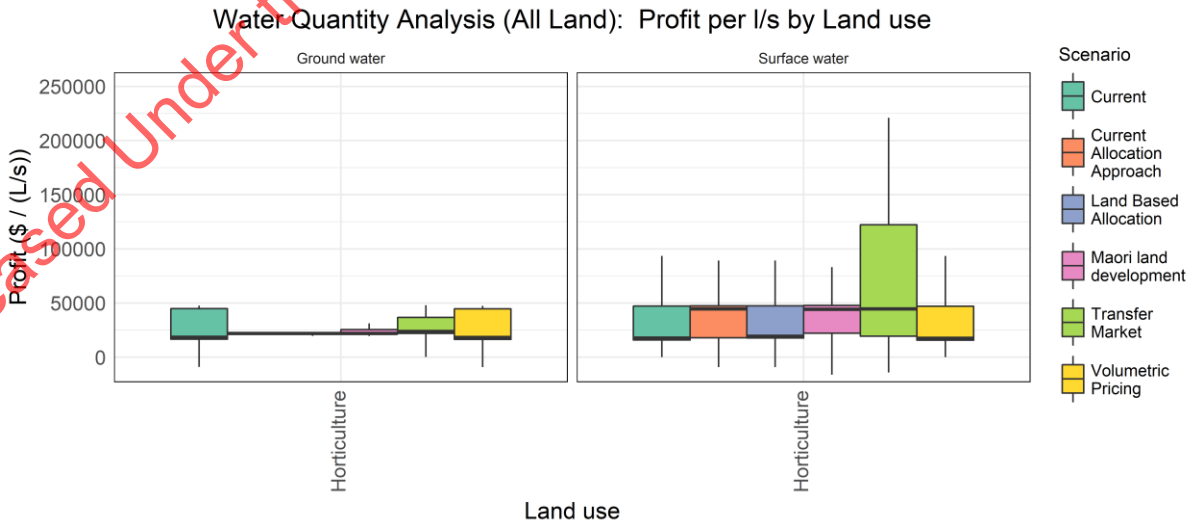




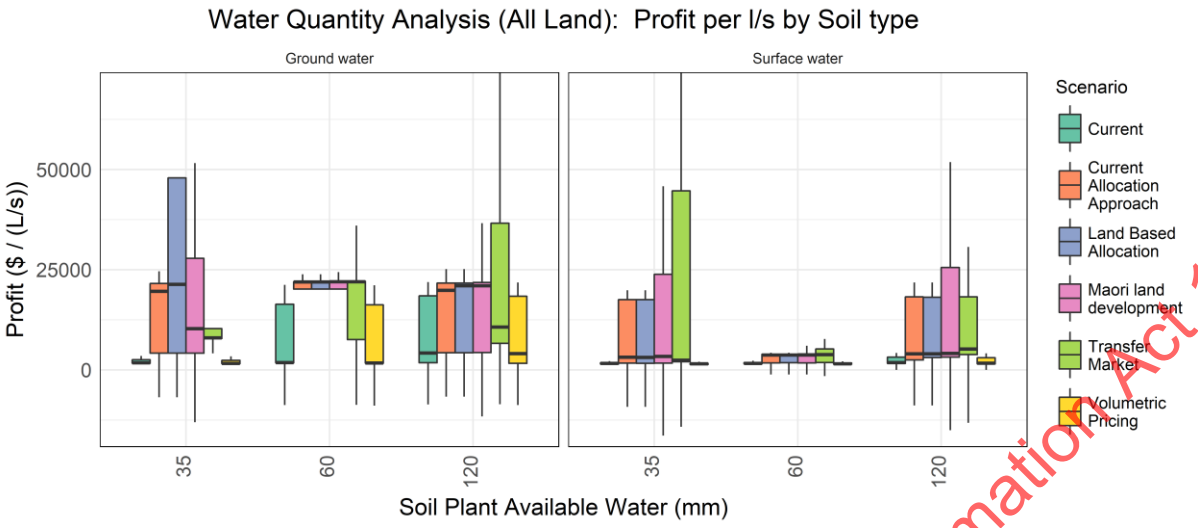
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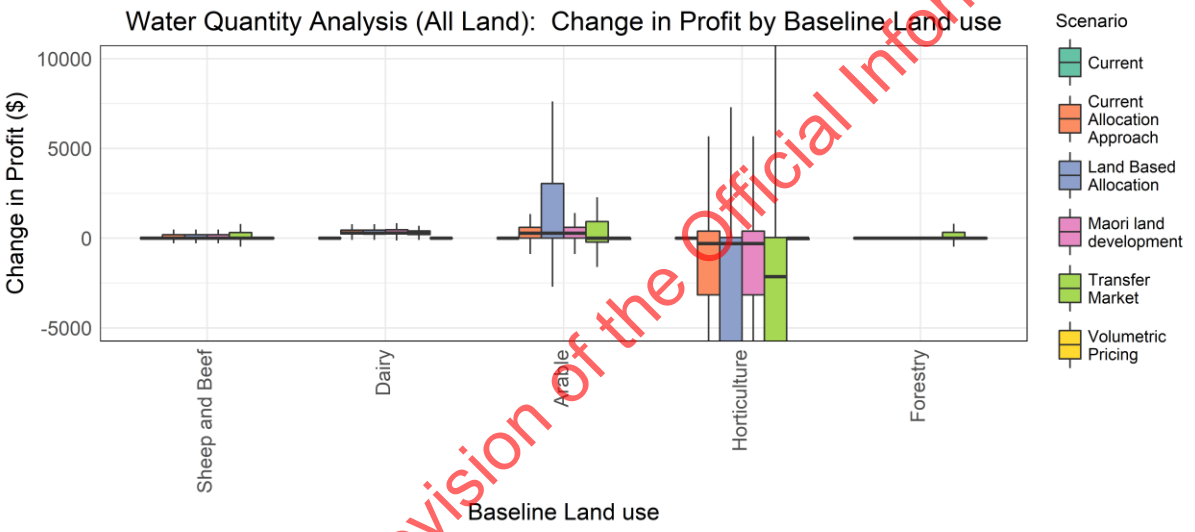




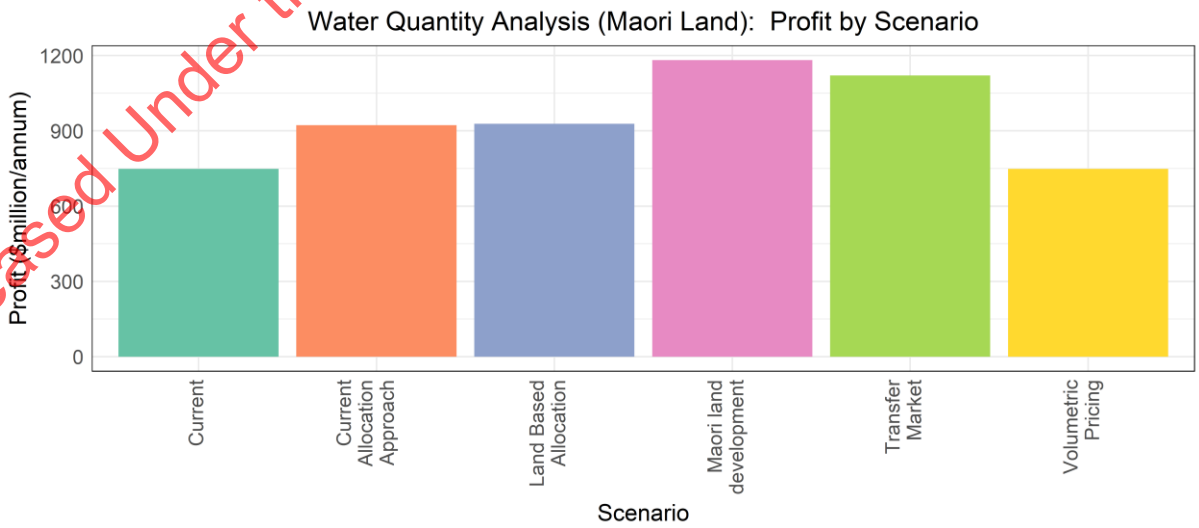


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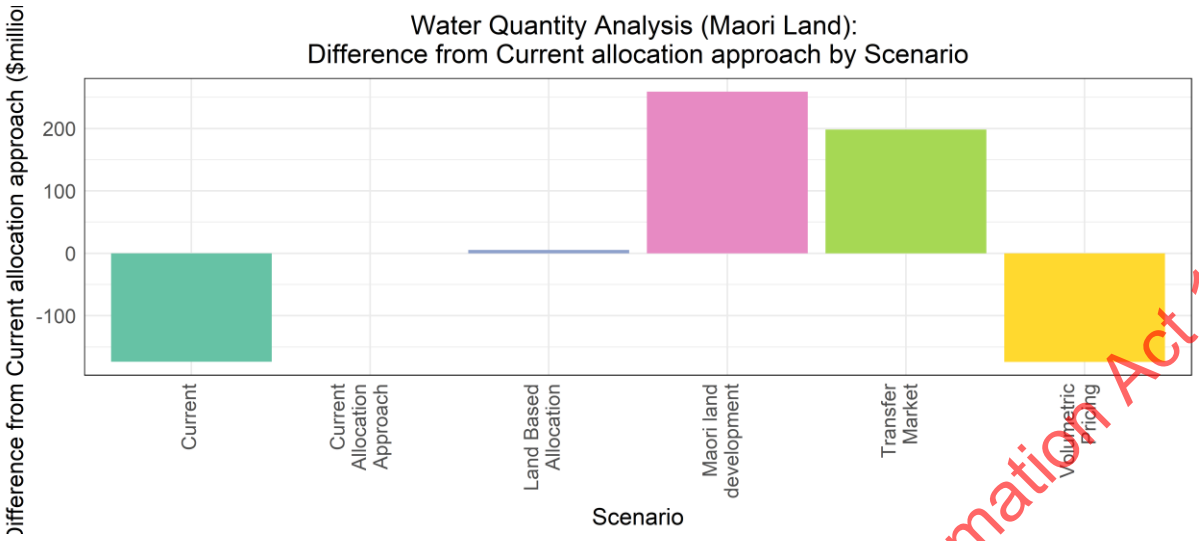


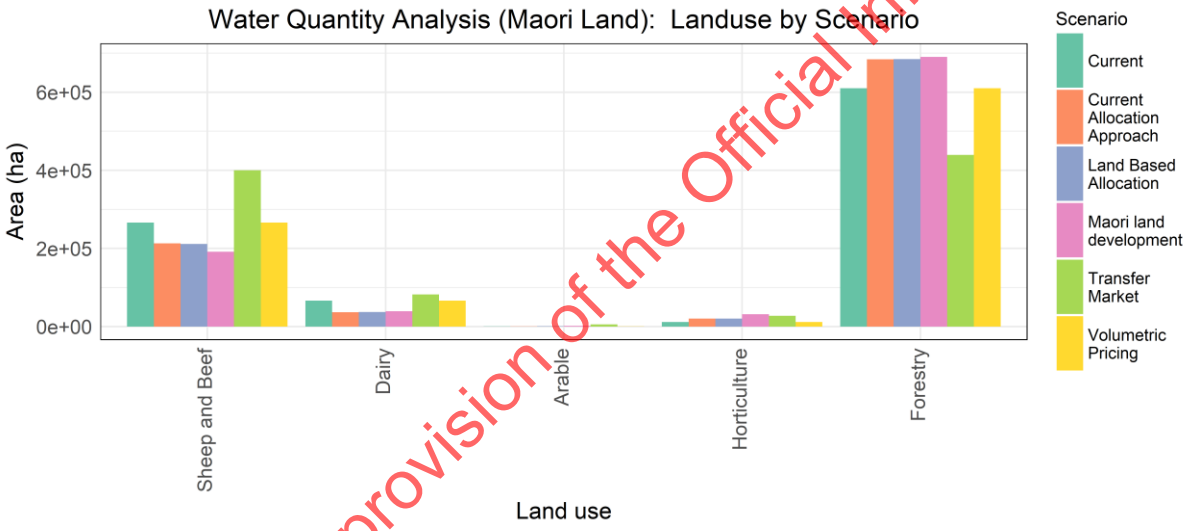


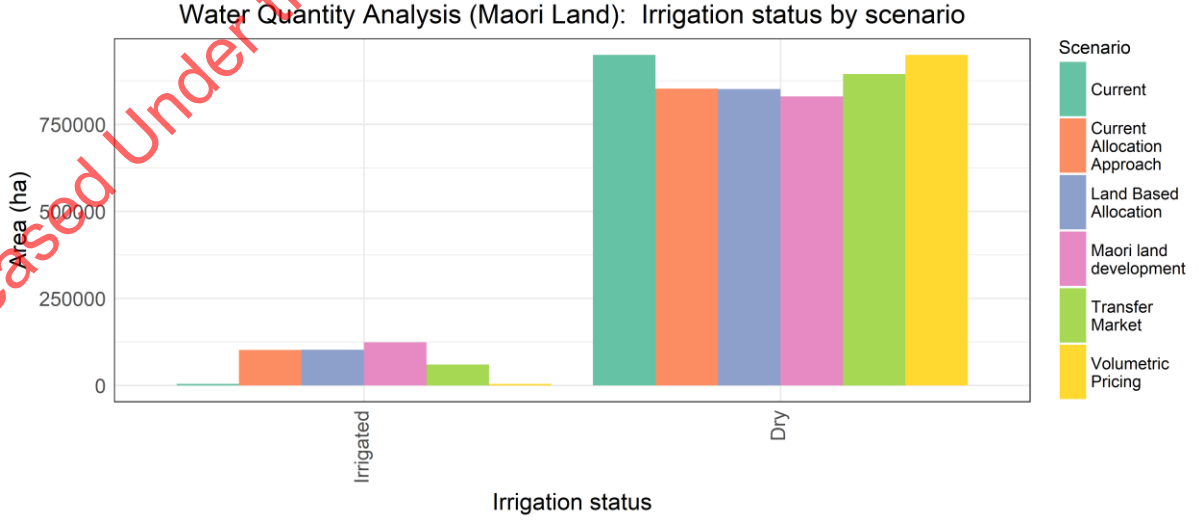
A11.6.2 Maori Owned Land



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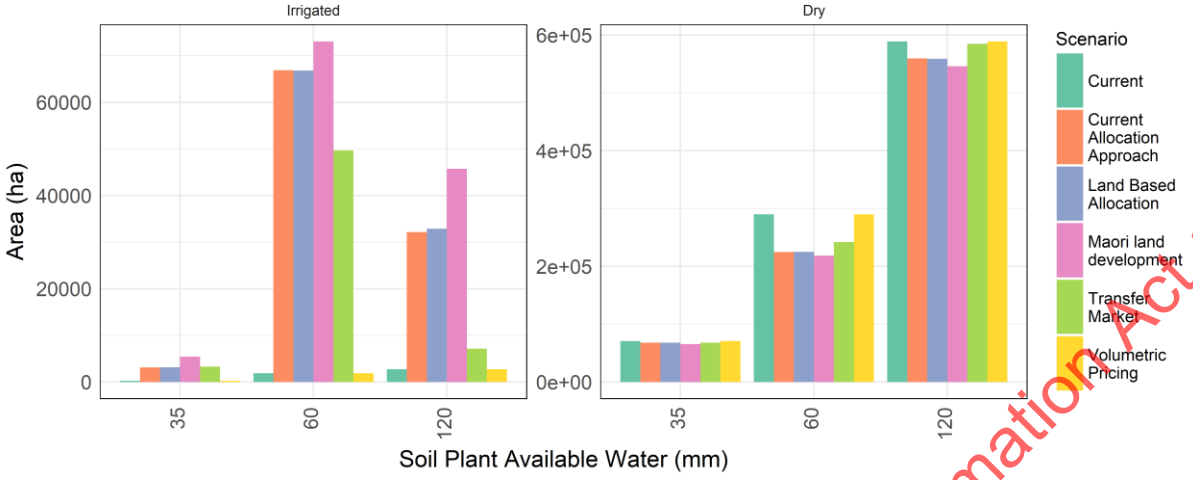




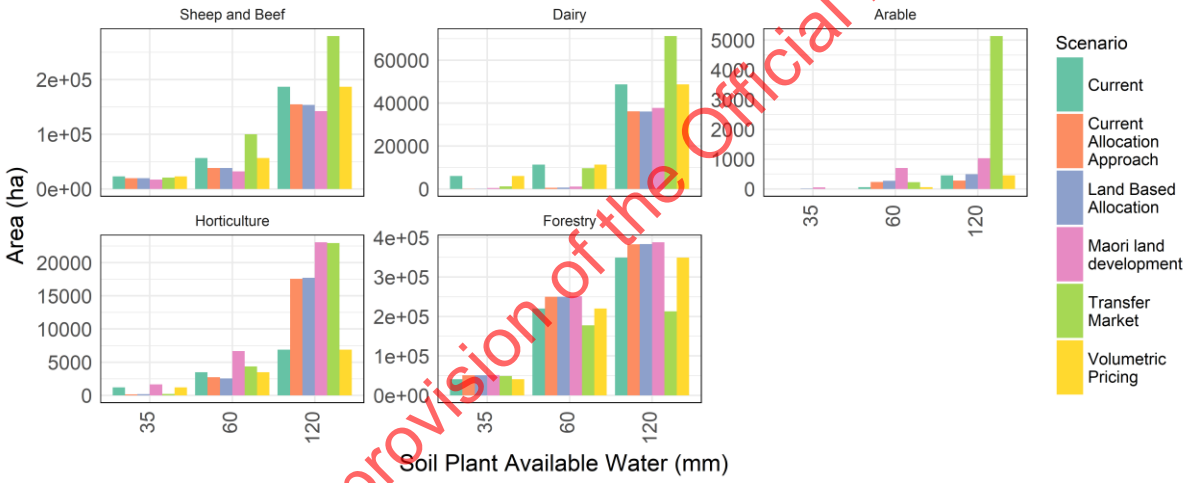


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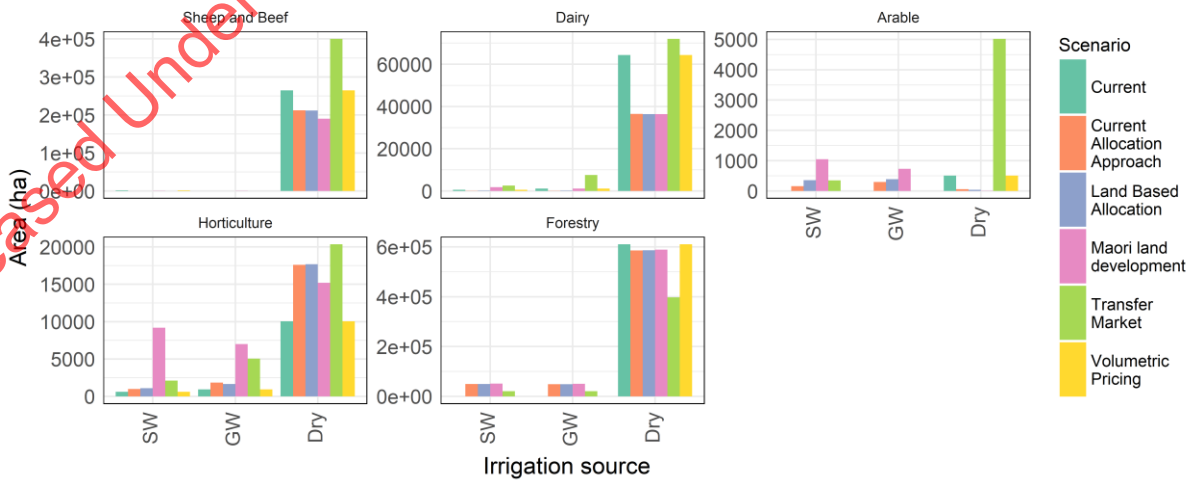
Water Quantity Analysis (Maori Land): Irrigation by soil type and scenario



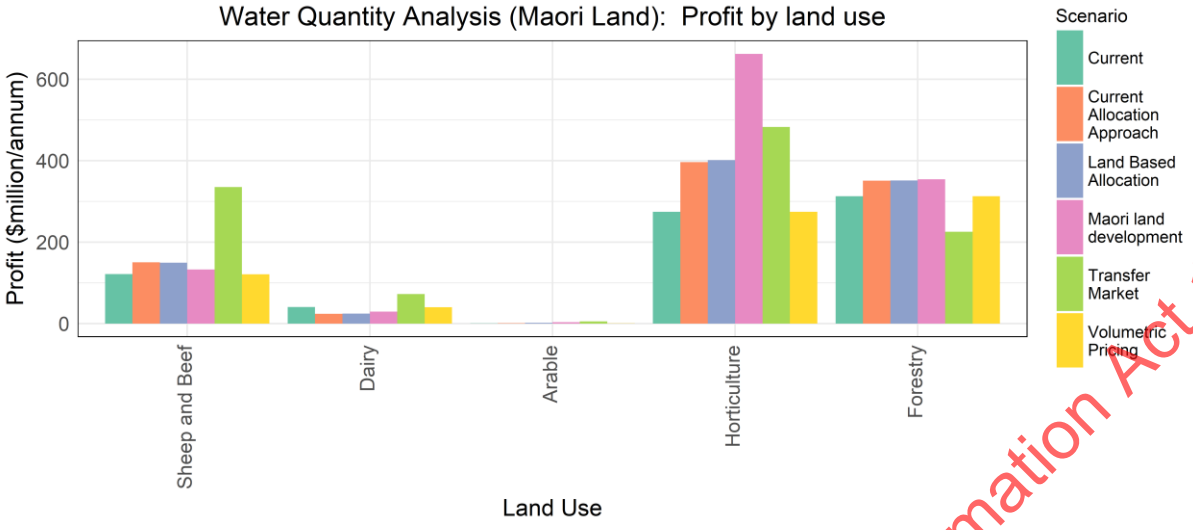
Water Quantity Analysis (Maori Land): Land use by soil type

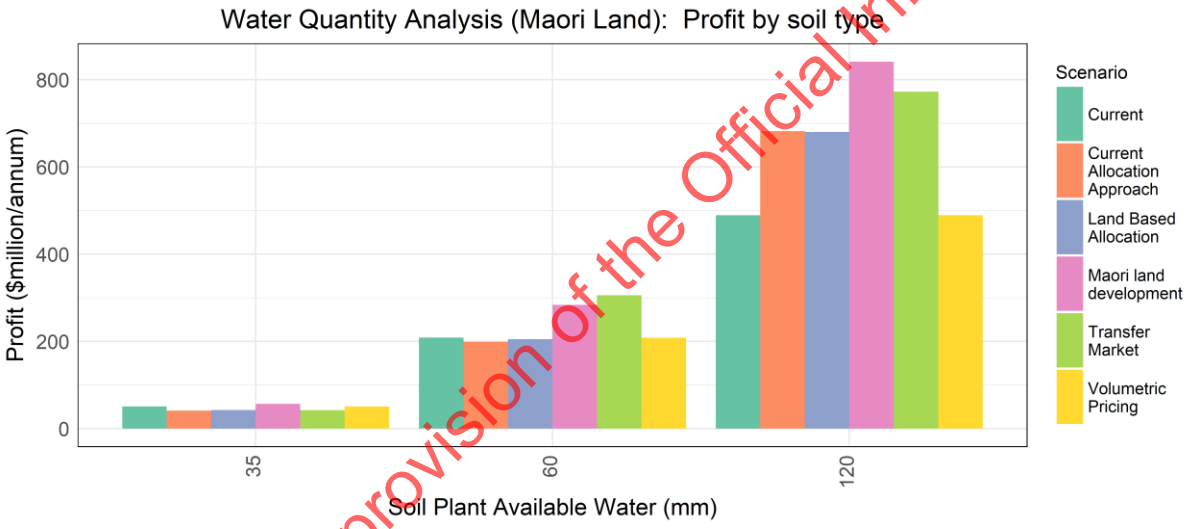


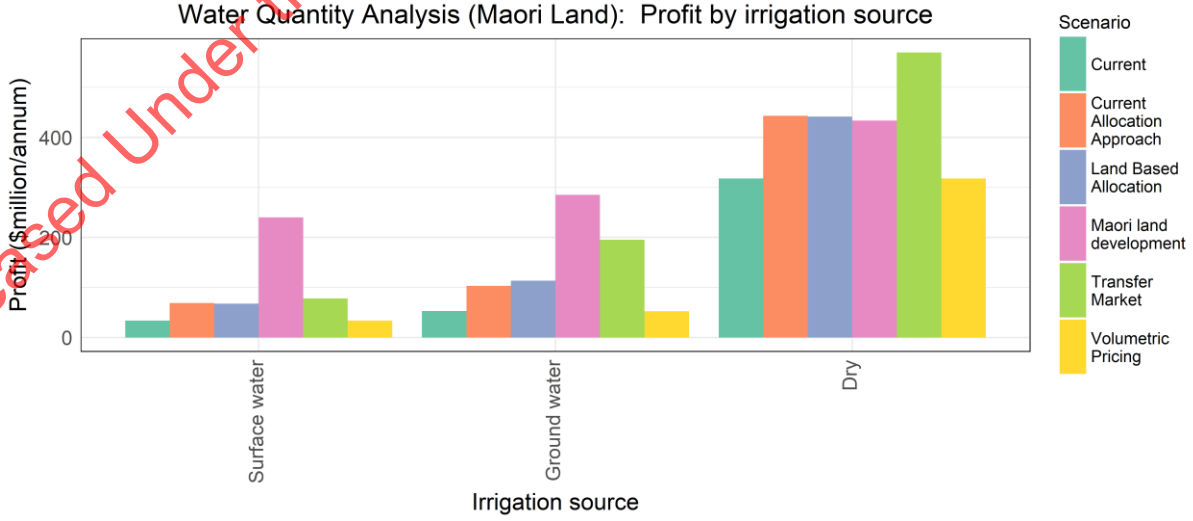
Water Quantity Analysis (Maori Land): Land use by irrigation source



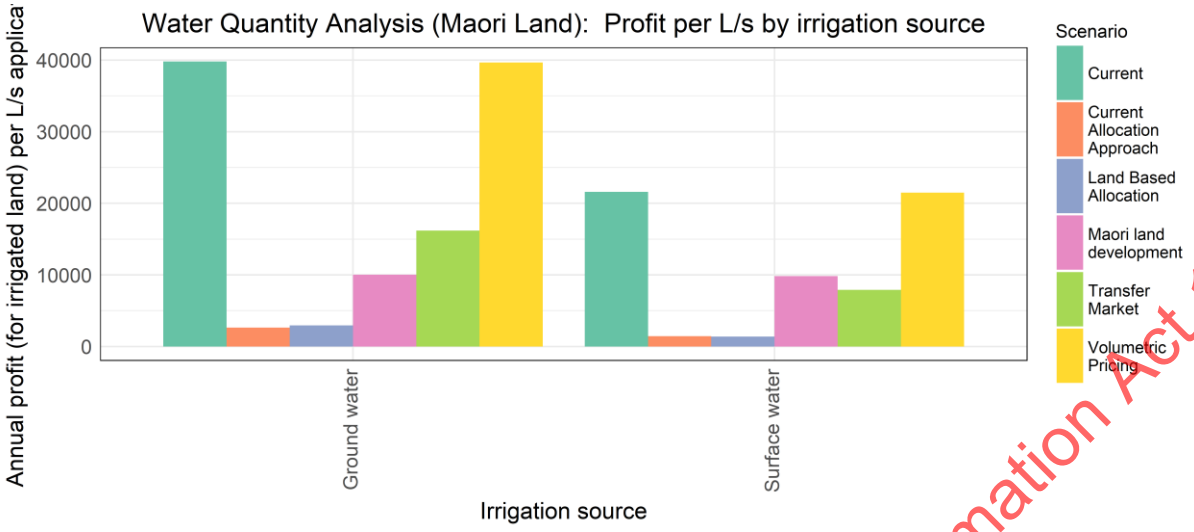
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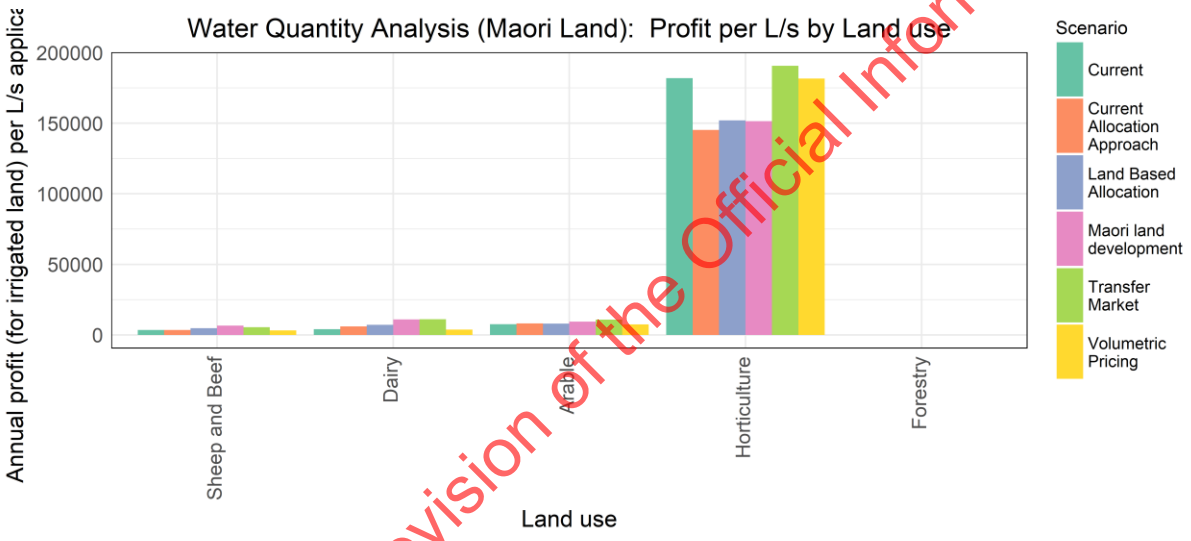


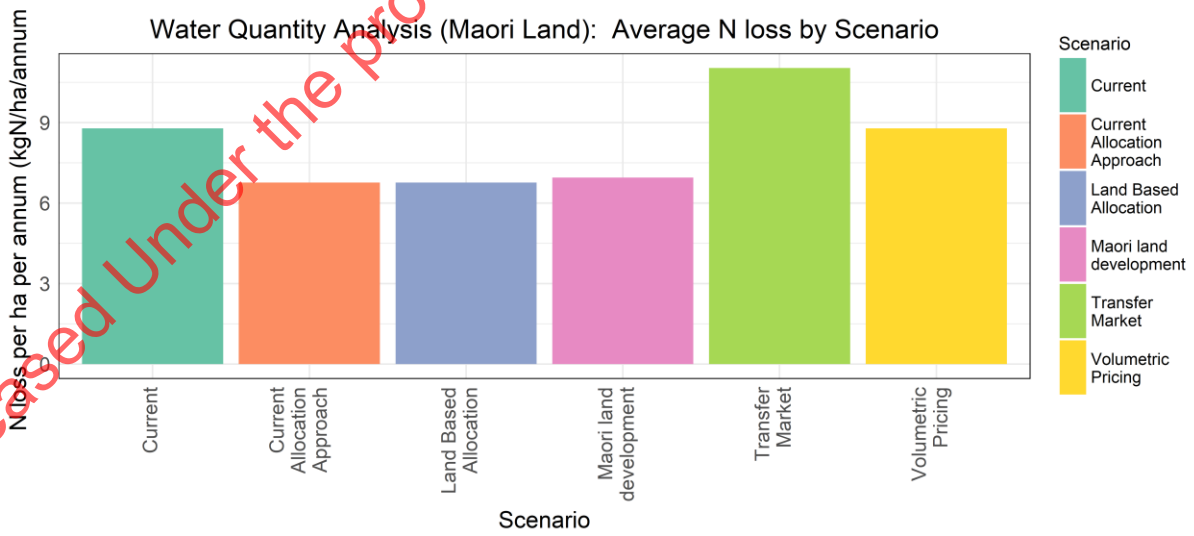




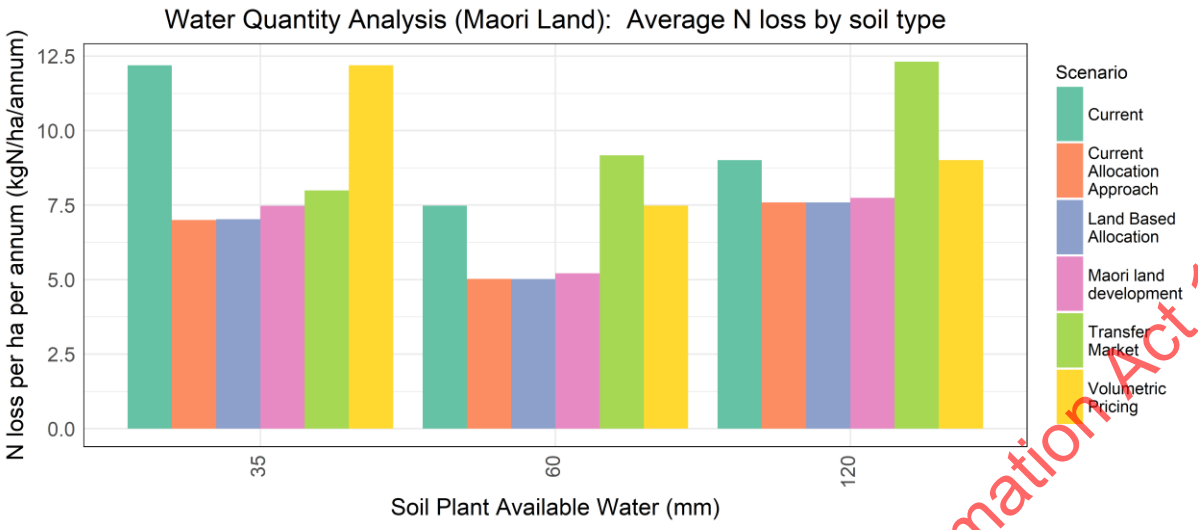
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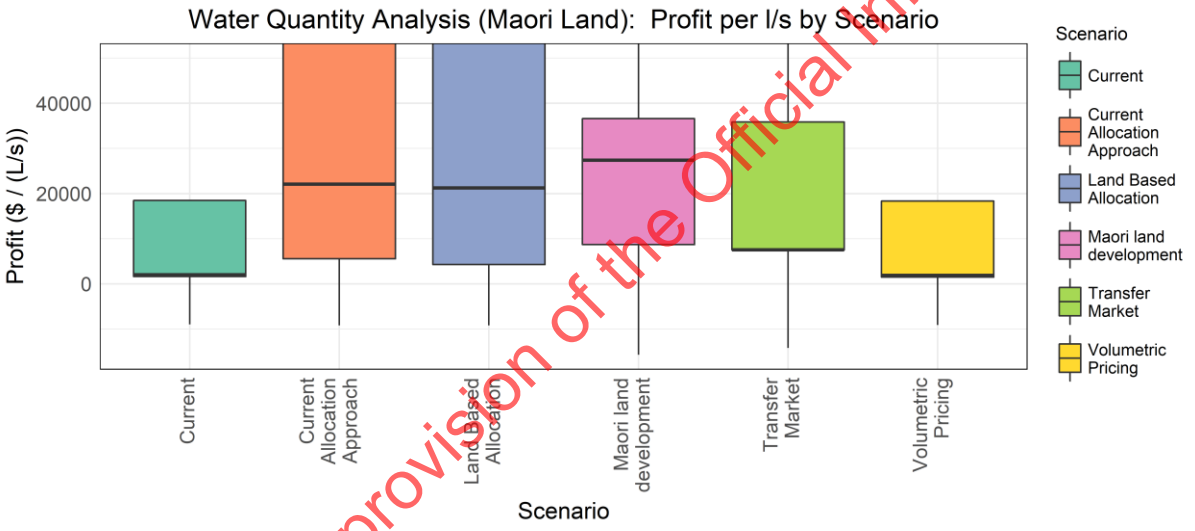


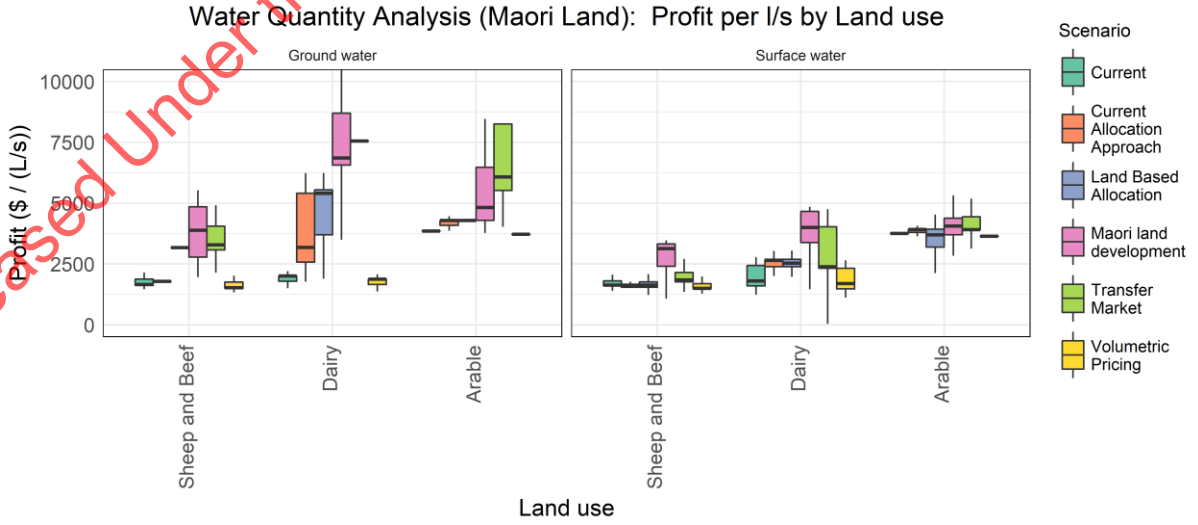




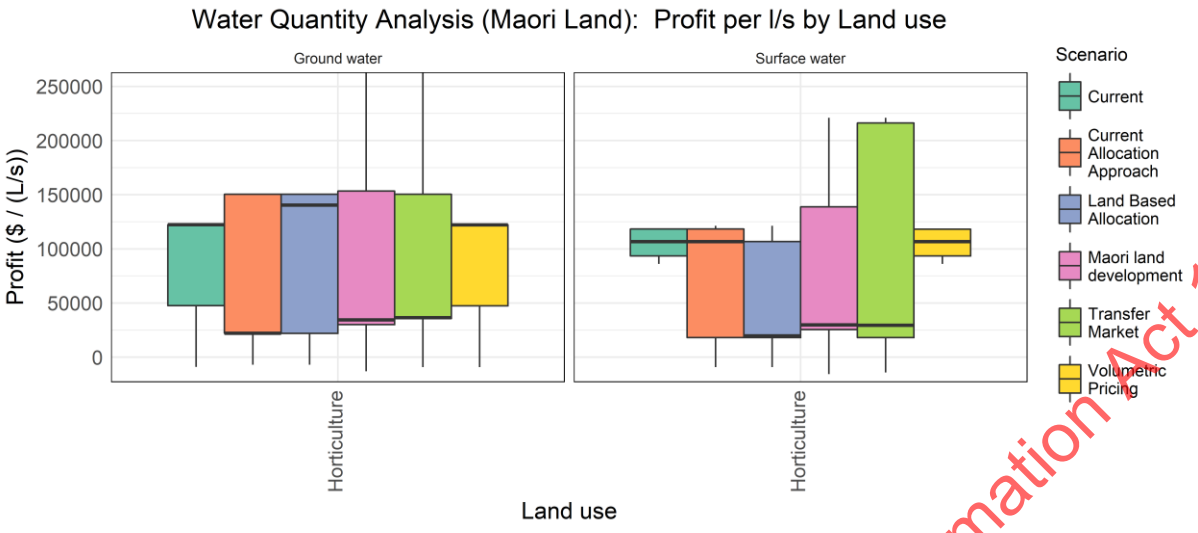
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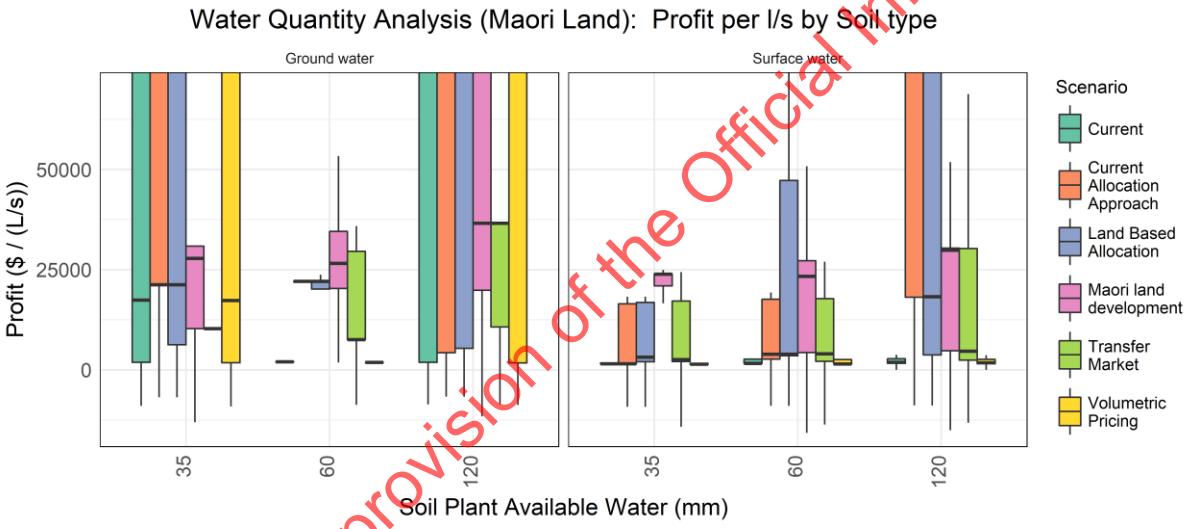


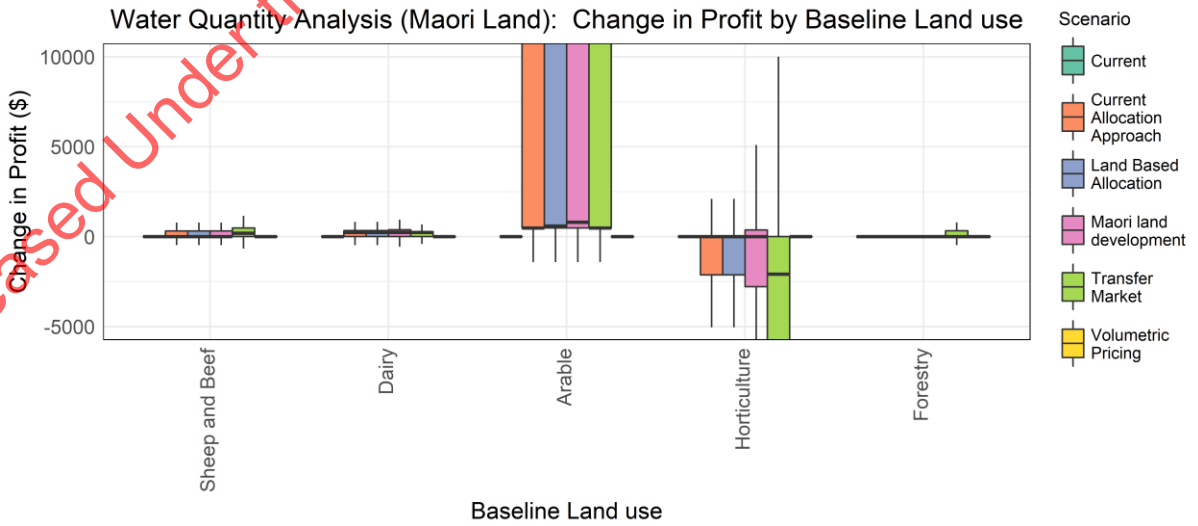




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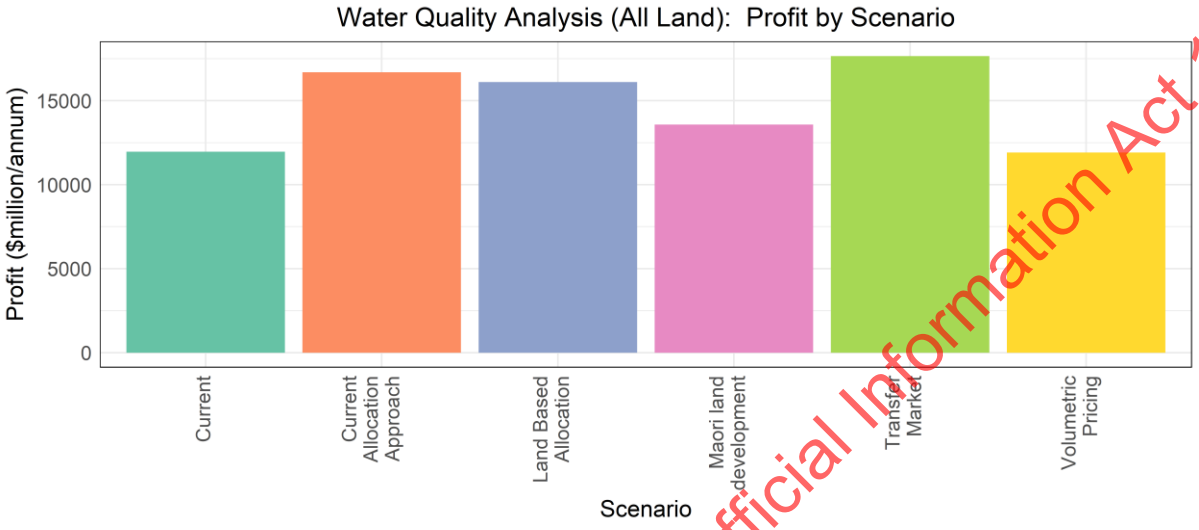


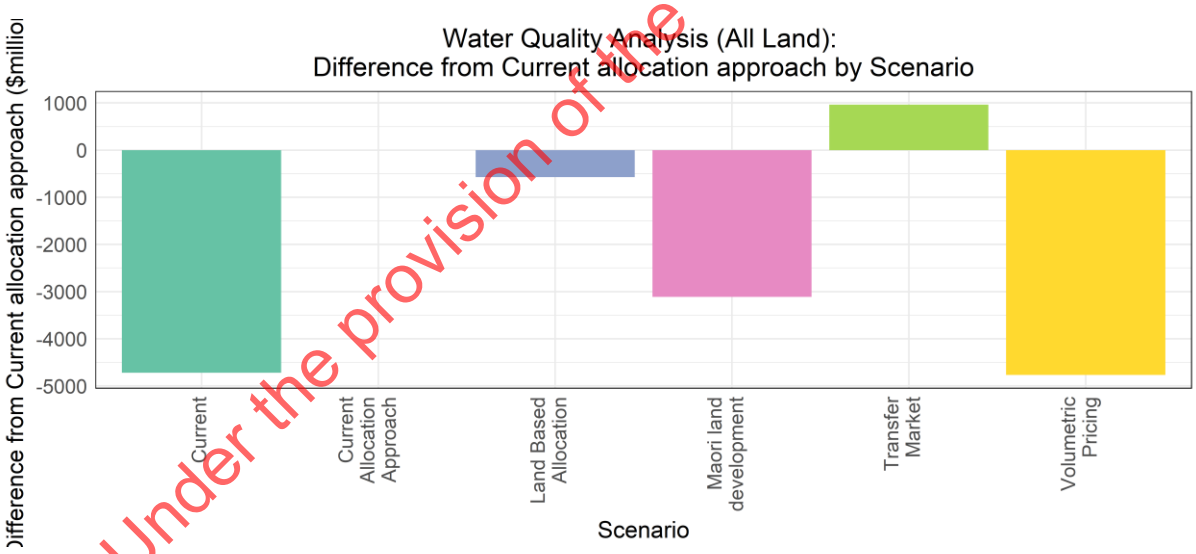
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A11.7 Quality Summaries

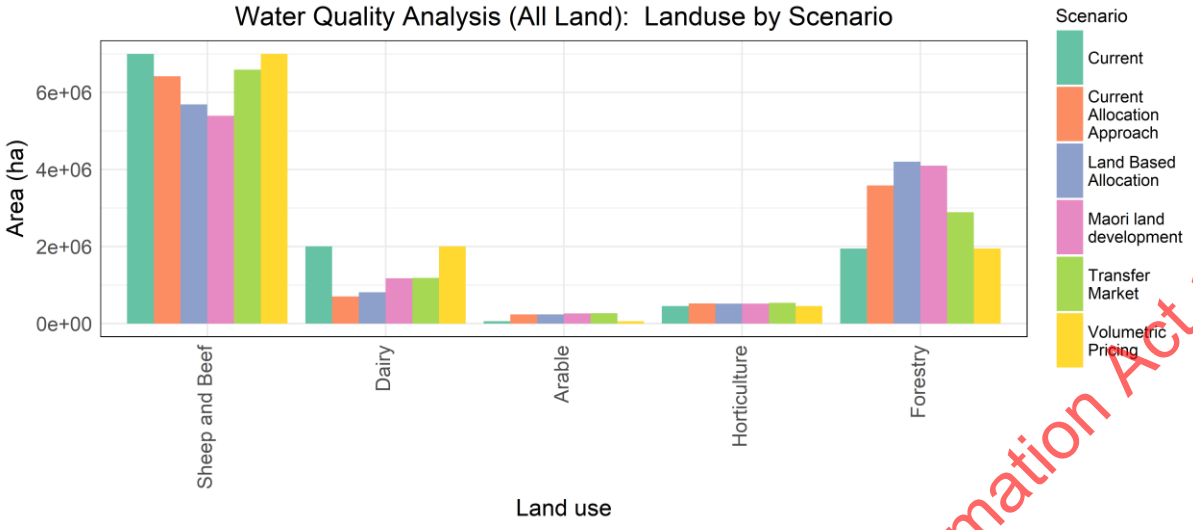
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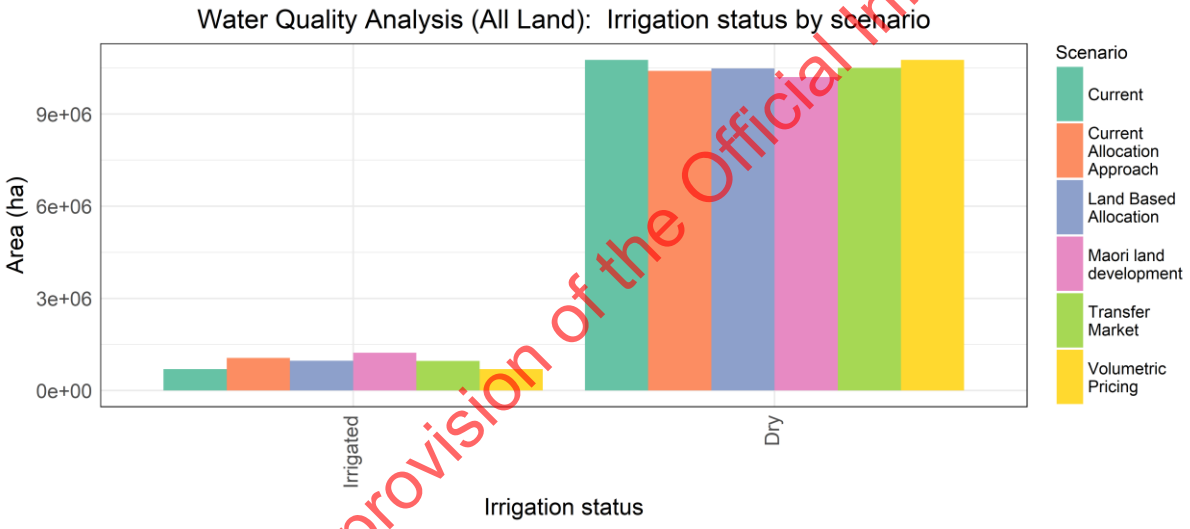
A11.7.1 All Land

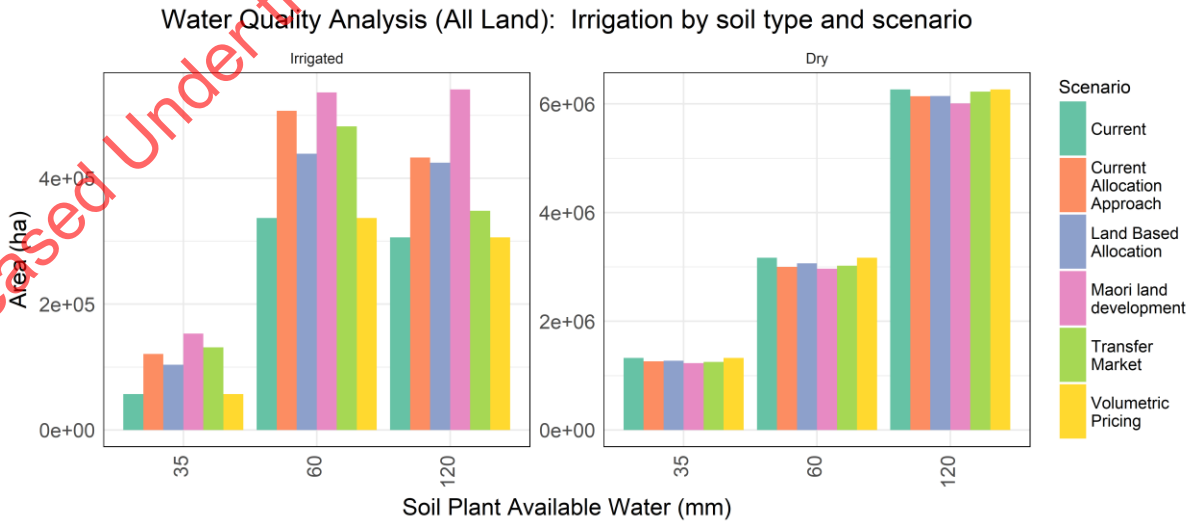




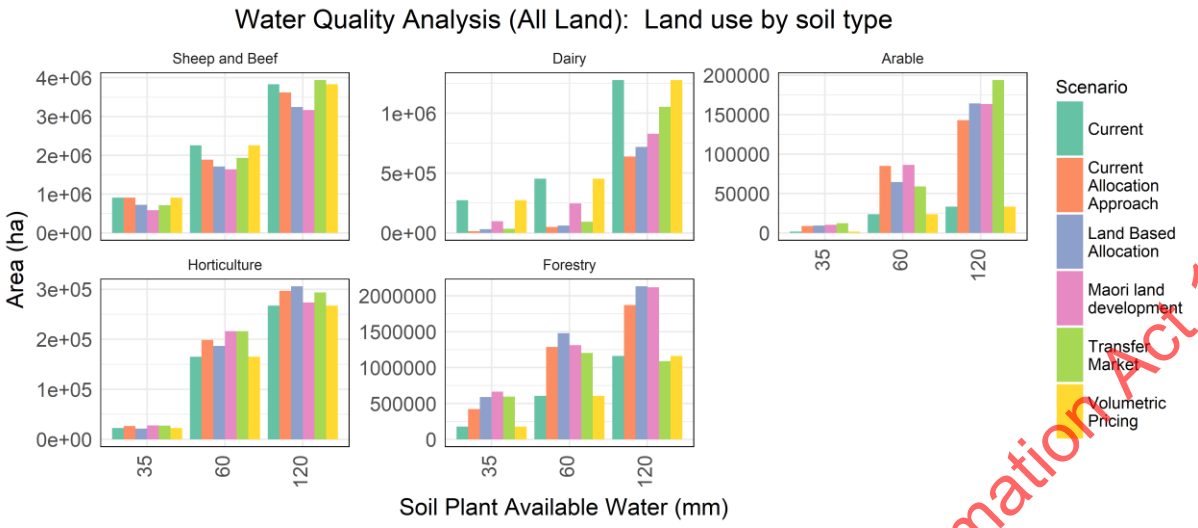
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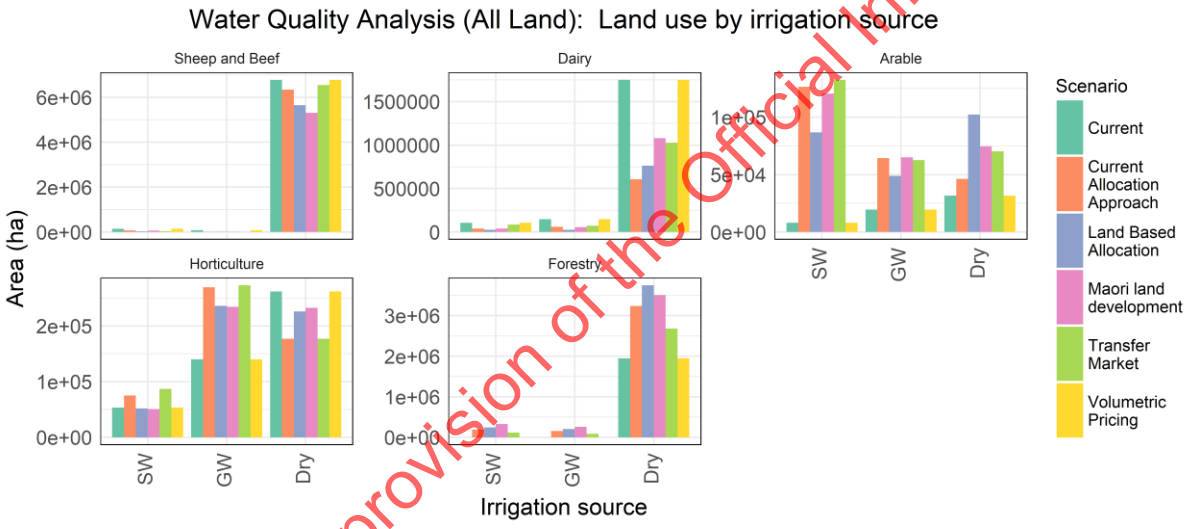


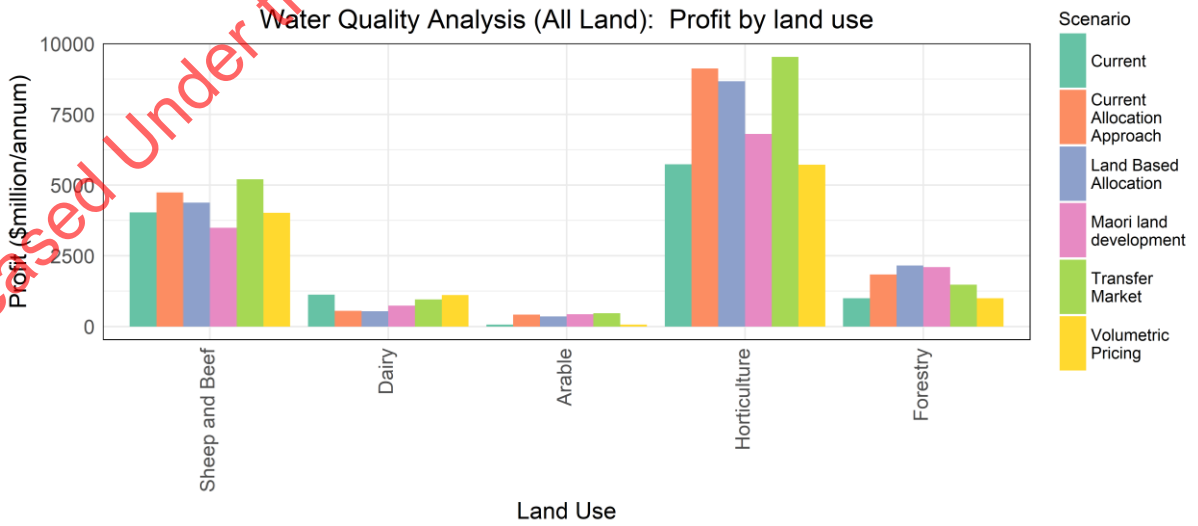




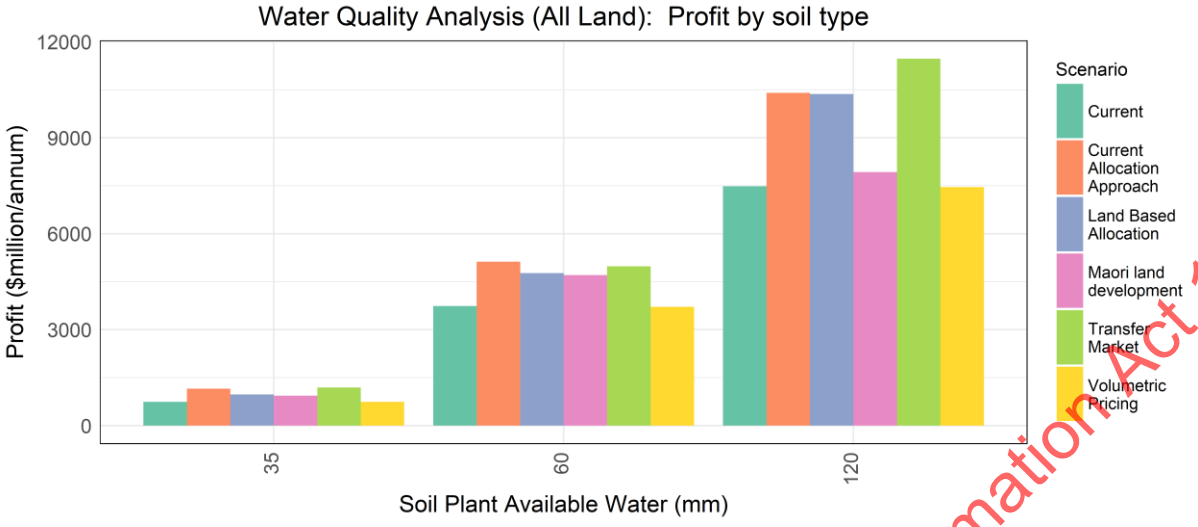
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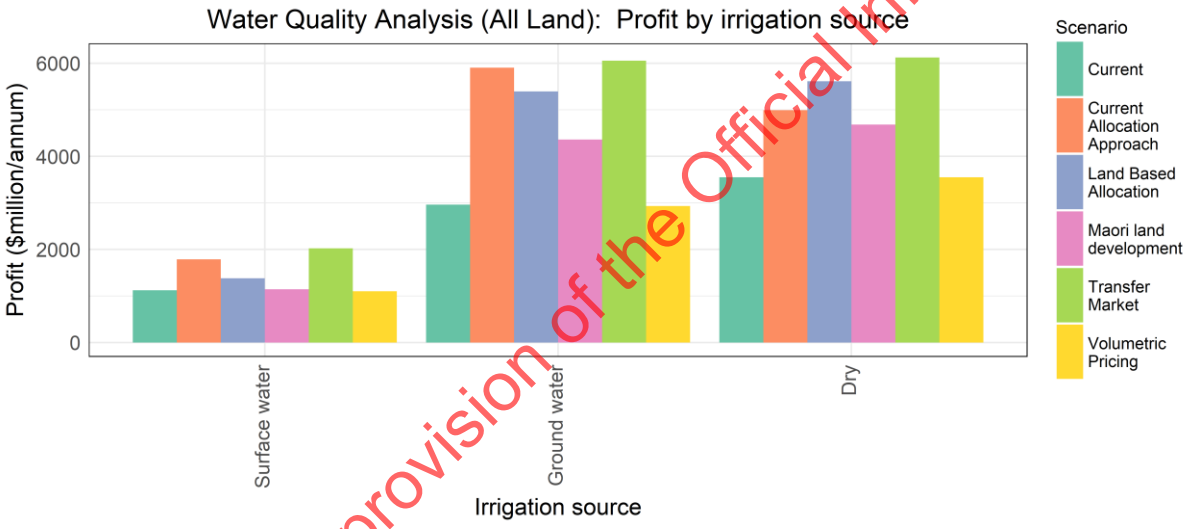


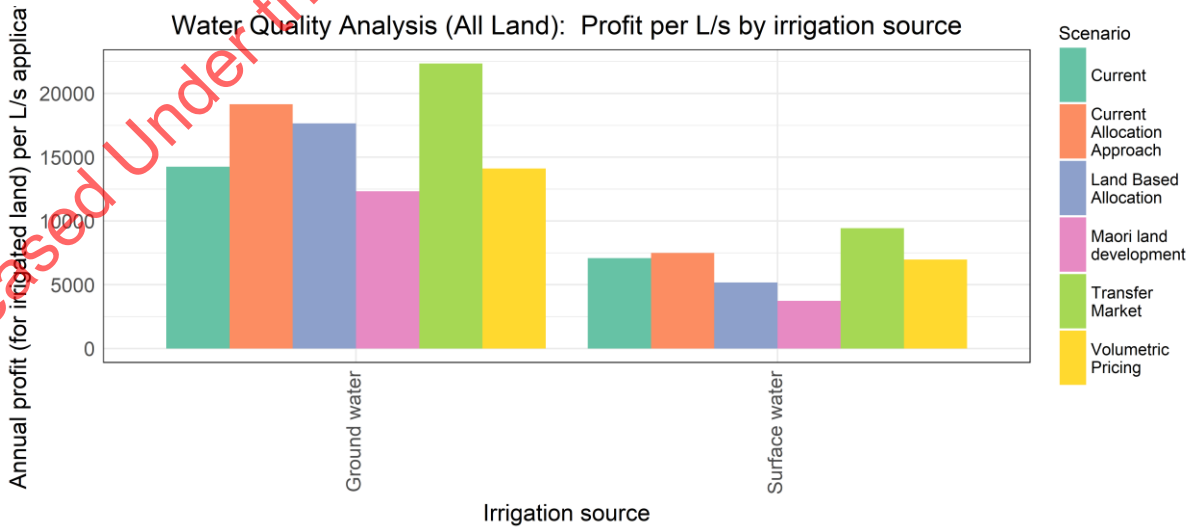




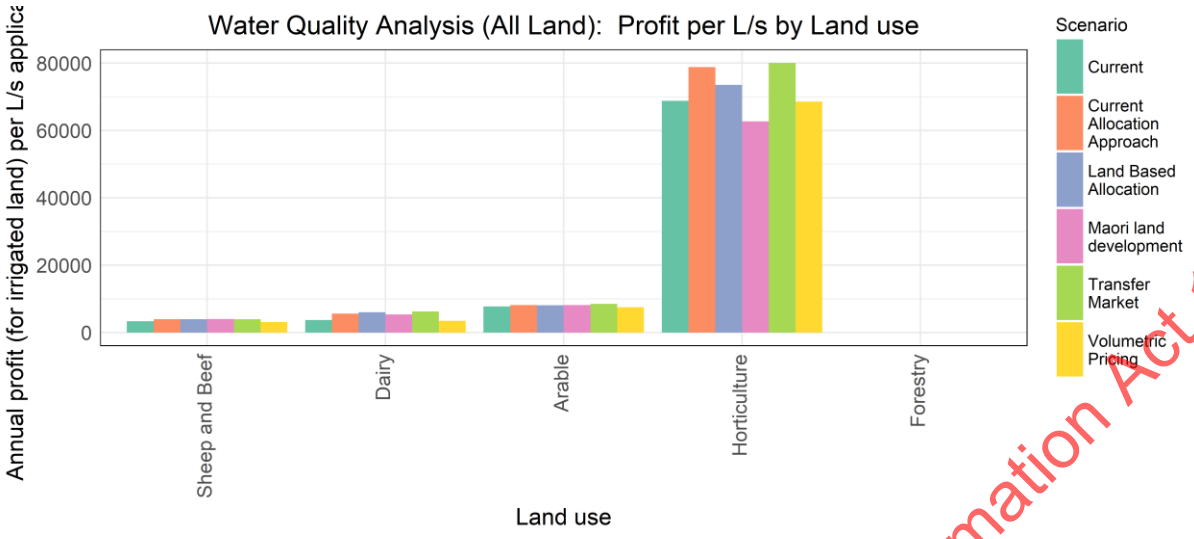
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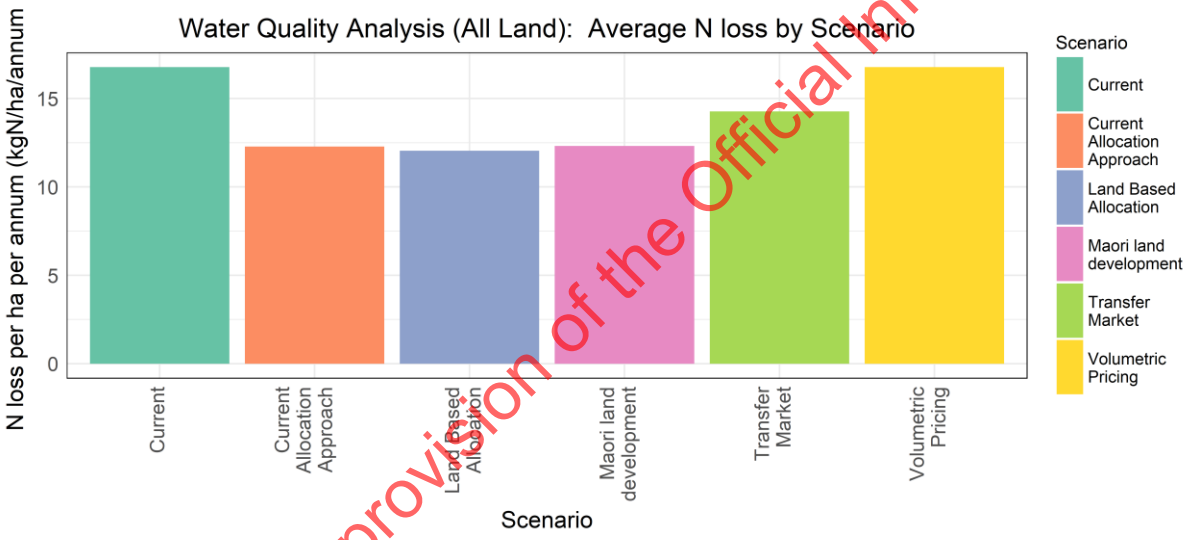


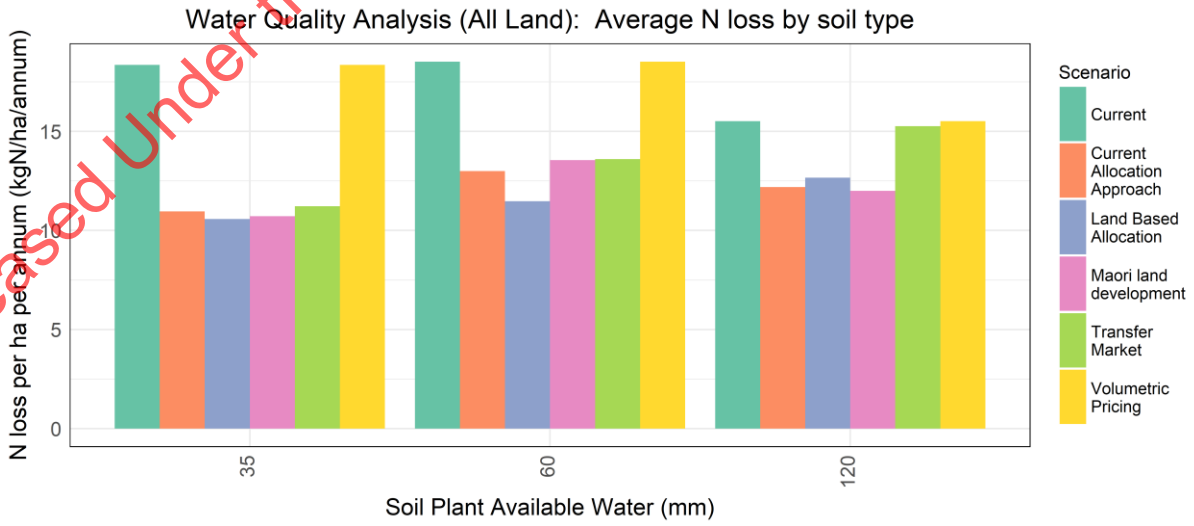




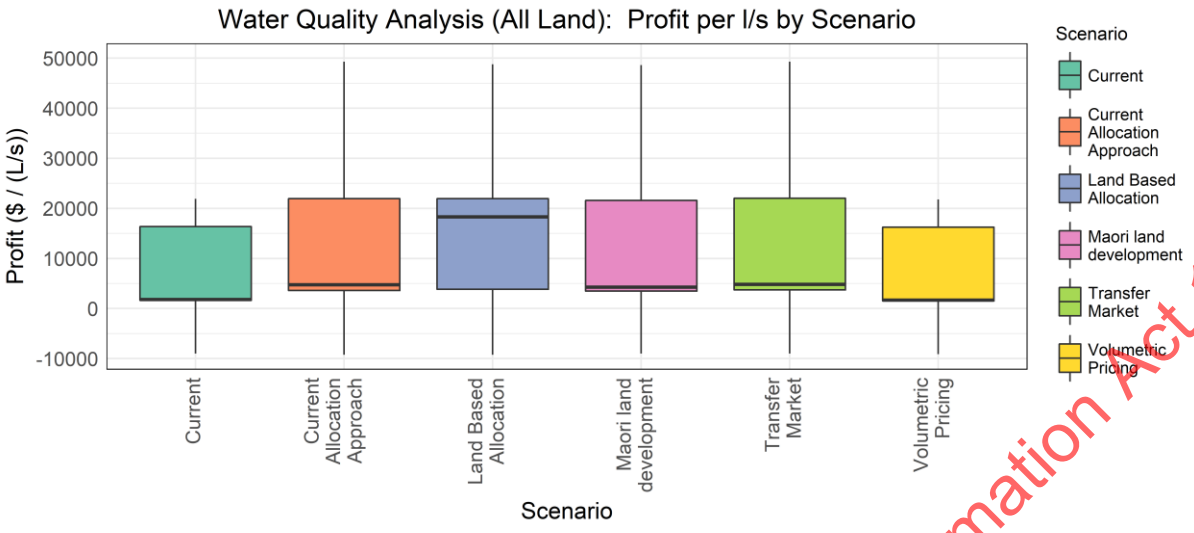
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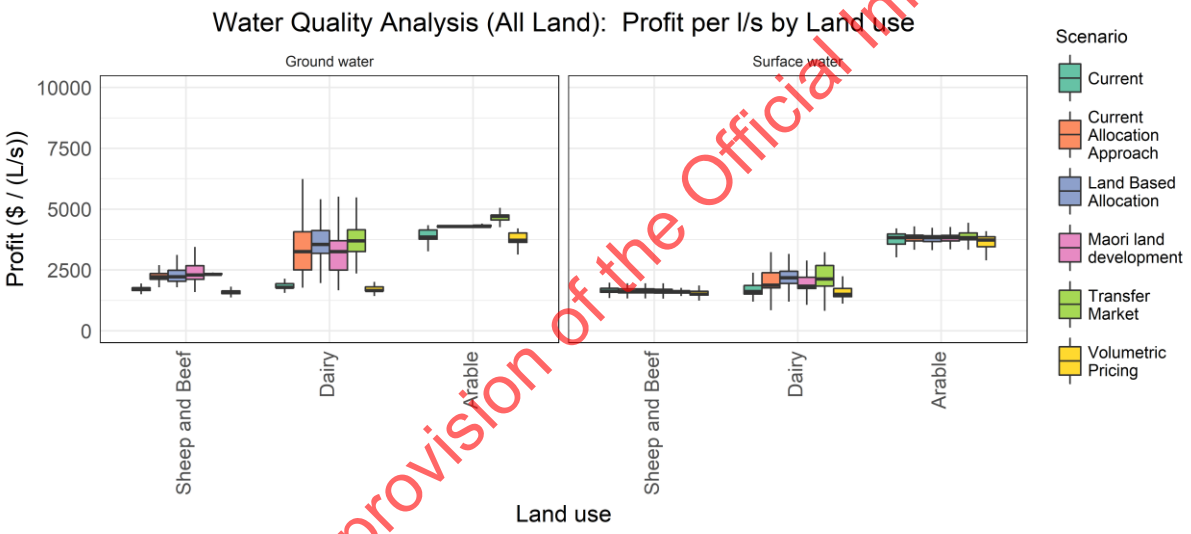


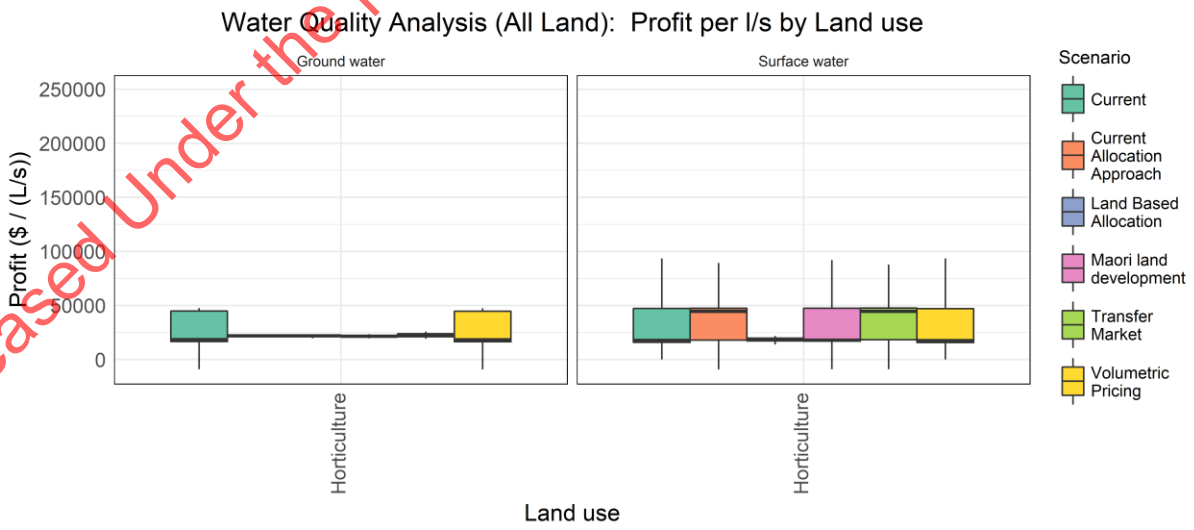




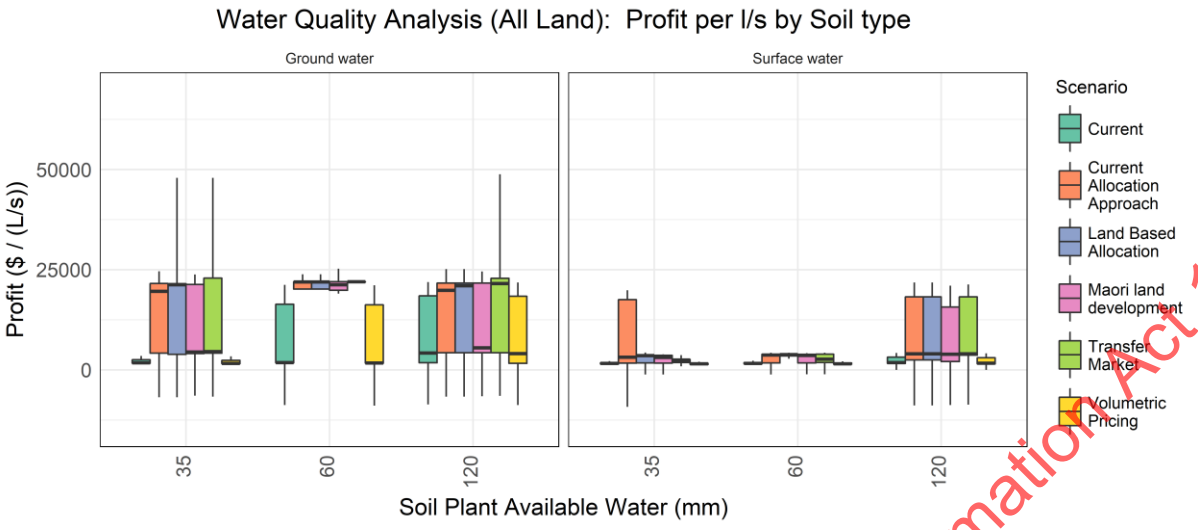
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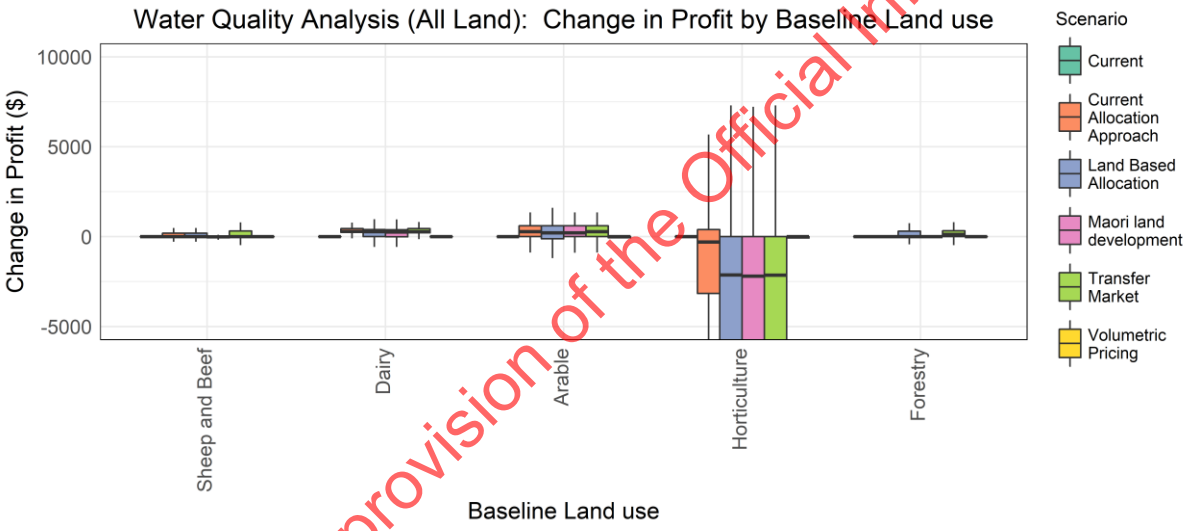




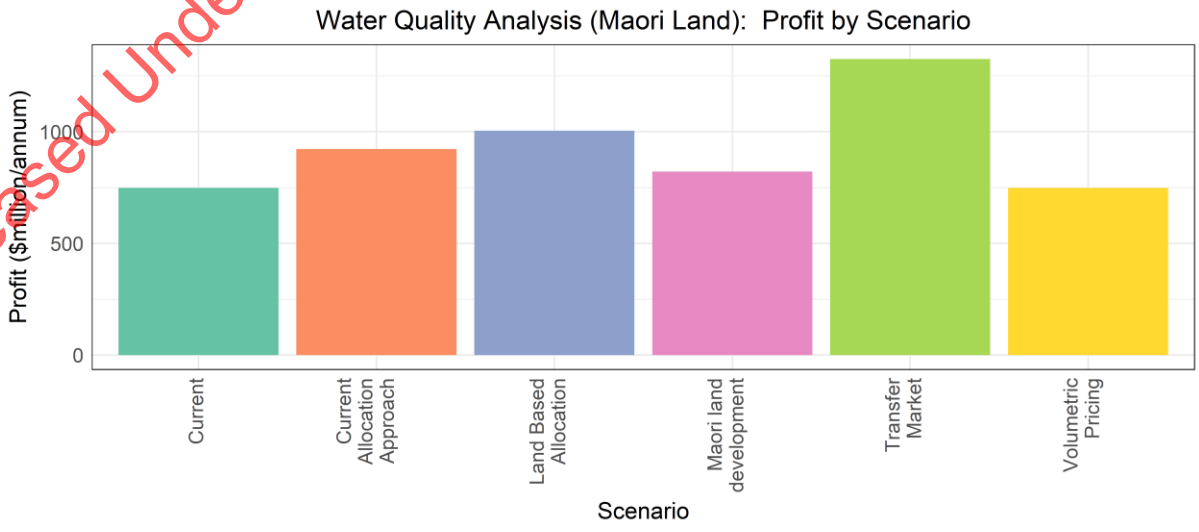


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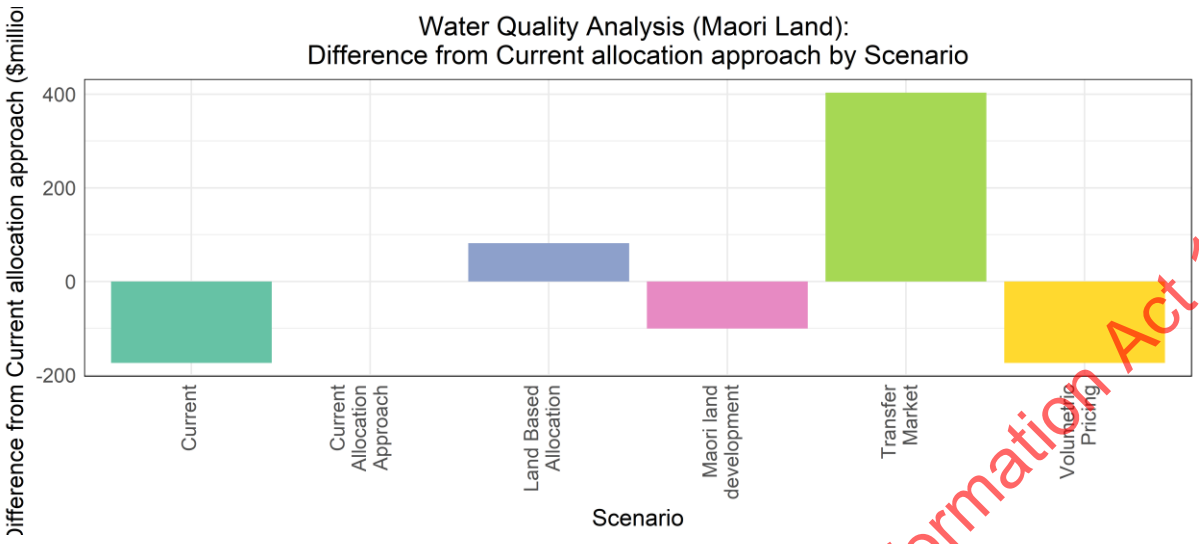


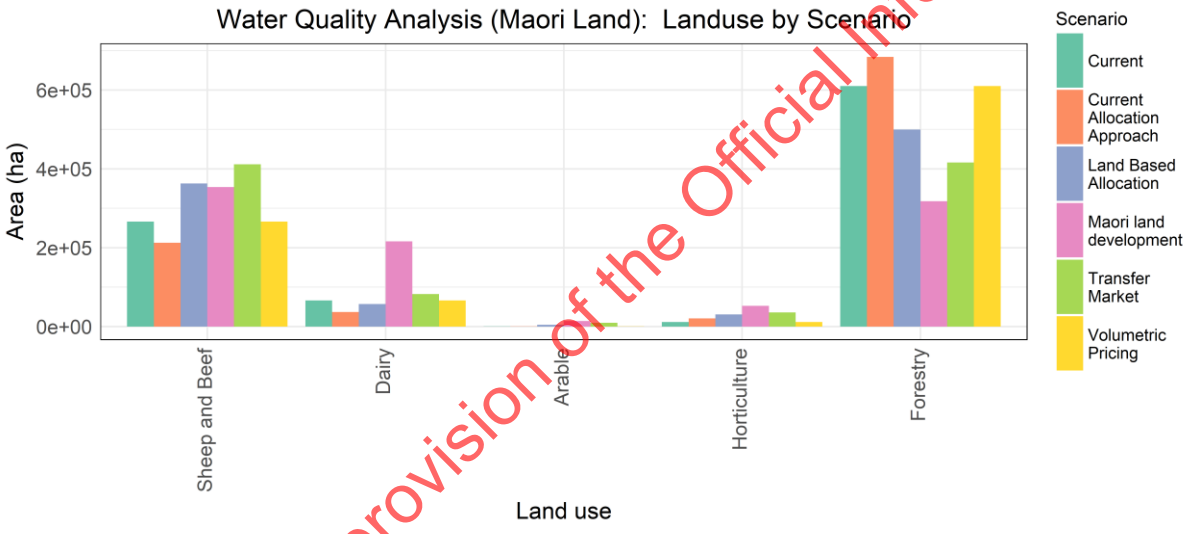


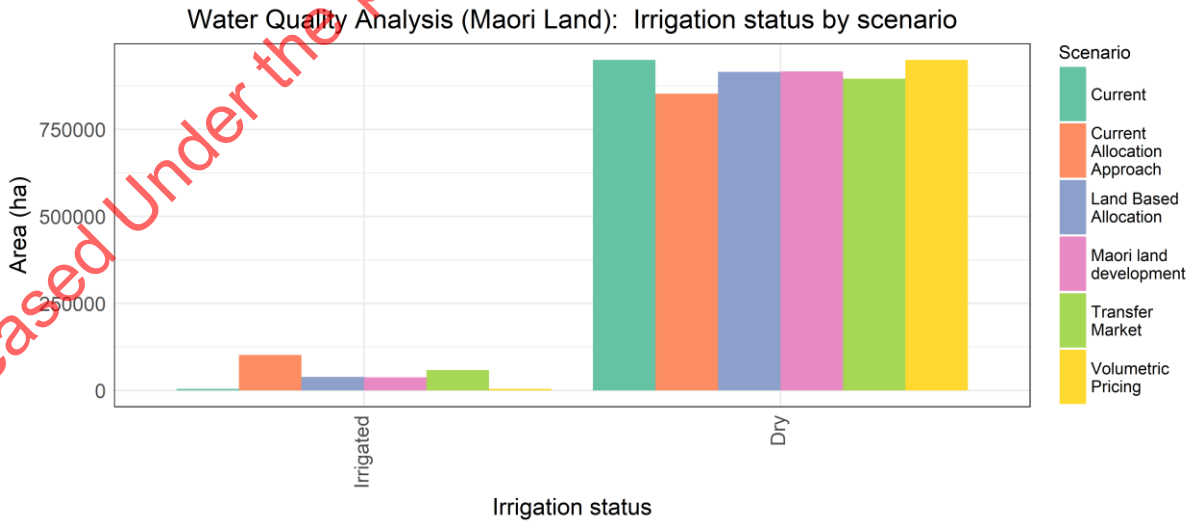
A11.7.2 Maori Owned Land



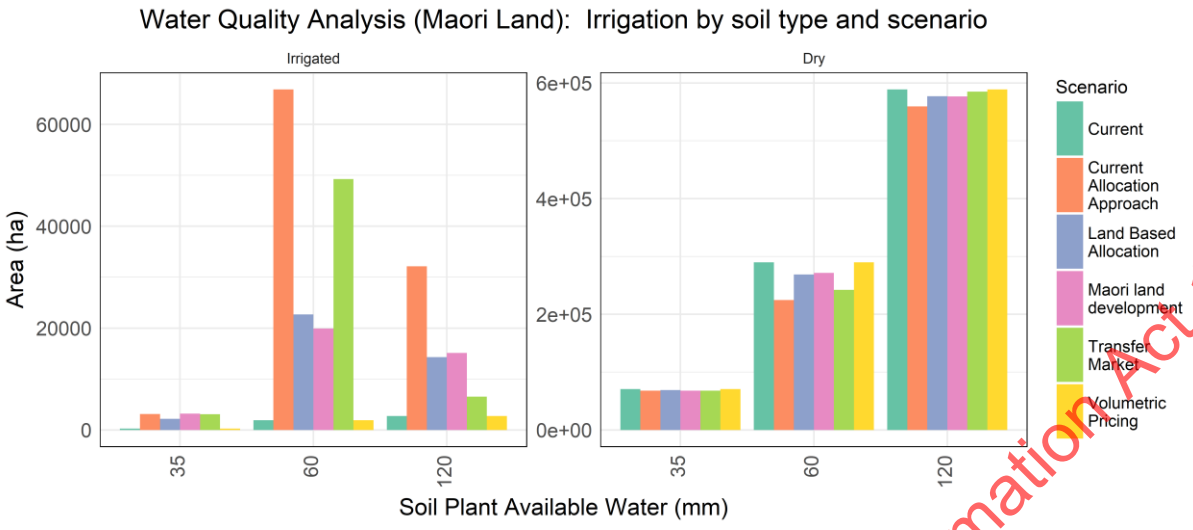
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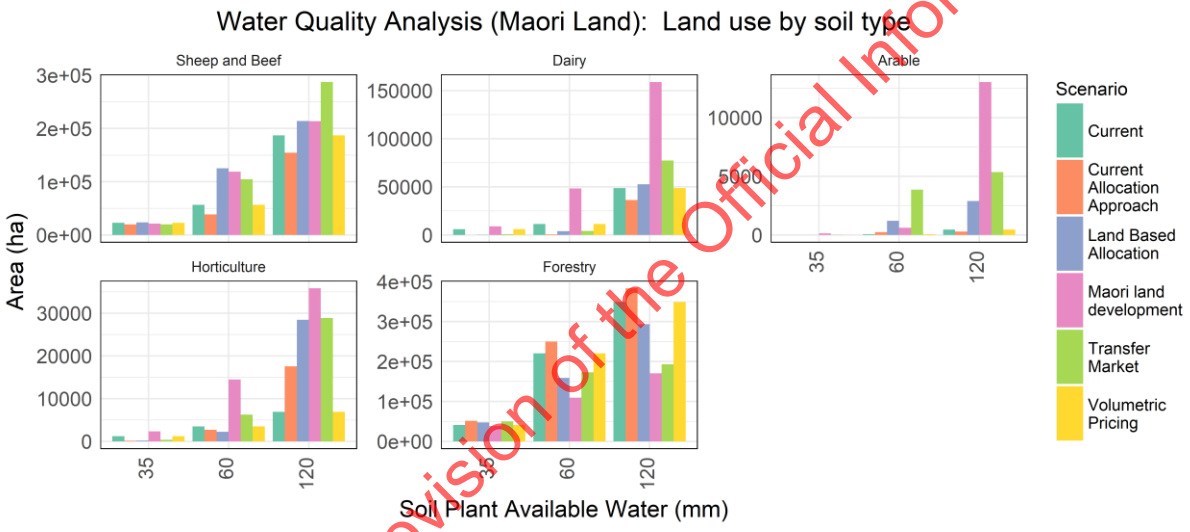


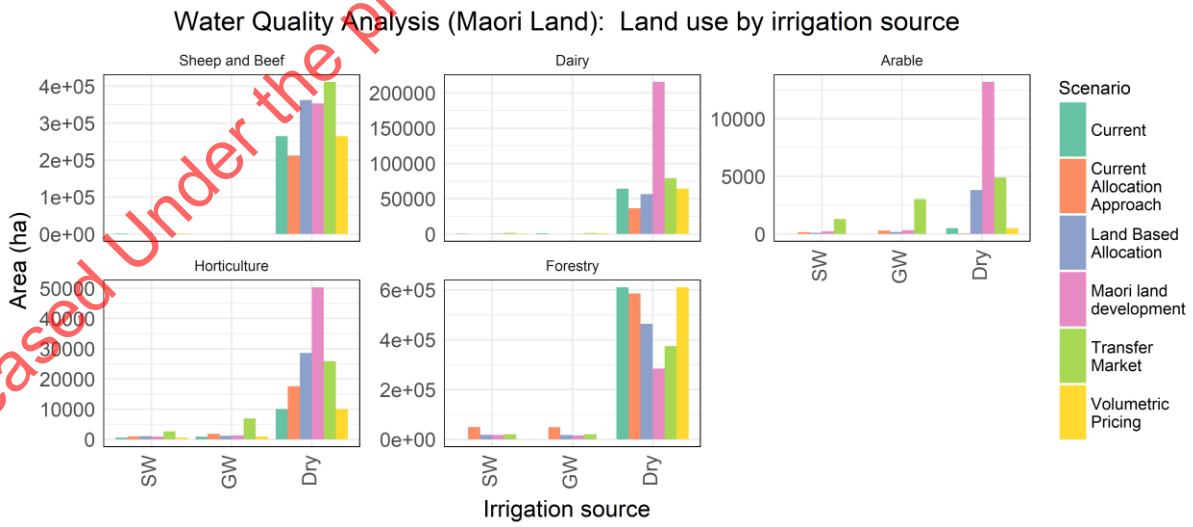




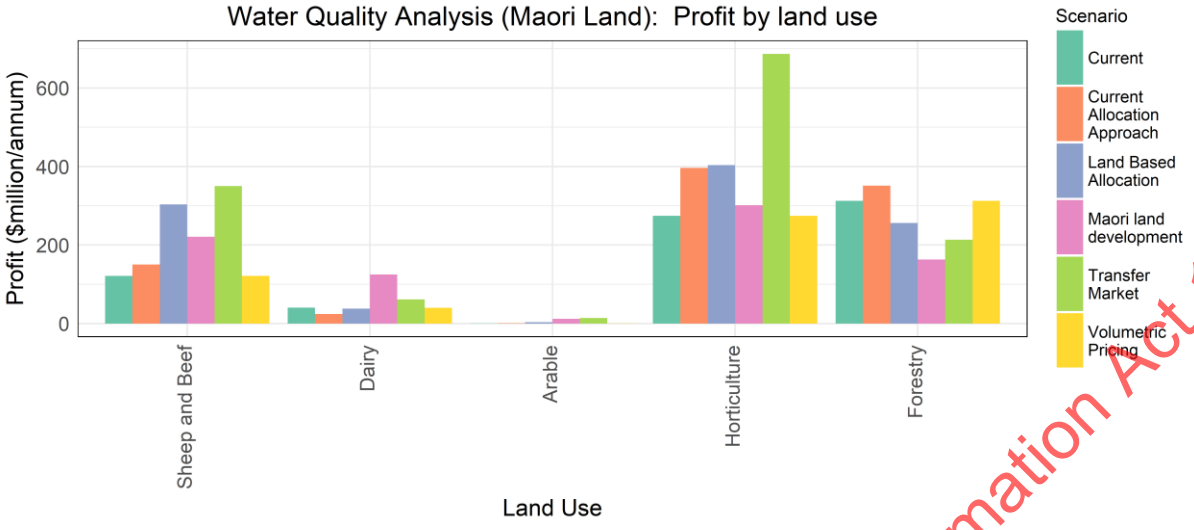
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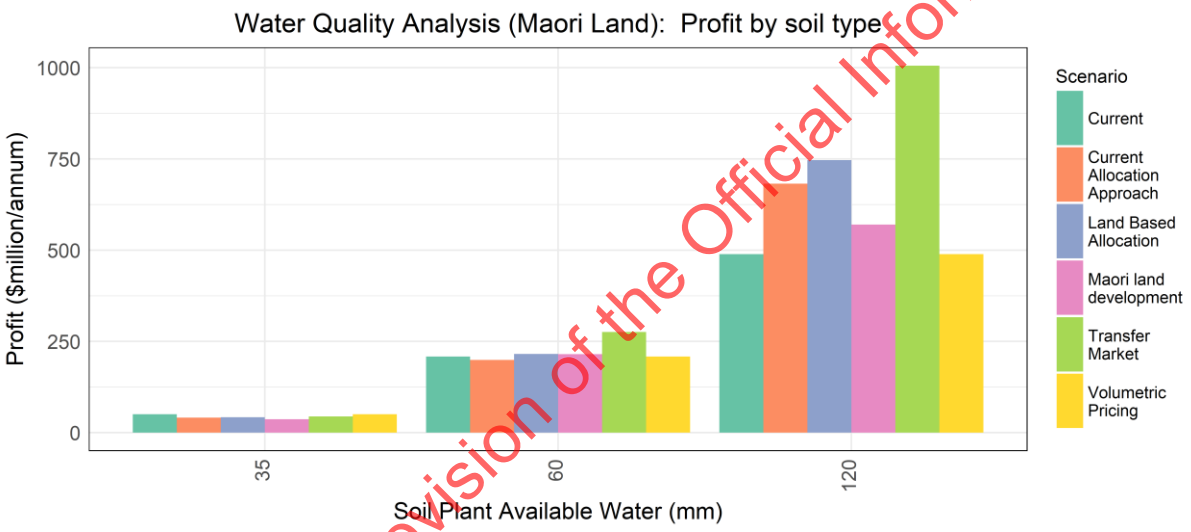


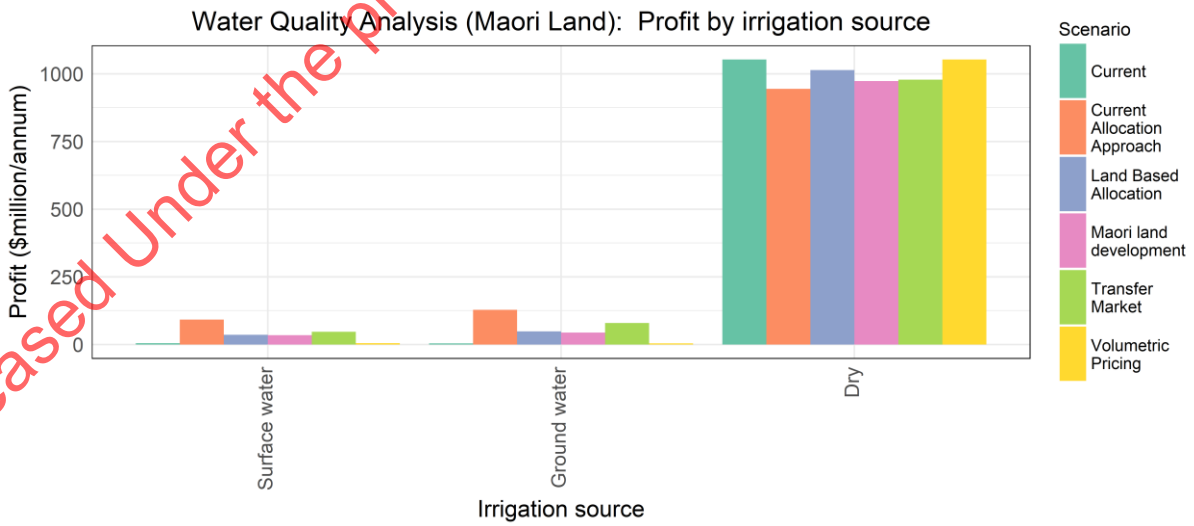




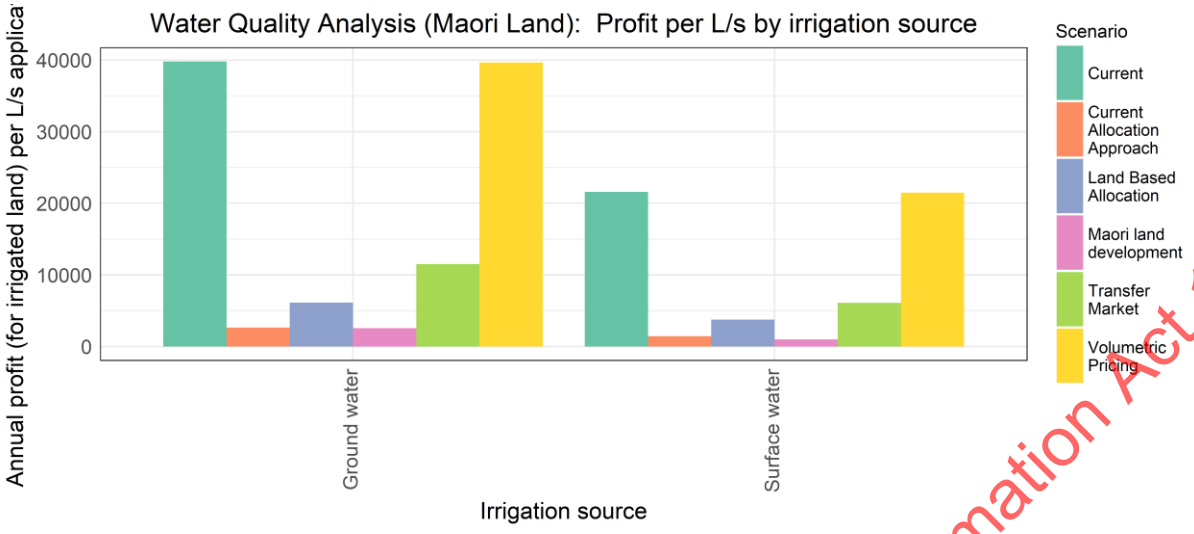
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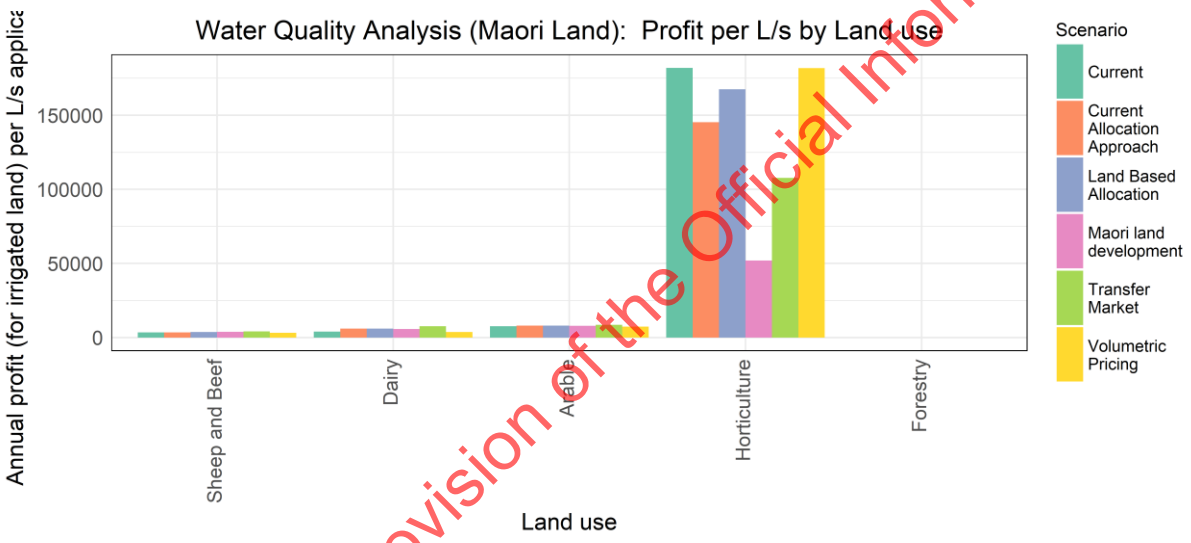


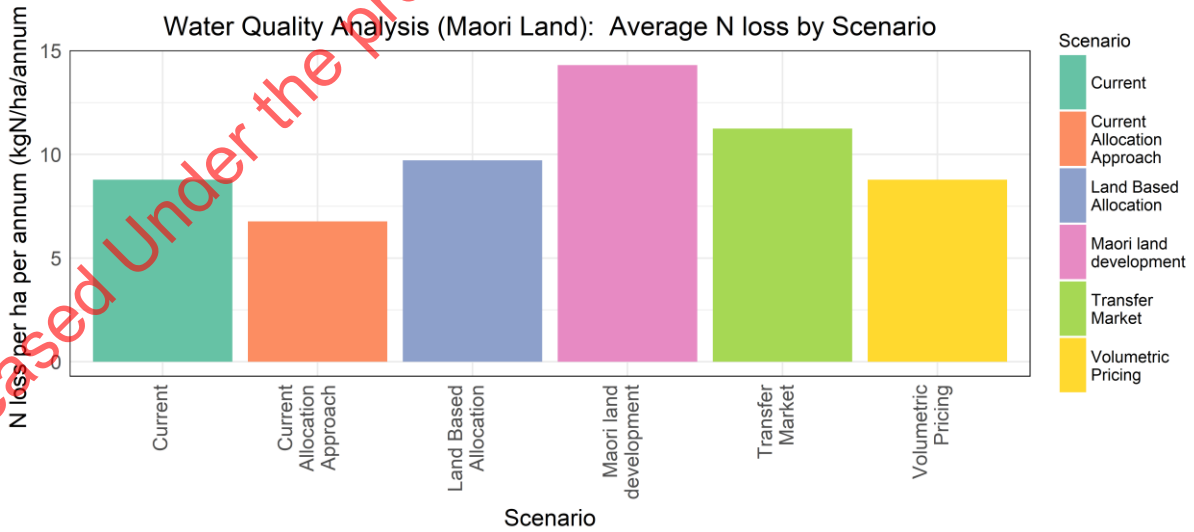




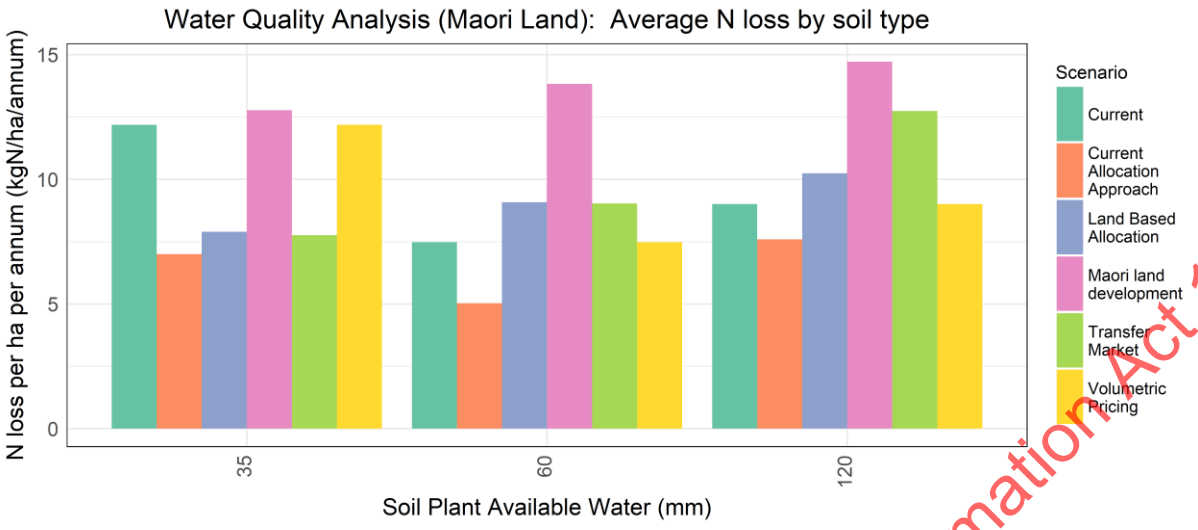
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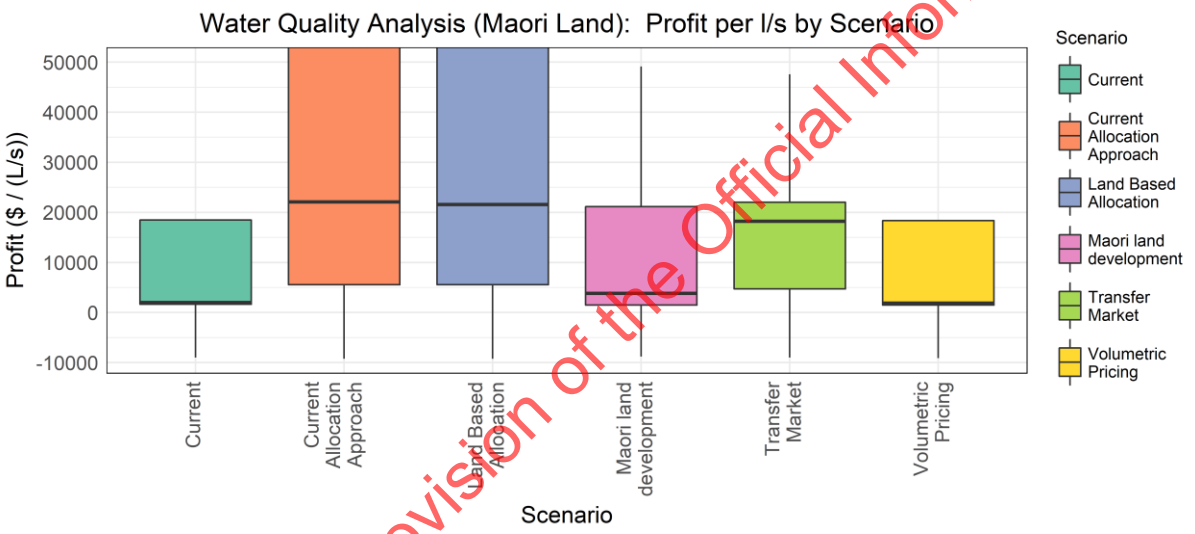


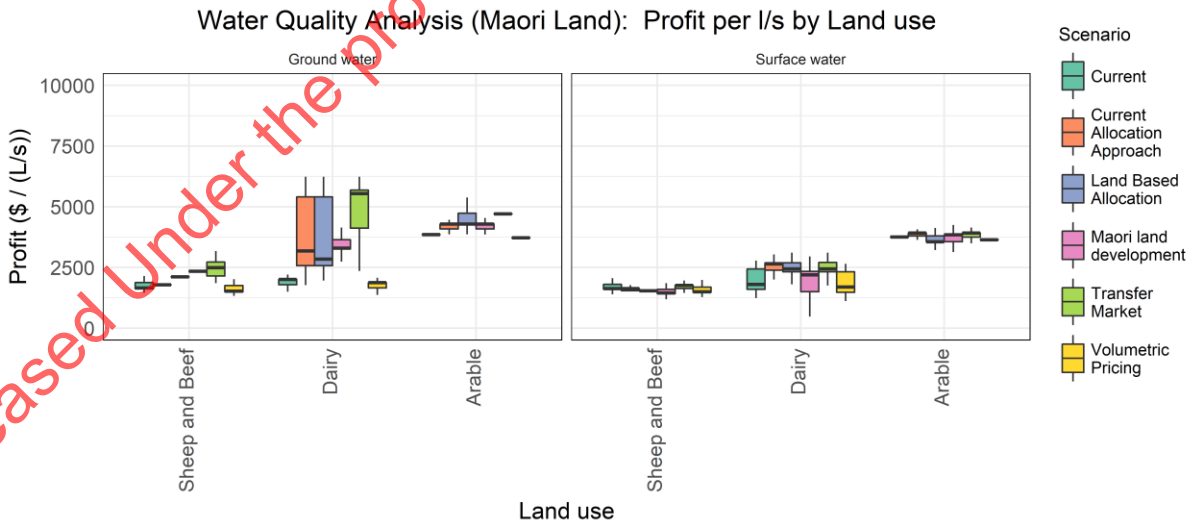




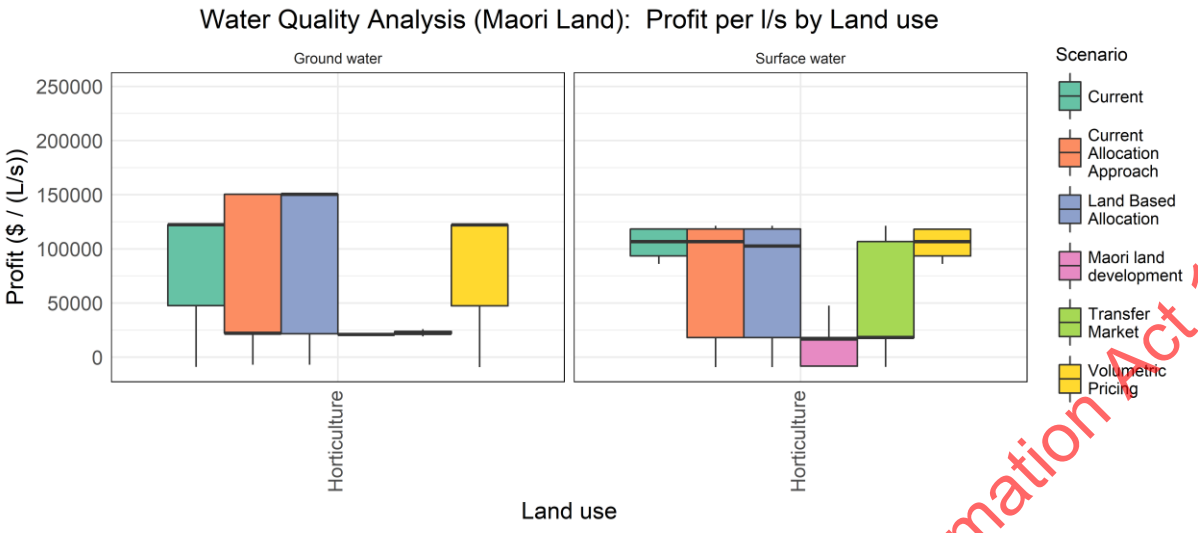
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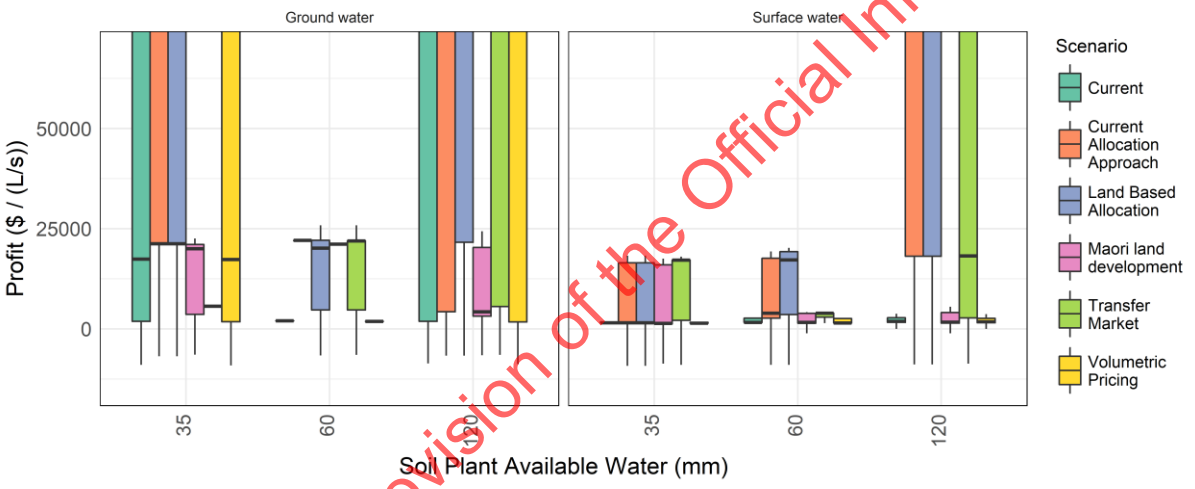


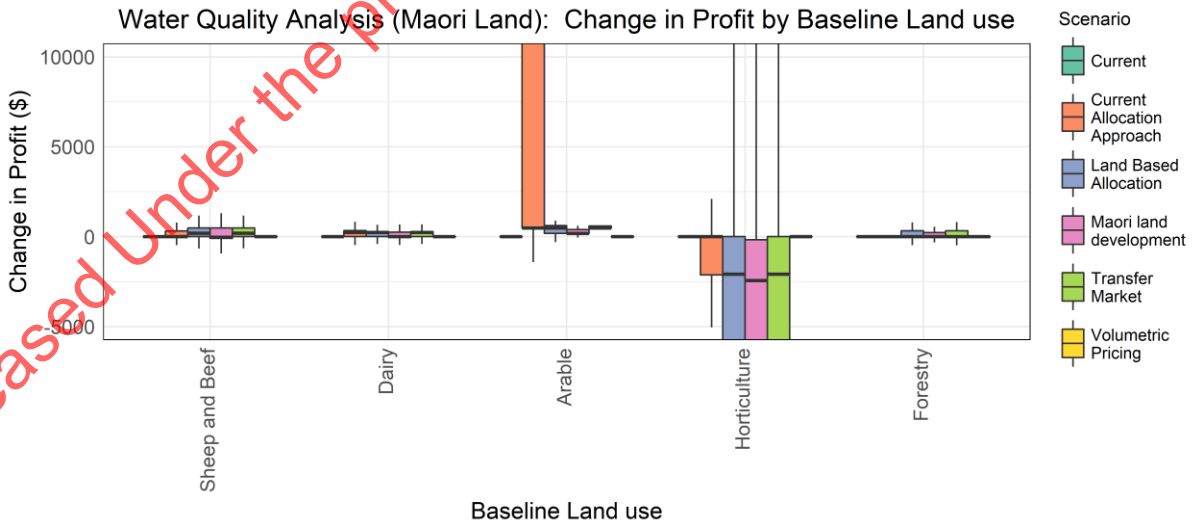




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Appendix B Detail on method for land use description

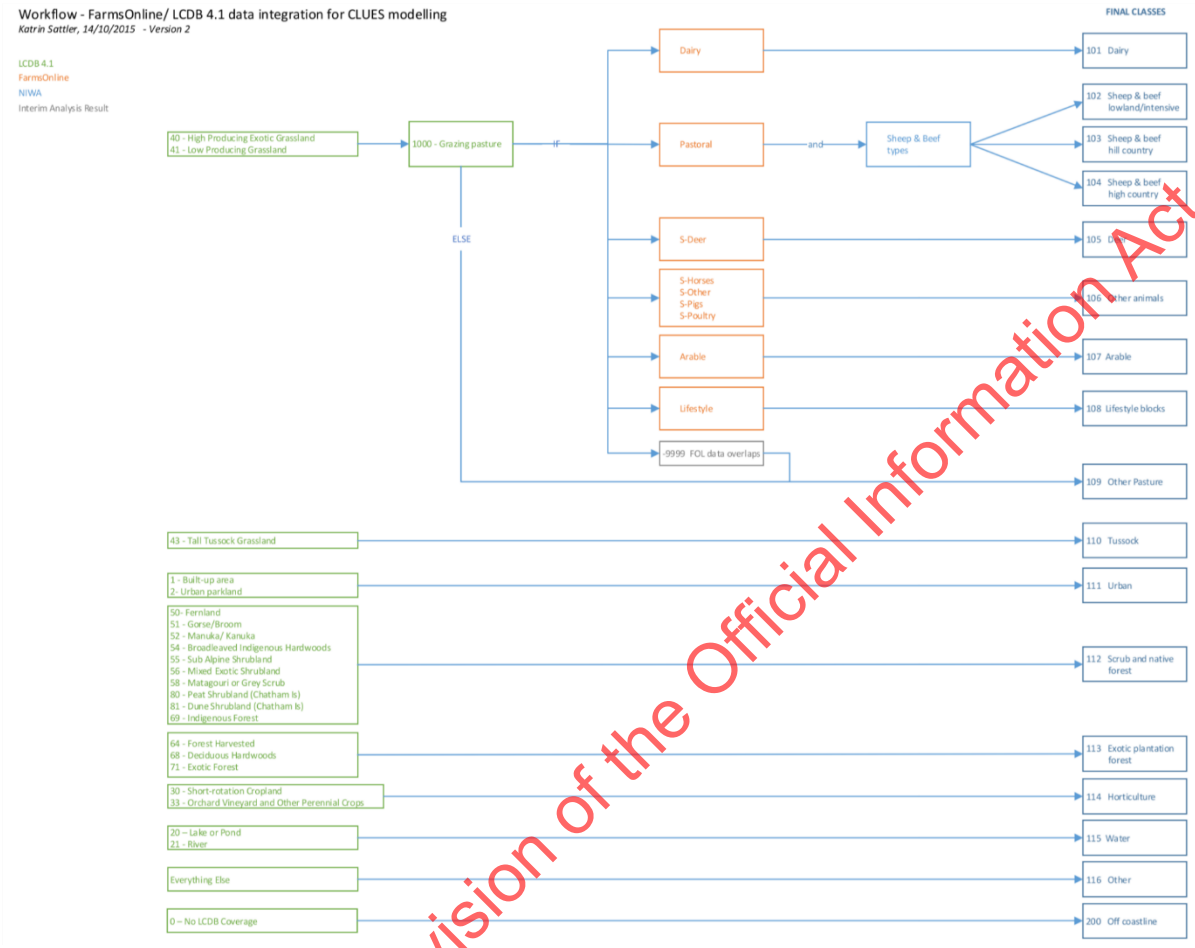
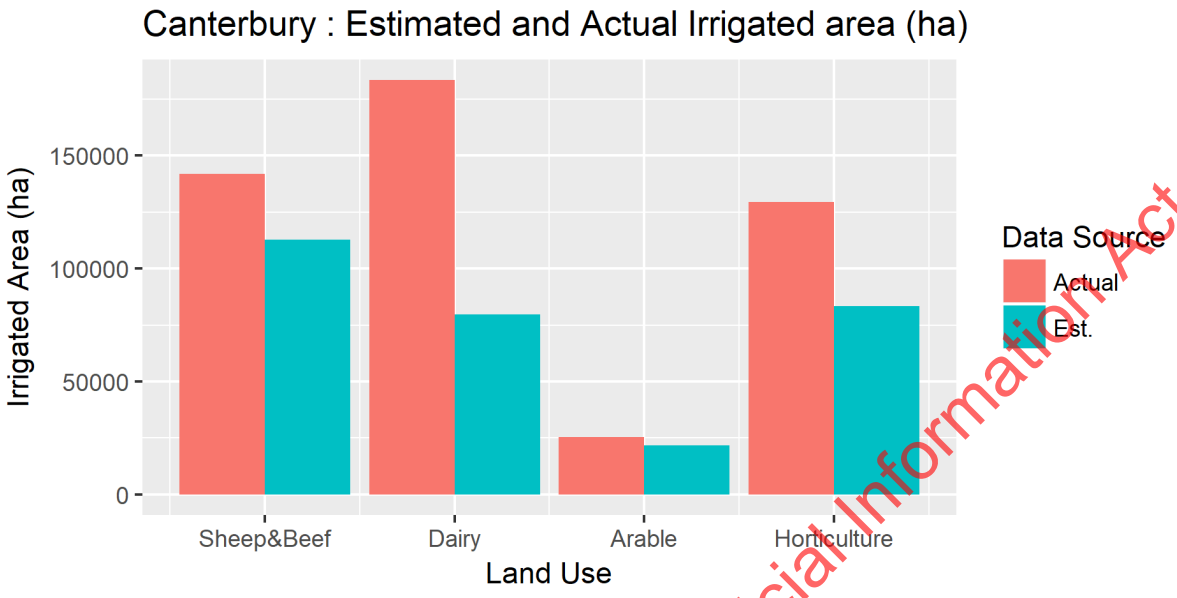
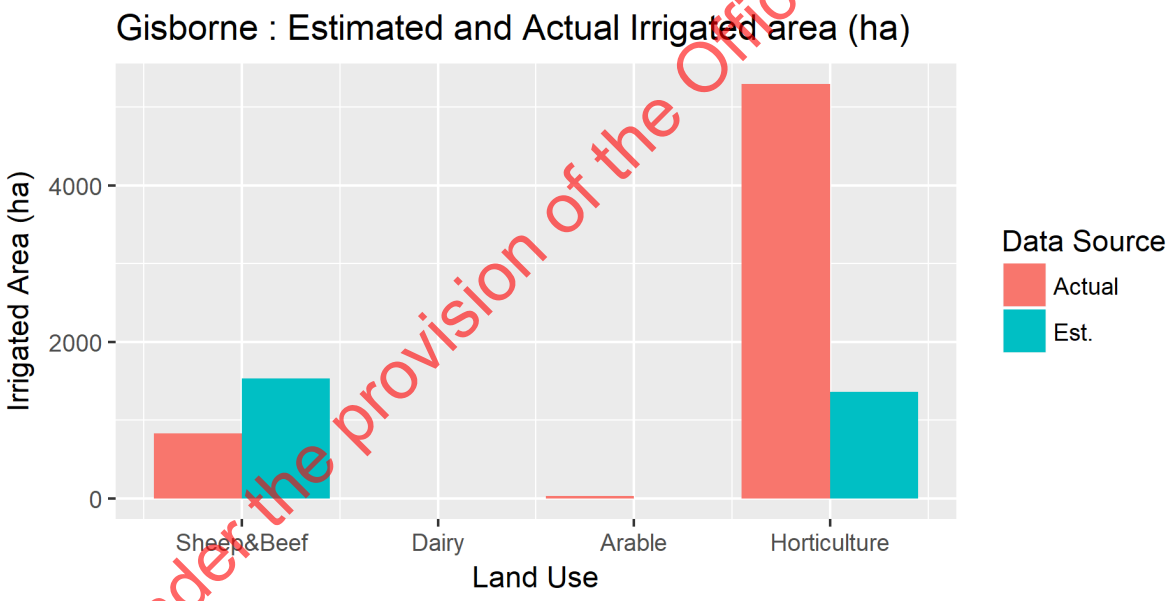


Figure 17: Description of land use definition process (Source: NIWA, pers.comm.)

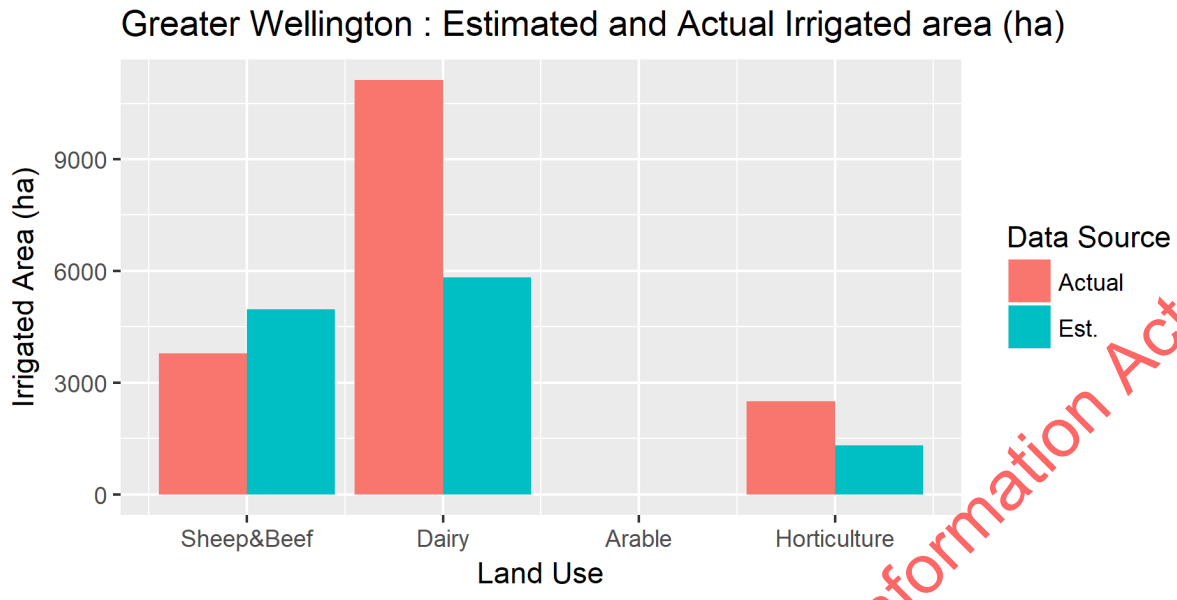
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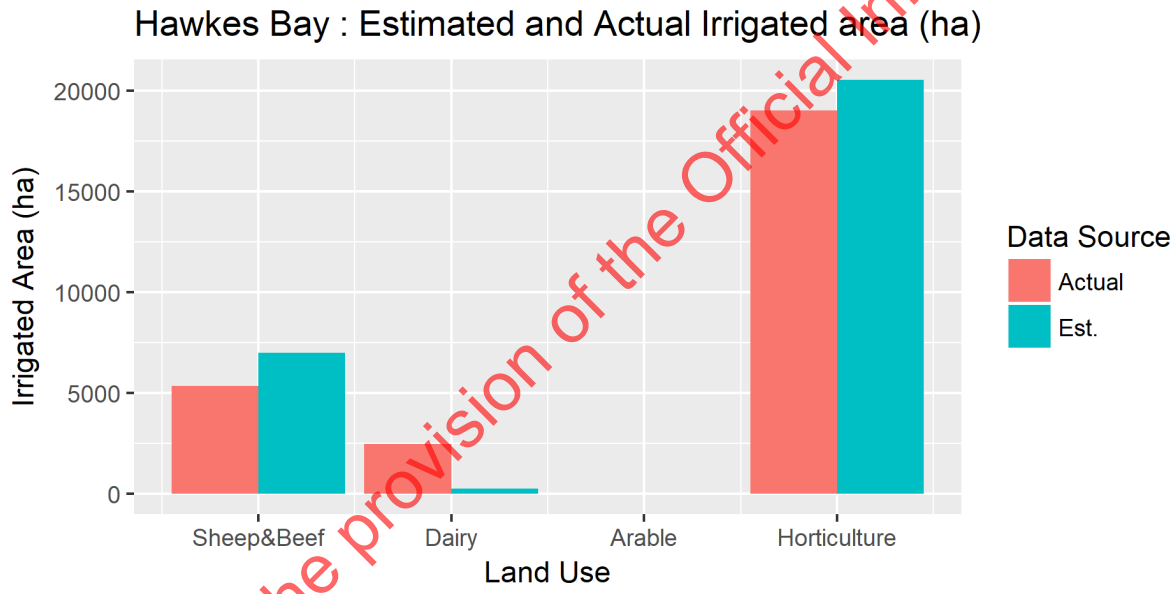
Appendix C Comparison of Estimated and Actual Irrigated Area by Region

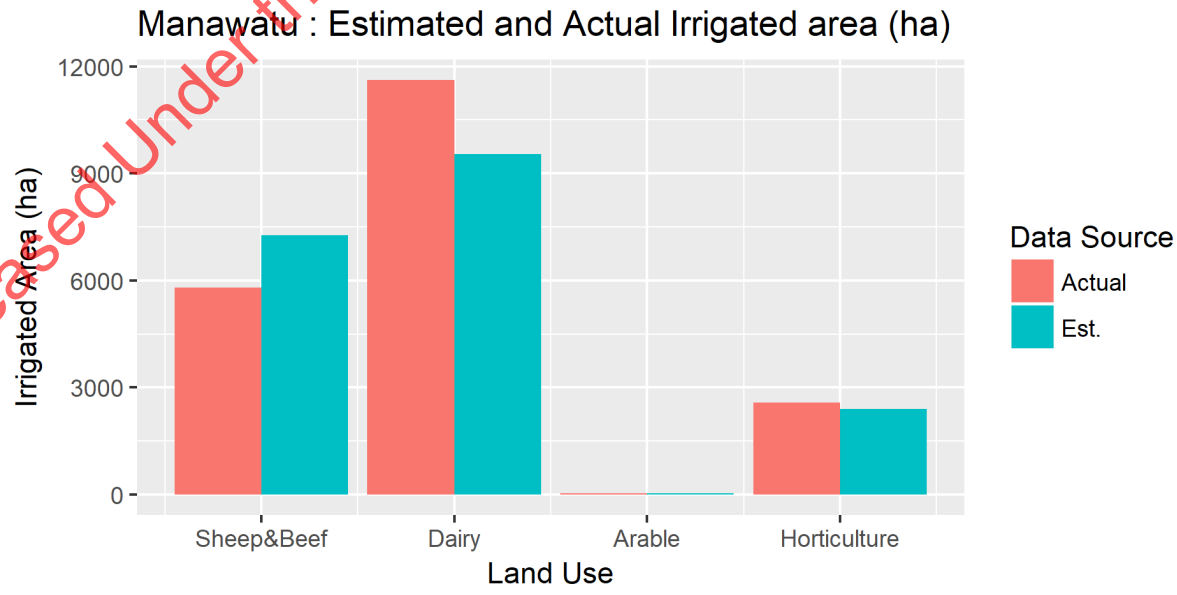




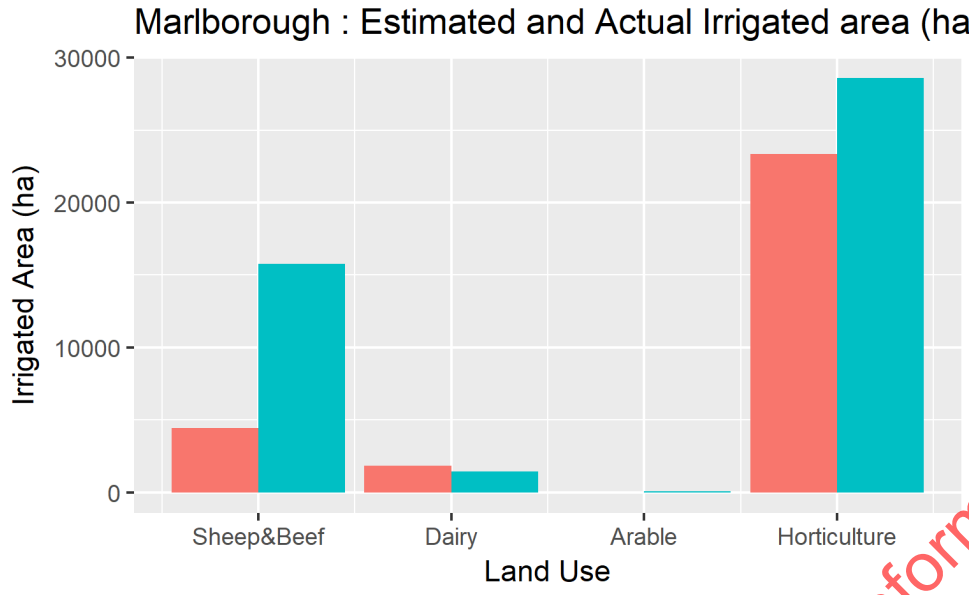
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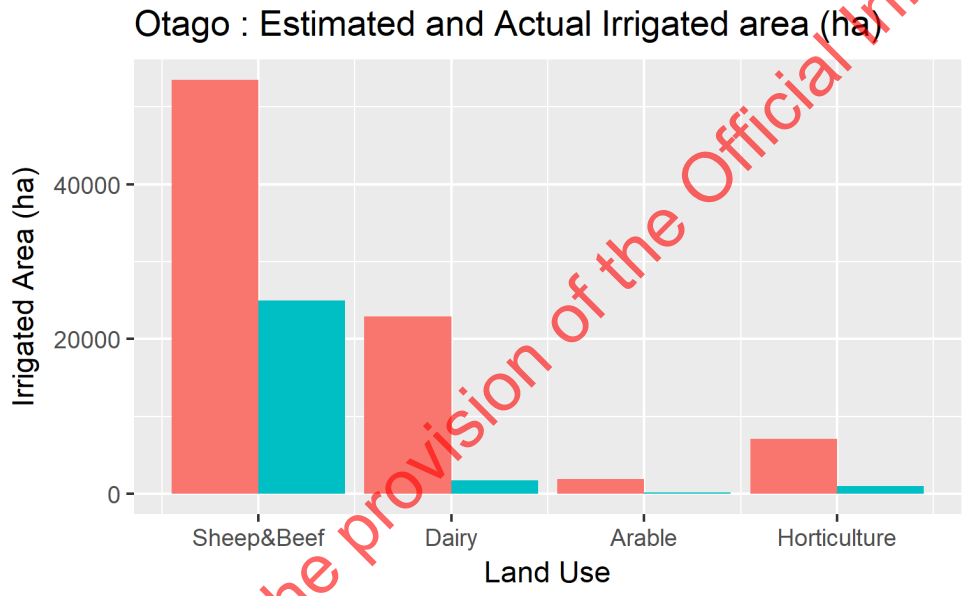


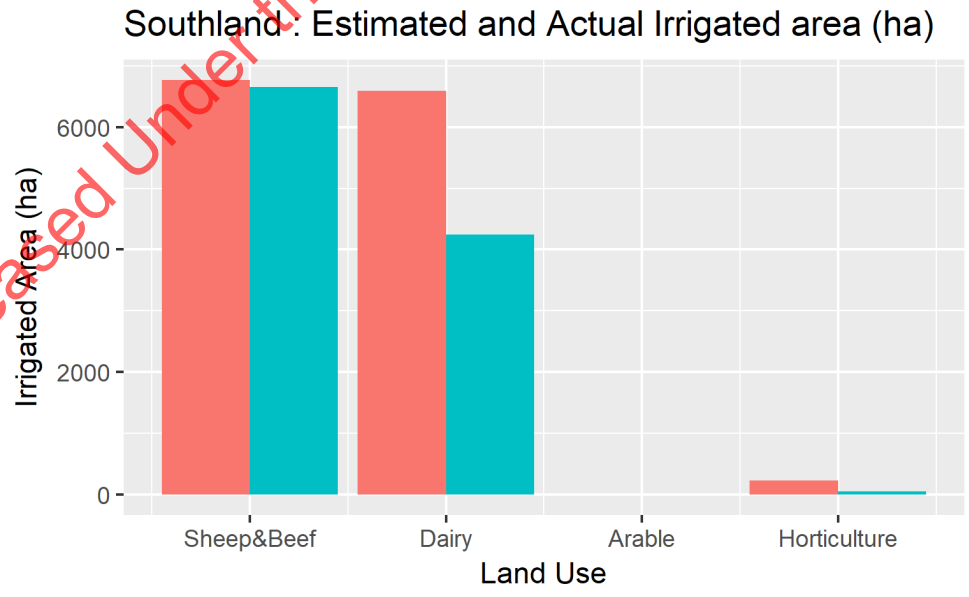




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Appendix D Fitting functions to profit data

This appendix provides a summary of the models fitted to the profit data provided by Part B of the project. For each Climate, land use and soil type, coefficients for model described in the body of the report were determined through least-squares optimisation.

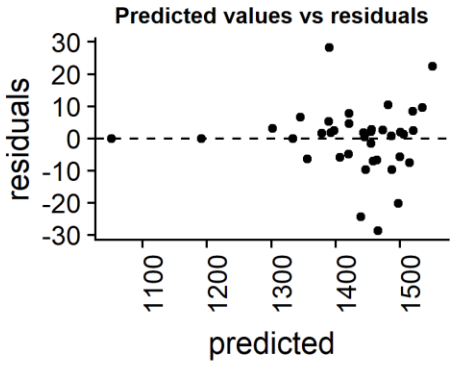
Each page of the following appendix presents a series of graphs to demonstrate the goodness of fit of these models. Graphs included are:

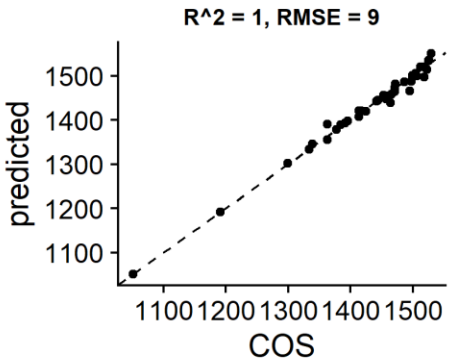
- Model predicted values versus residuals (includes models across all 3 PAW classes).
    - Enables an assessment of model bias.
- COS ("observed") versus Predicted (includes models across all 3 PAW classes).
    - Allows a visual summary of the model performance relative to the 1:1 Line.
    - Provides goodness of fit measures: R^2 and RMSE (in $).
- COS response surface (one plot per PAW class).
    - Demonstrates how COS varies with both reliability and system capacity.
- Variation of COS with system capacity.
    - Observed values are shown by dots. Allows comparison of model shape with input data patterns.
- Variation of COS with reliability.
    - Observed values are shown by dots. Allows comparison of model shape with input data patterns.
    - Enables a clearer visualisation of the piece-wise model with respect to reliability.

NOTE: Graphs are not shown for Forestry in all regions, or Arable or Horticulture in some select regions, as irrigation is not allowed on these land uses.

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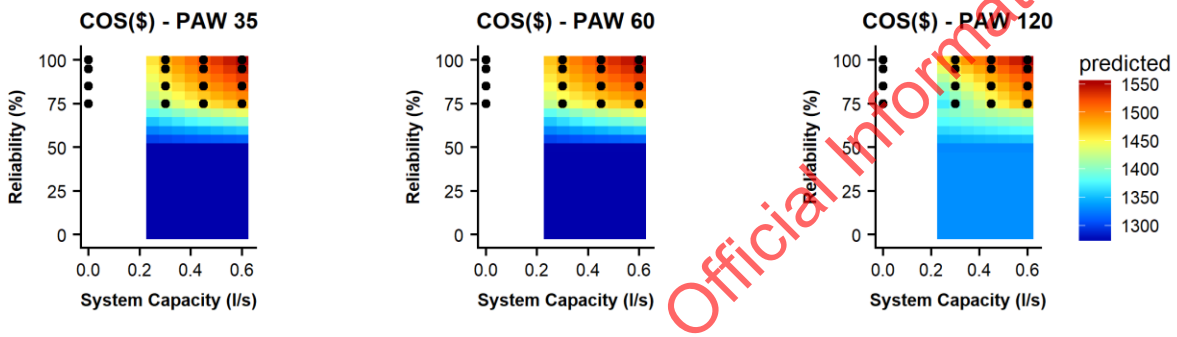
North Island: Bay of Plenty; Sheep and Beef



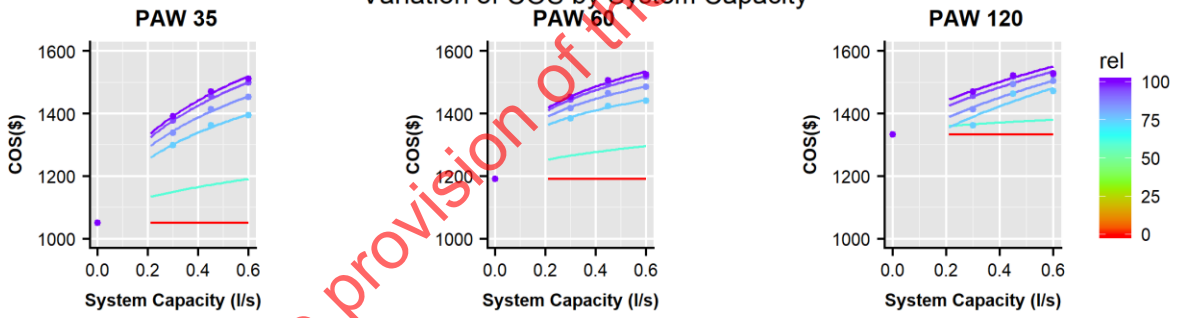


Modelled COS response surface

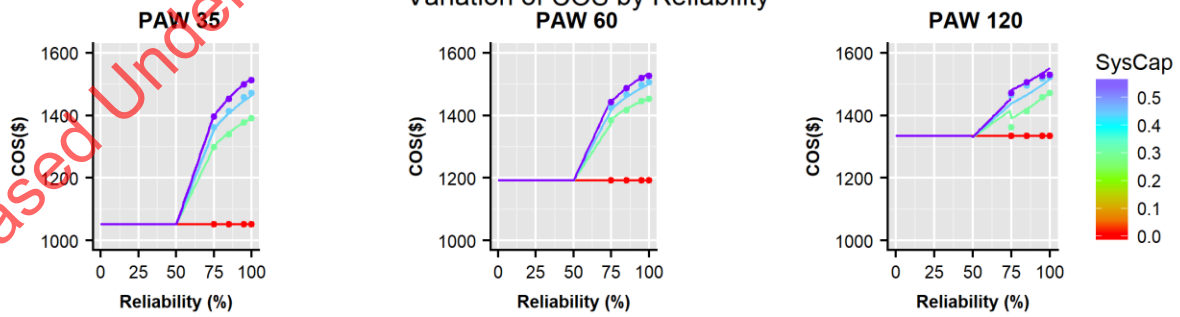
Black dots show actual sample points



Variation of COS by System Capacity



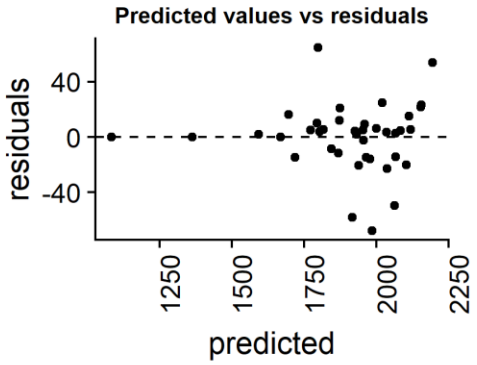
Variation of COS by Reliability

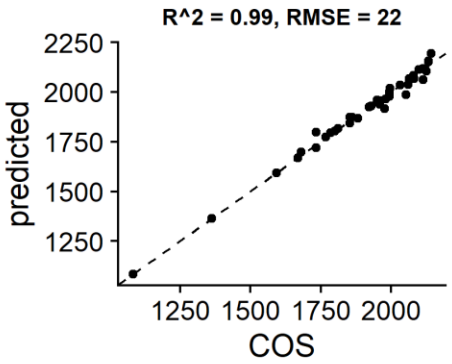


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

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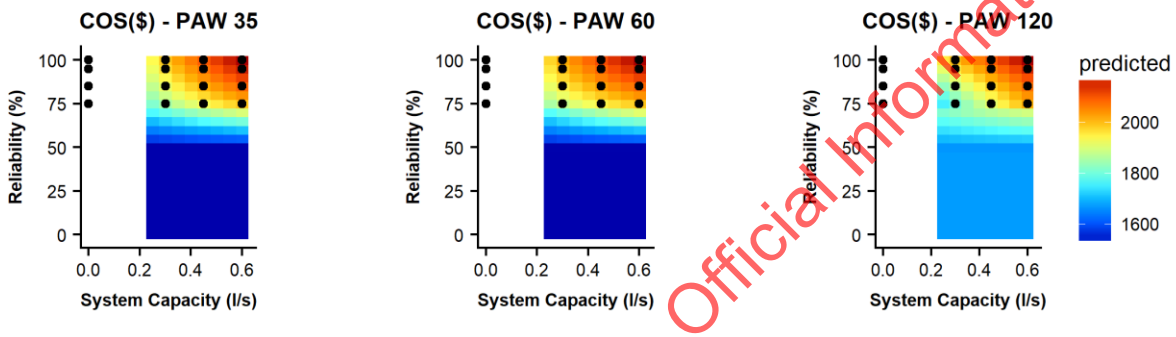
North Island: Bay of Plenty; Dairy



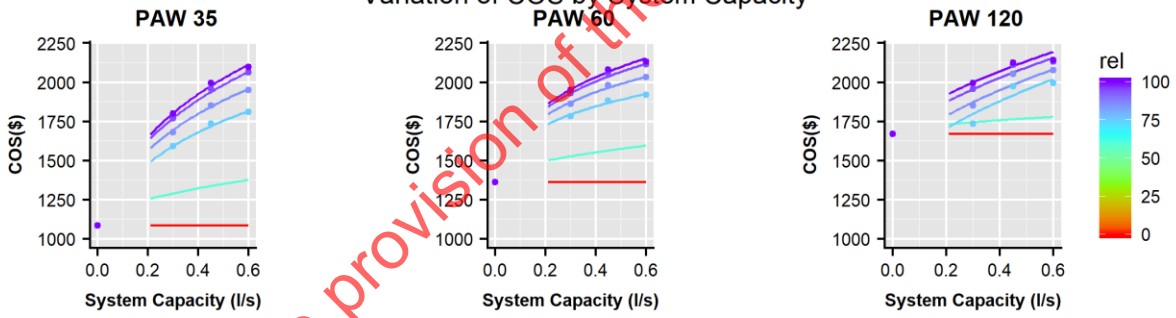


Modelled COS response surface

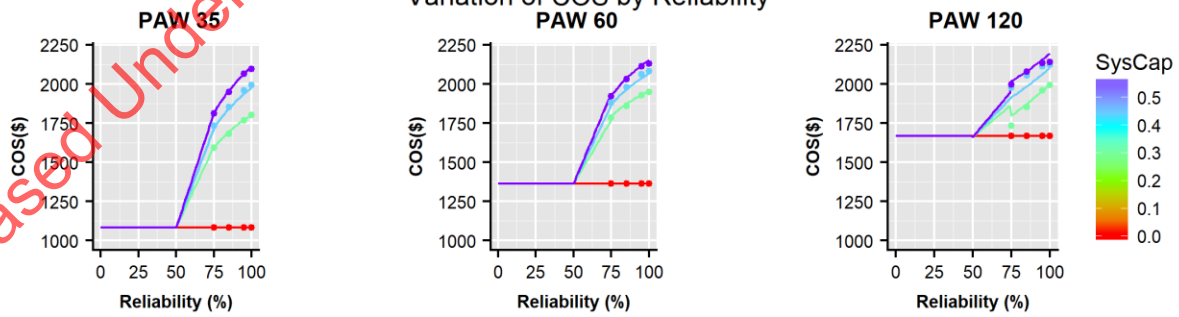
Black dots show actual sample points



Variation of COS by System Capacity



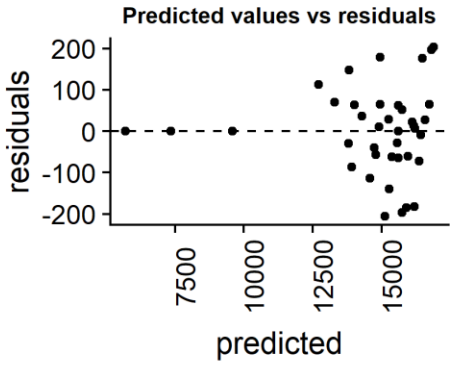
Variation of COS by Reliability

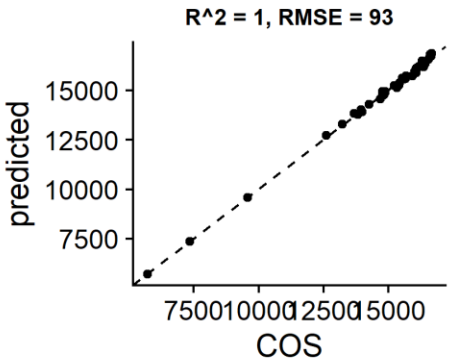


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

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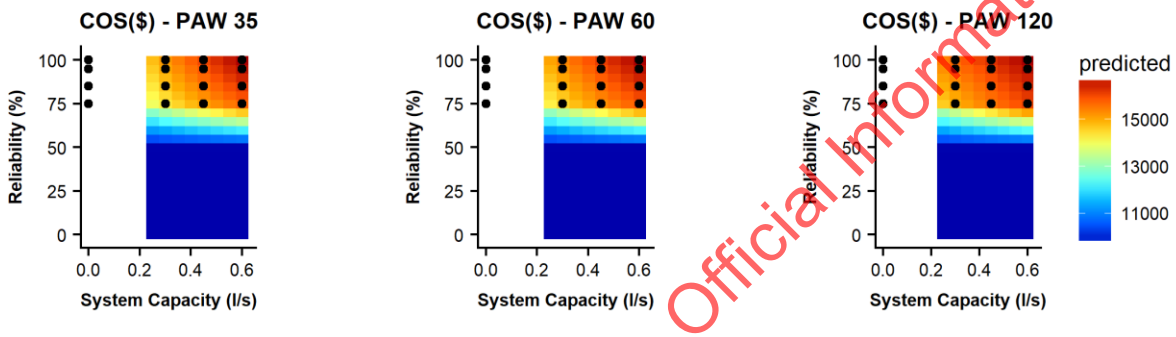
North Island: Bay of Plenty; Horticulture



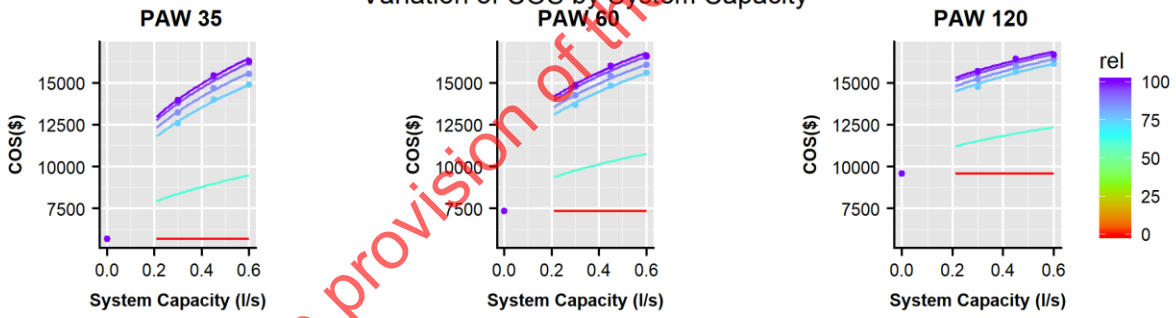


Modelled COS response surface

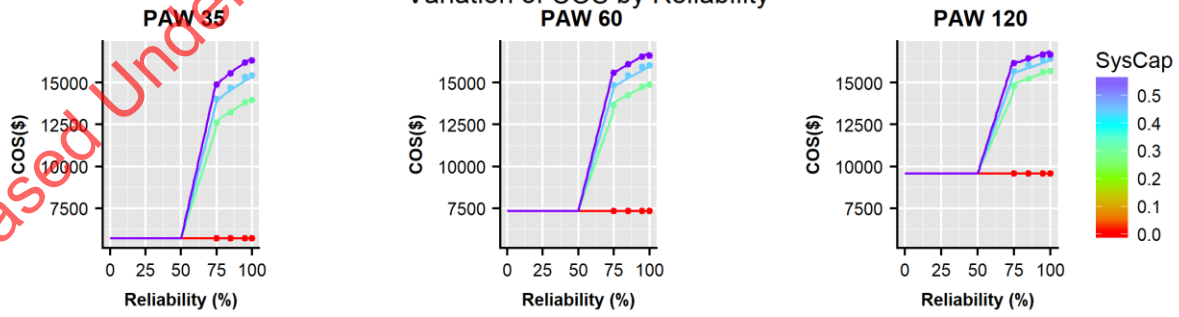
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

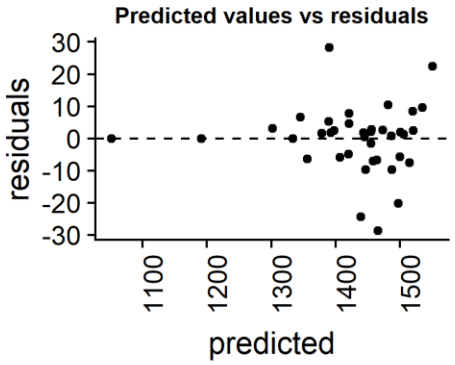


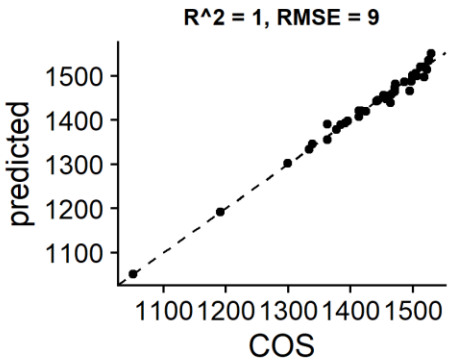
Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

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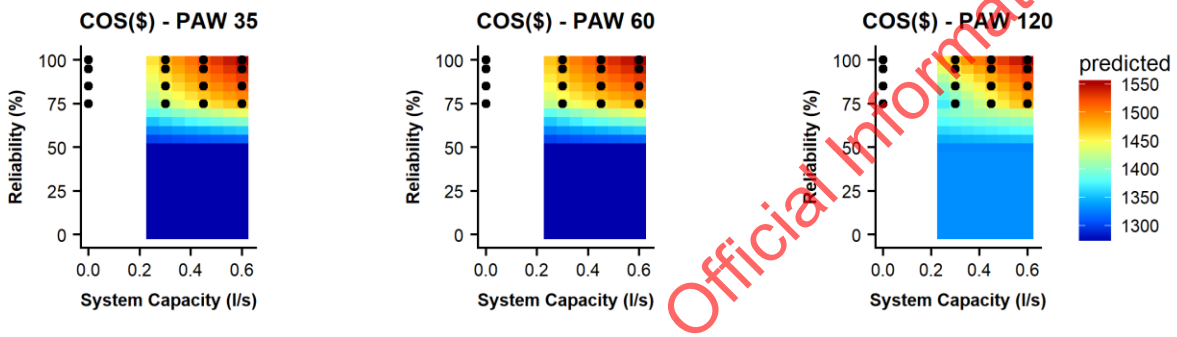
North Island: Central; Sheep and Beef



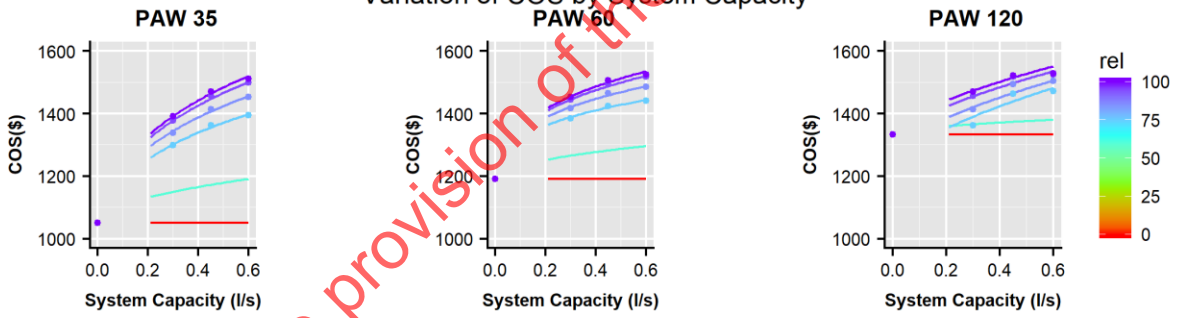


Modelled COS response surface

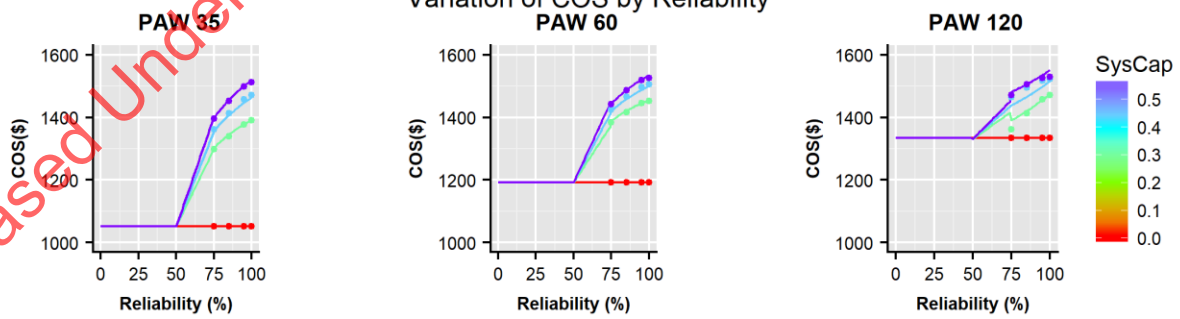
Black dots show actual sample points



Variation of COS by System Capacity



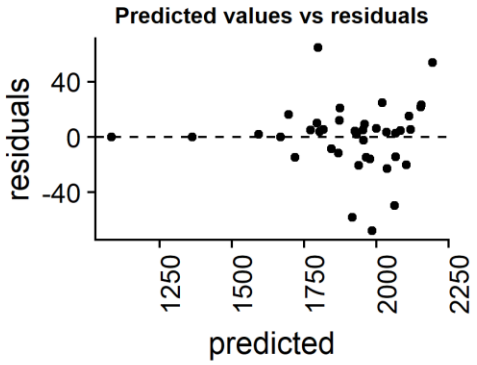
Variation of COS by Reliability

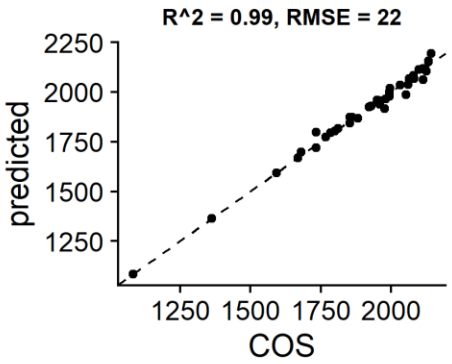


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

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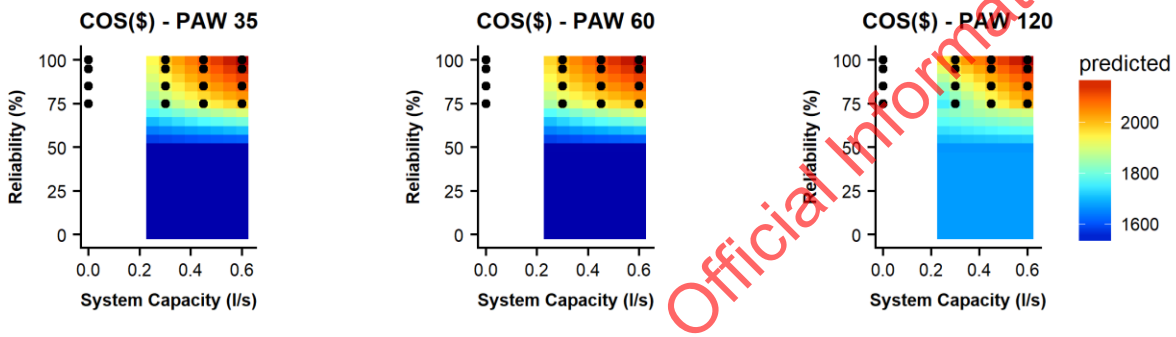
North Island: Central; Dairy



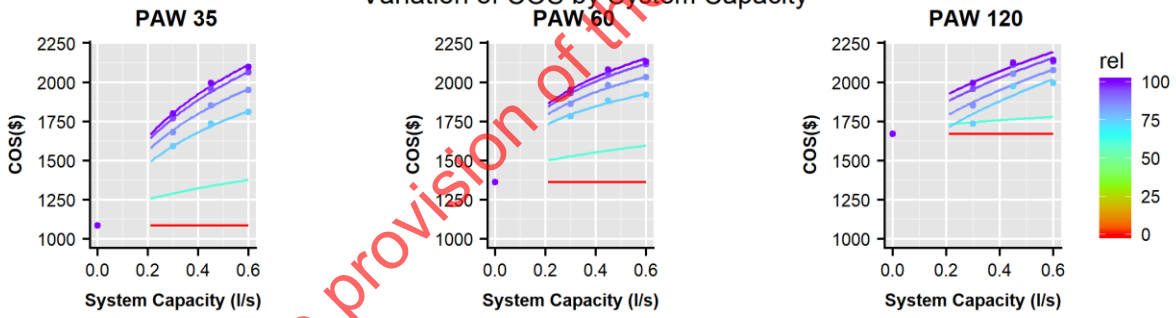


Modelled COS response surface

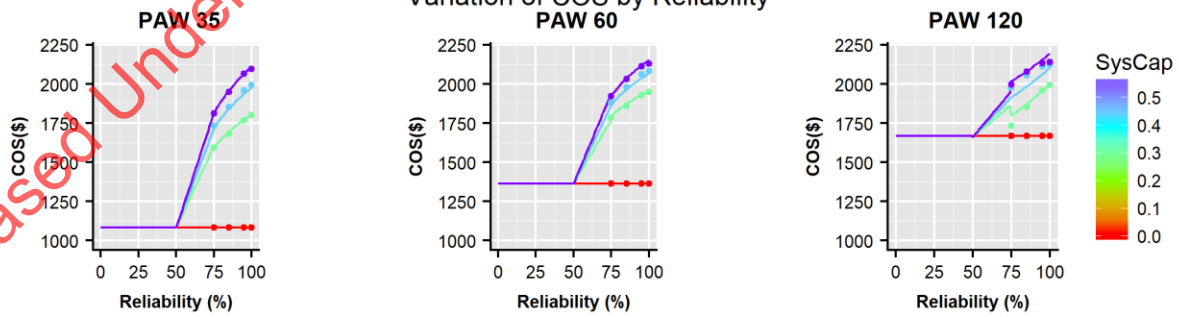
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

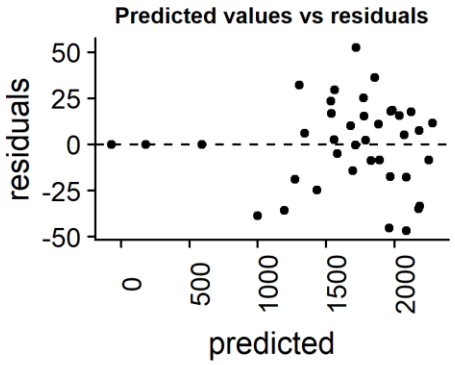


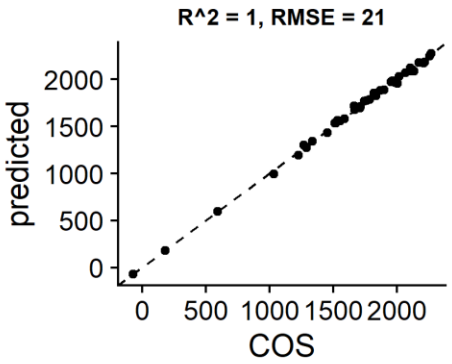
Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

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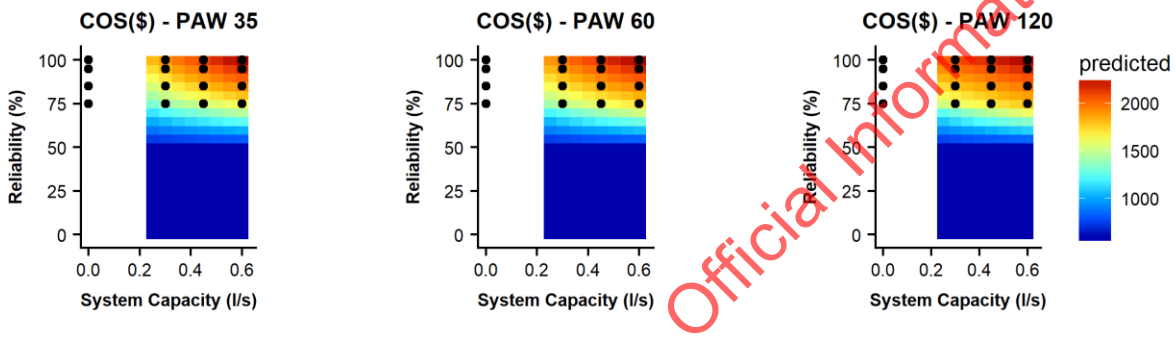
North Island: Central; Horticulture



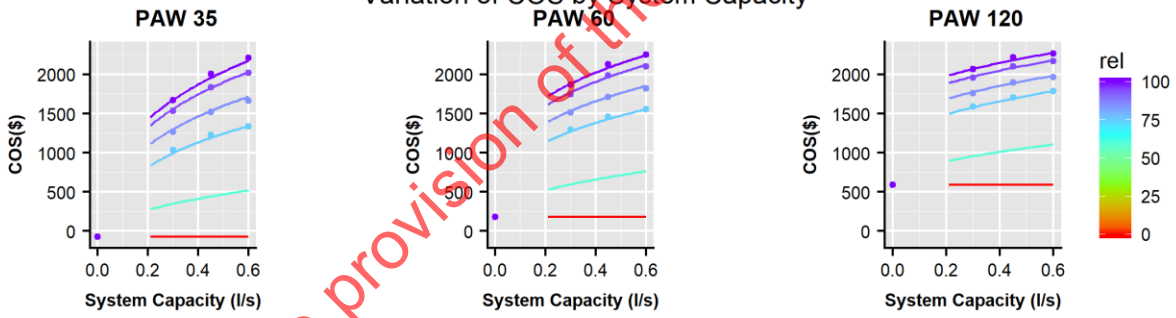


Modelled COS response surface

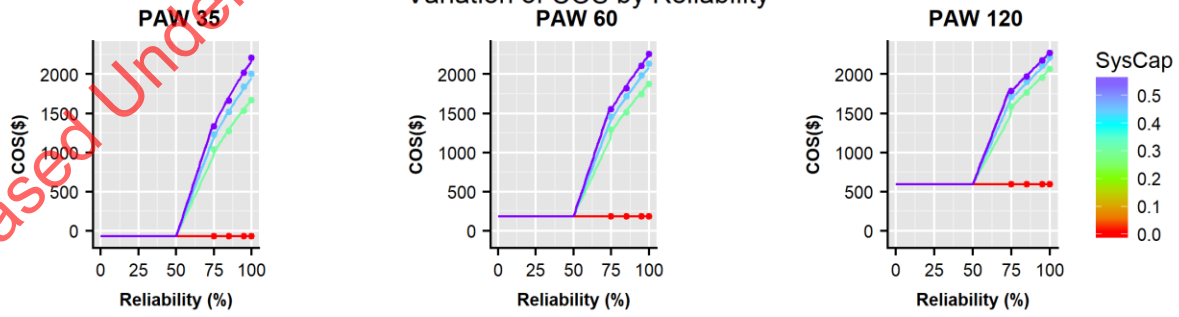
Black dots show actual sample points



Variation of COS by System Capacity



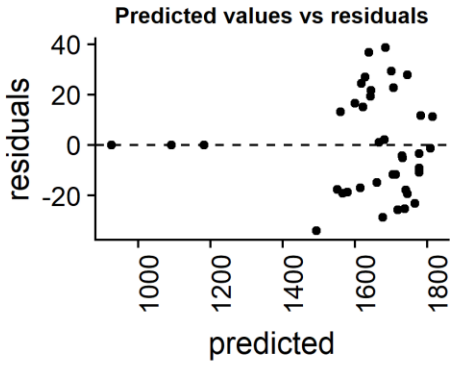
Variation of COS by Reliability

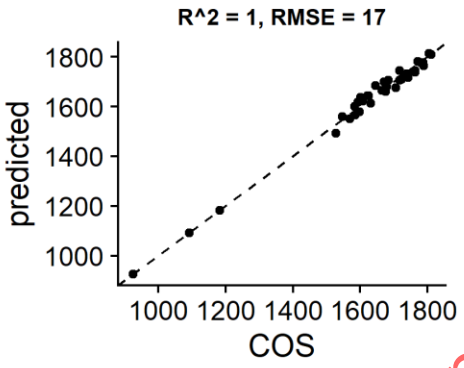


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

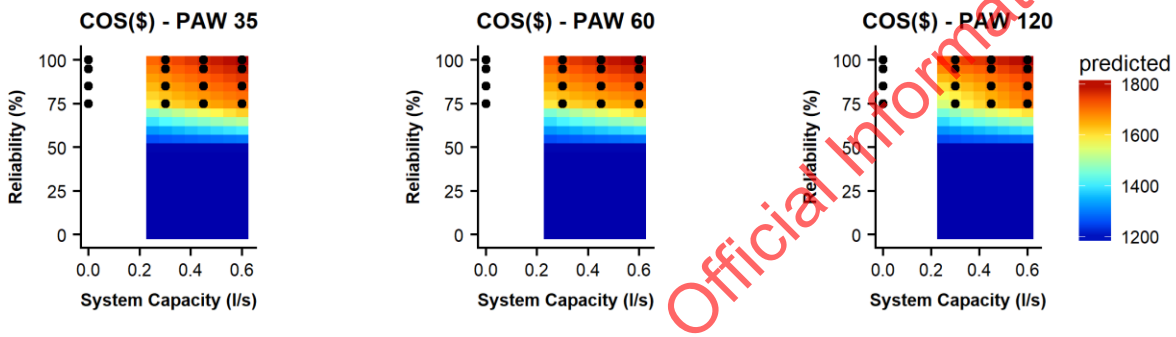
North Island: East Coast; Sheep and Beef



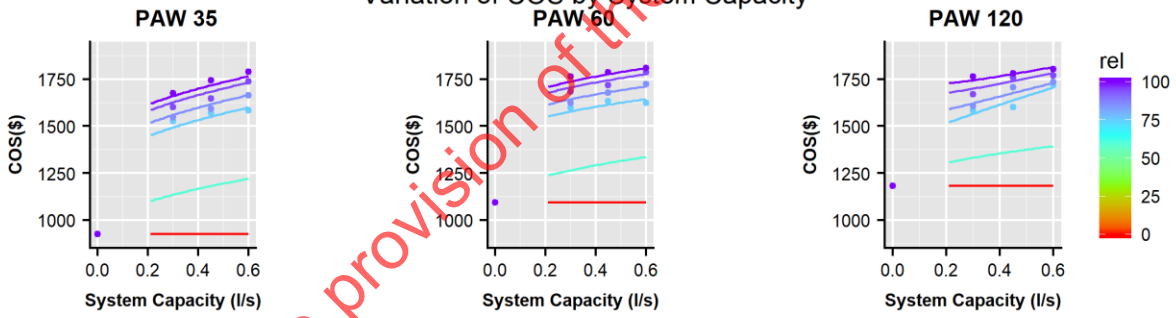


Modelled COS response surface

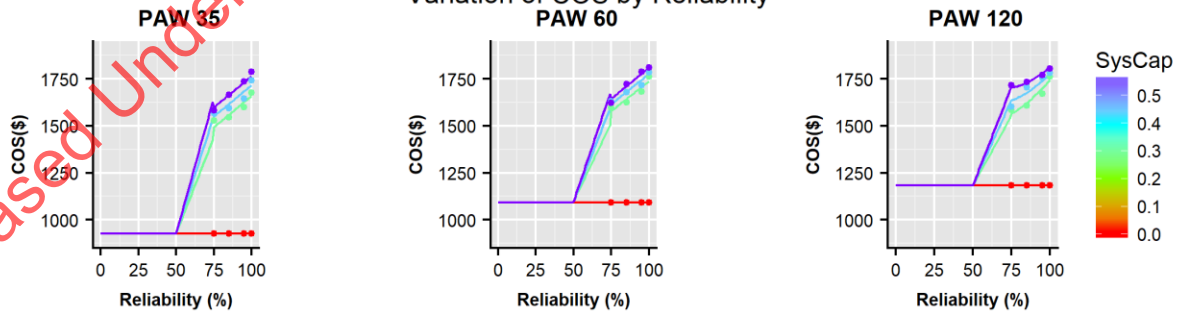
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

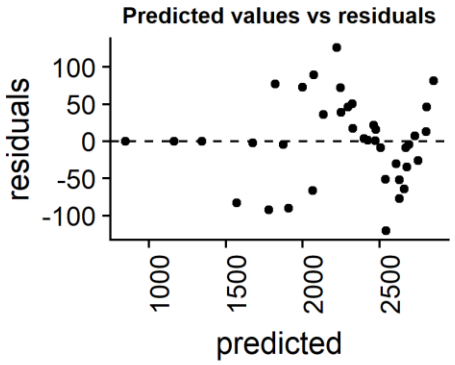


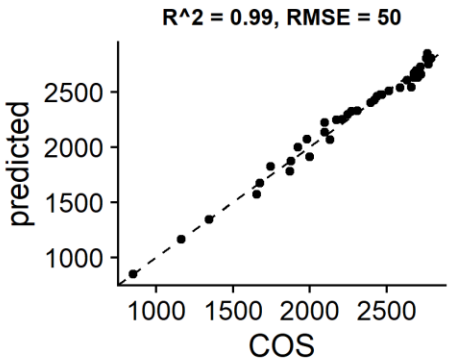
Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

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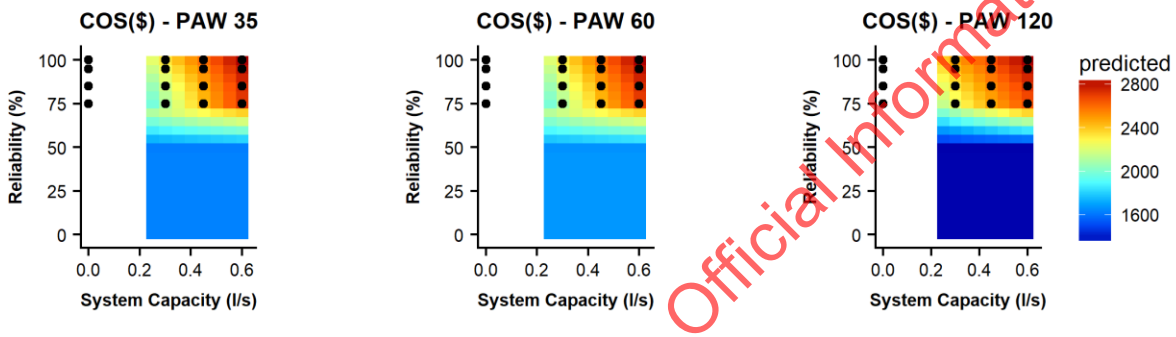
North Island: East Coast; Dairy



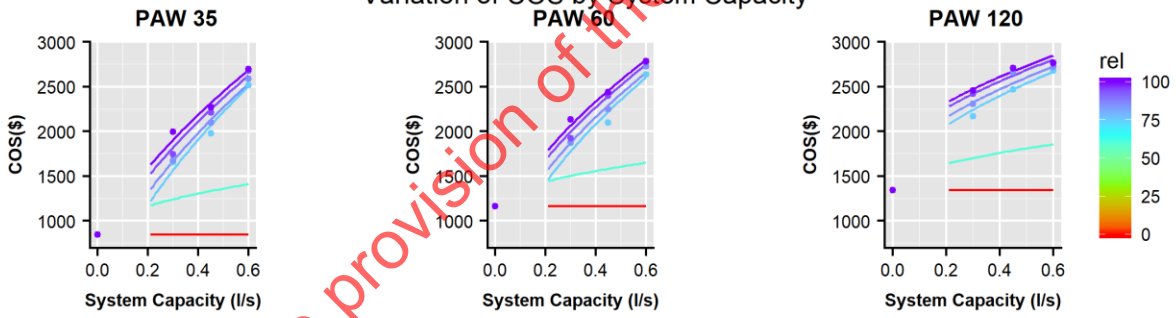


Modelled COS response surface

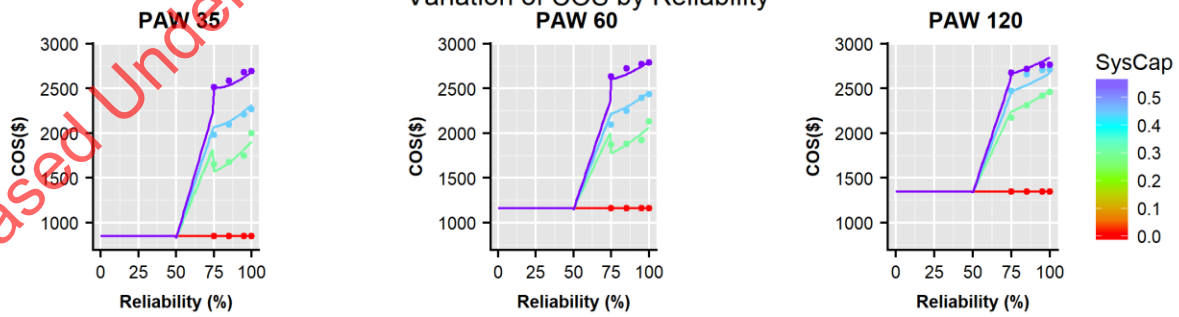
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

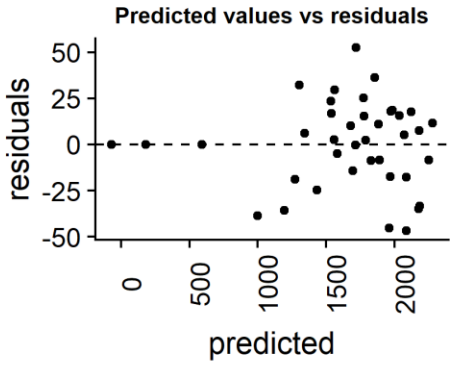


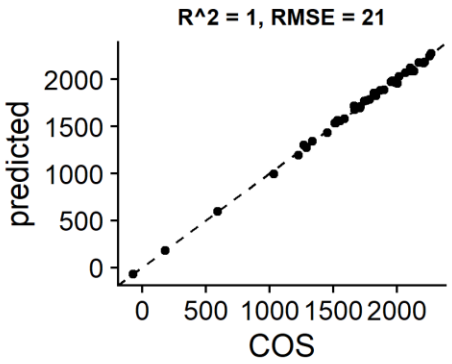
Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

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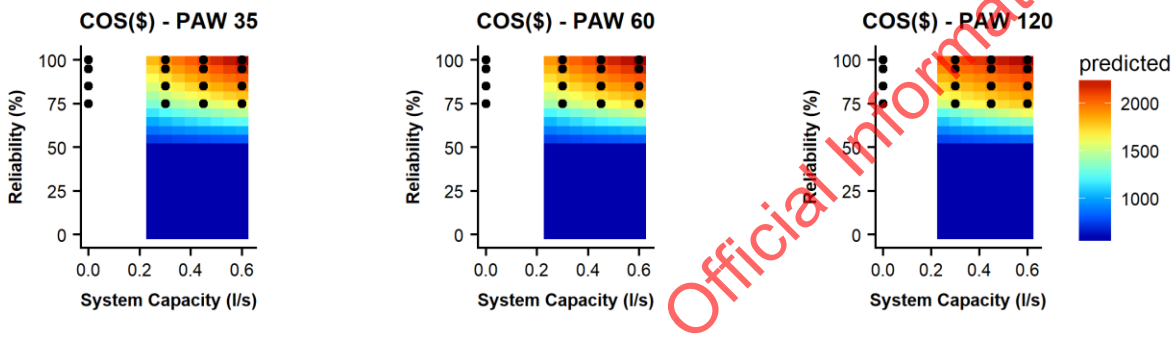
North Island: East Coast; Arable



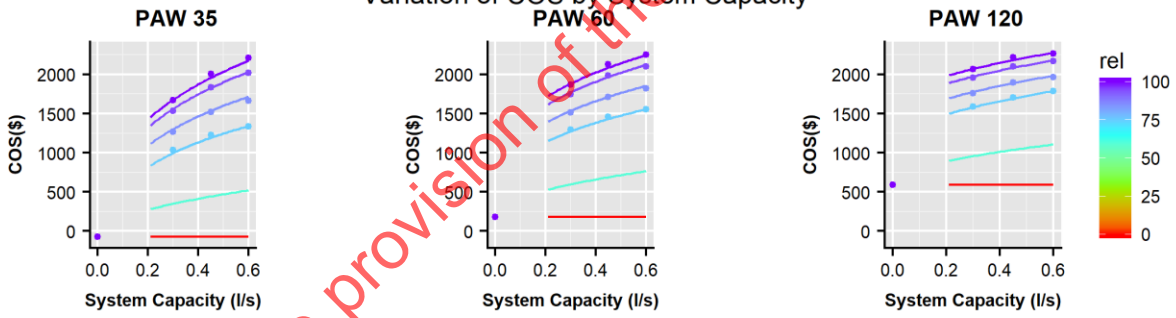


Modelled COS response surface

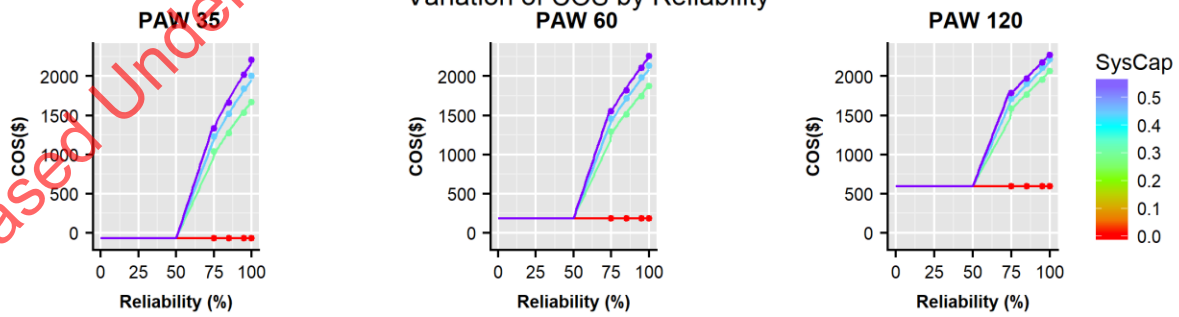
Black dots show actual sample points



Variation of COS by System Capacity



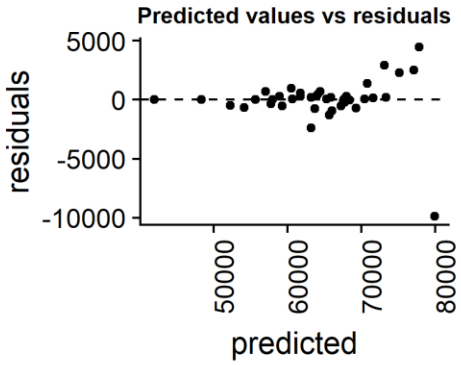
Variation of COS by Reliability

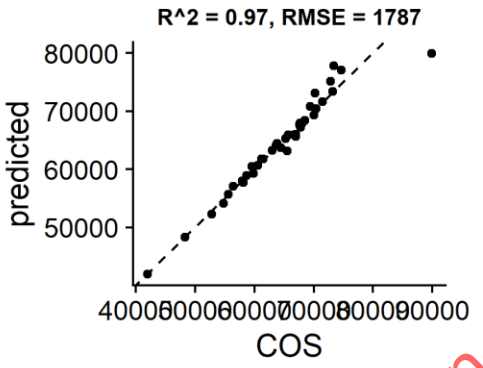


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

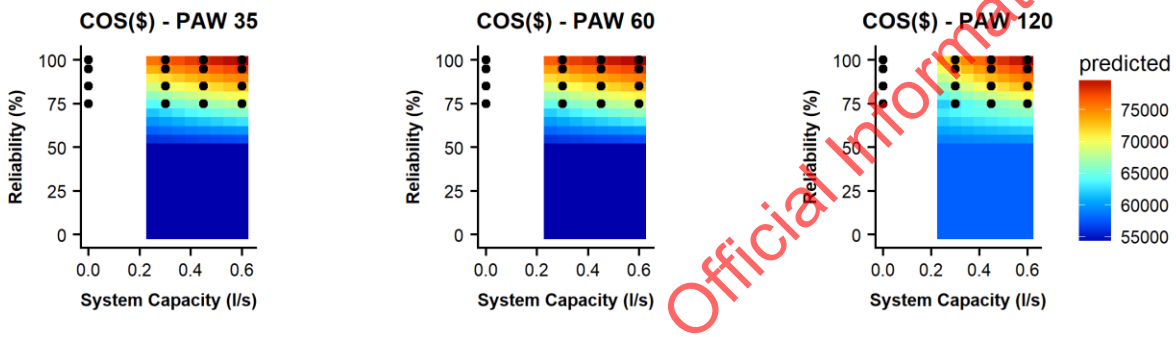
North Island: East Coast; Horticulture



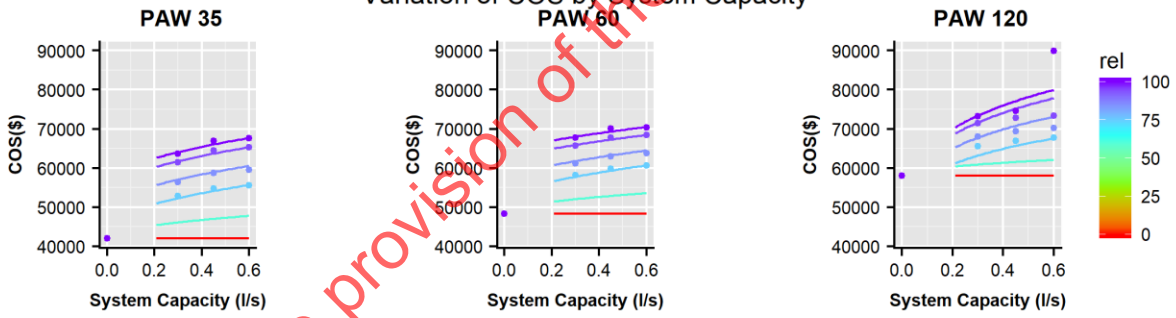


Modelled COS response surface

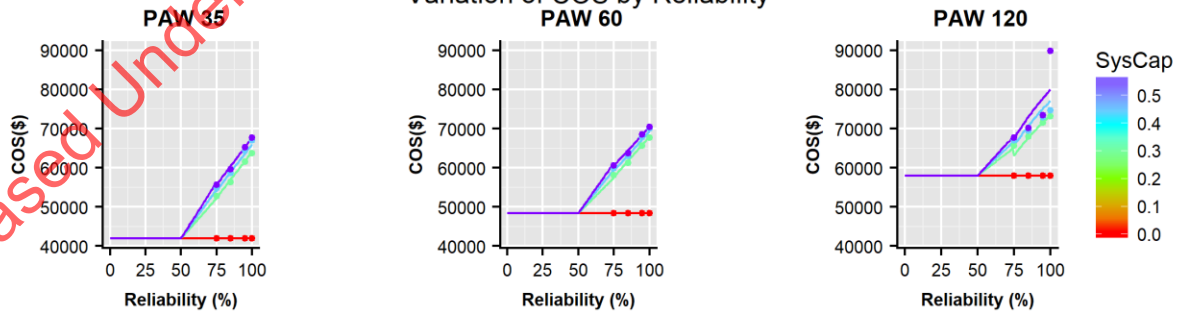
Black dots show actual sample points



Variation of COS by System Capacity



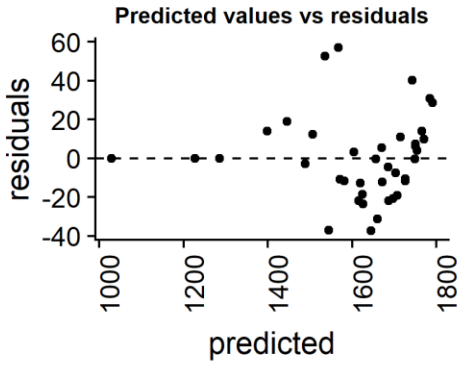
Variation of COS by Reliability

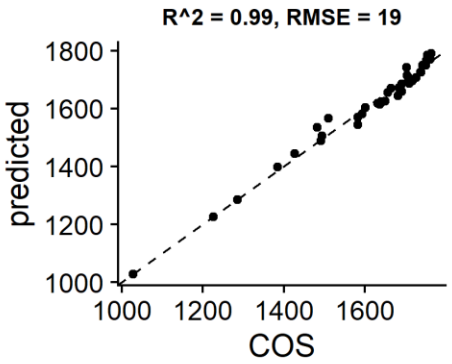


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

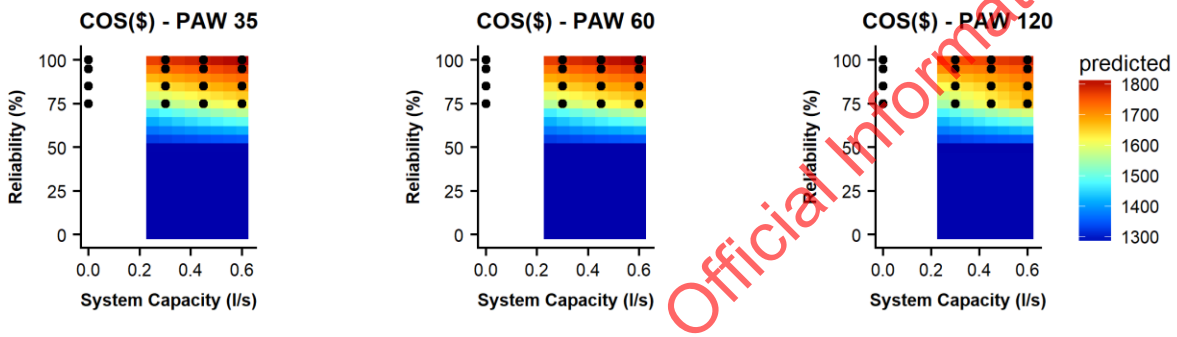
North Island: Lower Hill Country; Sheep and Beef



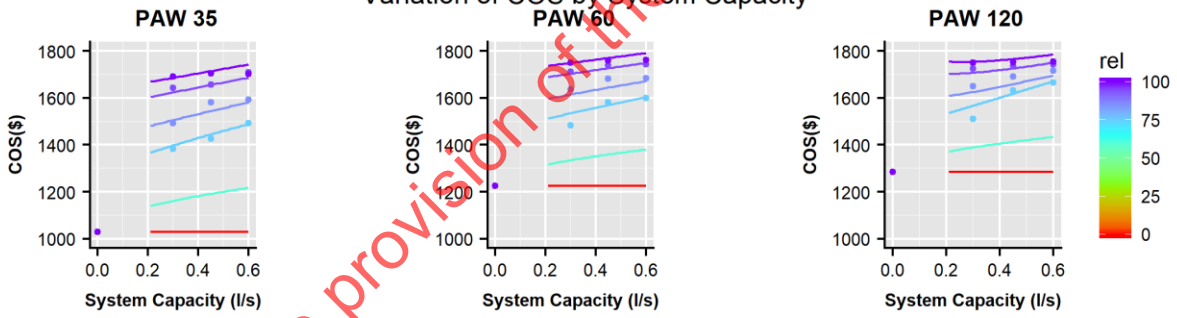


Modelled COS response surface

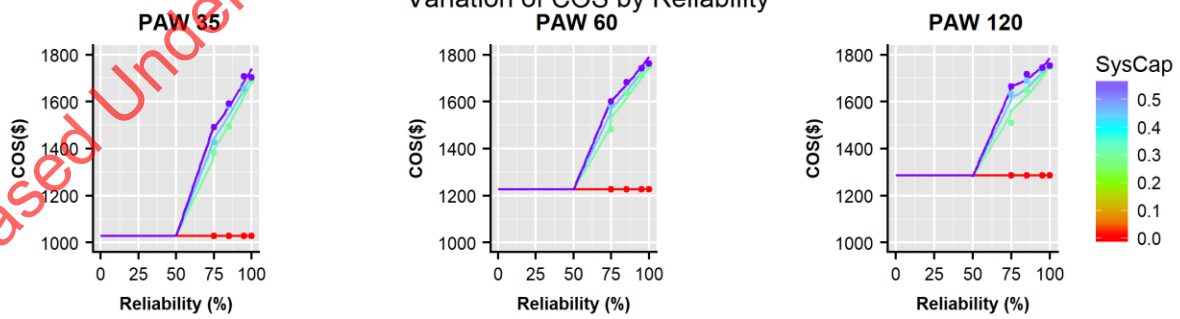
Black dots show actual sample points



Variation of COS by System Capacity



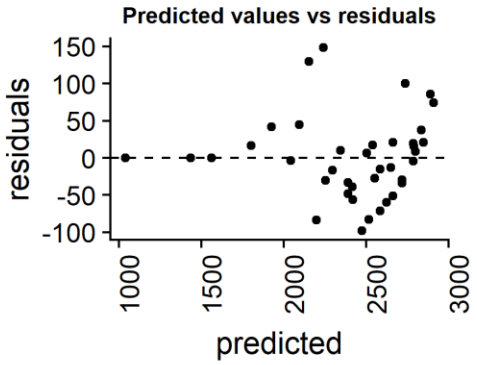
Variation of COS by Reliability

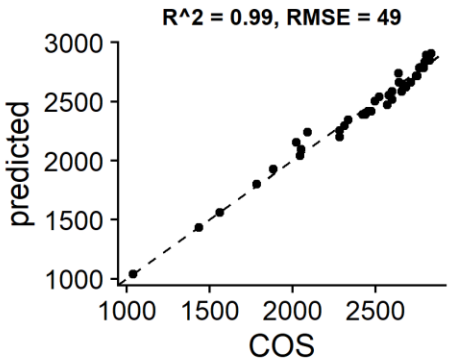


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

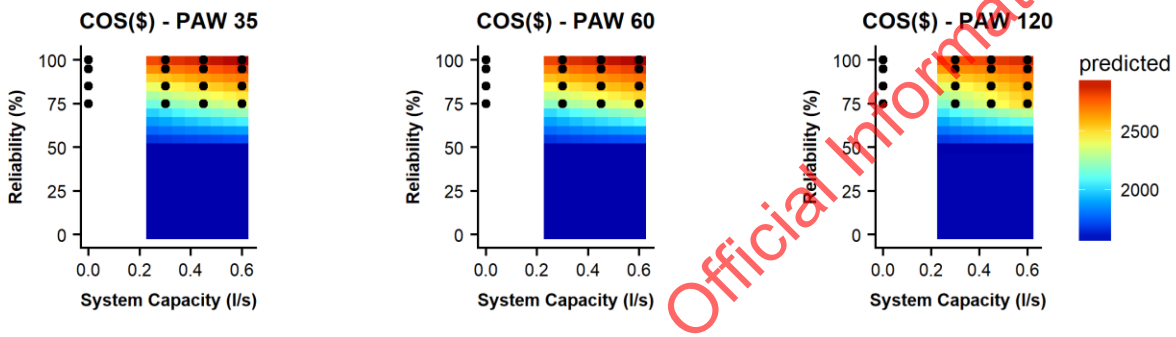
North Island: Lower Hill Country; Dairy



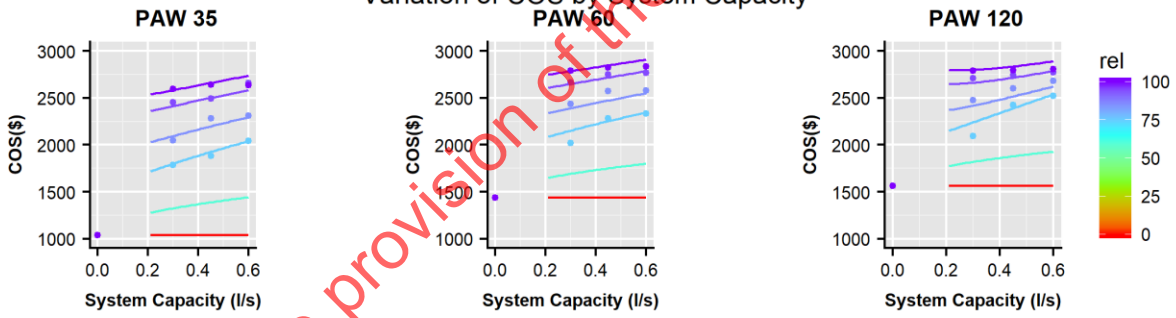


Modelled COS response surface

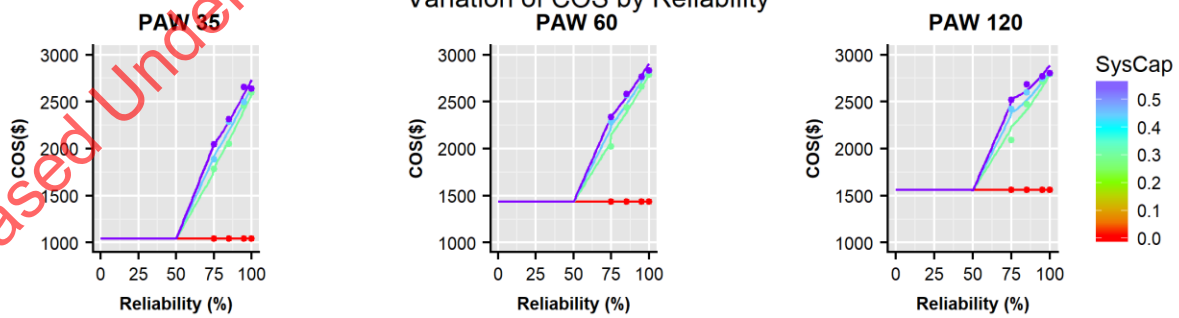
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

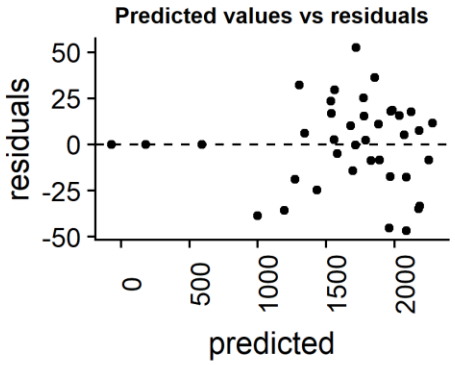


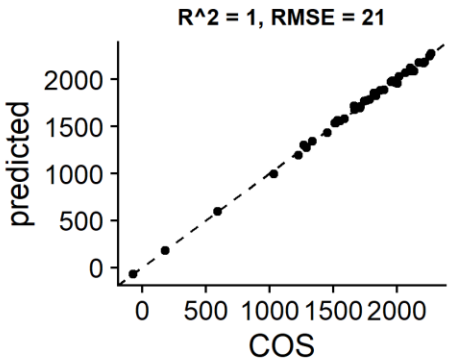
Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

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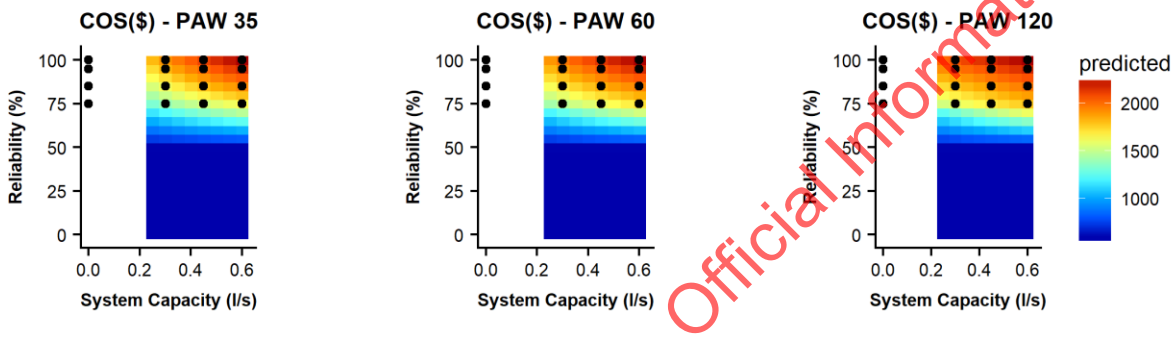
North Island: Lower Hill Country; Arable



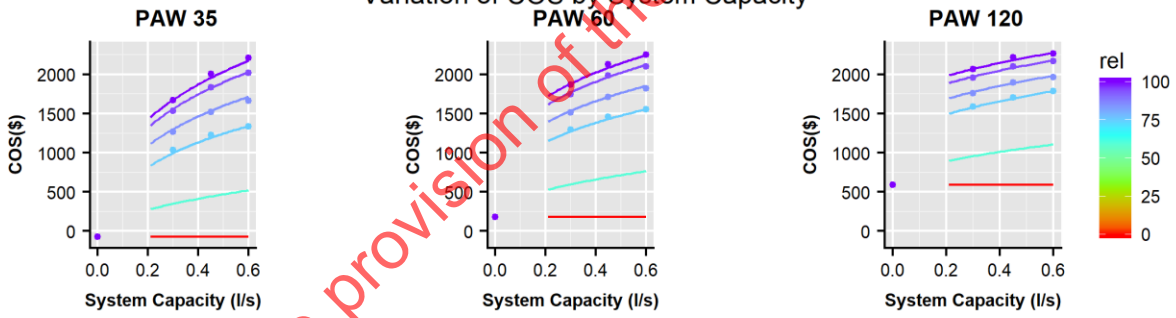


Modelled COS response surface

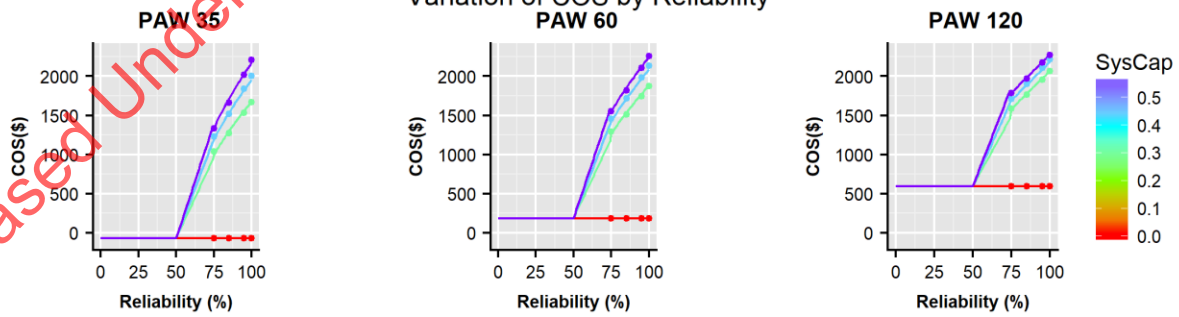
Black dots show actual sample points



Variation of COS by System Capacity



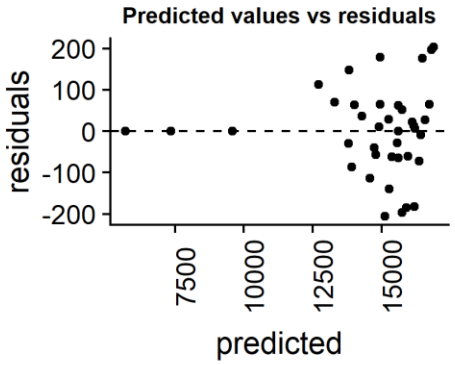
Variation of COS by Reliability

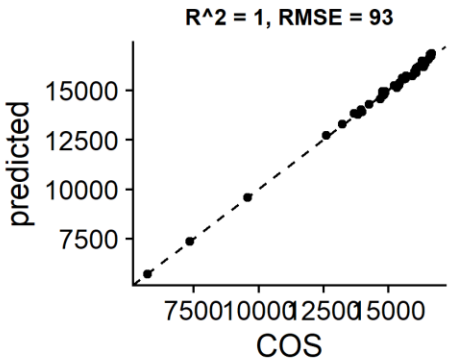


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

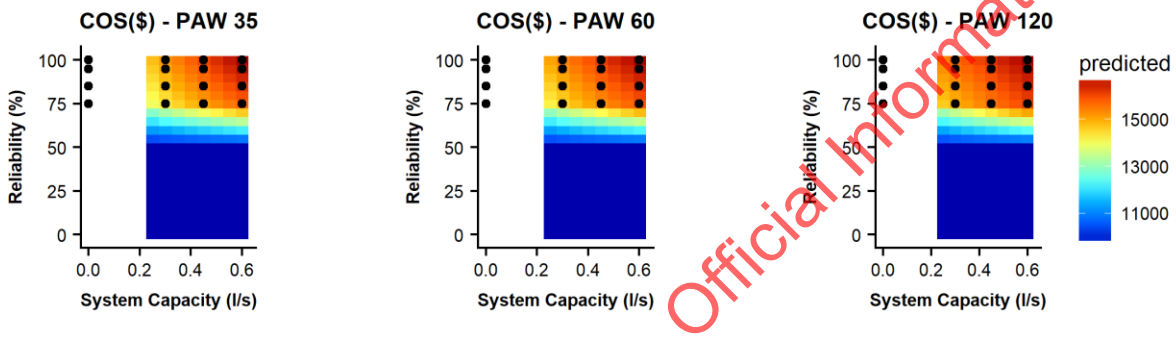
North Island: Lower Hill Country; Horticulture



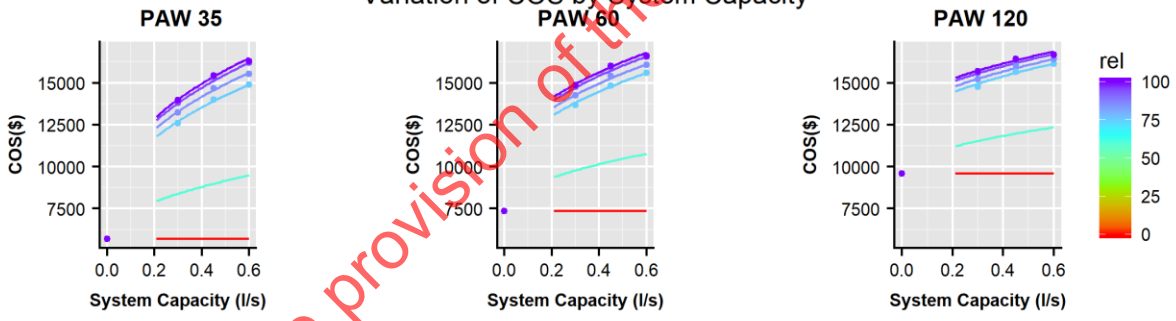


Modelled COS response surface

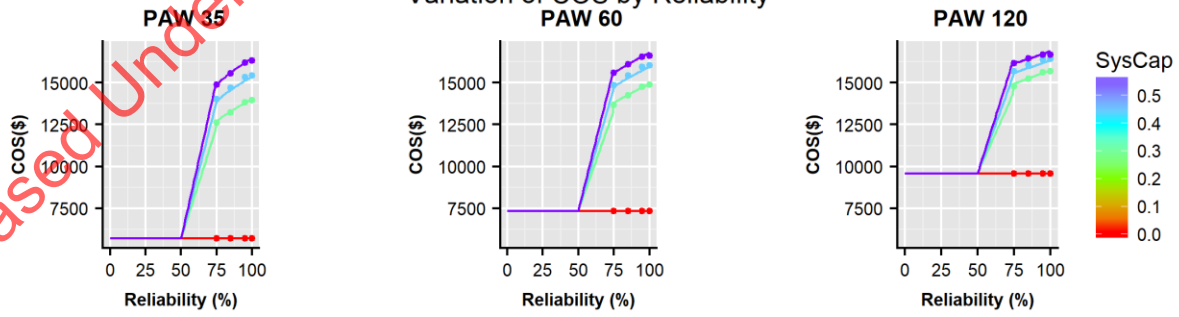
Black dots show actual sample points



Variation of COS by System Capacity



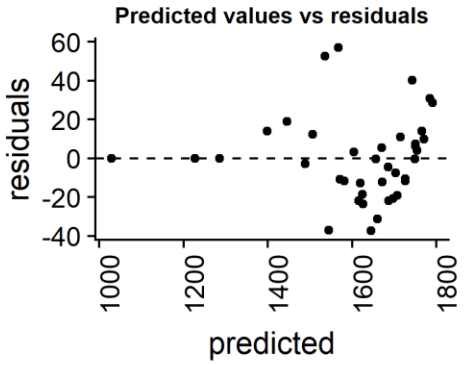
Variation of COS by Reliability

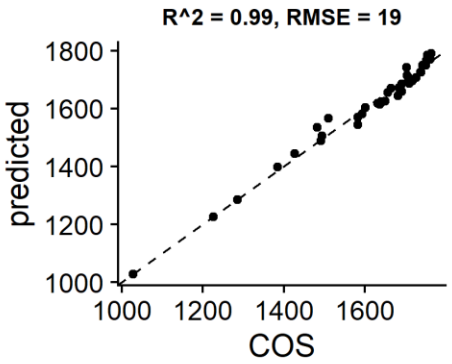


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

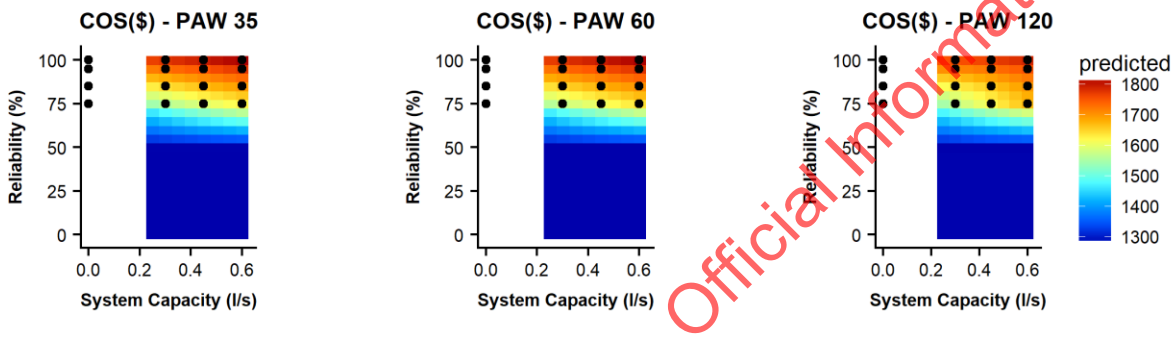
North Island: Mountains; Sheep and Beef



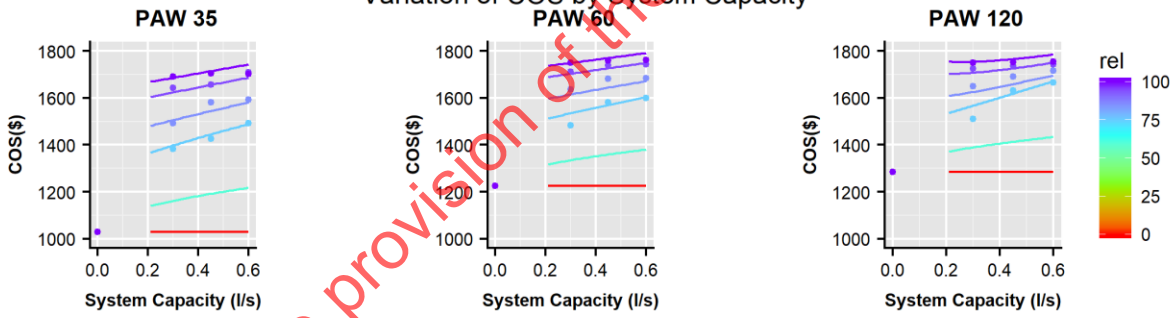


Modelled COS response surface

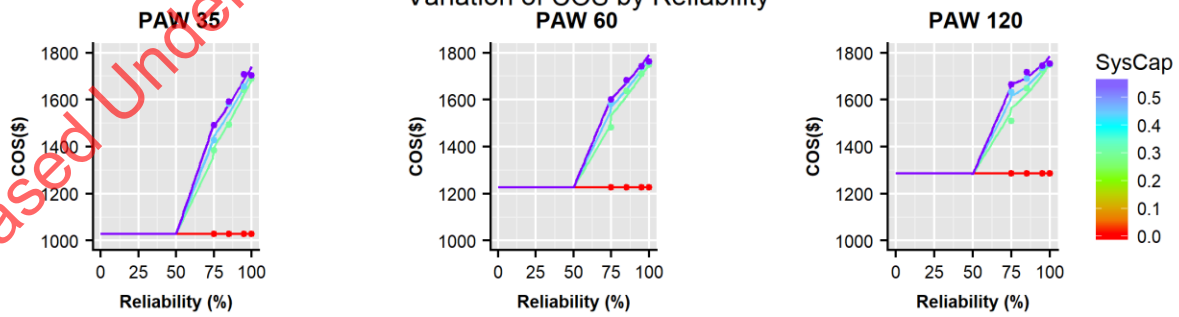
Black dots show actual sample points



Variation of COS by System Capacity



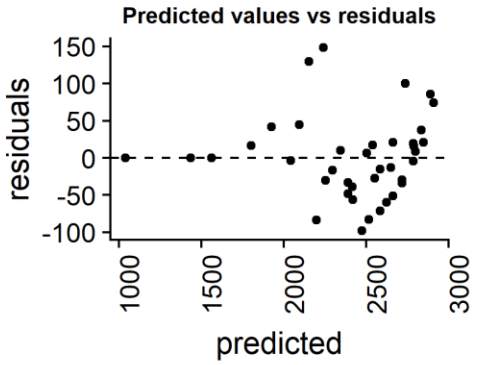
Variation of COS by Reliability

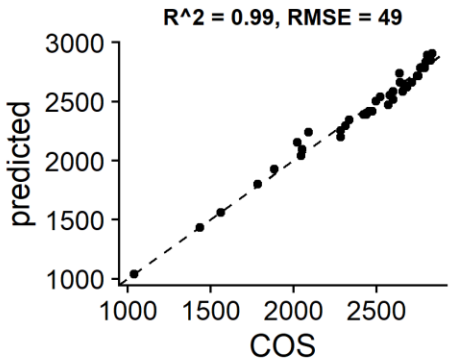


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

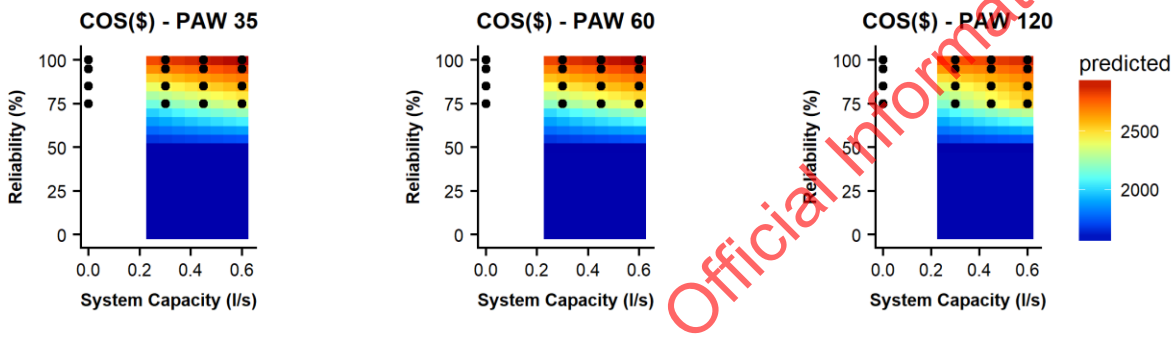
North Island: Mountains; Dairy



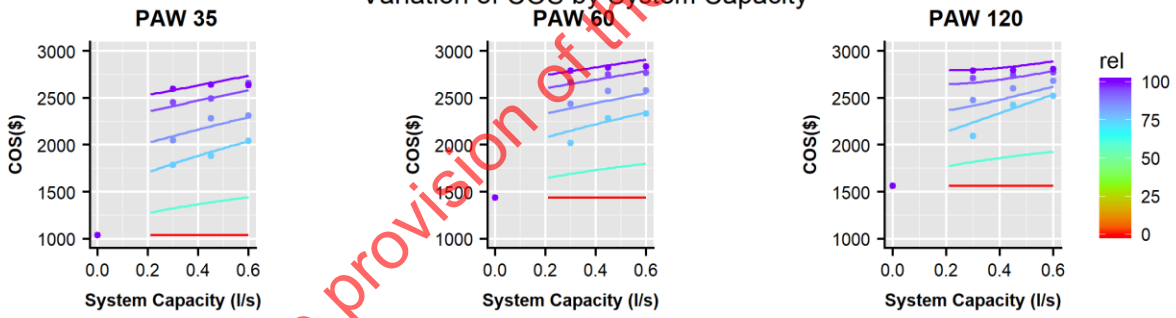


Modelled COS response surface

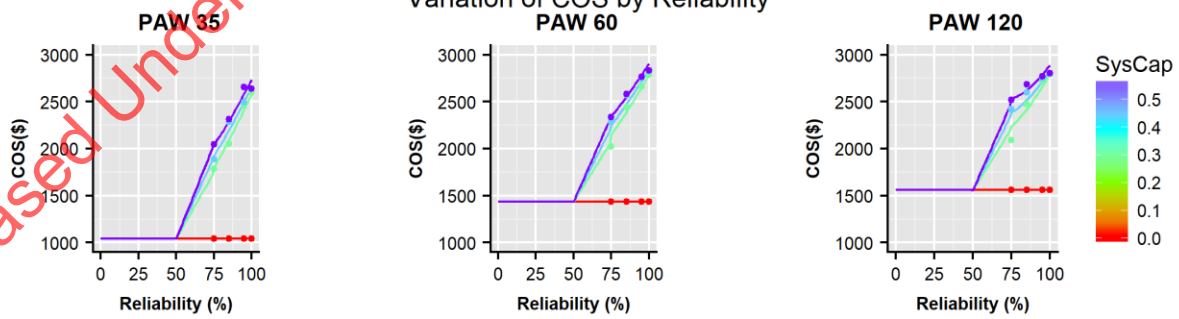
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

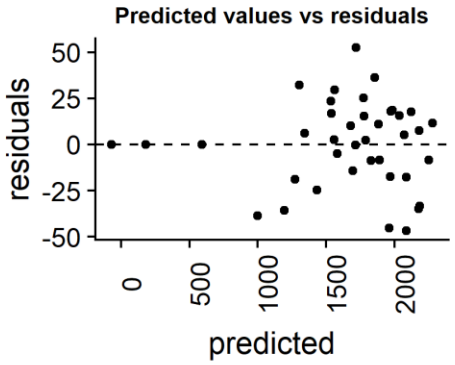


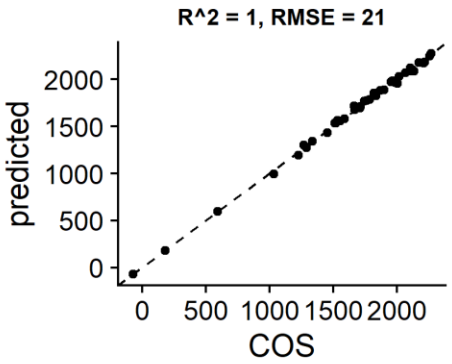
Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

20-D-00014

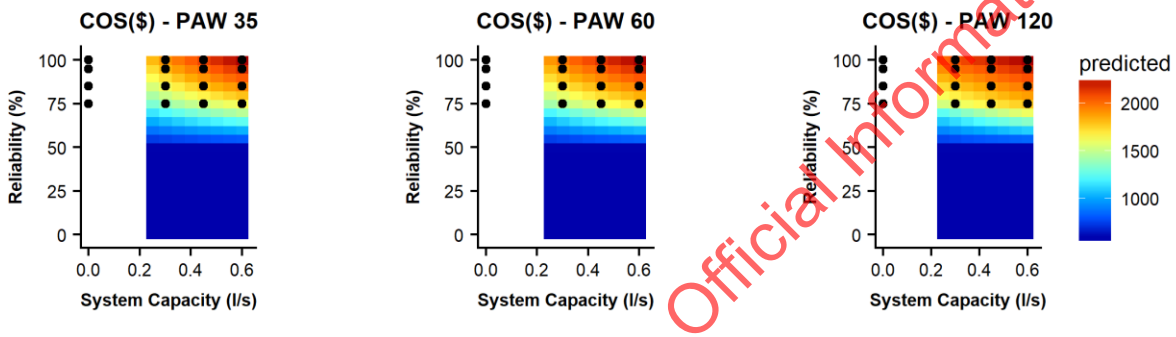
North Island: Mountains; Arable



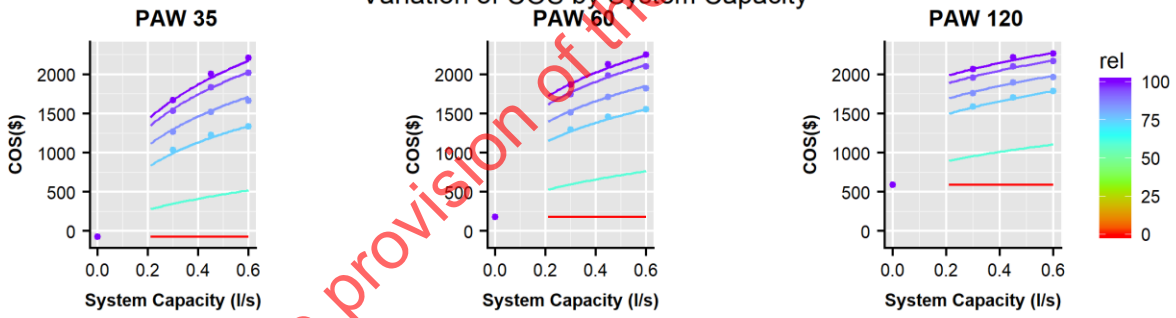


Modelled COS response surface

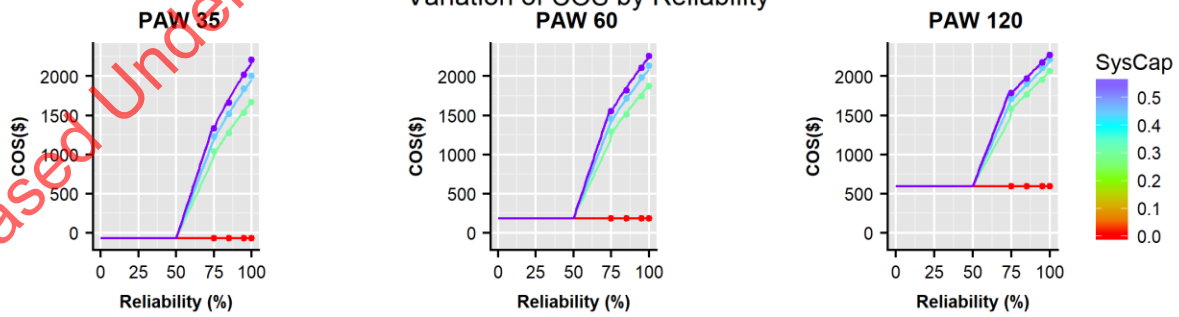
Black dots show actual sample points



Variation of COS by System Capacity



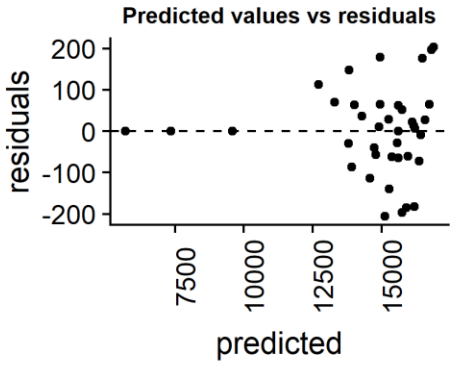
Variation of COS by Reliability

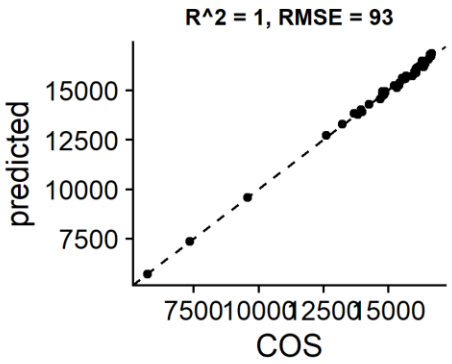


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

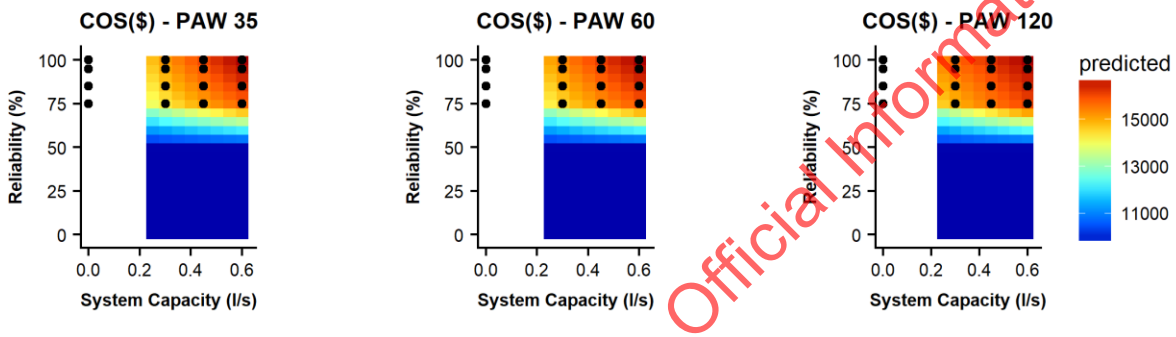
North Island: Mountains; Horticulture



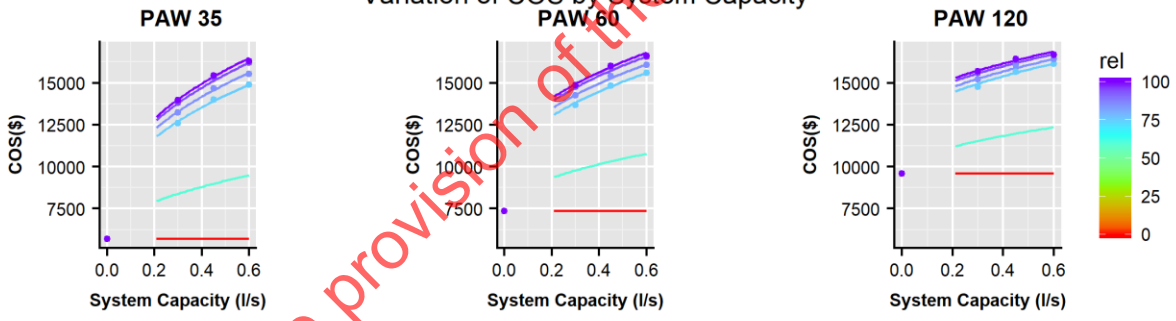


Modelled COS response surface

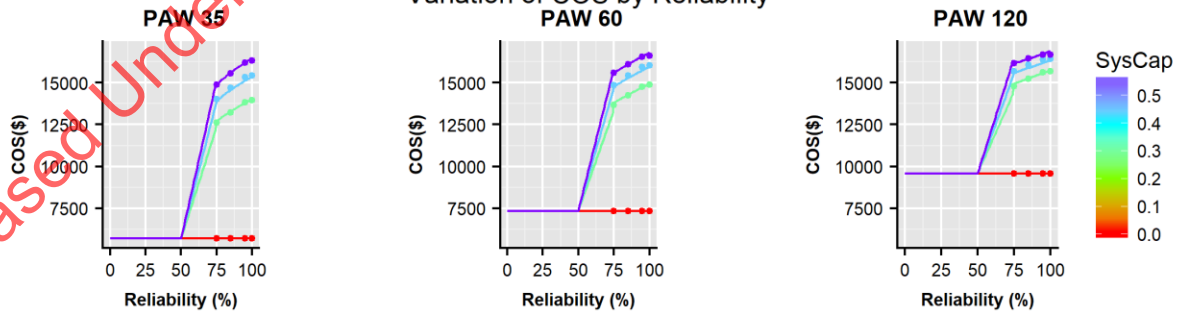
Black dots show actual sample points



Variation of COS by System Capacity



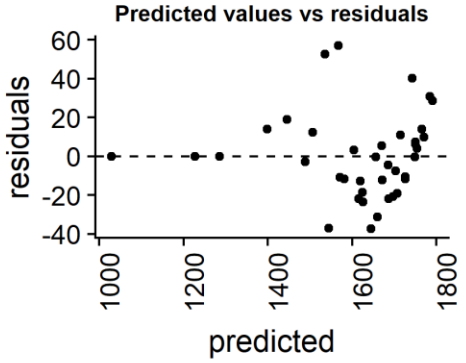
Variation of COS by Reliability

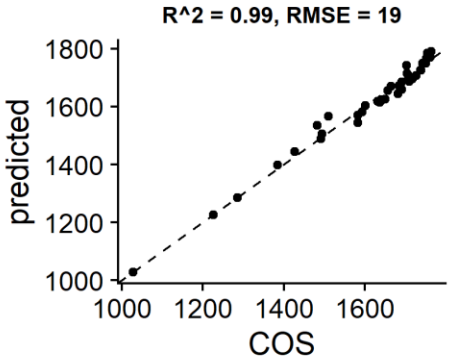


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
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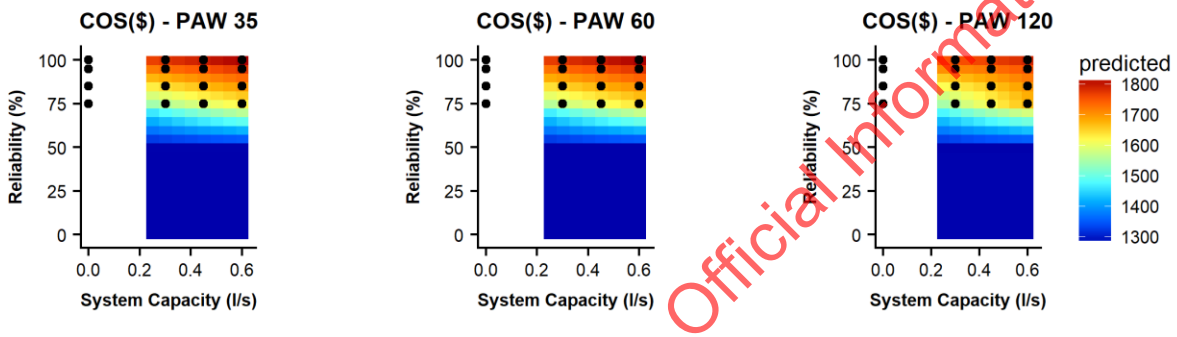
North Island: North-west; Sheep and Beef



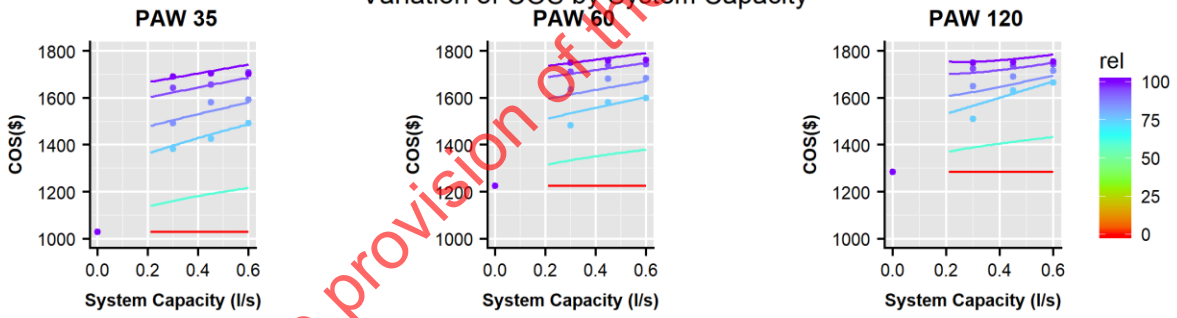


Modelled COS response surface

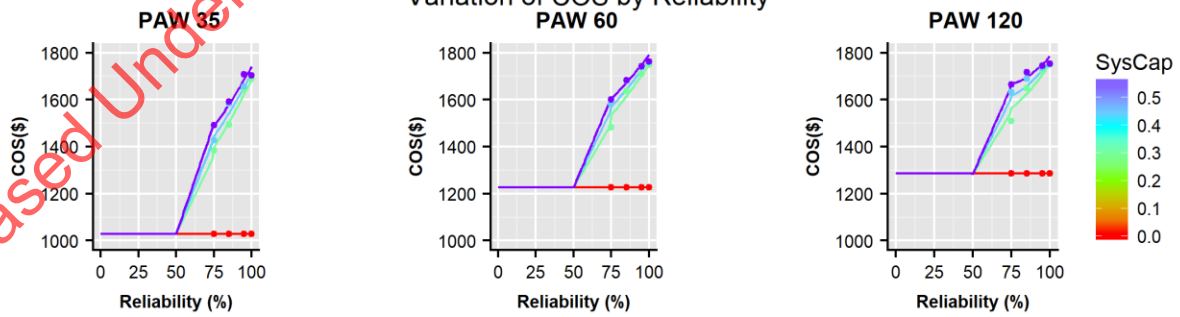
Black dots show actual sample points



Variation of COS by System Capacity



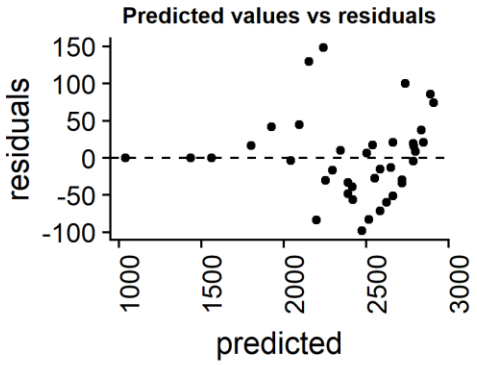
Variation of COS by Reliability

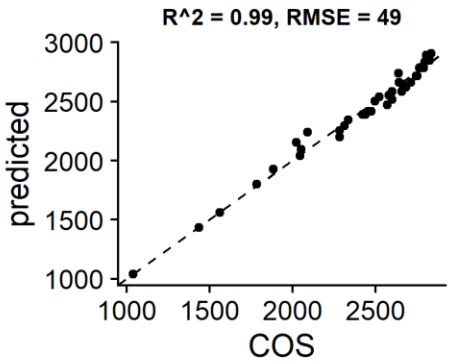


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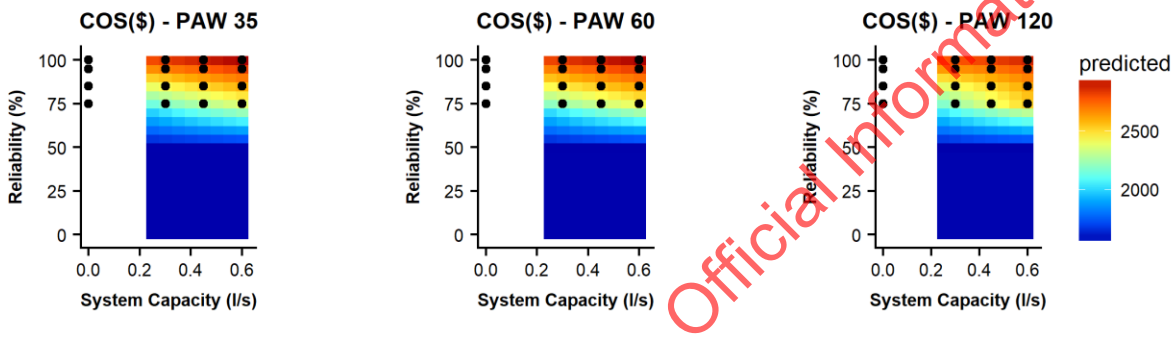
North Island: North-west; Dairy



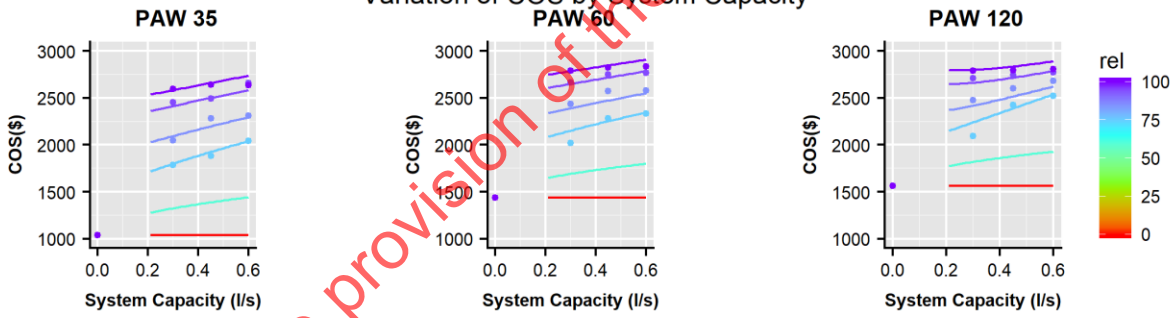


Modelled COS response surface

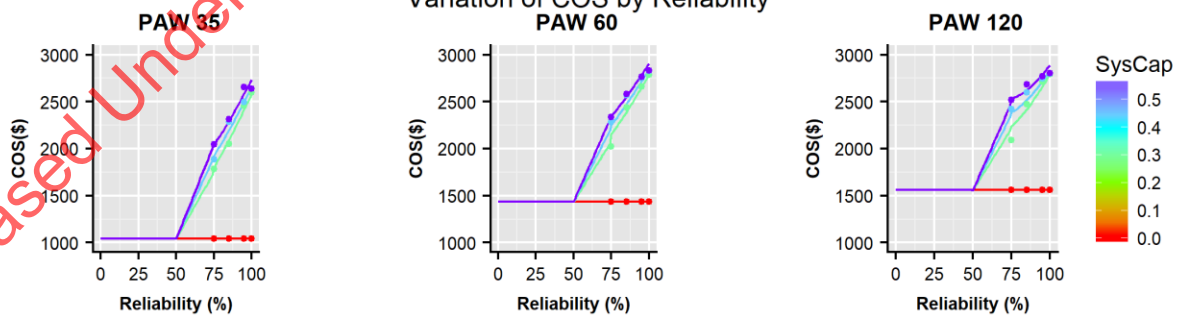
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

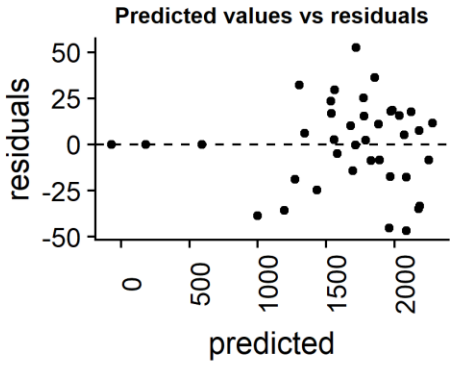


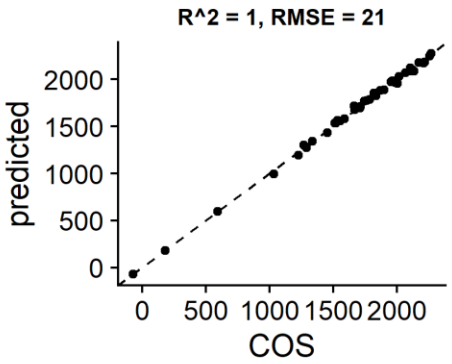
Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

20-D-00014

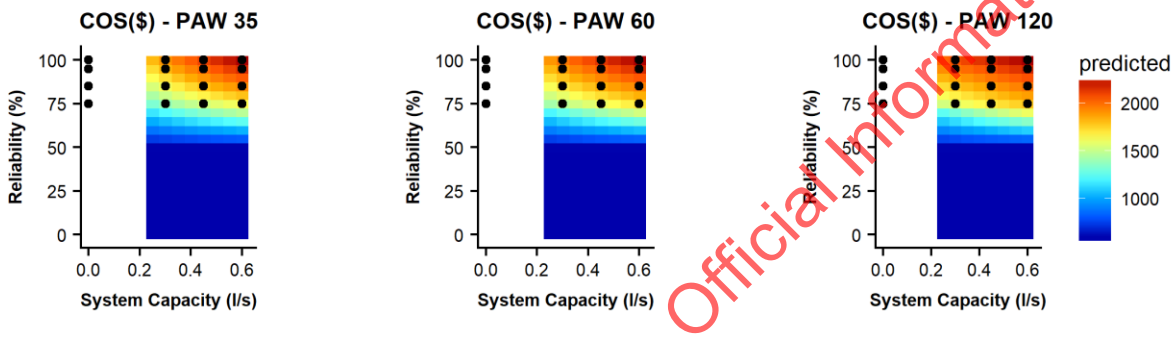
North Island: North-west; Arable



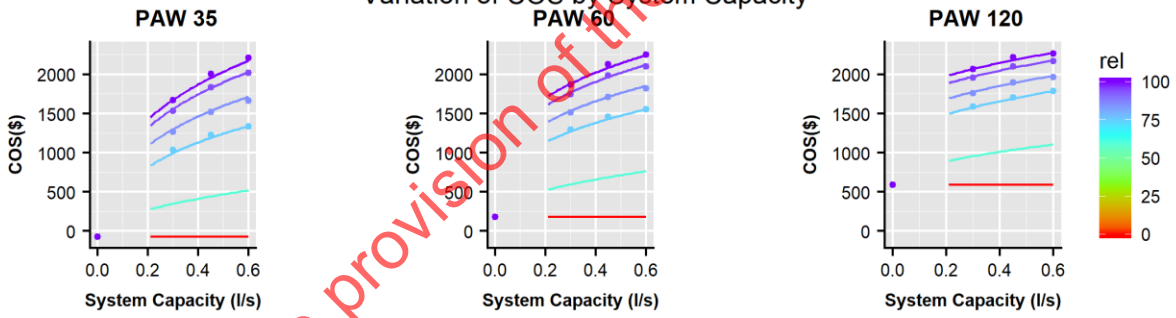


Modelled COS response surface

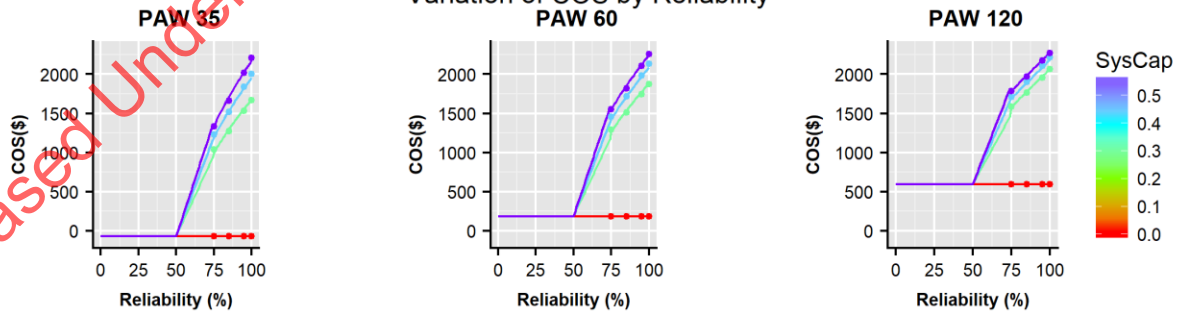
Black dots show actual sample points



Variation of COS by System Capacity



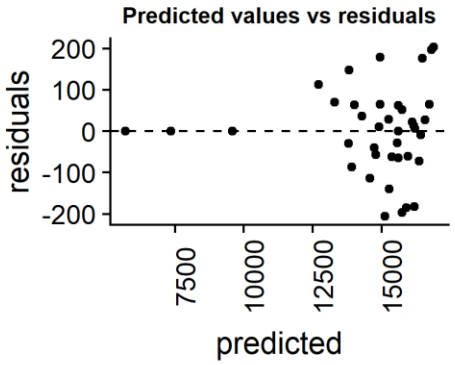
Variation of COS by Reliability

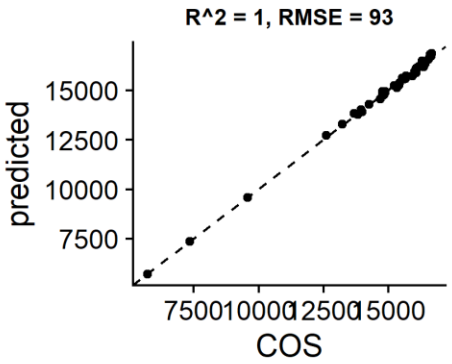


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

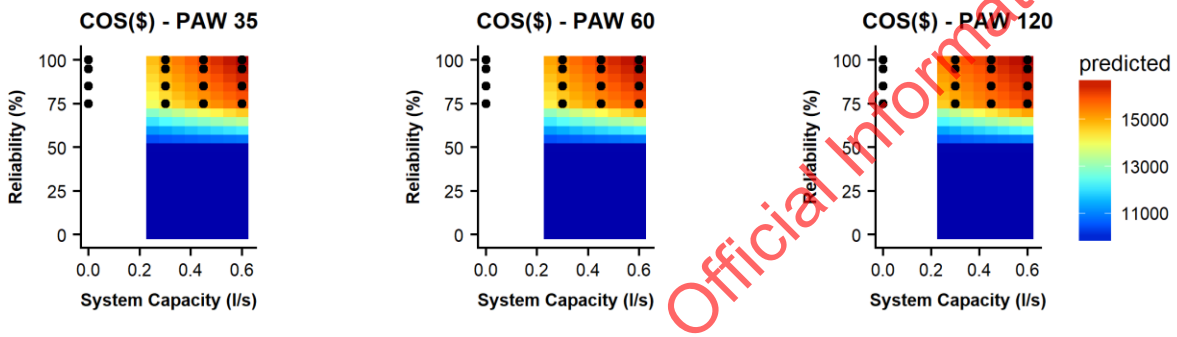
North Island: North-west; Horticulture



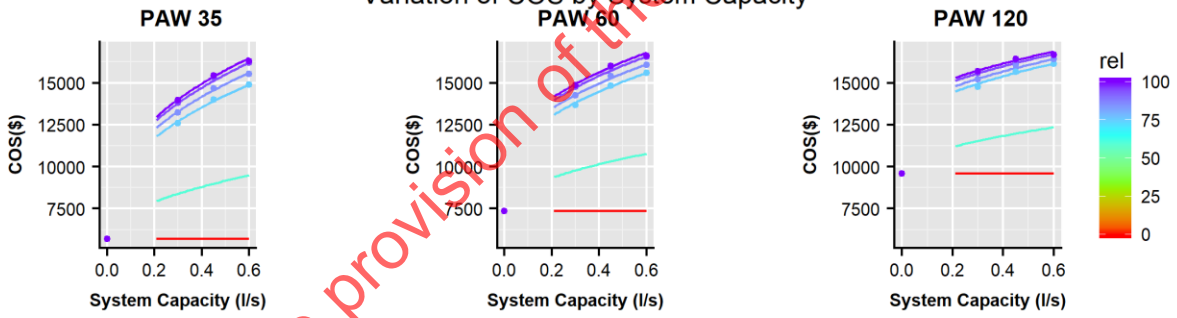


Modelled COS response surface

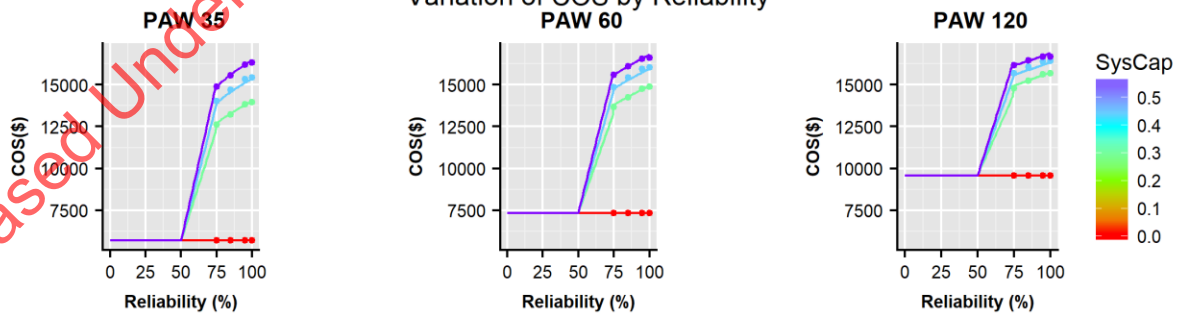
Black dots show actual sample points



Variation of COS by System Capacity



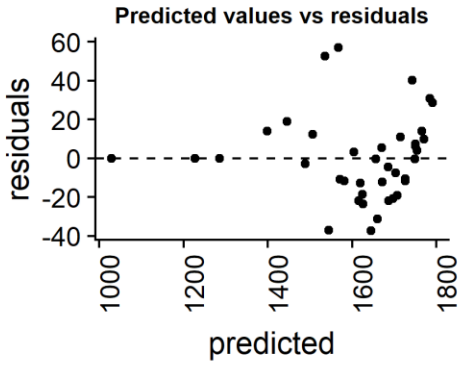
Variation of COS by Reliability

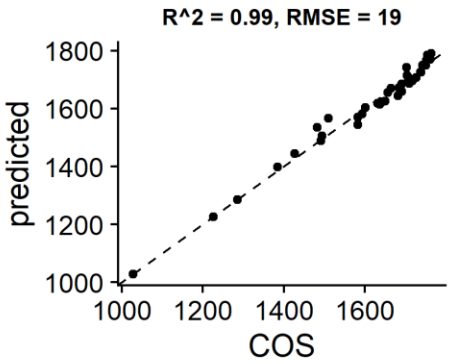


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
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Released Under the provision of the Official Information Act 1982

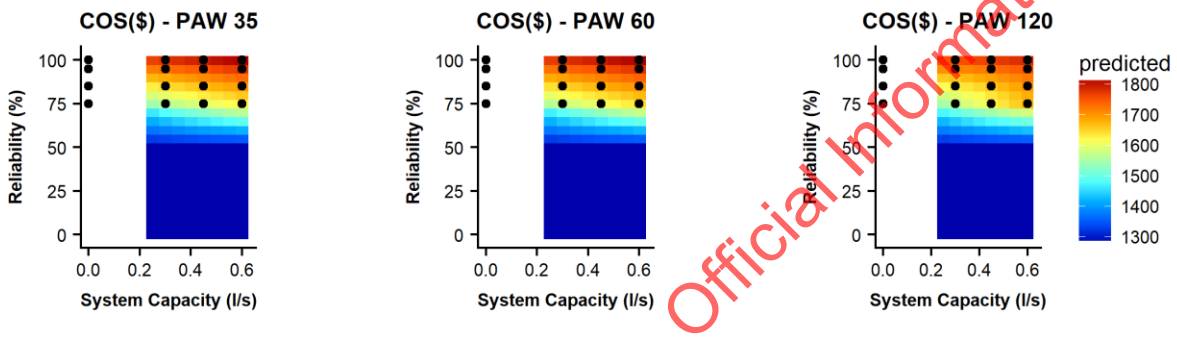
North Island: South-west coast; Sheep and Beef



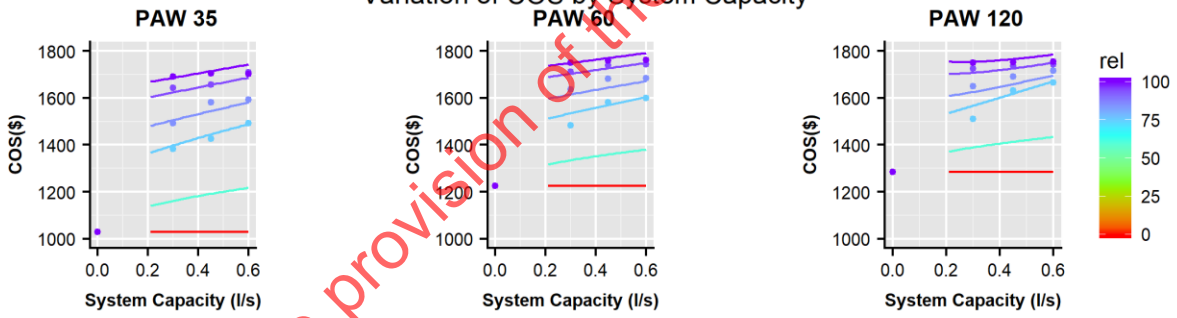


Modelled COS response surface

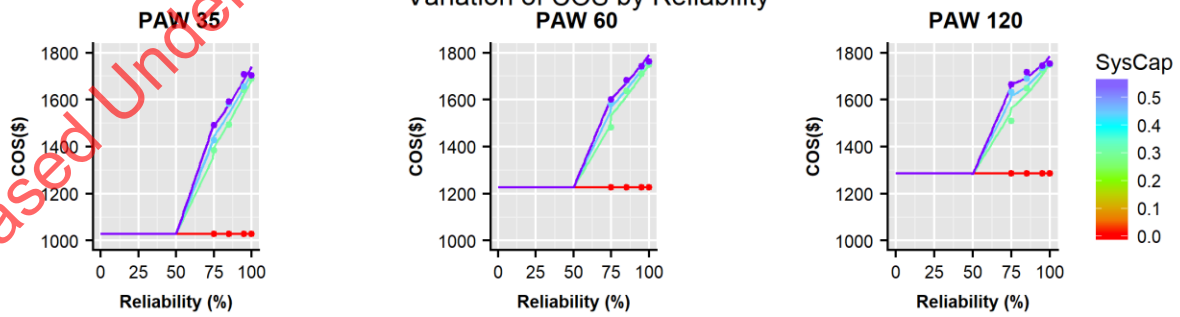
Black dots show actual sample points



Variation of COS by System Capacity



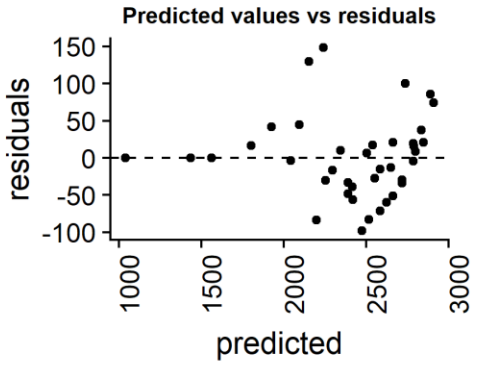
Variation of COS by Reliability

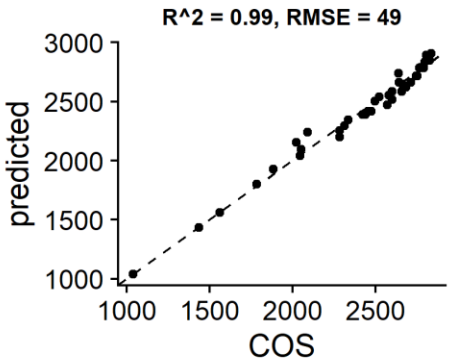


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

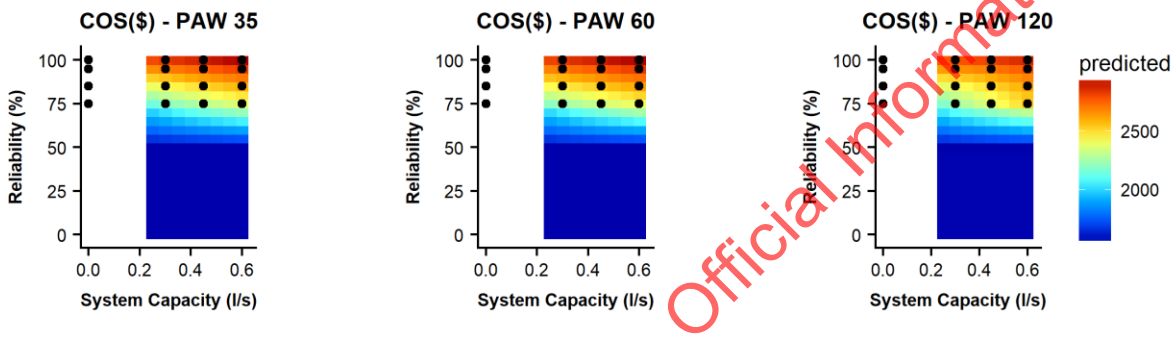
North Island: South-west coast; Dairy



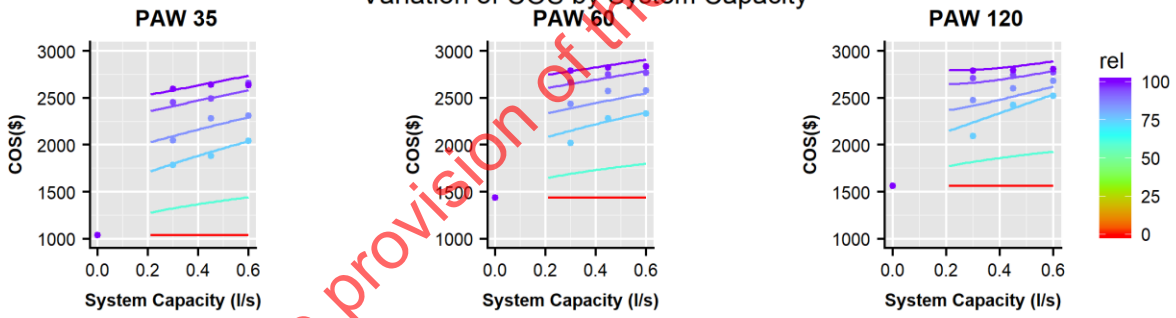


Modelled COS response surface

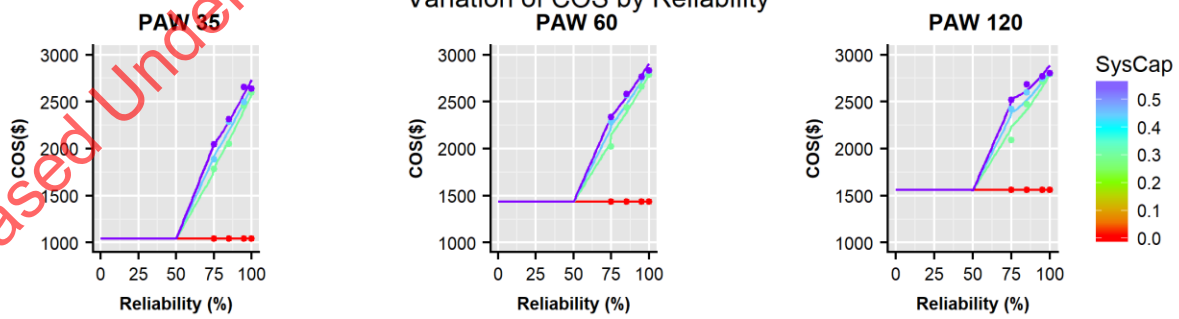
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

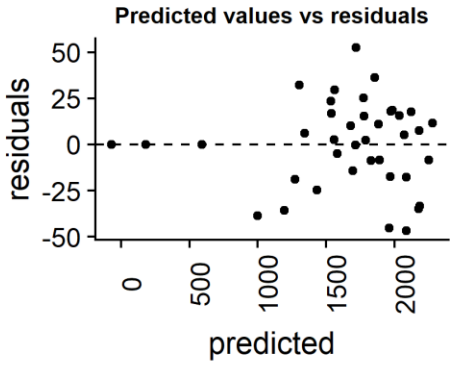


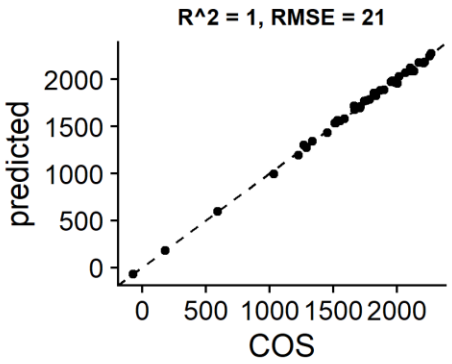
Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

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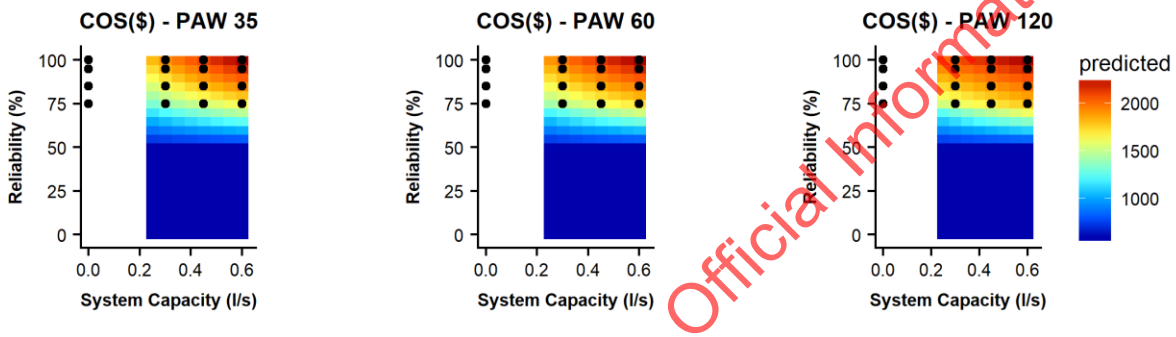
North Island: South-west coast; Arable



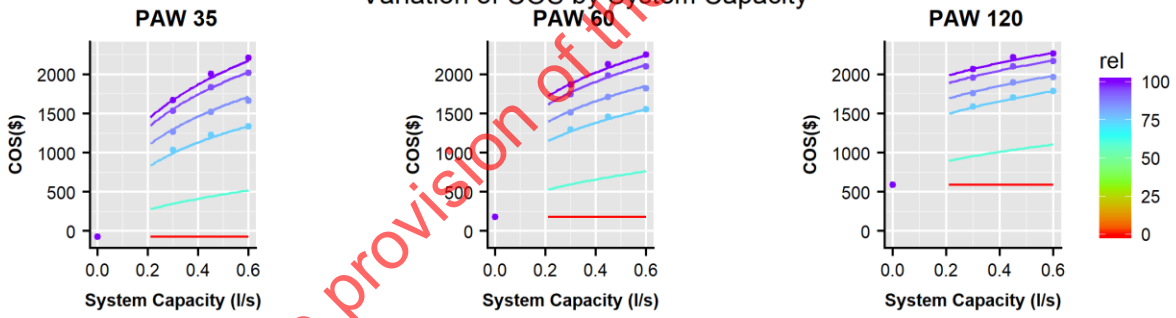


Modelled COS response surface

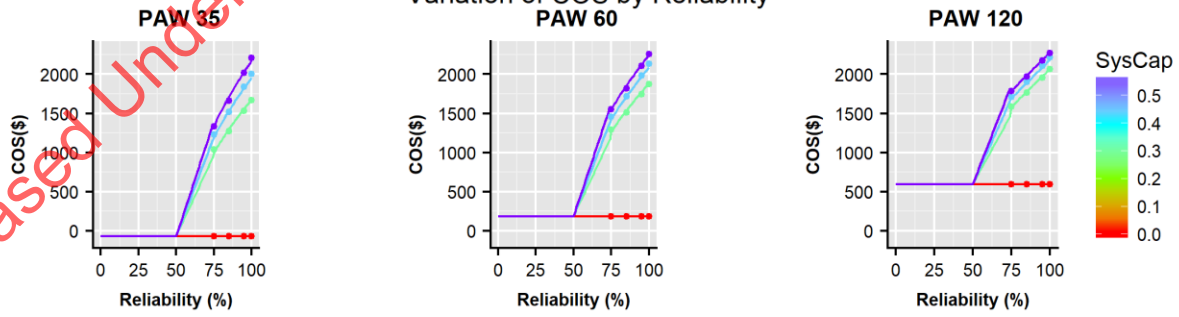
Black dots show actual sample points



Variation of COS by System Capacity



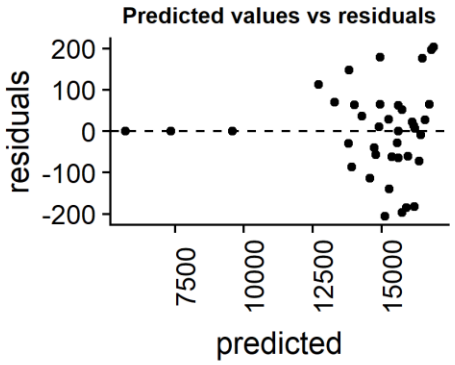
Variation of COS by Reliability

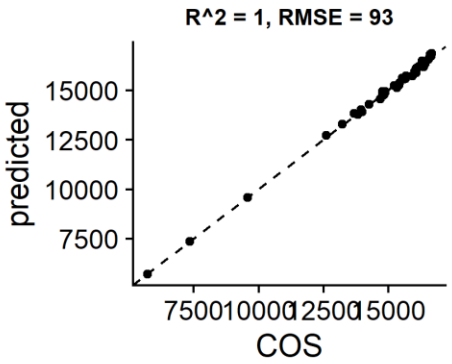


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

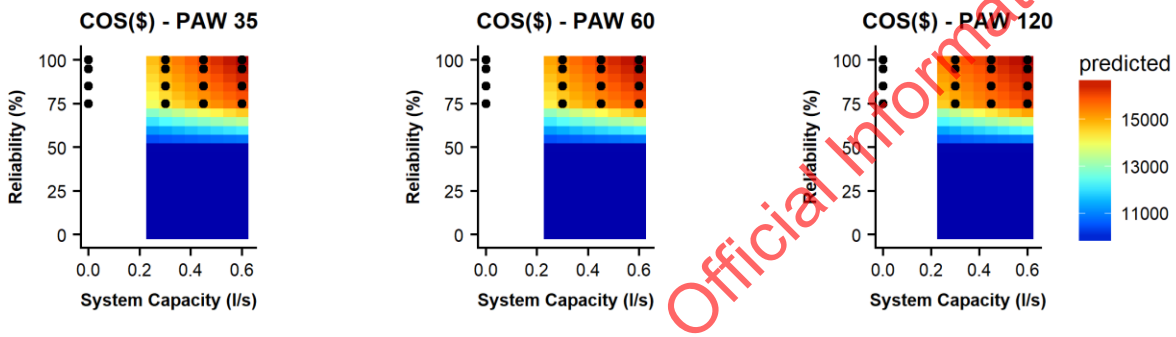
North Island: South-west coast; Horticulture



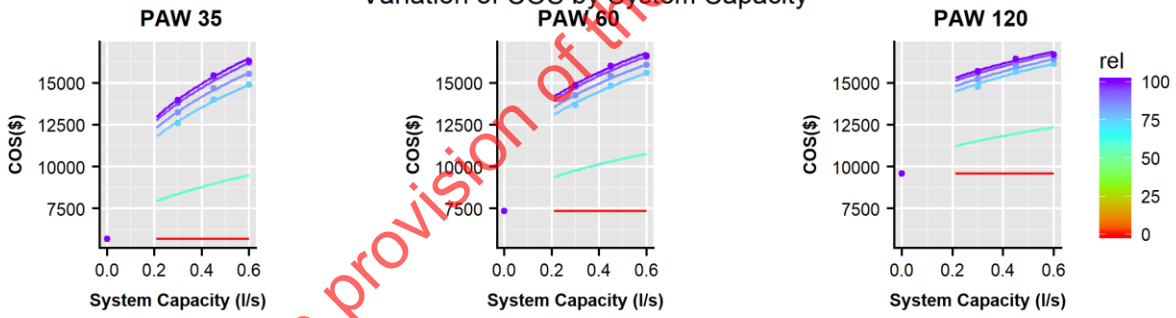


Modelled COS response surface

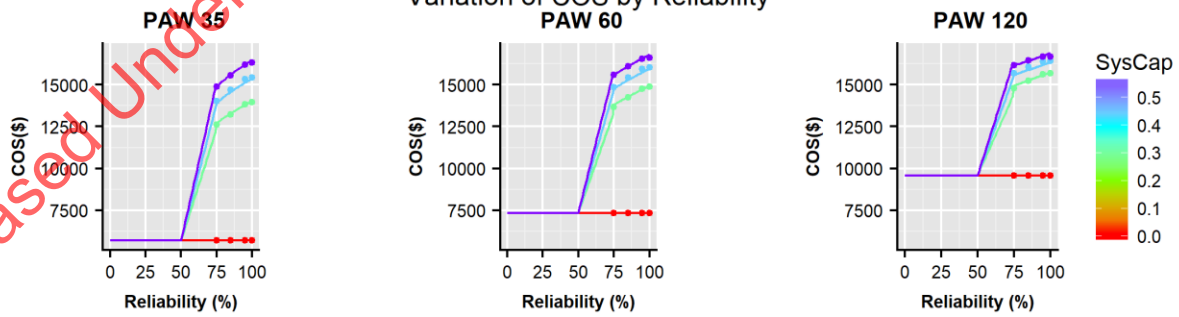
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

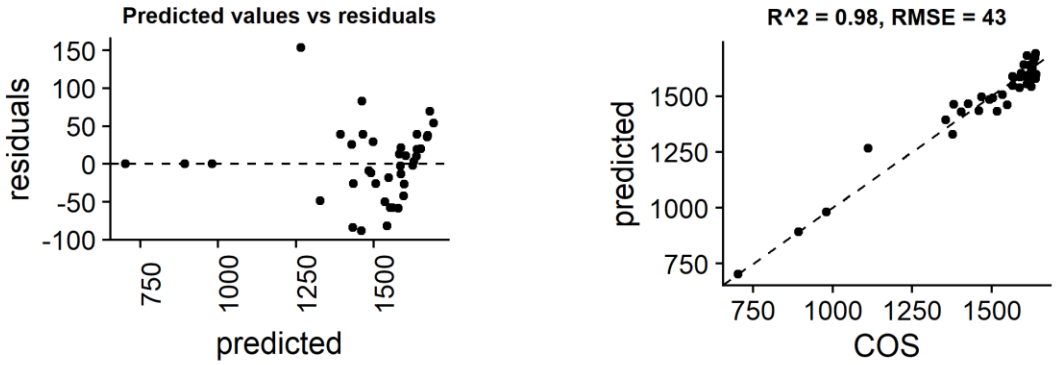


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

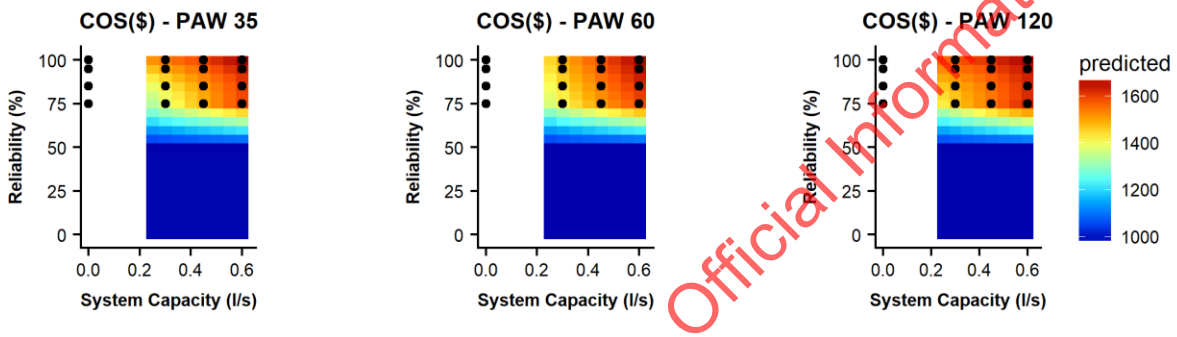
20-D-00014

South Island: East Coast (Rain=650mm); Sheep and Beef

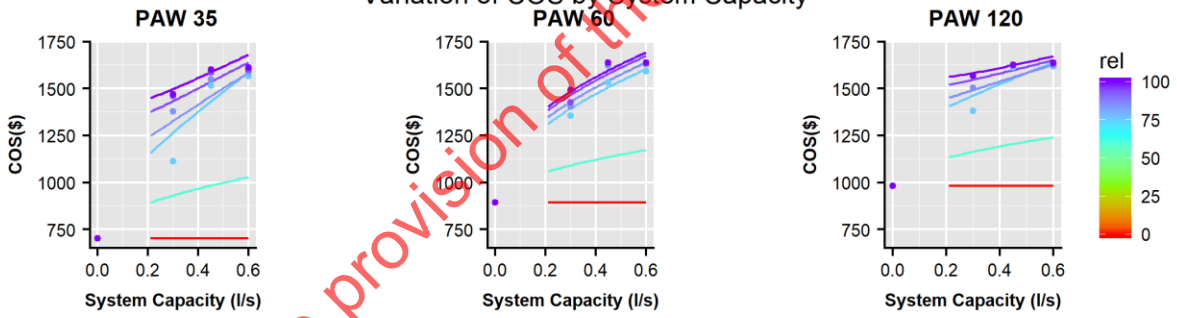


Modelled COS response surface

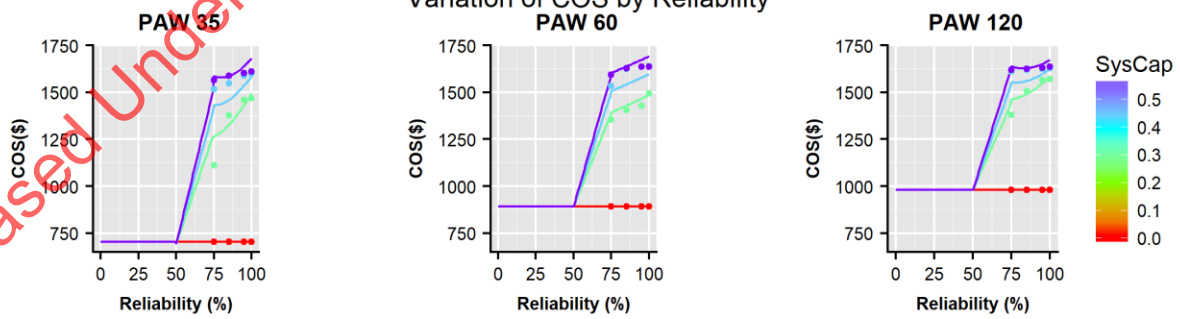
Black dots show actual sample points



Variation of COS by System Capacity



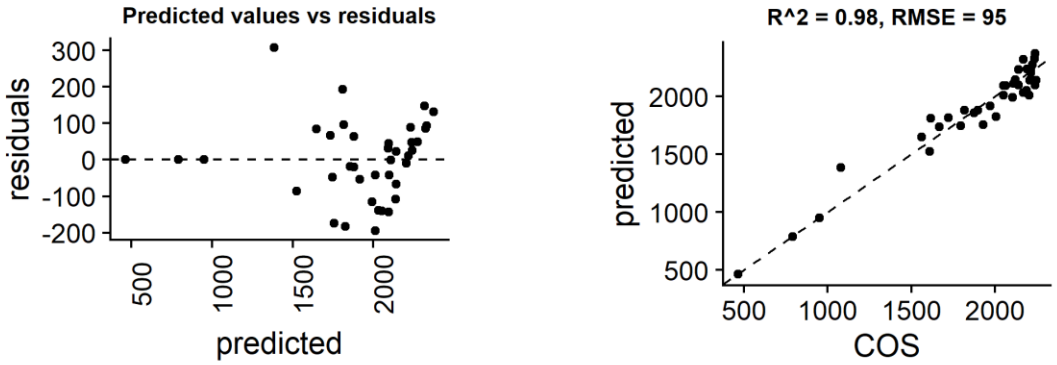
Variation of COS by Reliability



Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

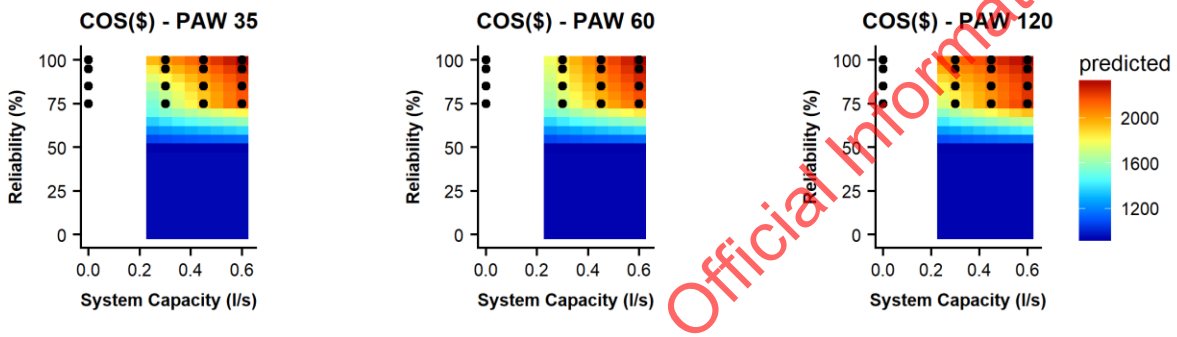
Released Under the provision of the Official Information Act 1982

South Island: East Coast (Rain=650mm); Dairy

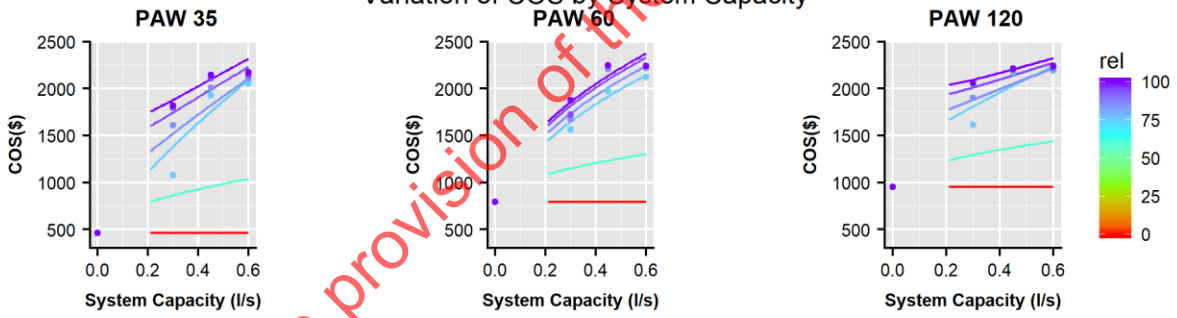


Modelled COS response surface

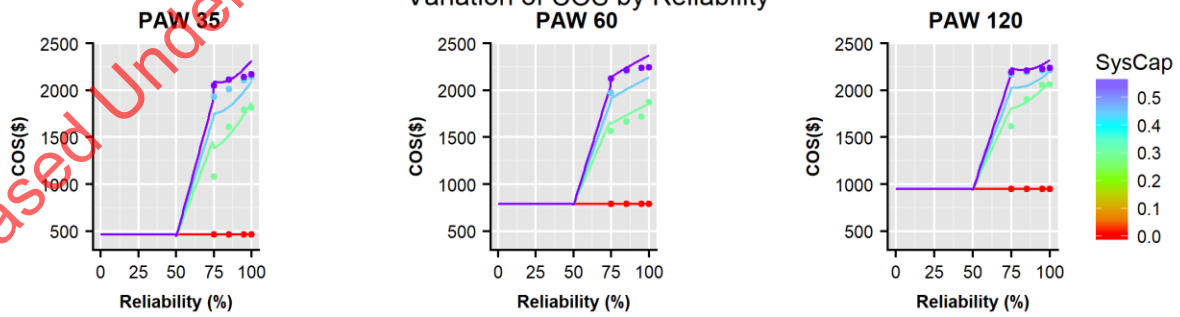
Black dots show actual sample points



Variation of COS by System Capacity



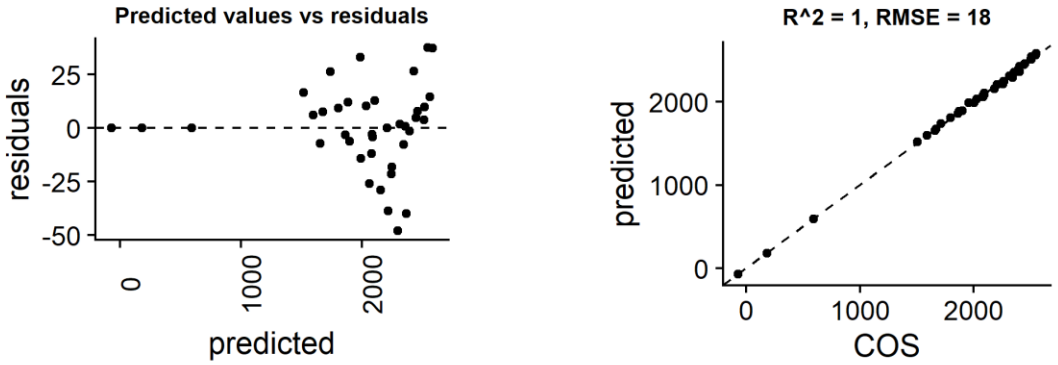
Variation of COS by Reliability



Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

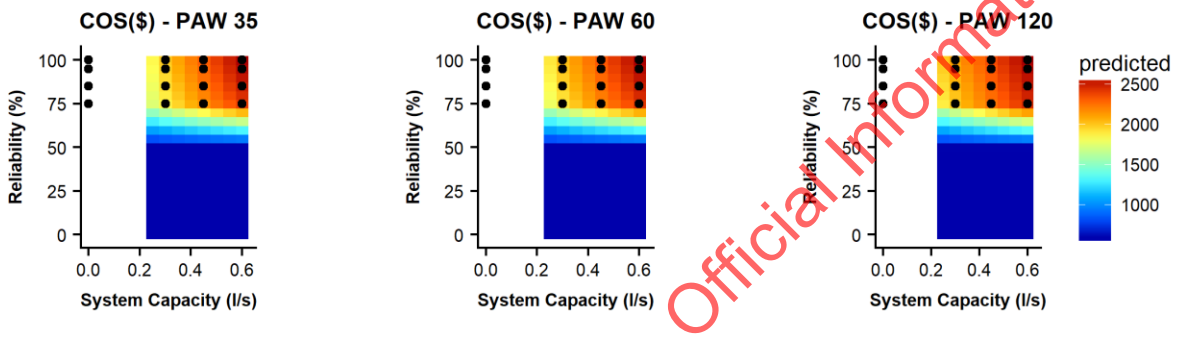
Released Under the provision of the Official Information Act 1982

South Island: East Coast (Rain=650mm); Arable

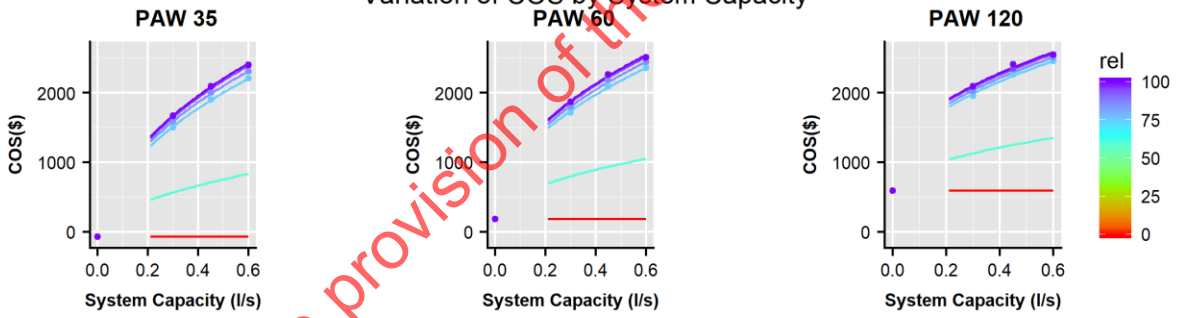


Modelled COS response surface

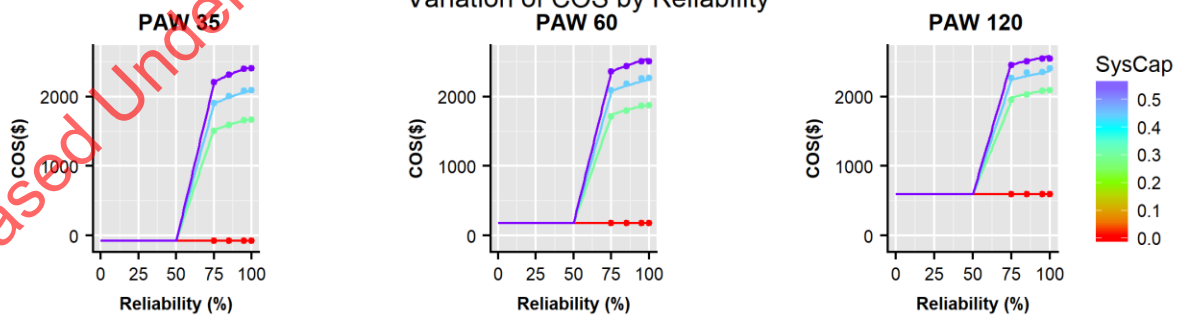
Black dots show actual sample points



Variation of COS by System Capacity



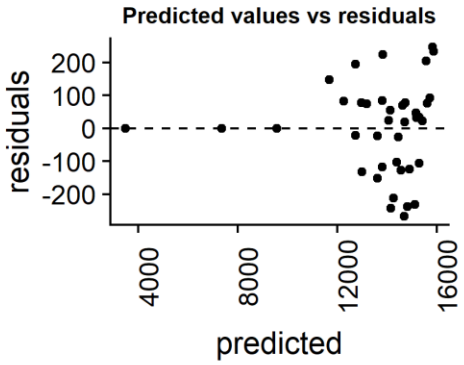
Variation of COS by Reliability

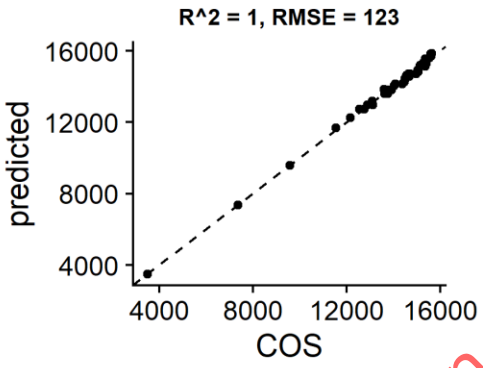


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

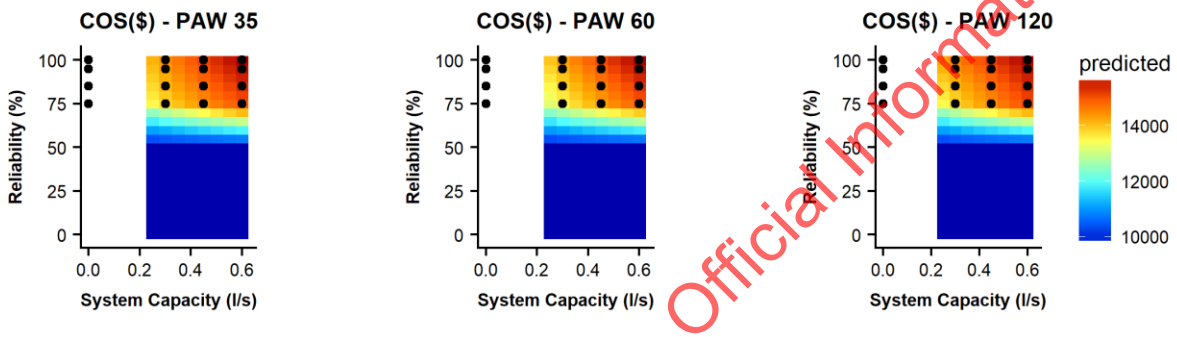
South Island: East Coast (Rain=650mm); Horticulture



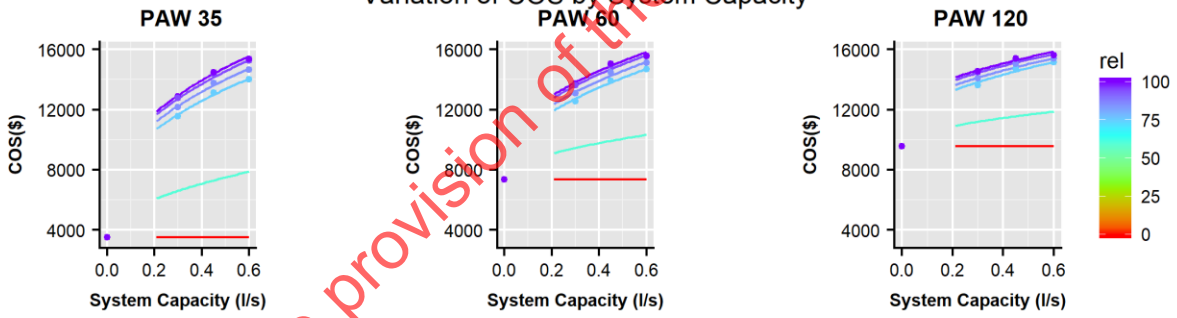


Modelled COS response surface

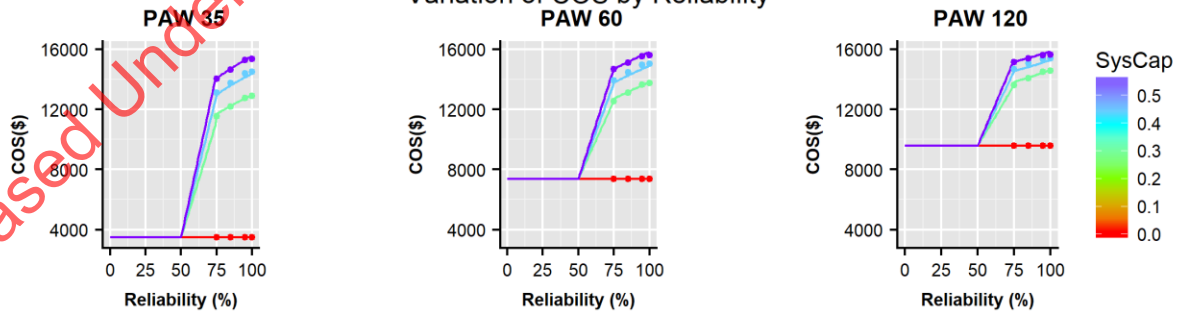
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

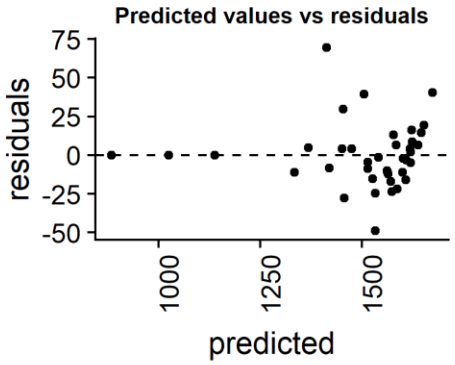


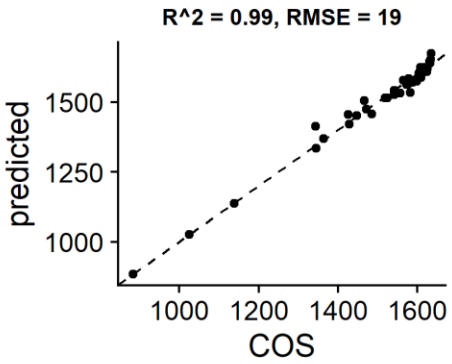
Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

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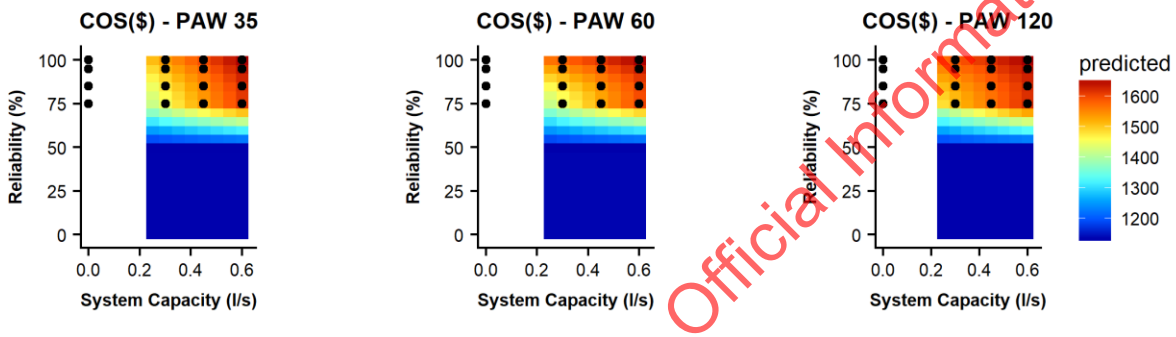
South Island: East Coast (Rain=750mm); Sheep and Beef



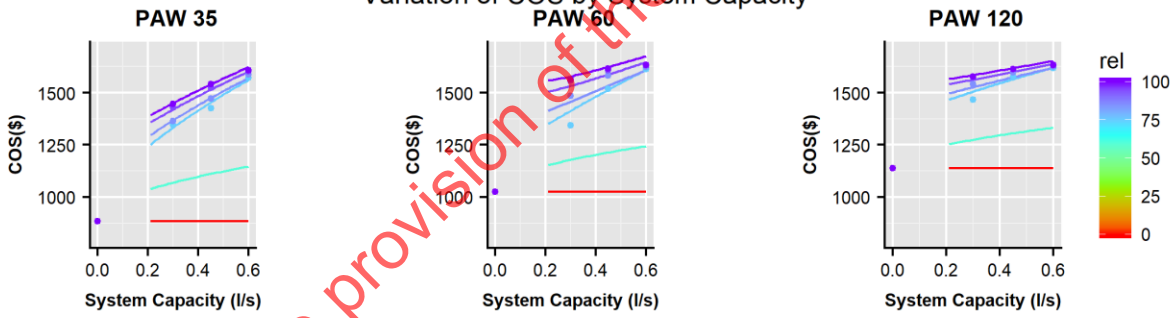


Modelled COS response surface

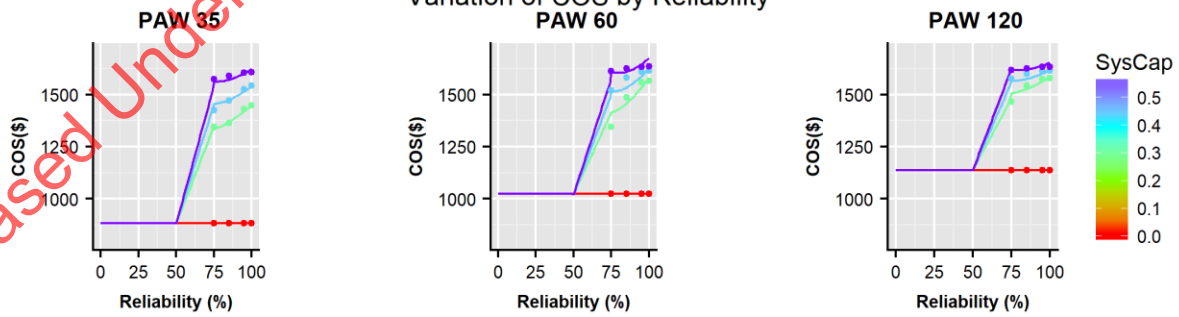
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

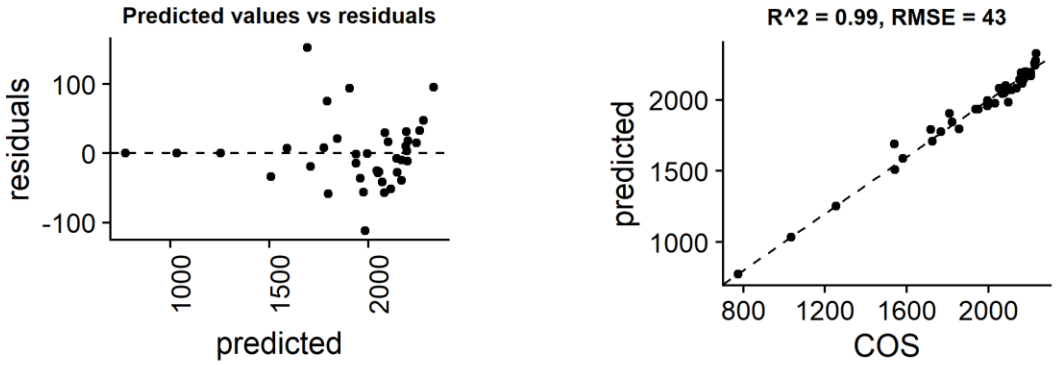


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

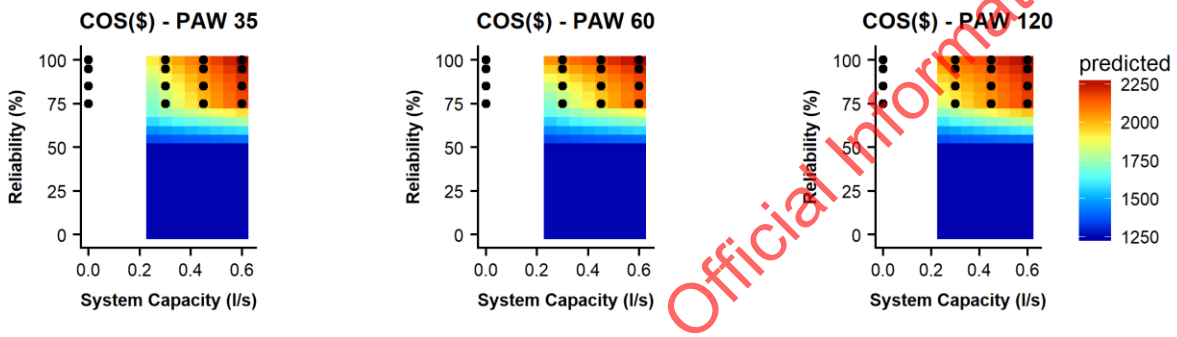
20-D-00014

South Island: East Coast (Rain=750mm); Dairy

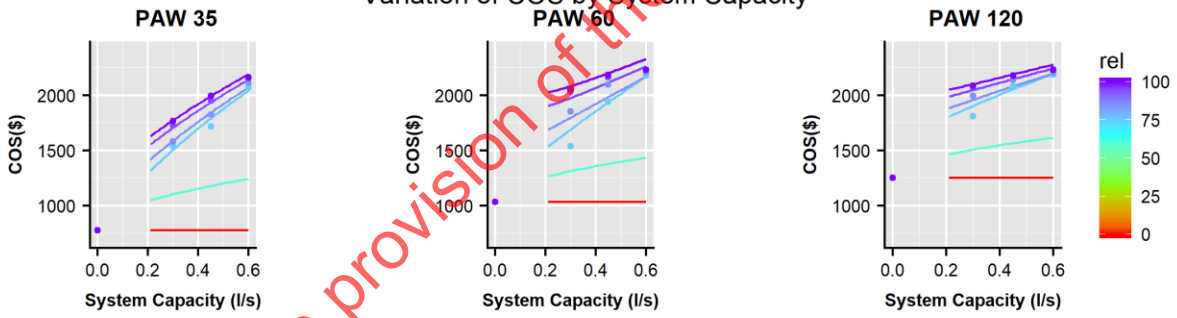


Modelled COS response surface

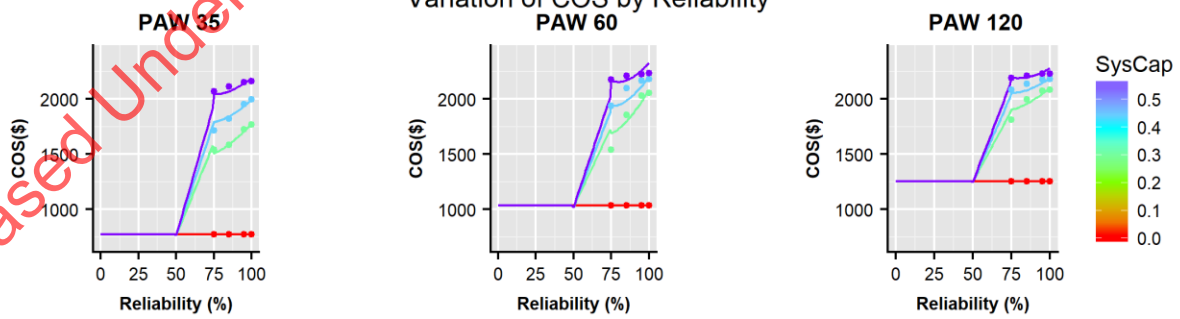
Black dots show actual sample points



Variation of COS by System Capacity



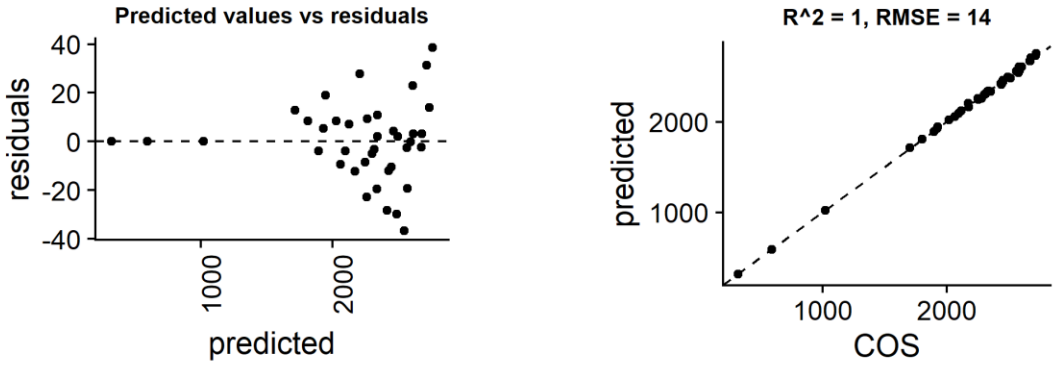
Variation of COS by Reliability



Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

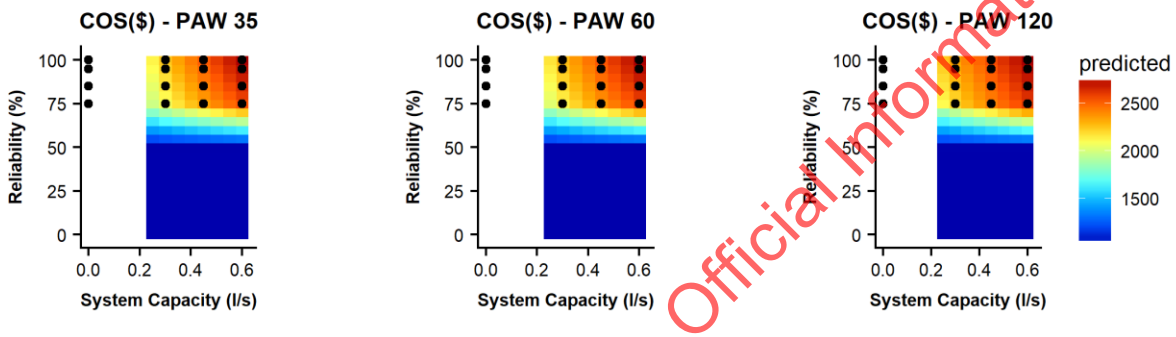
Released Under the provision of the Official Information Act 1982

South Island: East Coast (Rain=750mm); Arable

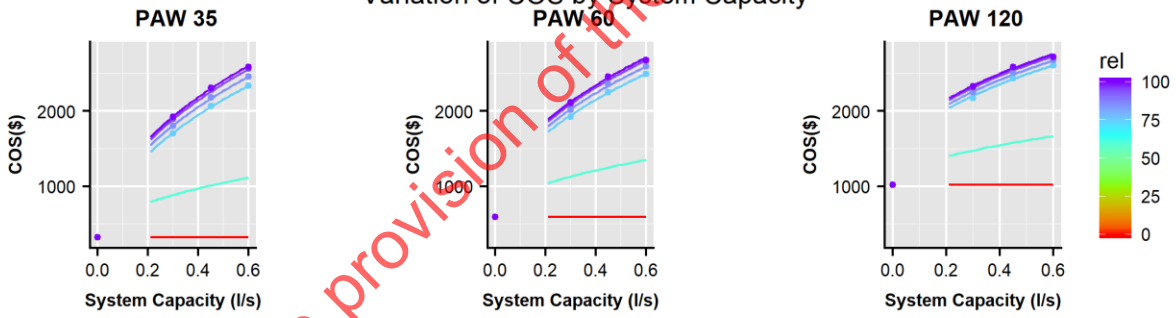


Modelled COS response surface

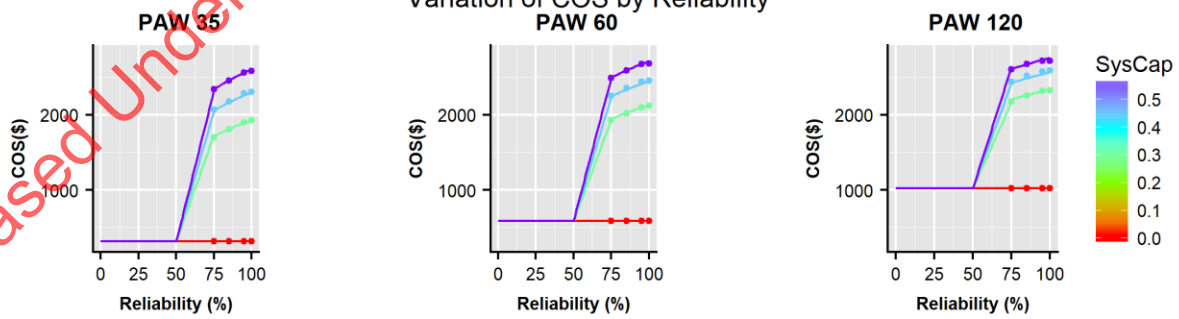
Black dots show actual sample points



Variation of COS by System Capacity



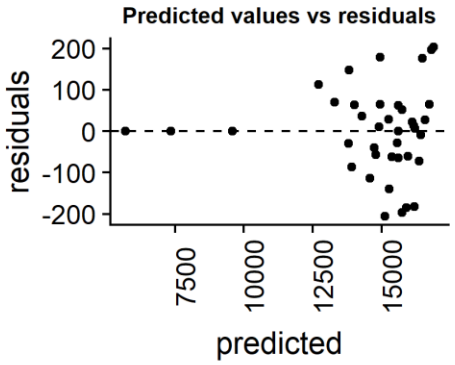
Variation of COS by Reliability

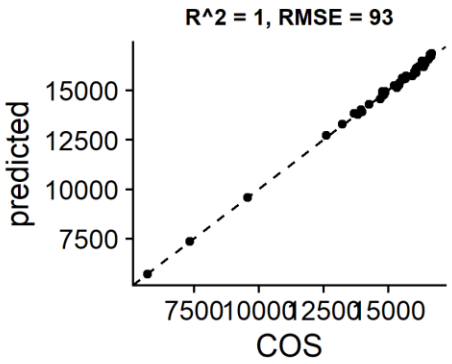


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

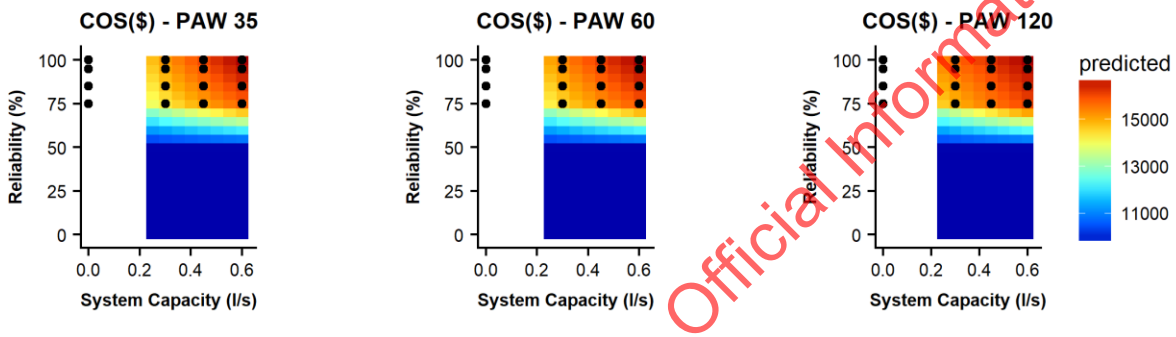
South Island: East Coast (Rain=750mm); Horticulture



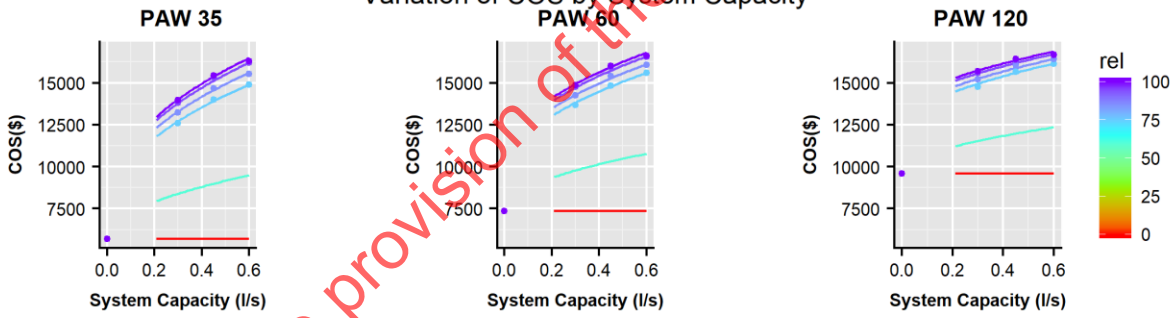


Modelled COS response surface

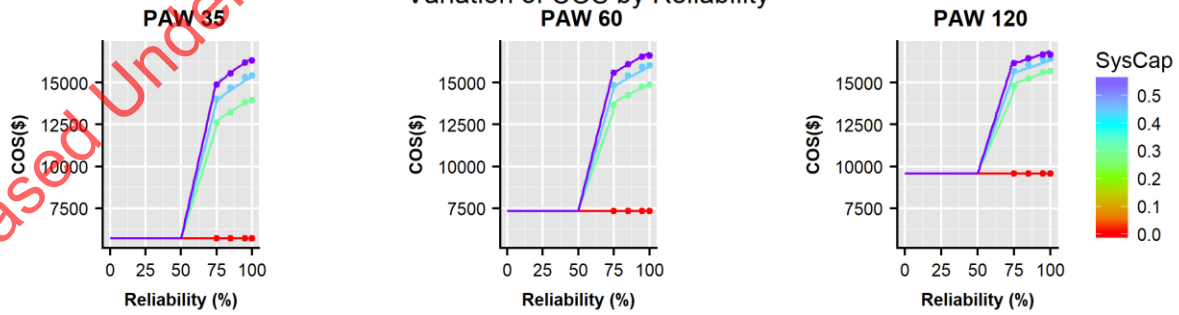
Black dots show actual sample points



Variation of COS by System Capacity

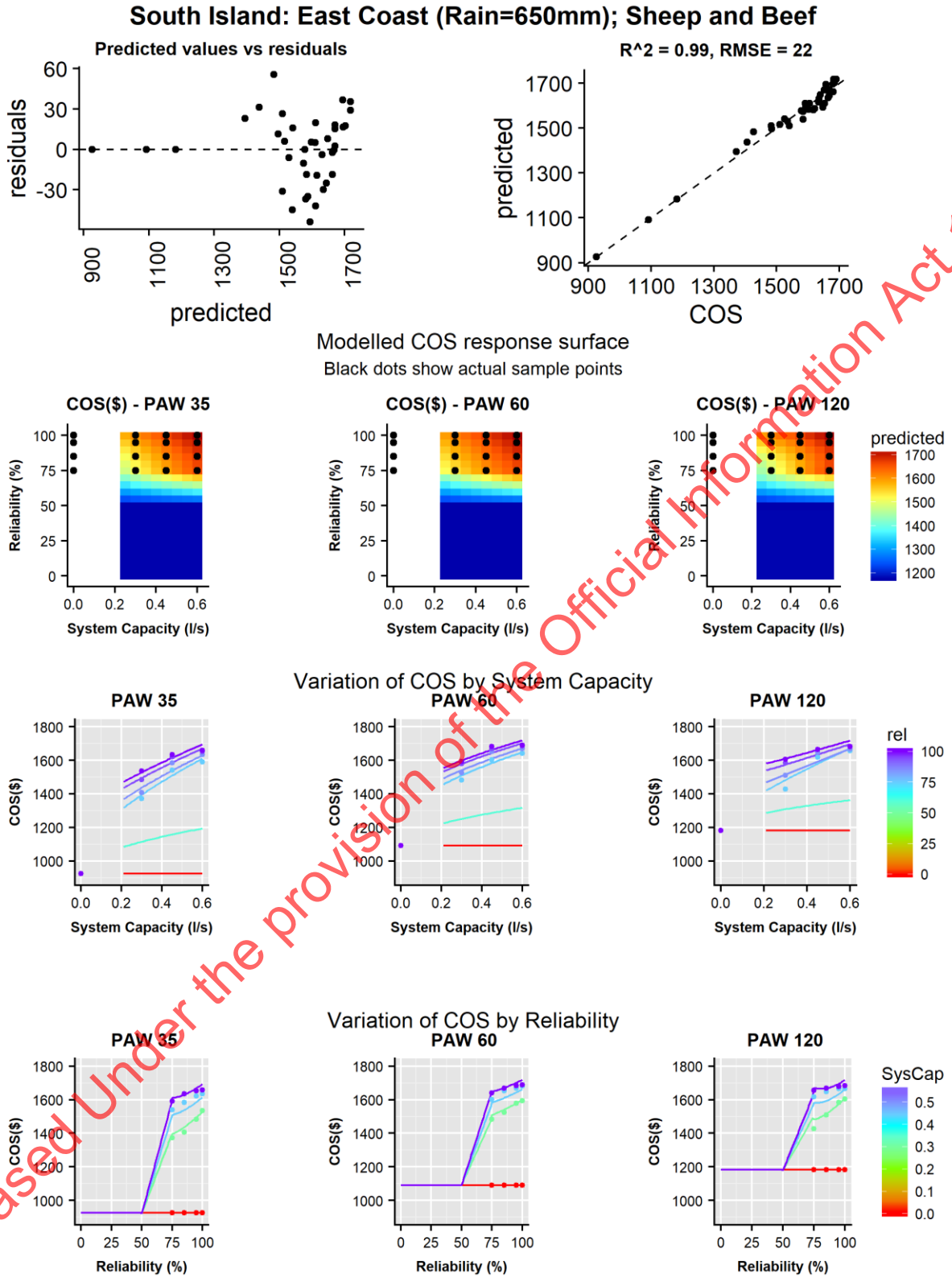


Variation of COS by Reliability



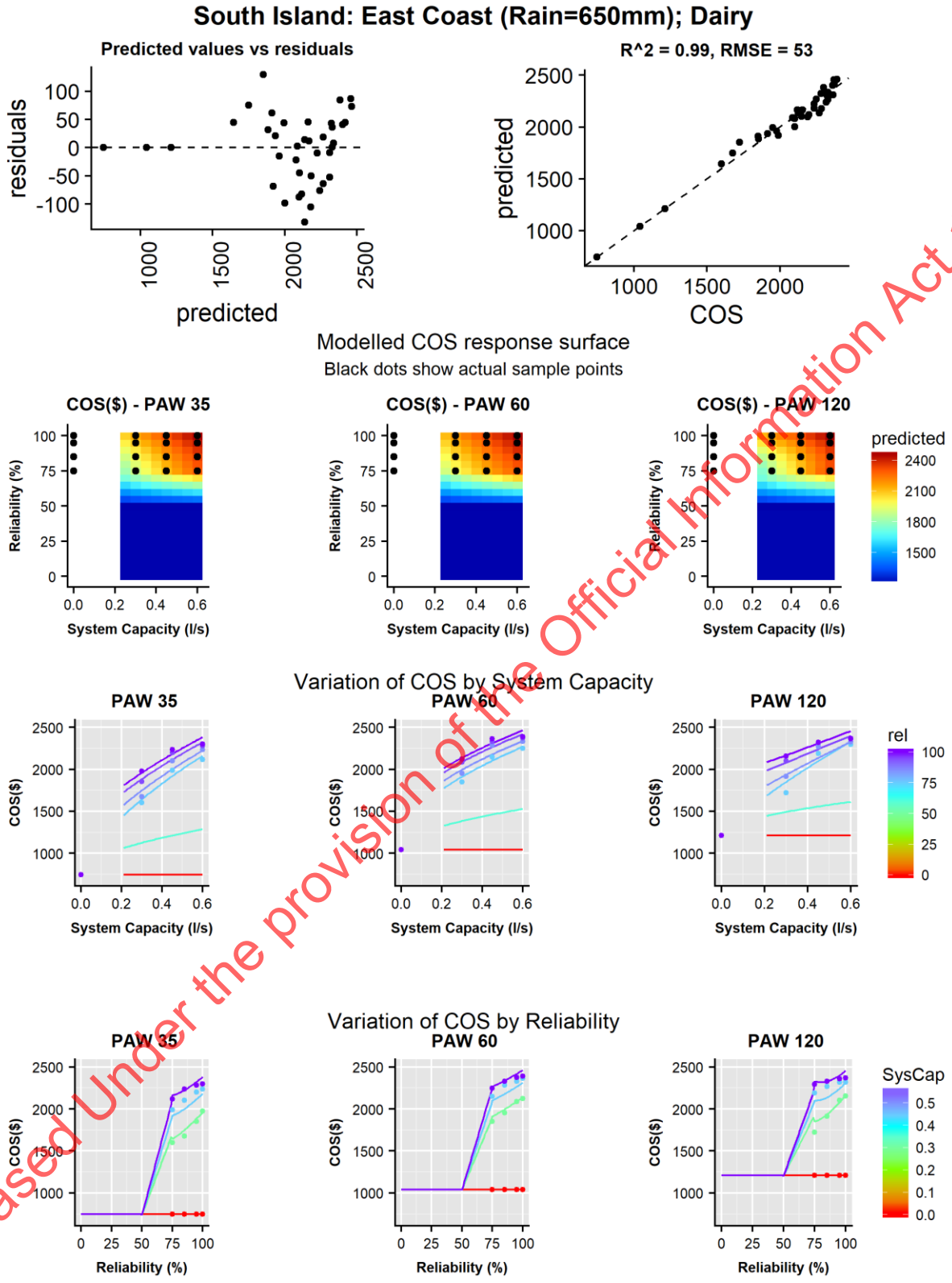
Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

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Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

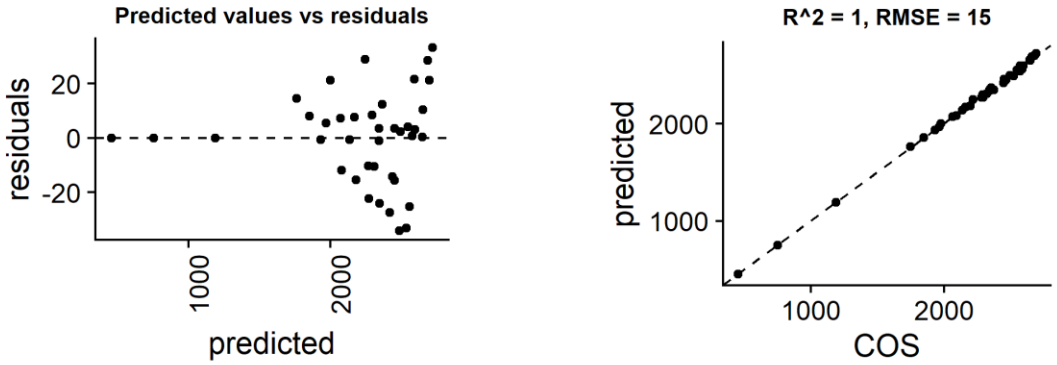
Released Under the provision of the Official Information Act 1982



Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

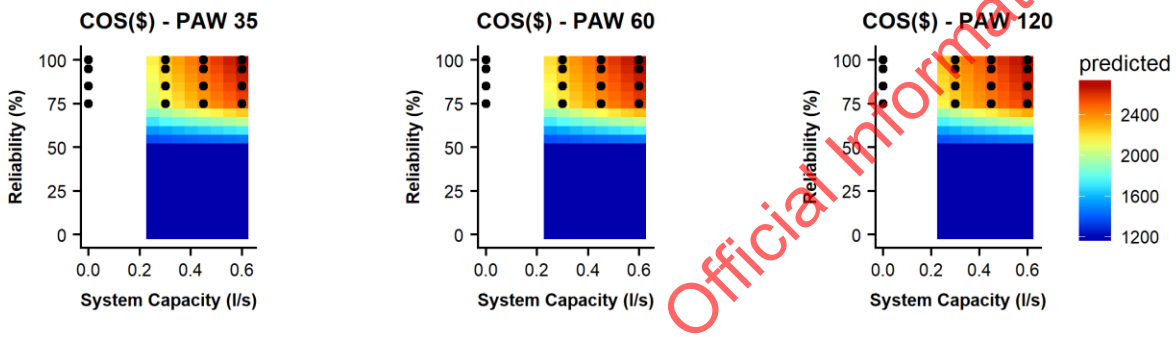
Released Under the provision of the Official Information Act 1982

South Island: East Coast (Rain=650mm); Arable

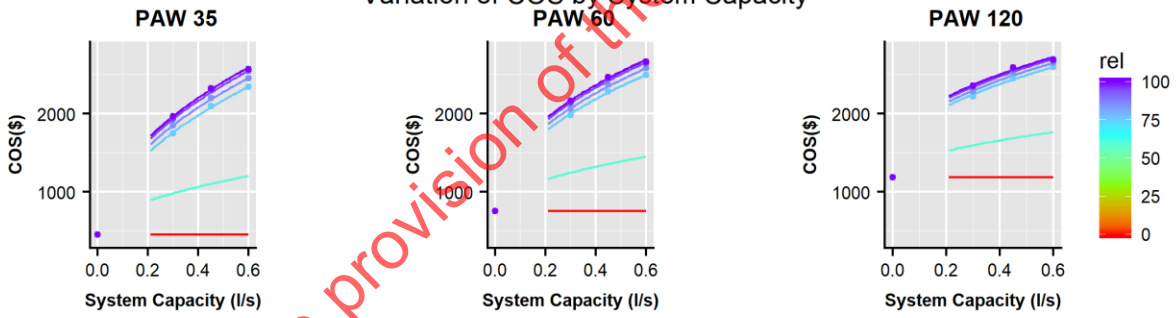


Modelled COS response surface

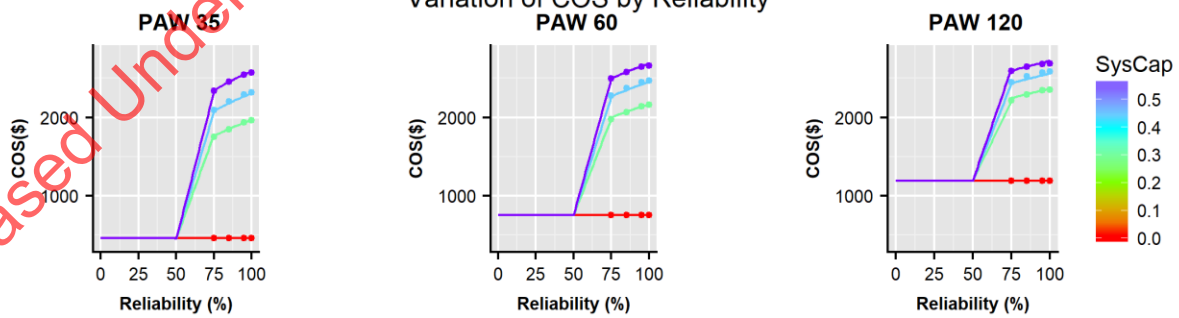
Black dots show actual sample points



Variation of COS by System Capacity



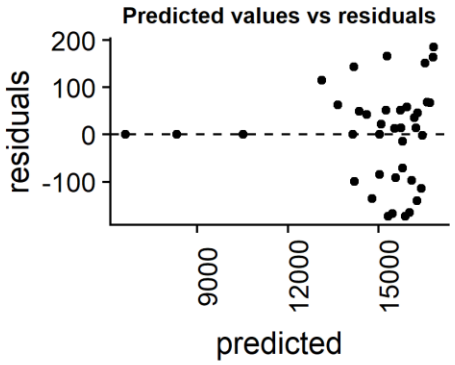
Variation of COS by Reliability

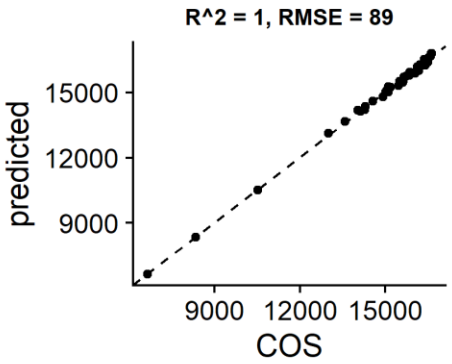


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

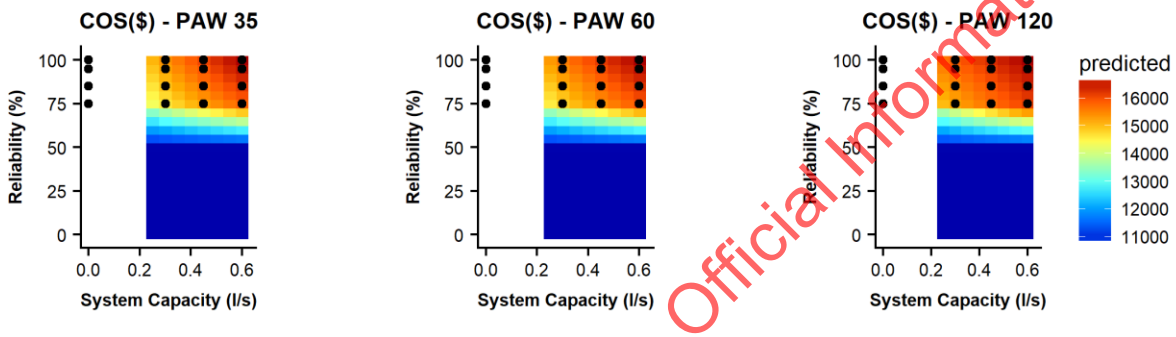
South Island: East Coast (Rain=650mm); Horticulture



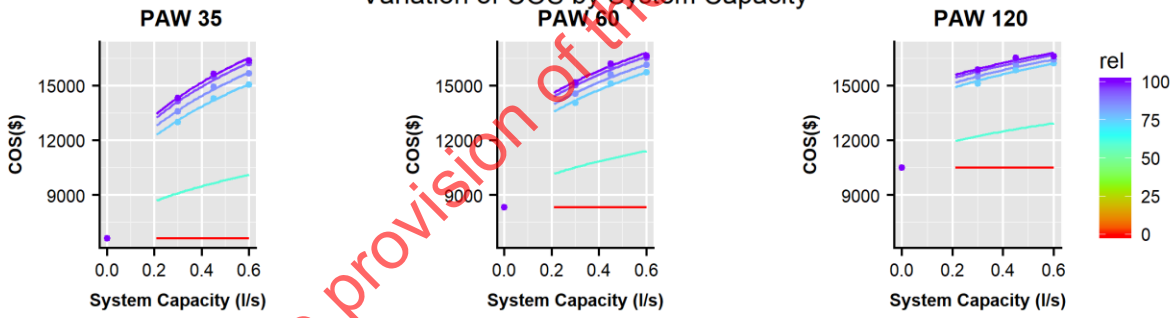


Modelled COS response surface

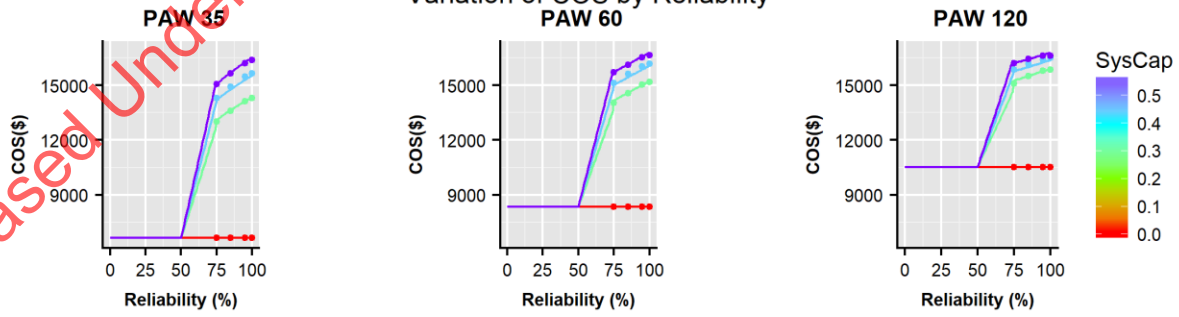
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

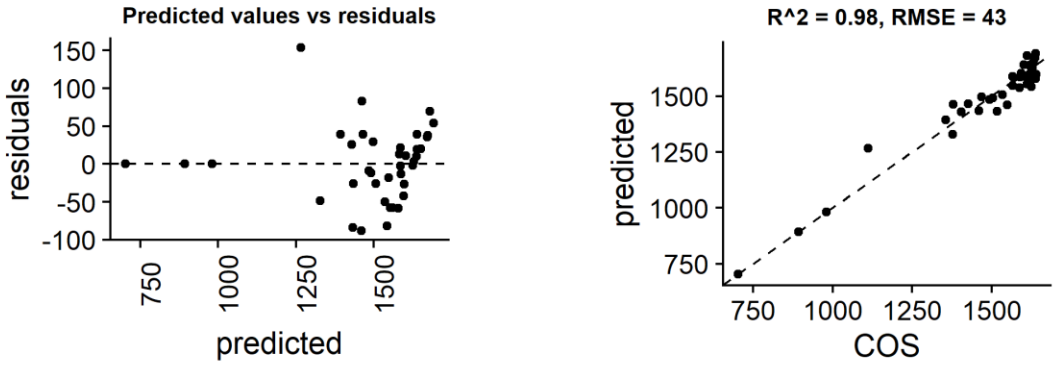


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

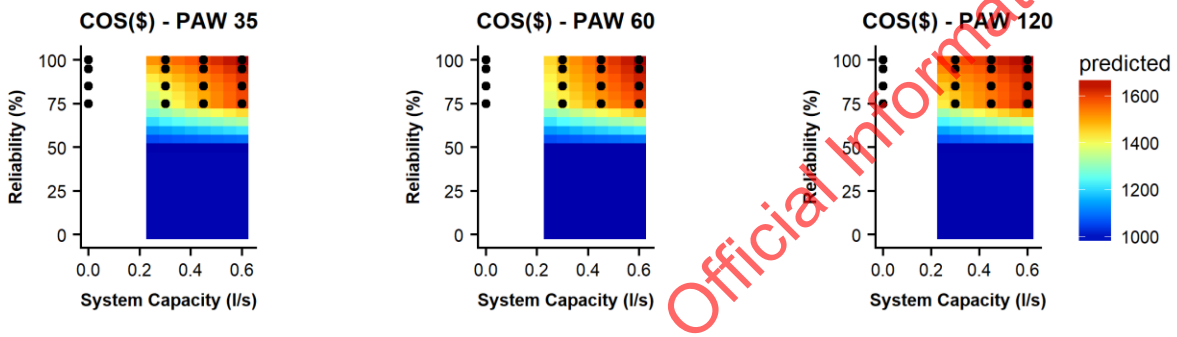
20-D-00014

South Island: Marlborough; Sheep and Beef

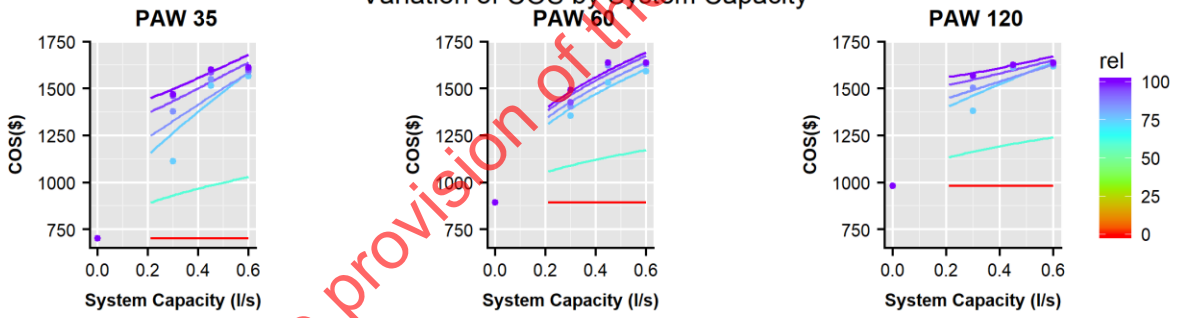


Modelled COS response surface

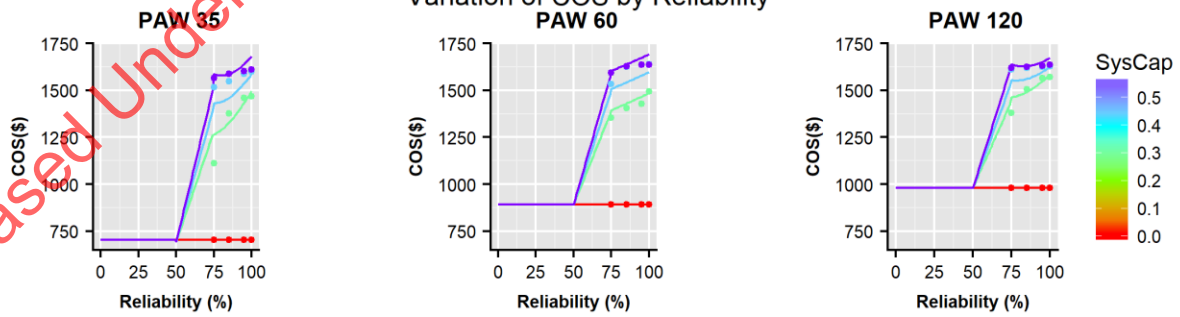
Black dots show actual sample points



Variation of COS by System Capacity



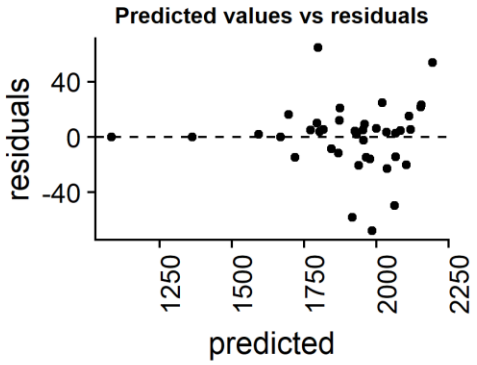
Variation of COS by Reliability

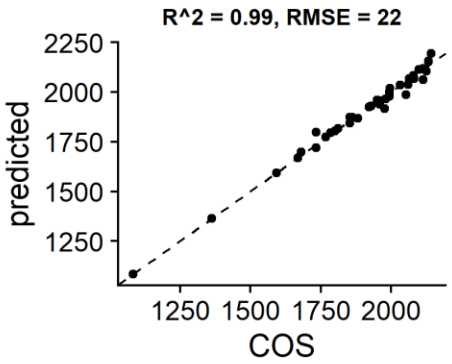


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

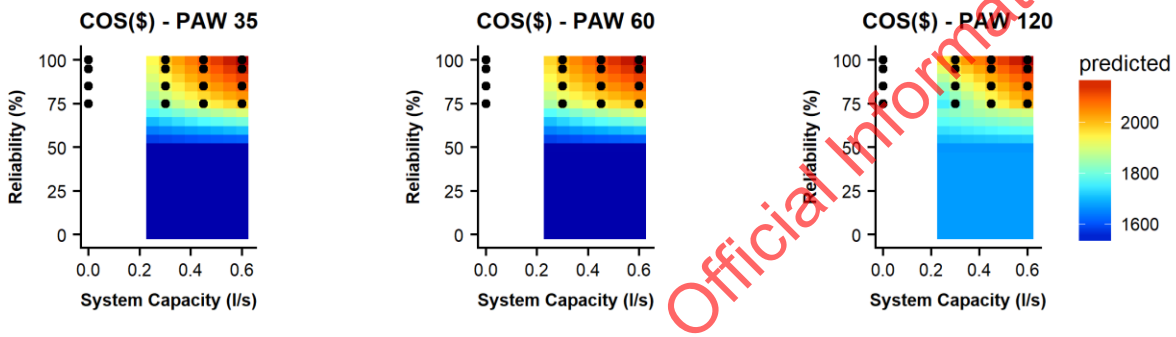
South Island: Marlborough; Dairy



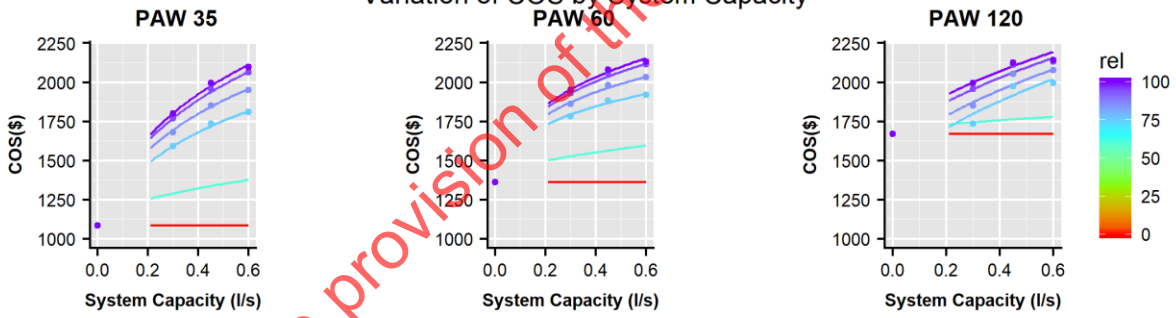


Modelled COS response surface

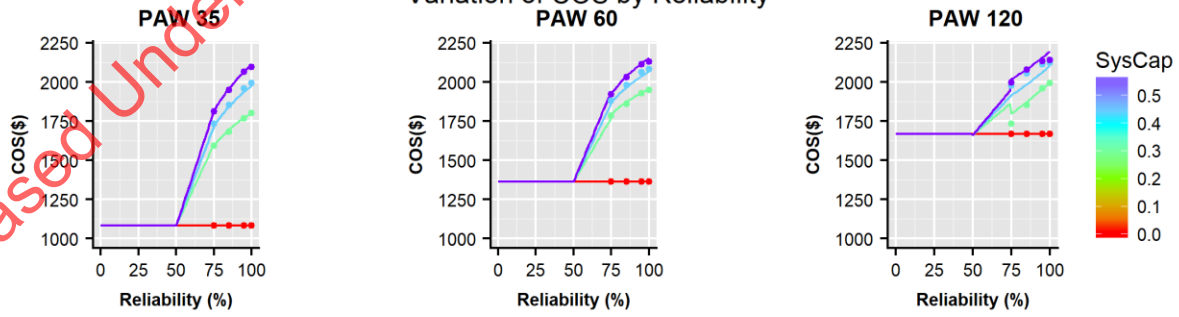
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

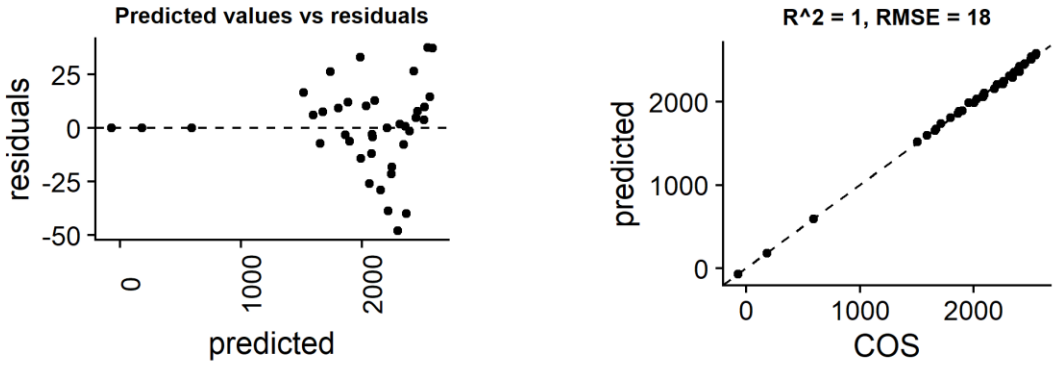


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

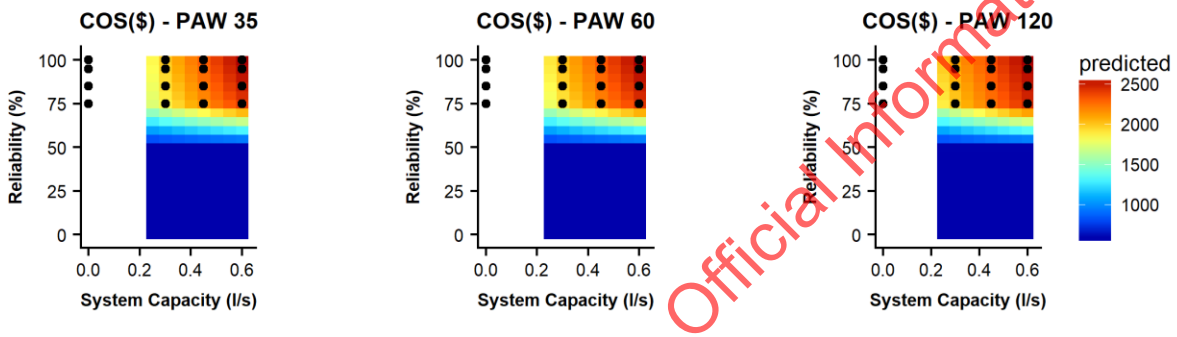
20-D-00014

South Island: Marlborough; Arable

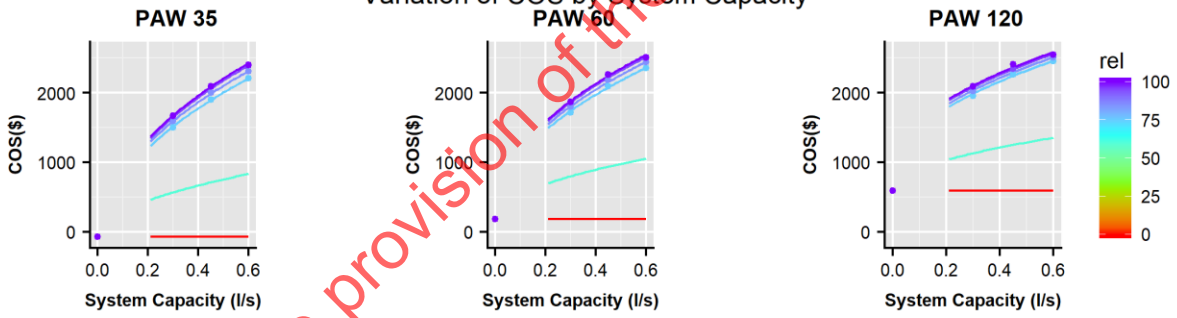


Modelled COS response surface

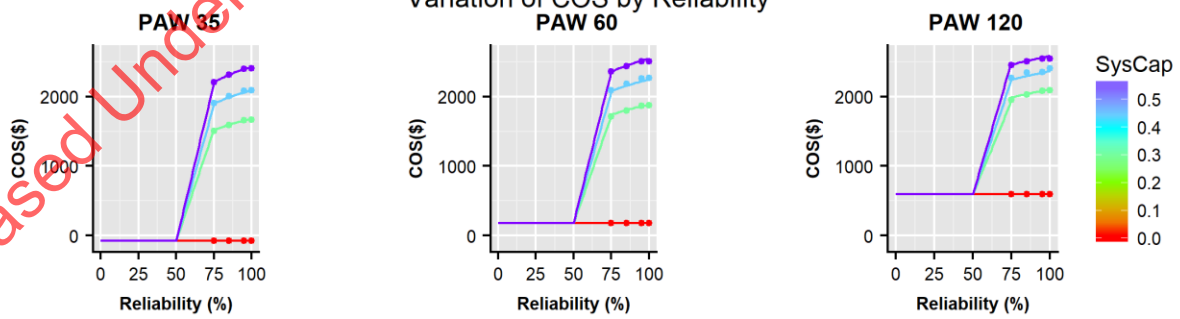
Black dots show actual sample points



Variation of COS by System Capacity



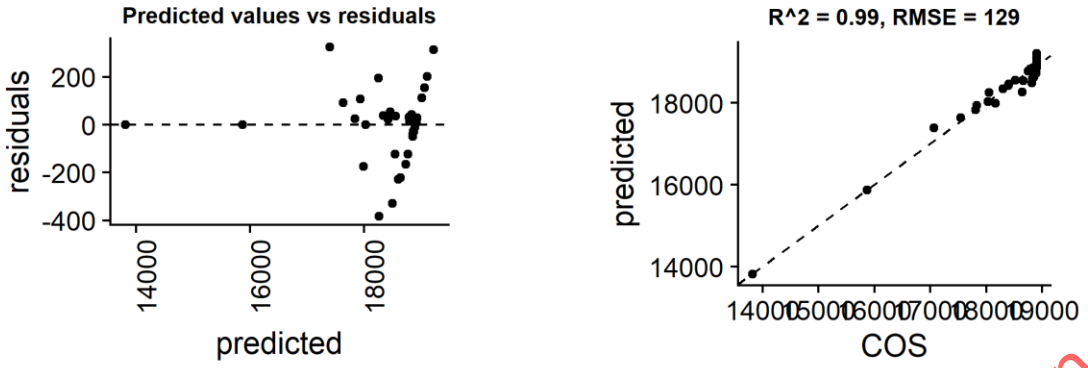
Variation of COS by Reliability



Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

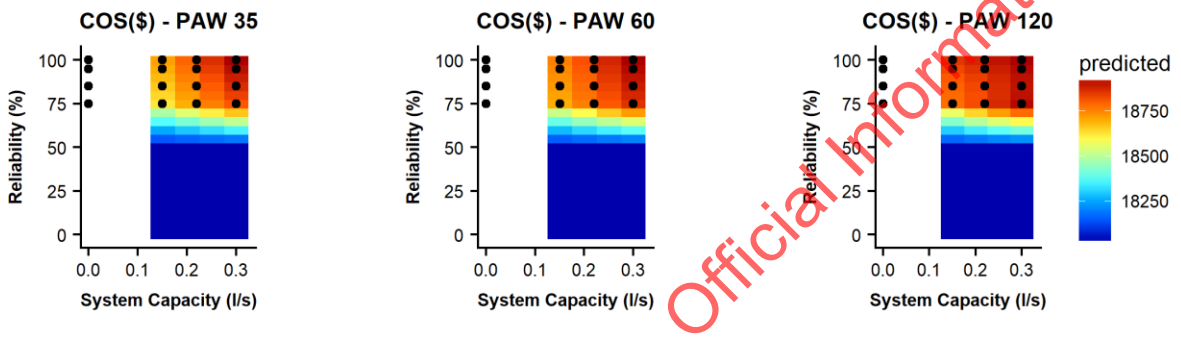
Released Under the provision of the Official Information Act 1982

South Island: Marlborough; Horticulture

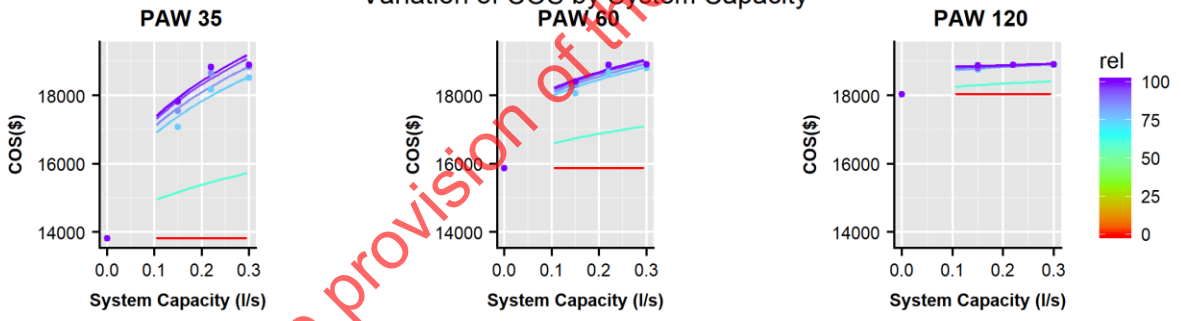


Modelled COS response surface

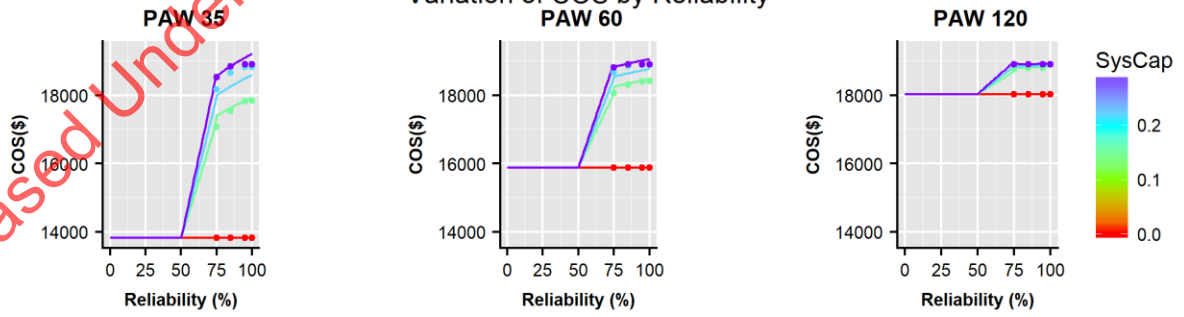
Black dots show actual sample points



Variation of COS by System Capacity



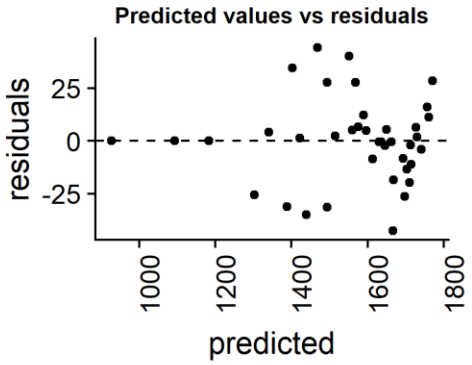
Variation of COS by Reliability

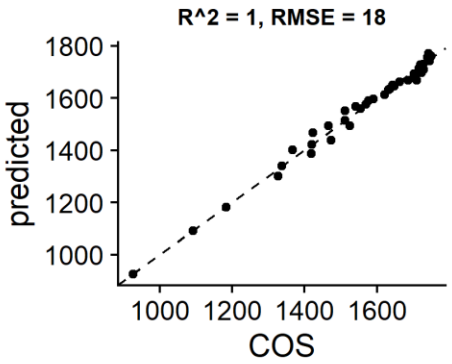


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

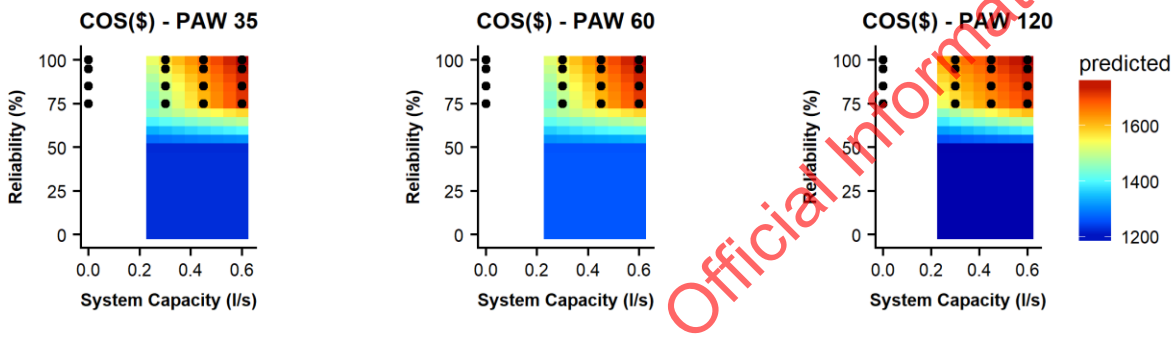
South Island: Hillcountry; Sheep and Beef



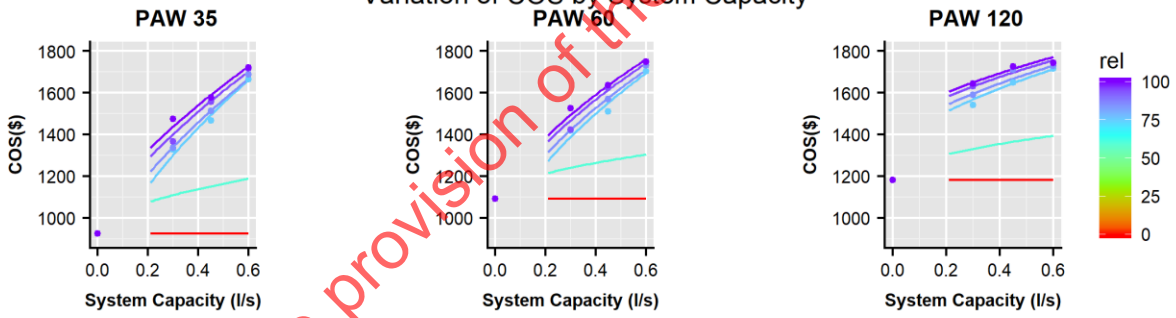


Modelled COS response surface

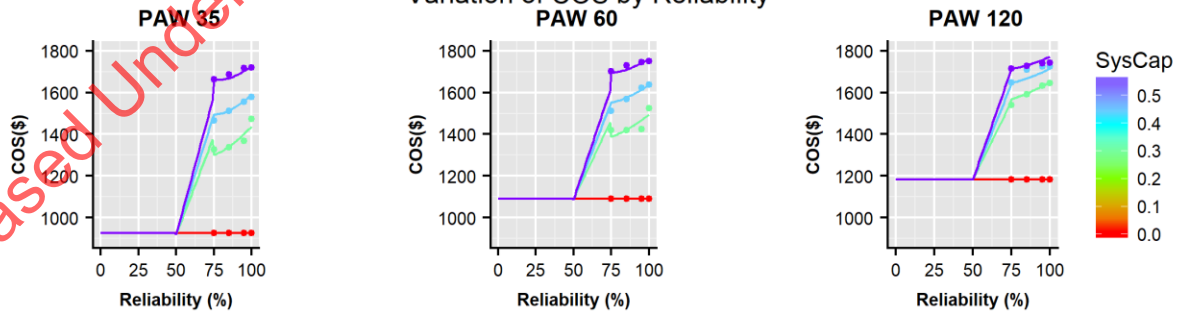
Black dots show actual sample points



Variation of COS by System Capacity



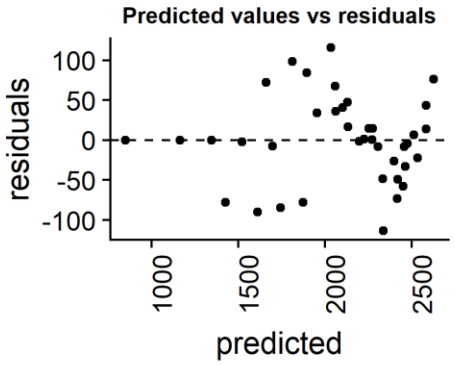
Variation of COS by Reliability

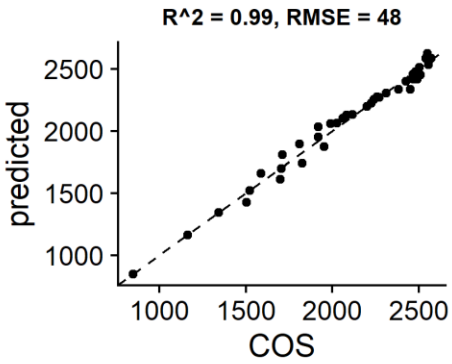


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

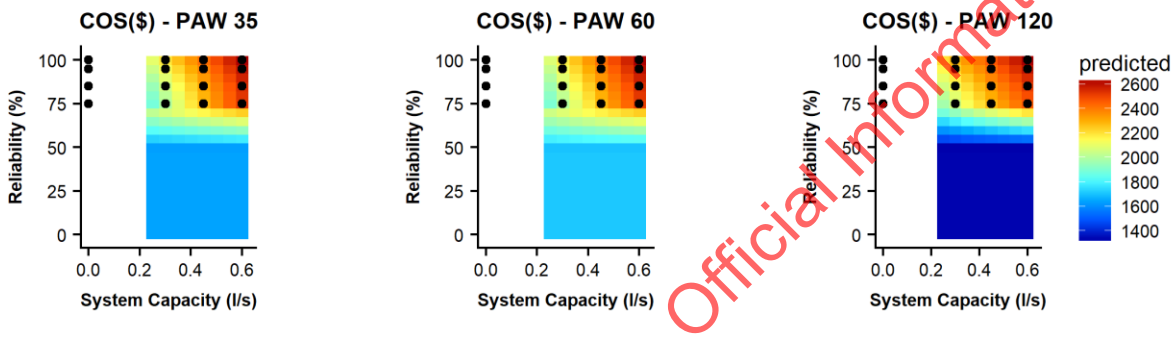
South Island: Hillcountry; Dairy



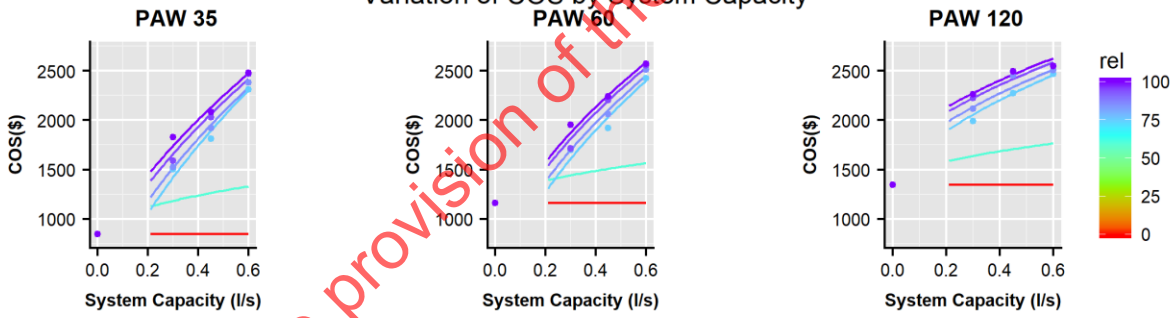


Modelled COS response surface

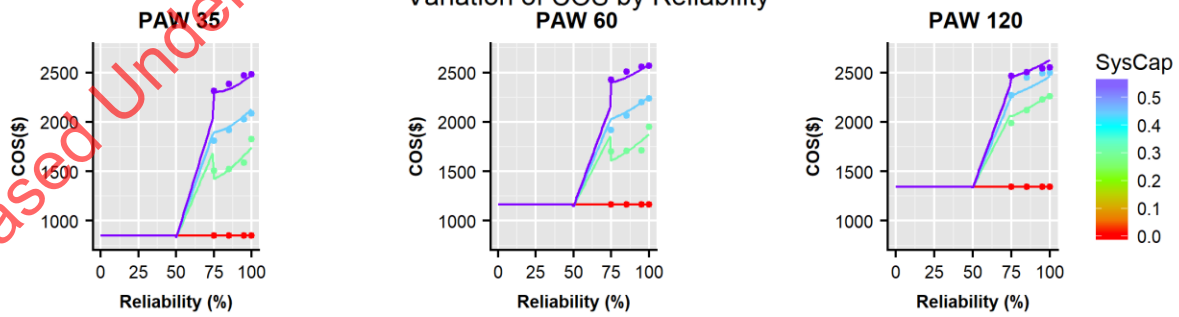
Black dots show actual sample points



Variation of COS by System Capacity



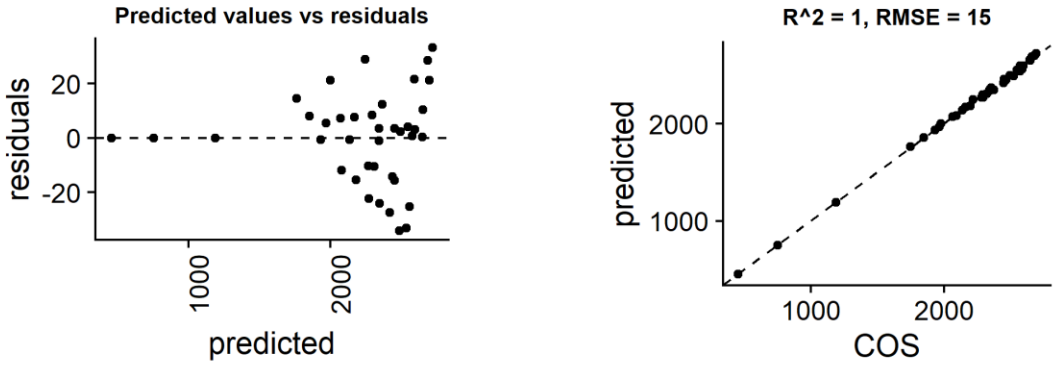
Variation of COS by Reliability



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COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

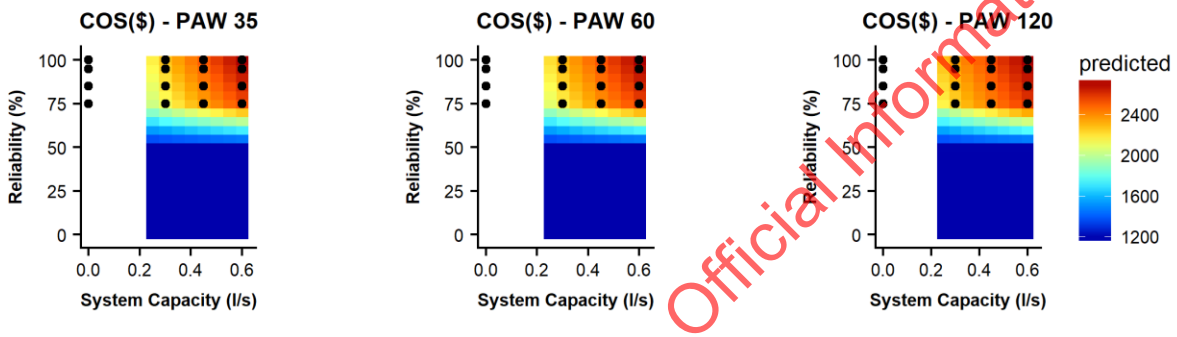
Released Under the provision of the Official Information Act 1982

South Island: Hillcountry; Arable

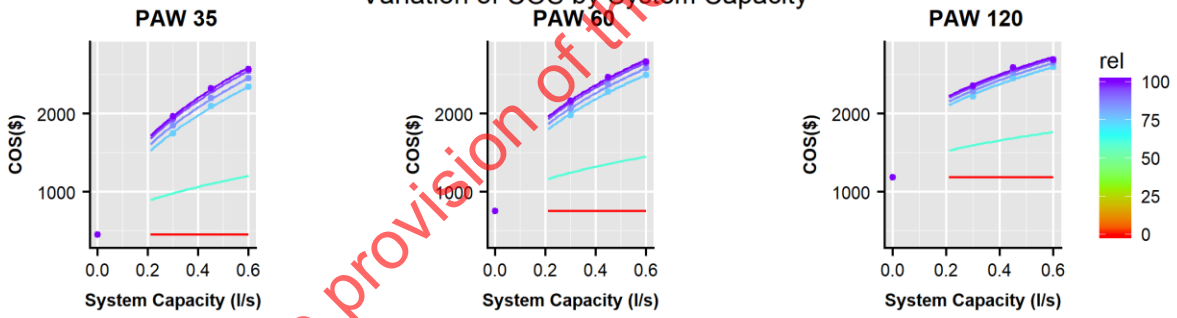


Modelled COS response surface

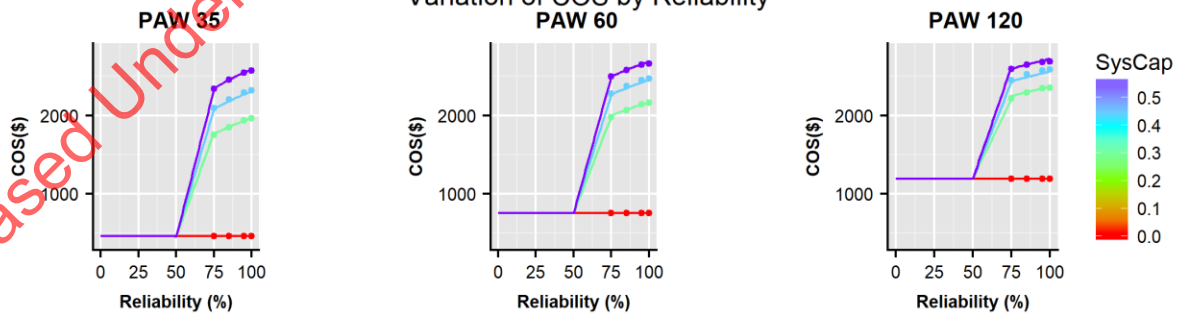
Black dots show actual sample points



Variation of COS by System Capacity



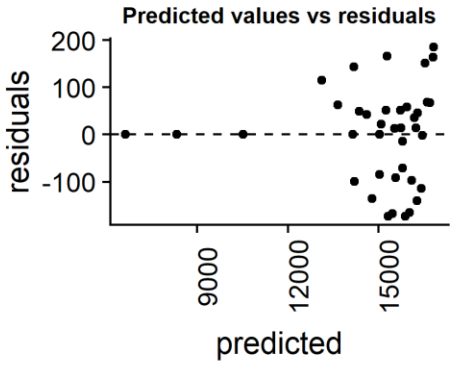
Variation of COS by Reliability

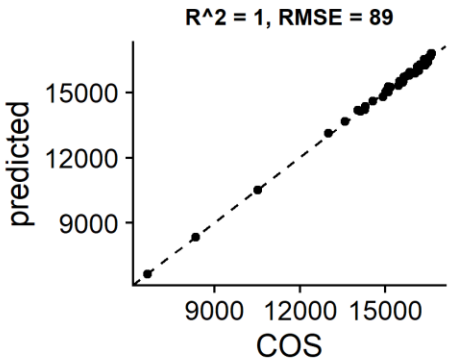


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

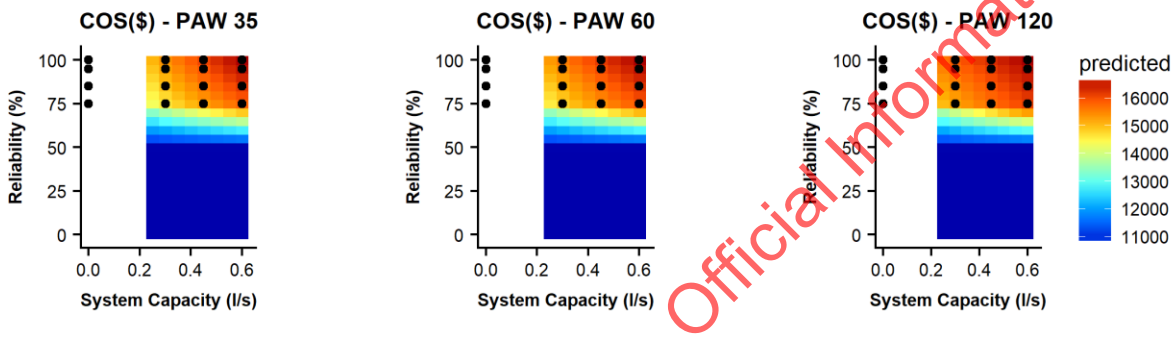
South Island: Hillcountry; Horticulture



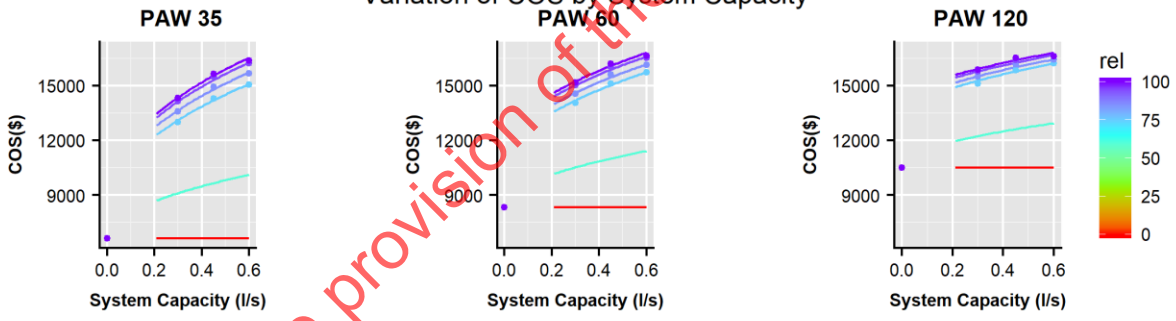


Modelled COS response surface

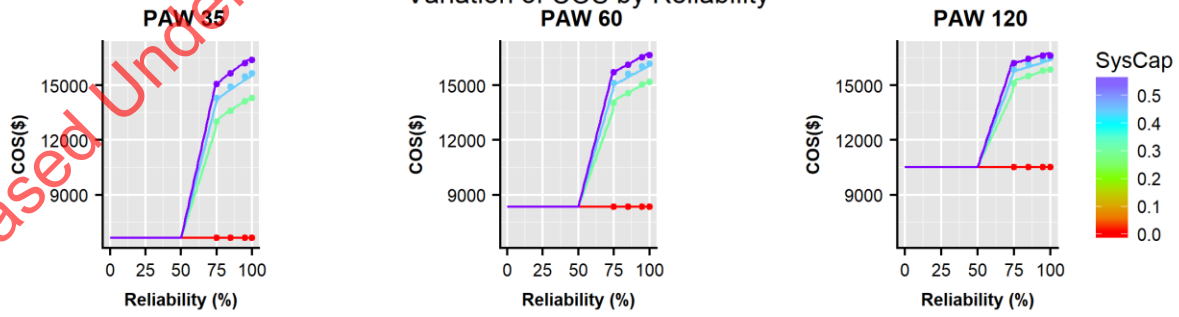
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

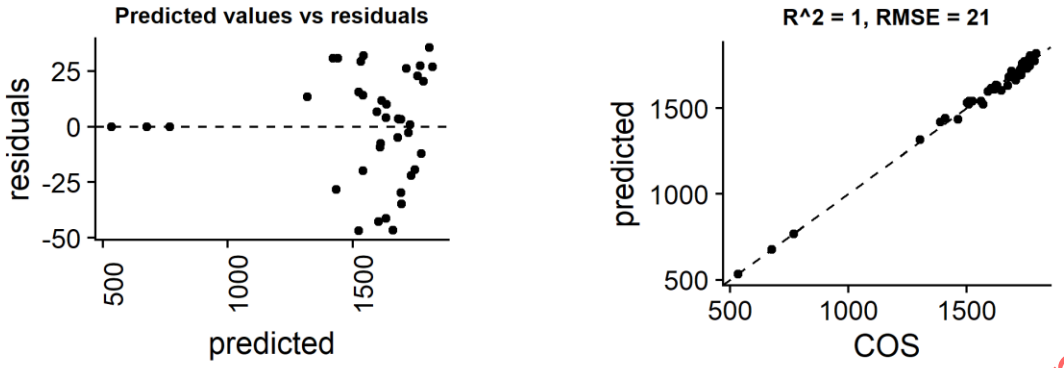


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

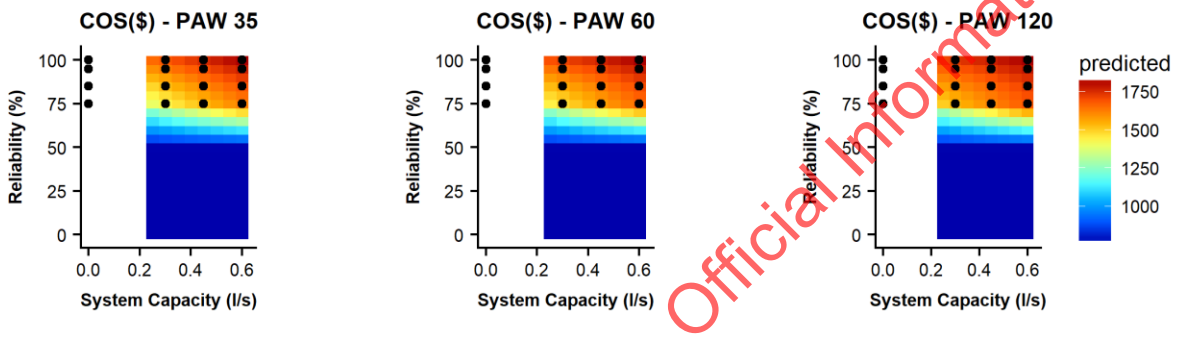
20-D-00014

South Island: Inland Basins; Sheep and Beef

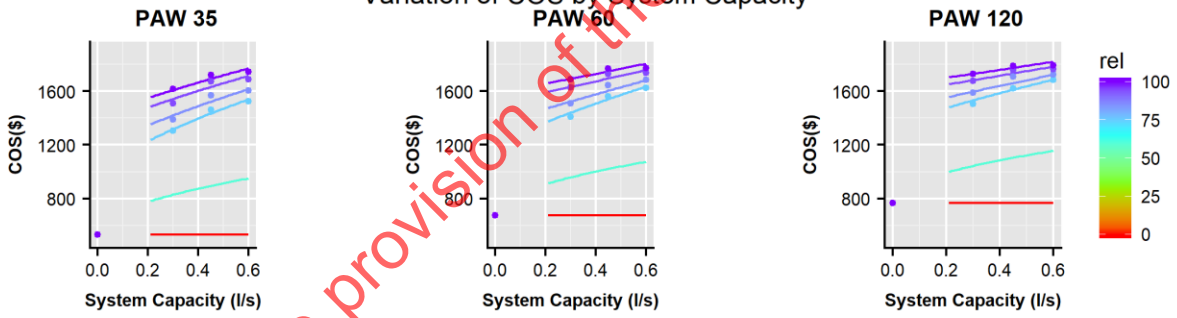


Modelled COS response surface

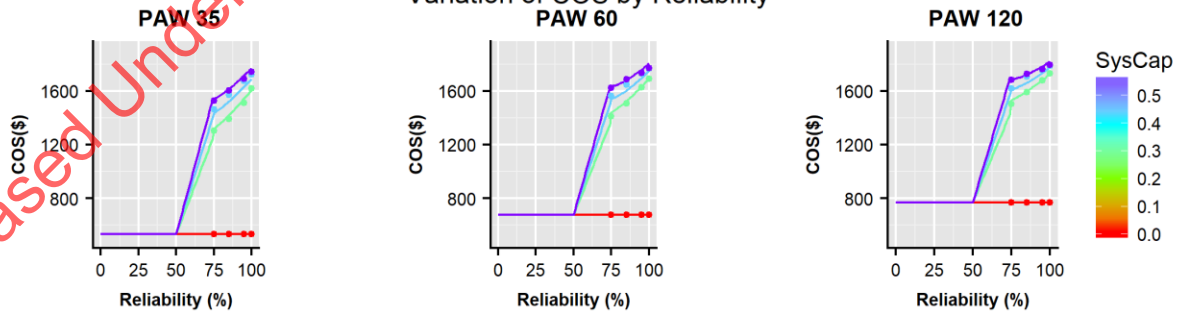
Black dots show actual sample points



Variation of COS by System Capacity



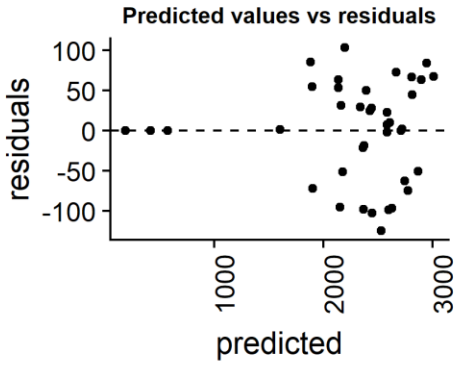
Variation of COS by Reliability

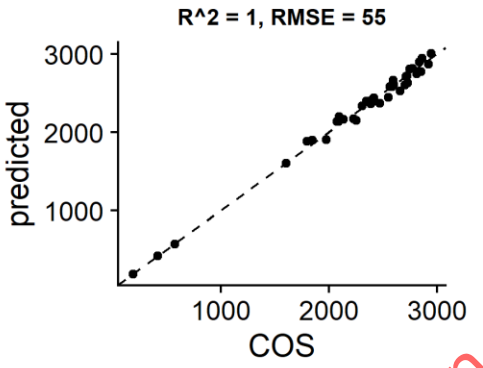


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

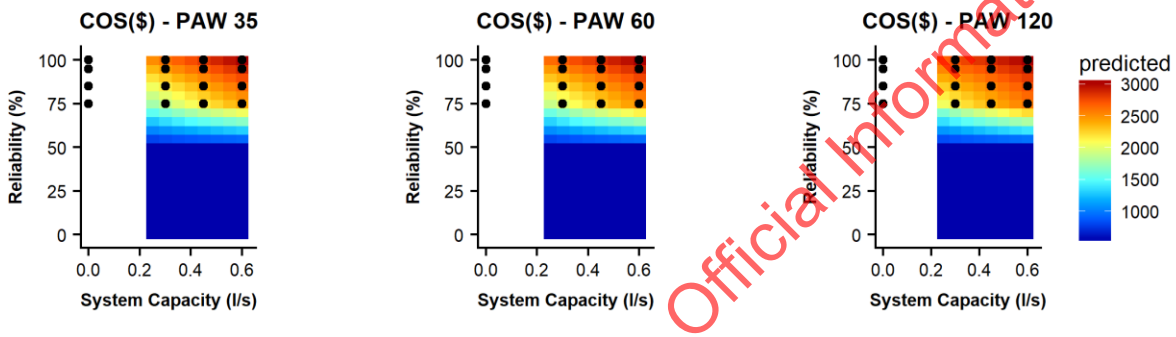
South Island: Inland Basins; Dairy



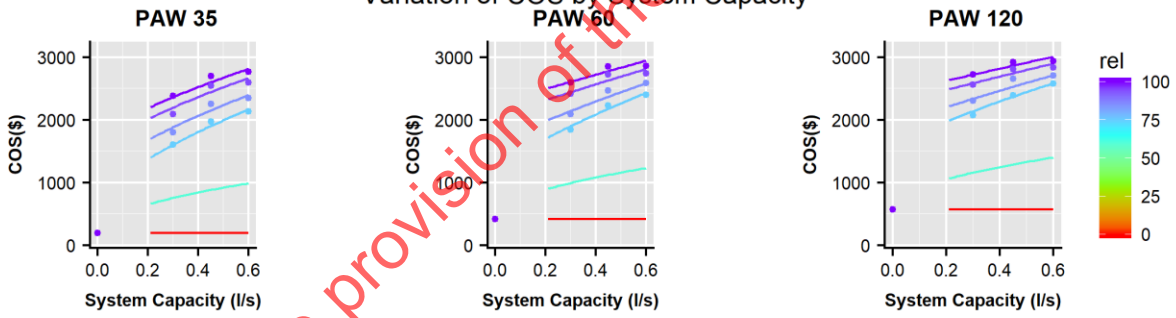


Modelled COS response surface

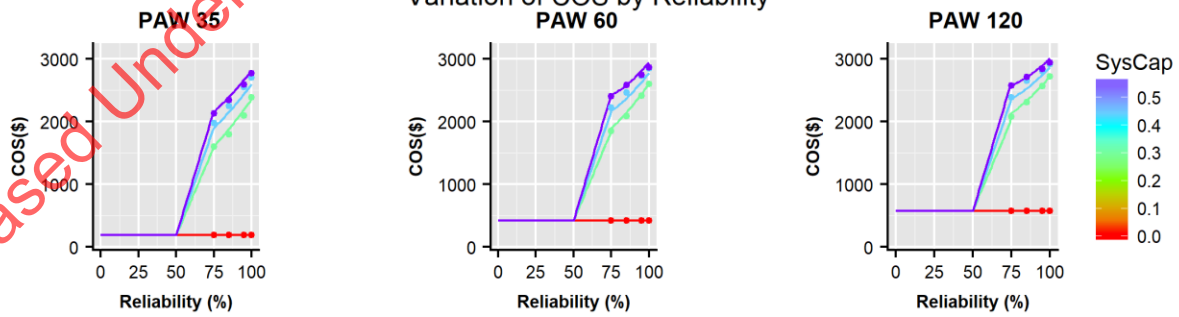
Black dots show actual sample points



Variation of COS by System Capacity



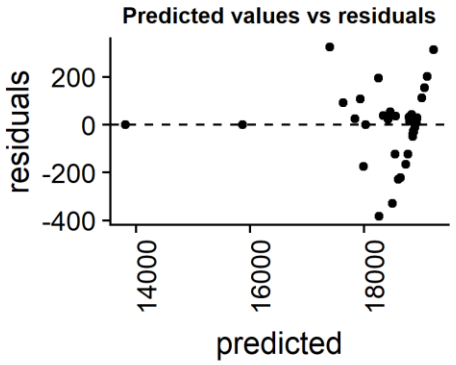
Variation of COS by Reliability

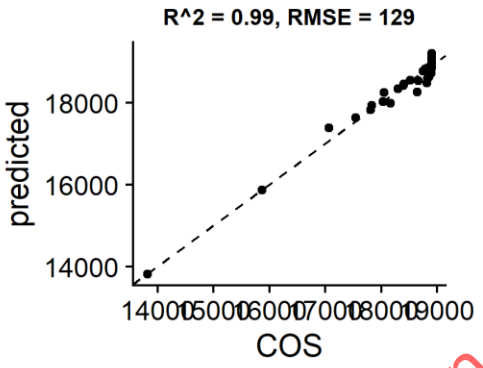


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

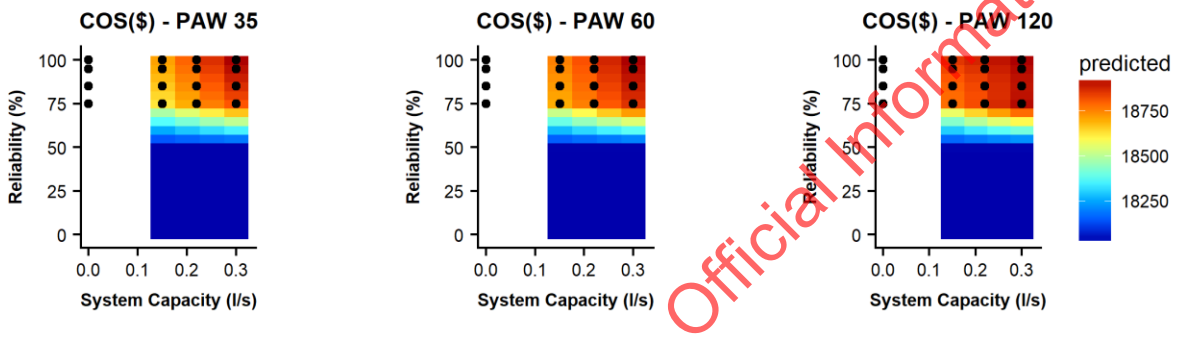
South Island: Inland Basins; Horticulture



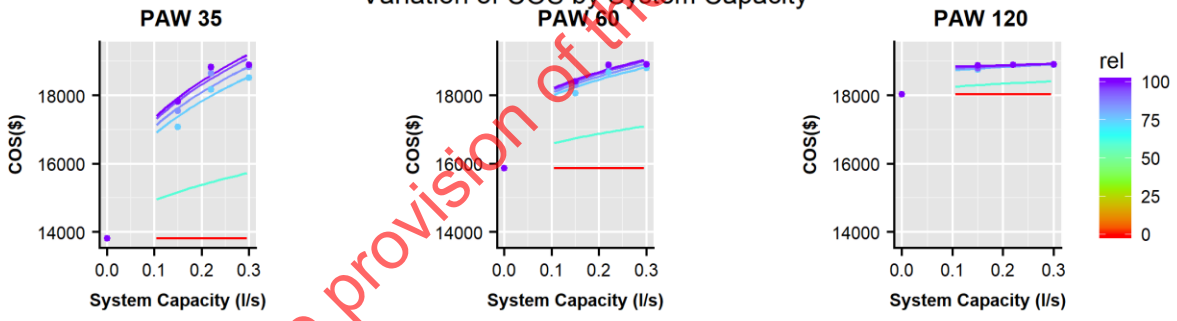


Modelled COS response surface

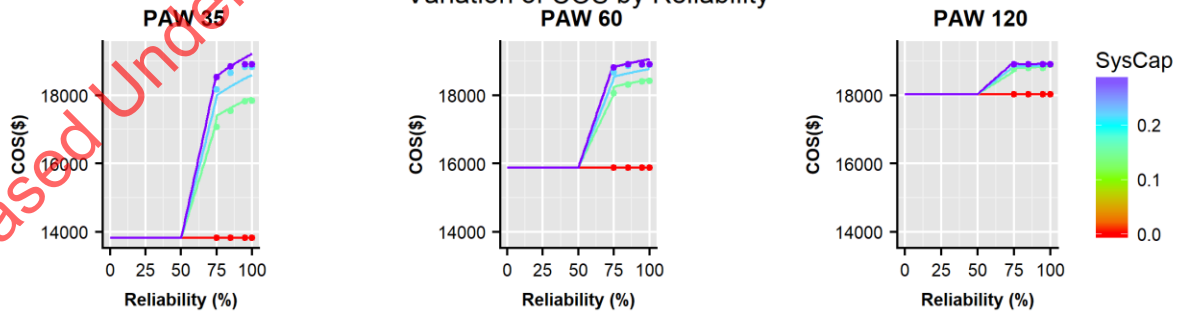
Black dots show actual sample points



Variation of COS by System Capacity



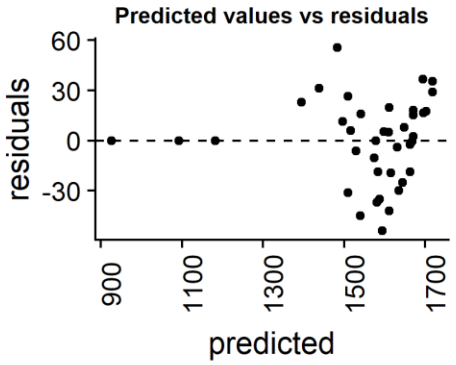
Variation of COS by Reliability

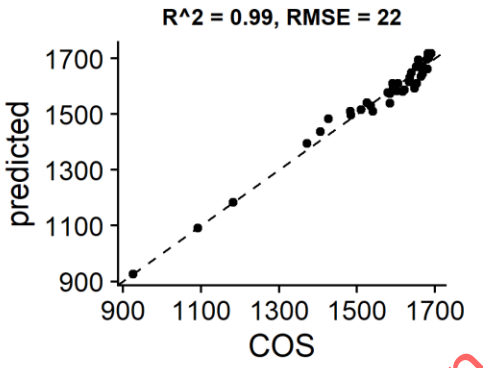


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
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Released Under the provision of the Official Information Act 1982

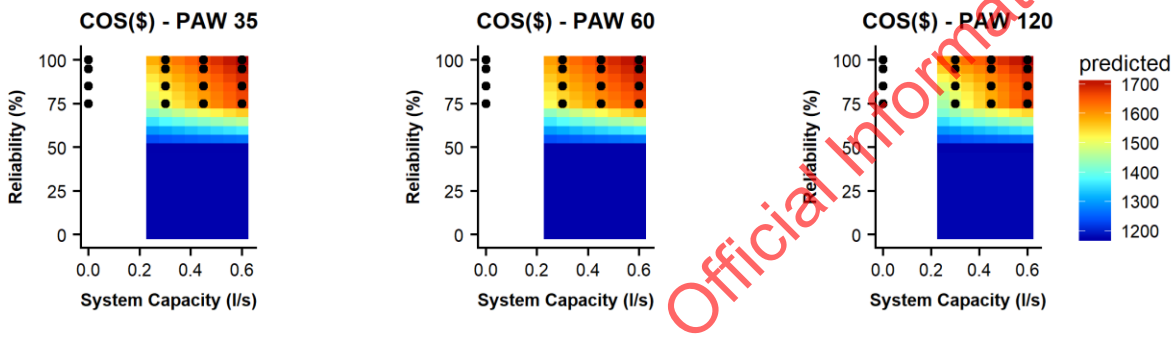
South Island: Inland Otago/Southland; Sheep and Beef



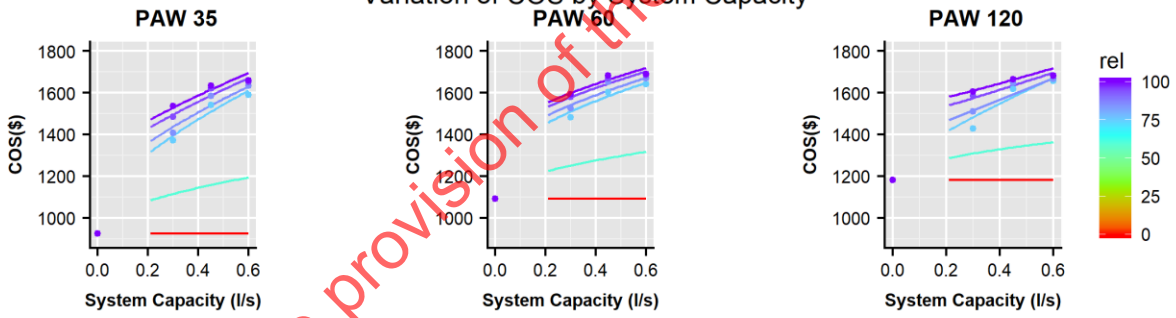


Modelled COS response surface

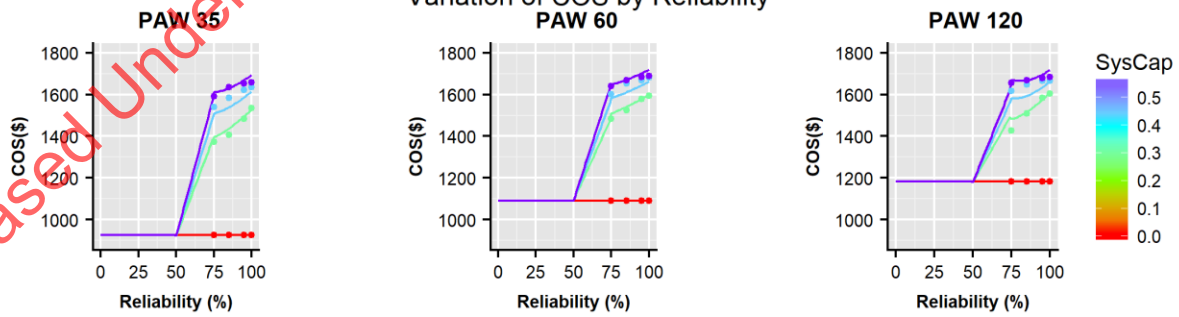
Black dots show actual sample points



Variation of COS by System Capacity



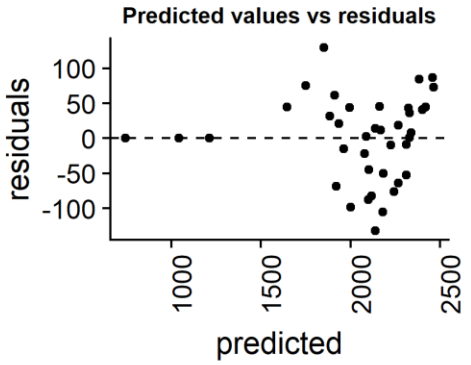
Variation of COS by Reliability

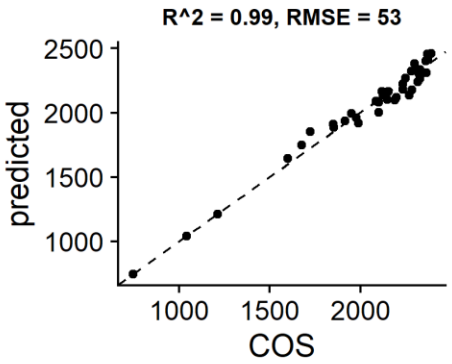


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
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Released Under the provision of the Official Information Act 1982

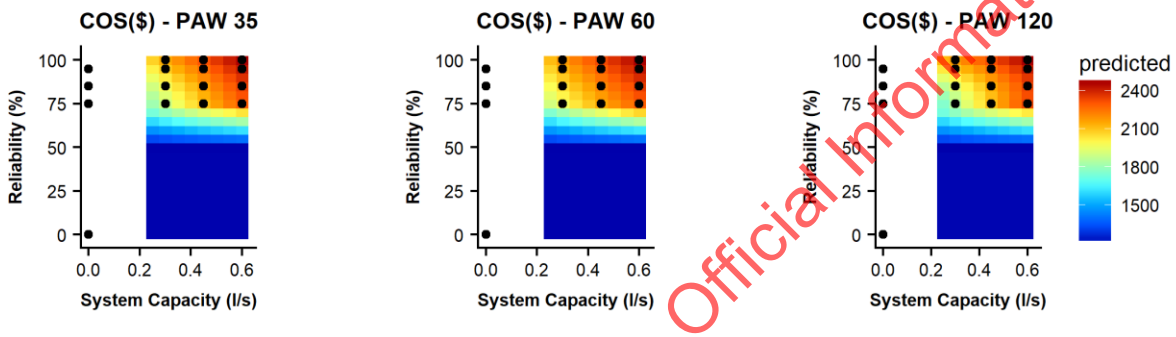
South Island: Inland Otago/Southland; Dairy



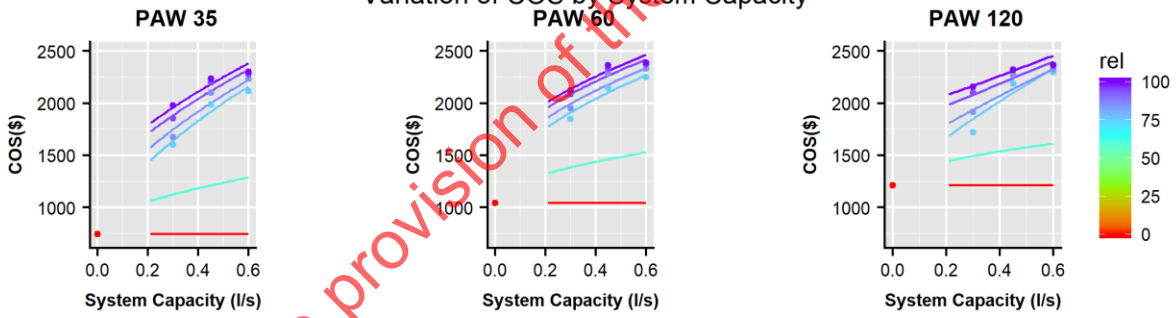


Modelled COS response surface

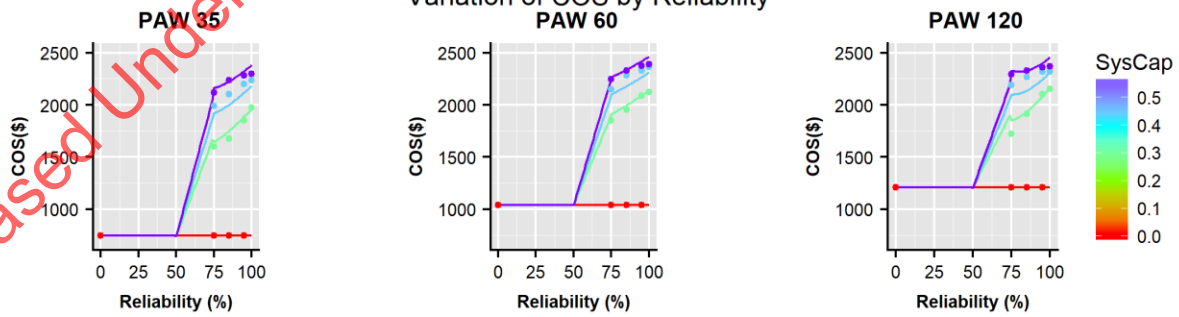
Black dots show actual sample points



Variation of COS by System Capacity



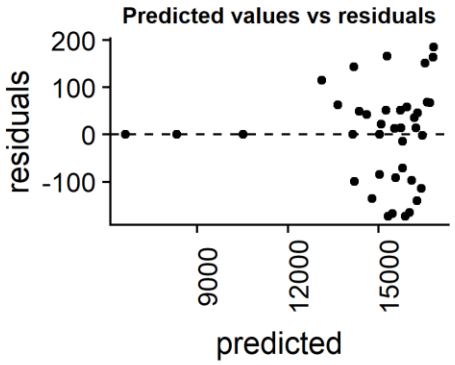
Variation of COS by Reliability

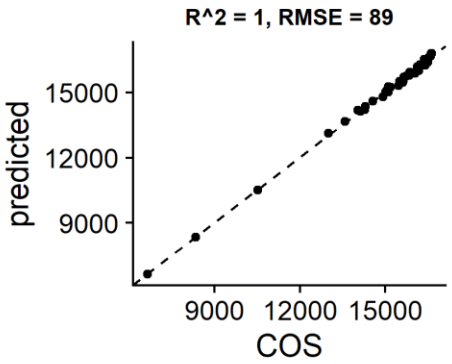


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
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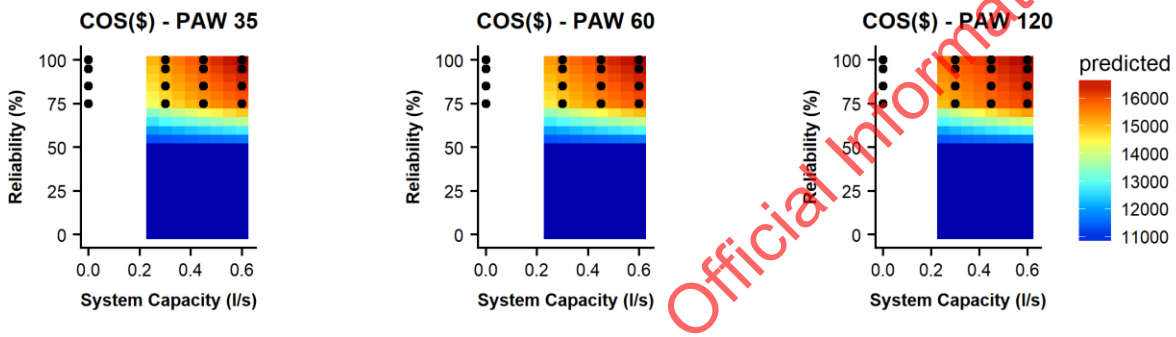
South Island: Inland Otago/Southland; Horticulture



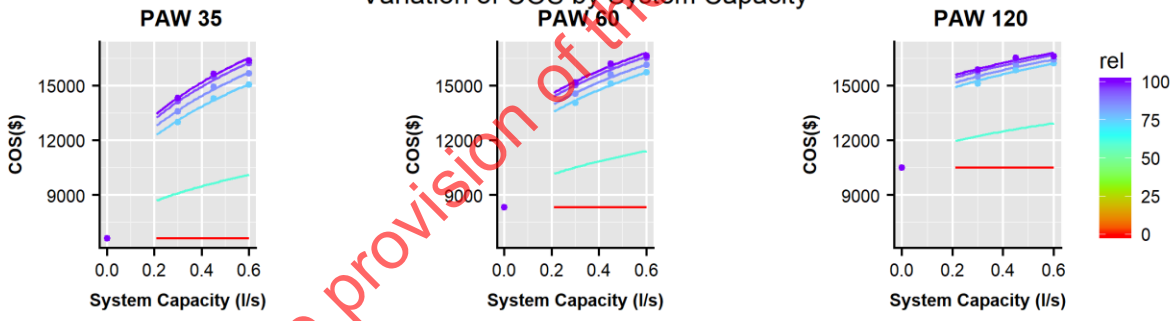


Modelled COS response surface

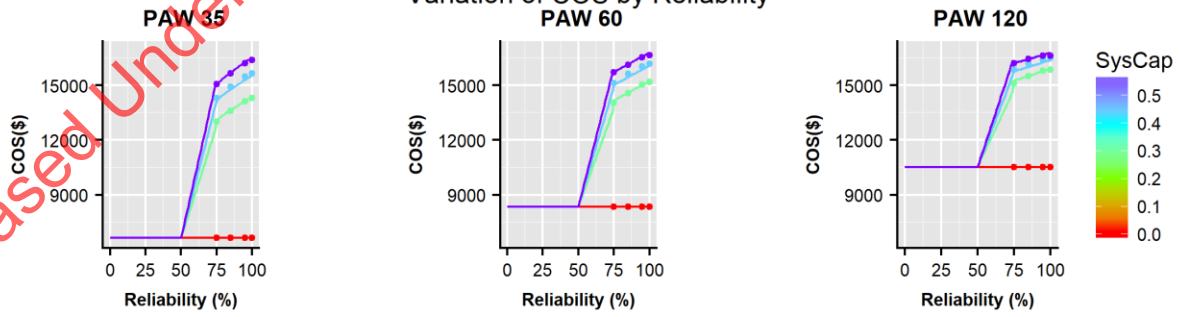
Black dots show actual sample points



Variation of COS by System Capacity

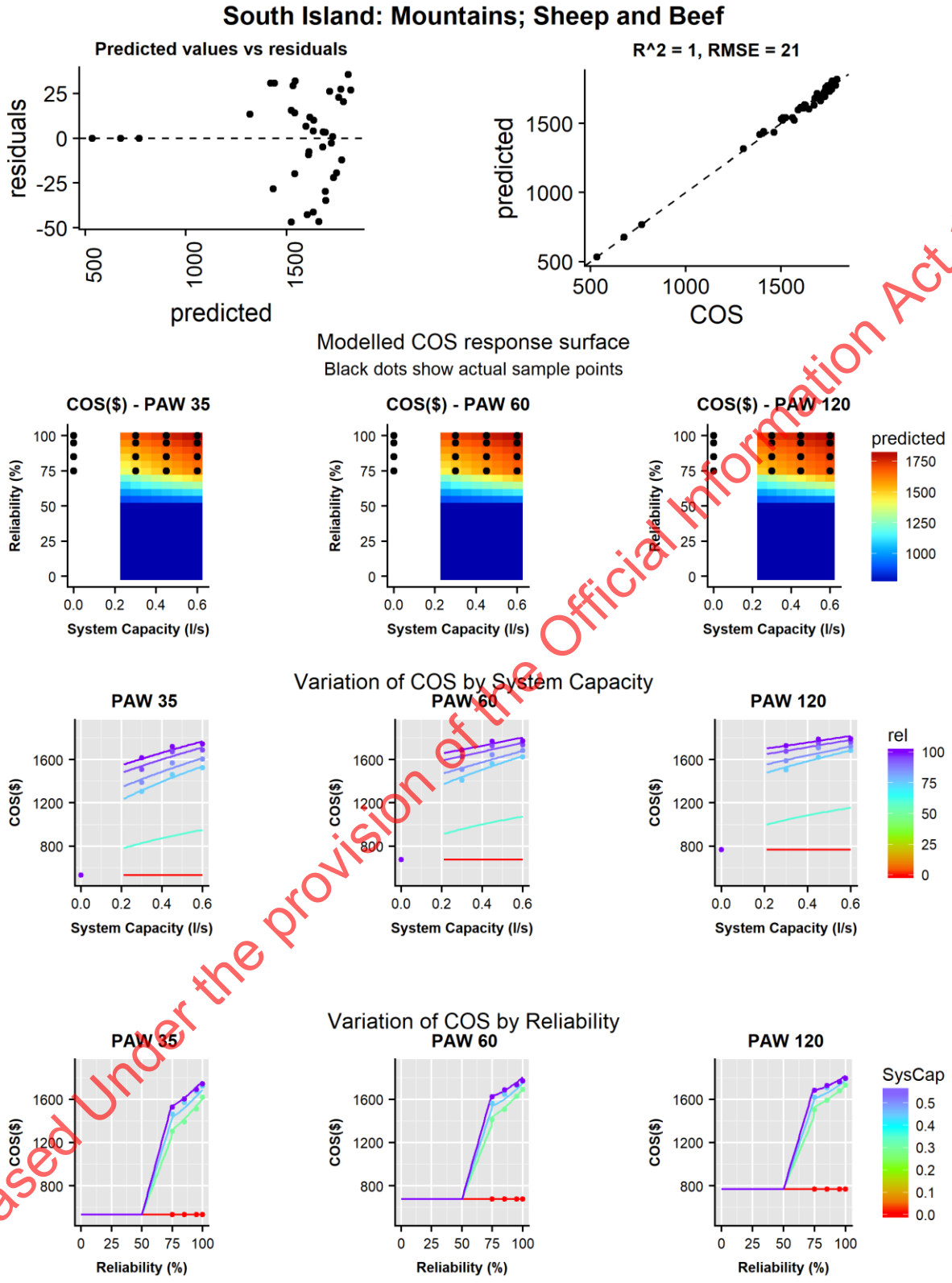


Variation of COS by Reliability



Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

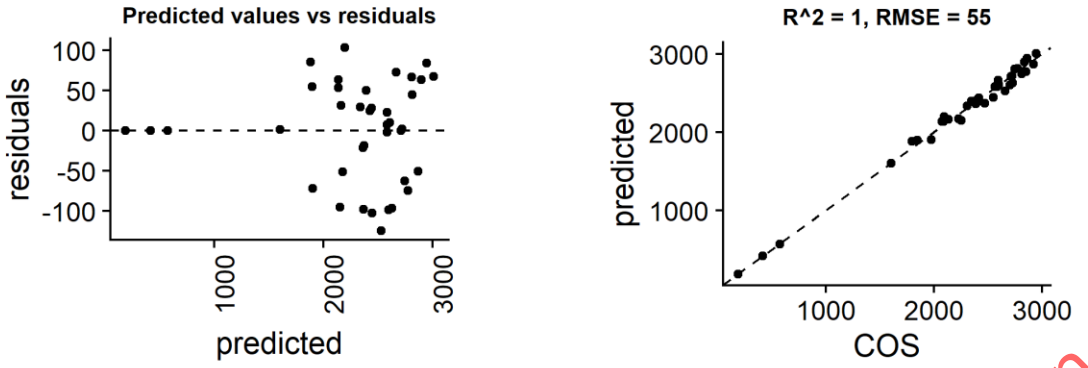
Released Under the provision of the Official Information Act 1982



Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

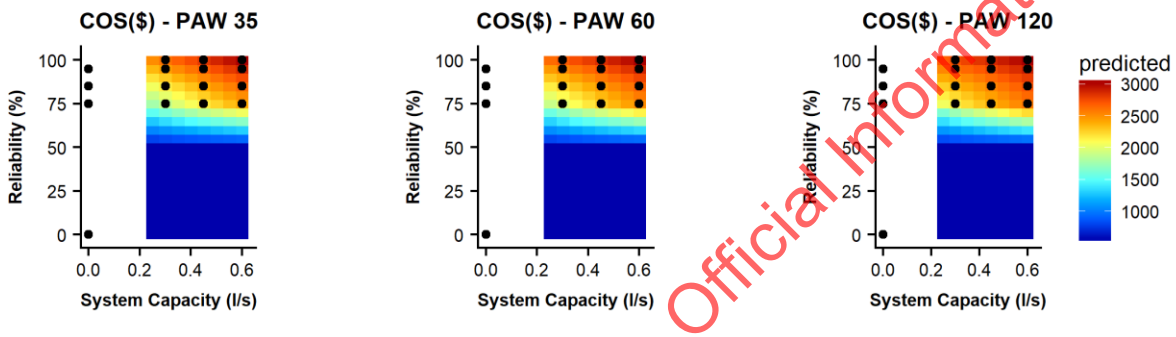
Released Under the provision of the Official Information Act 1982

South Island: Mountains; Dairy

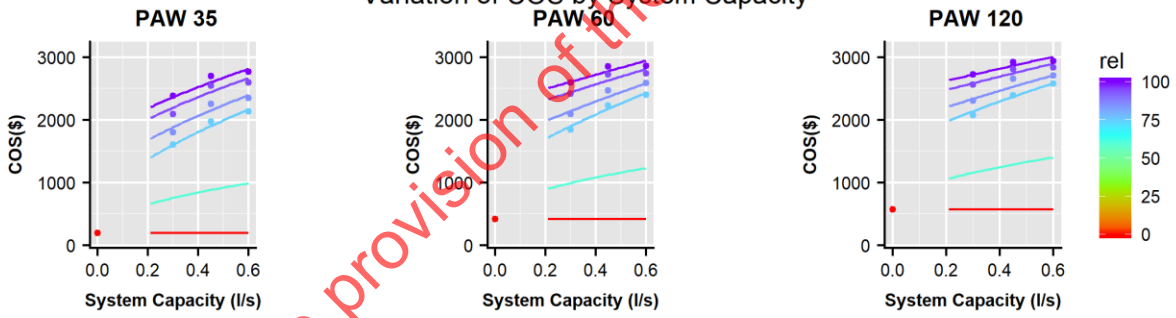


Modelled COS response surface

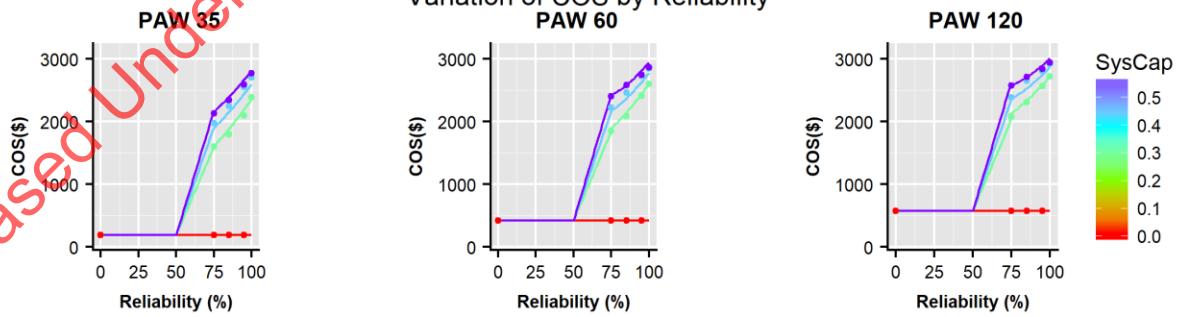
Black dots show actual sample points



Variation of COS by System Capacity



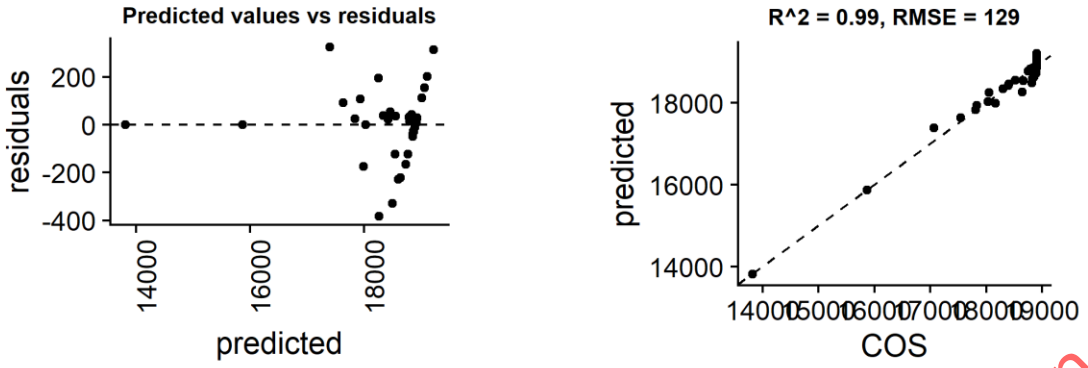
Variation of COS by Reliability



Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

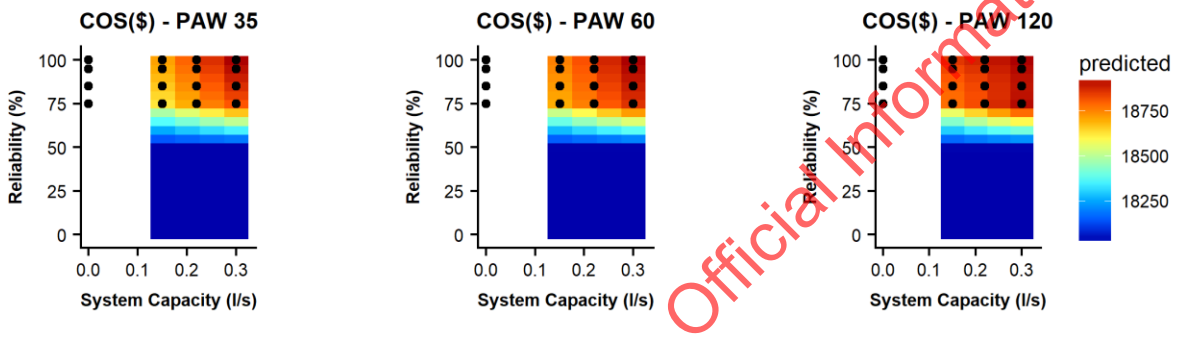
Released Under the provision of the Official Information Act 1982

South Island: Mountains; Horticulture

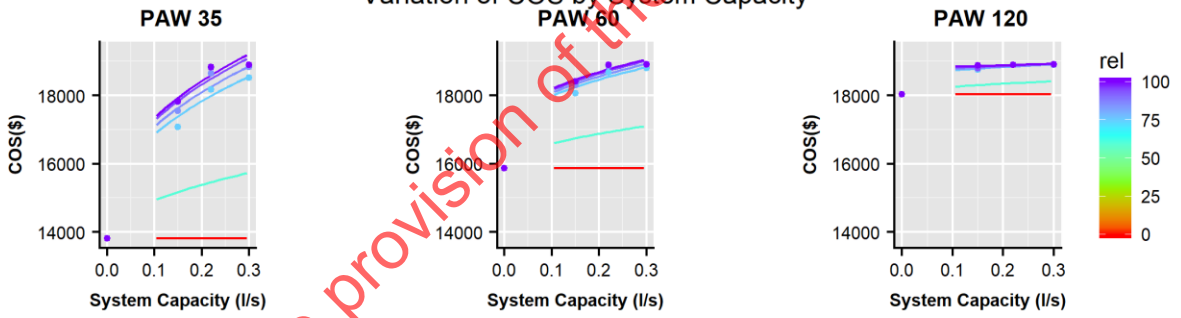


Modelled COS response surface

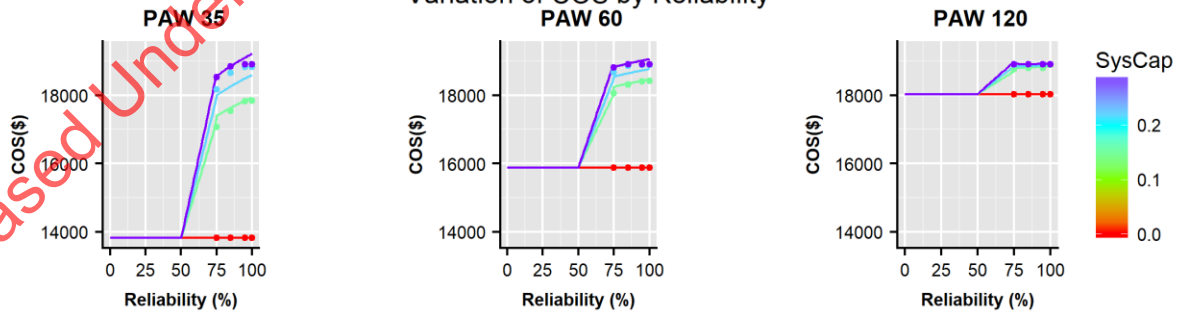
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

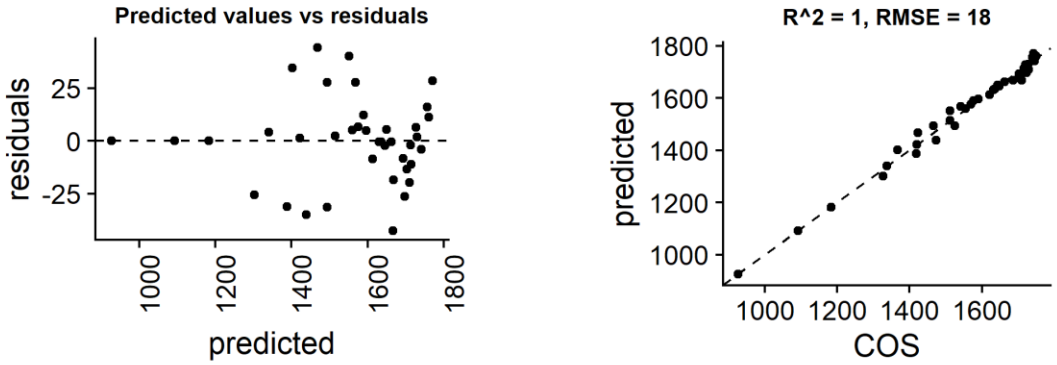


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

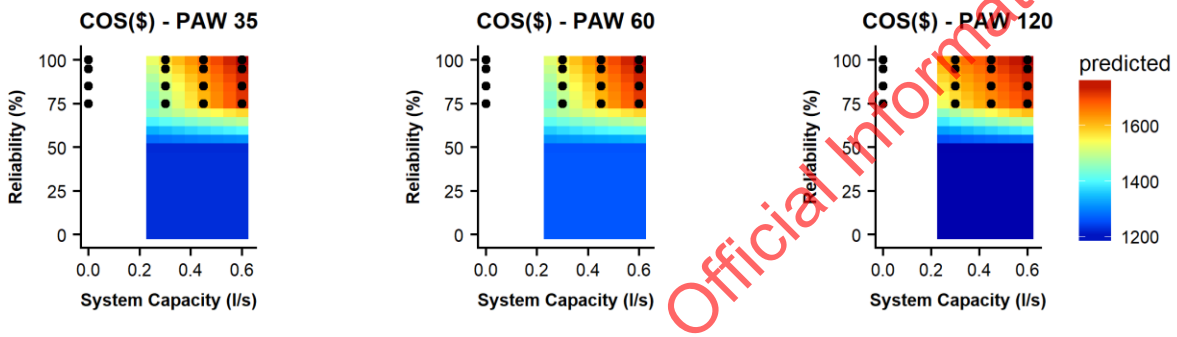
20-D-00014

South Island: South Coast; Sheep and Beef

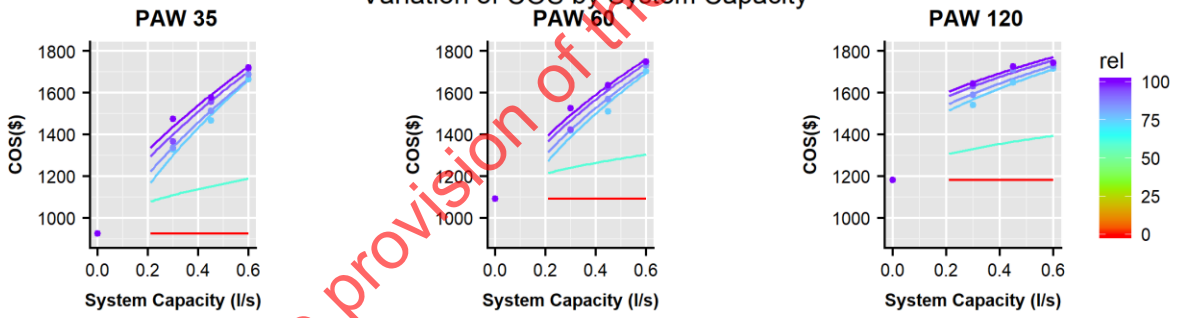


Modelled COS response surface

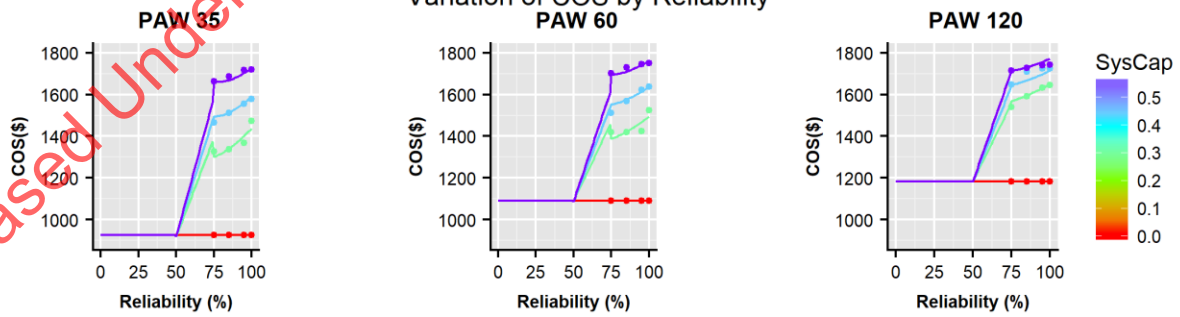
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

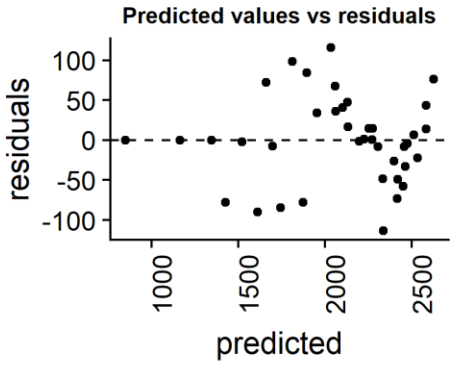


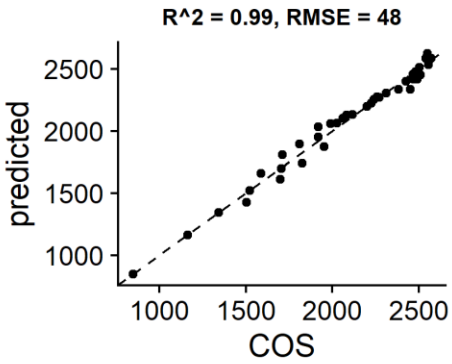
Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

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20-D-00014

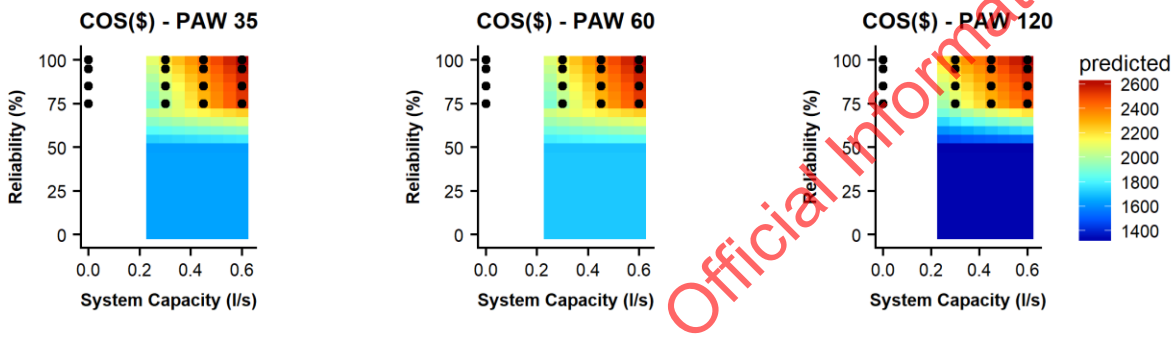
South Island: South Coast; Dairy



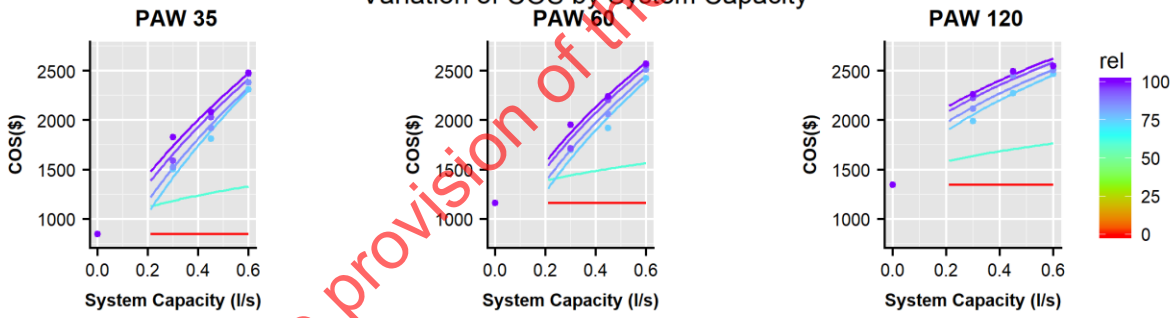


Modelled COS response surface

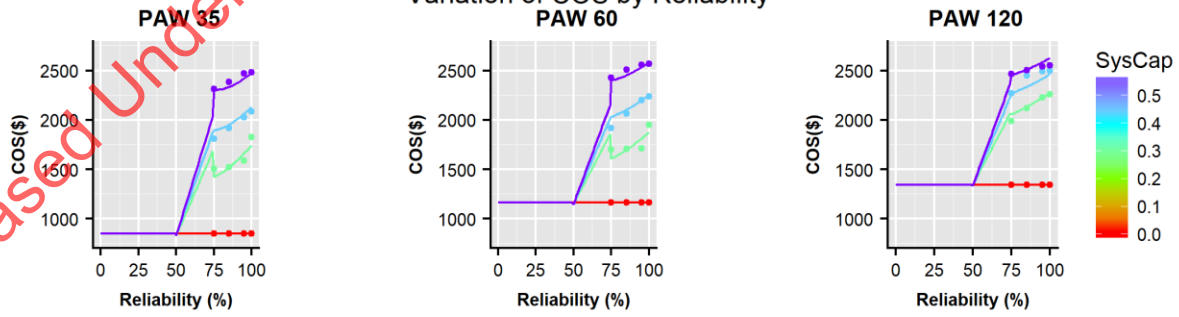
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

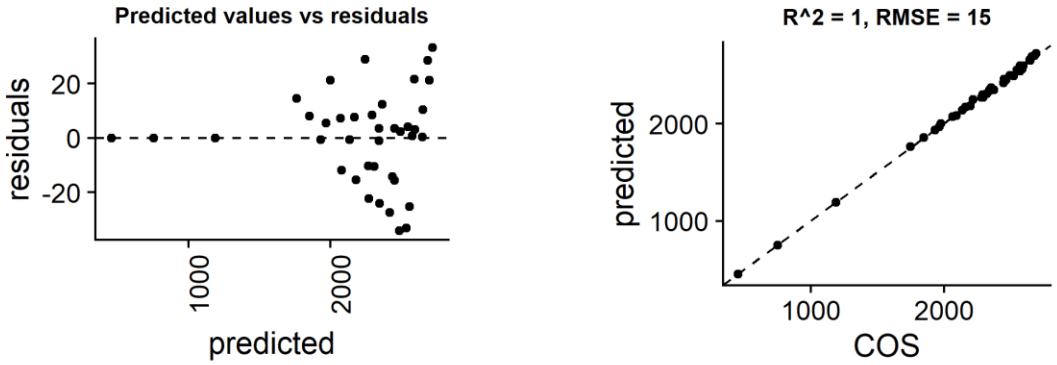


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

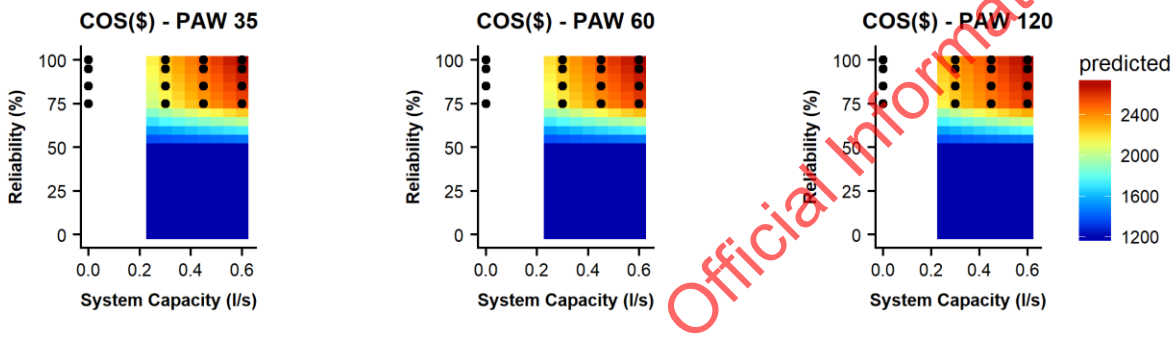
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South Island: South Coast; Arable

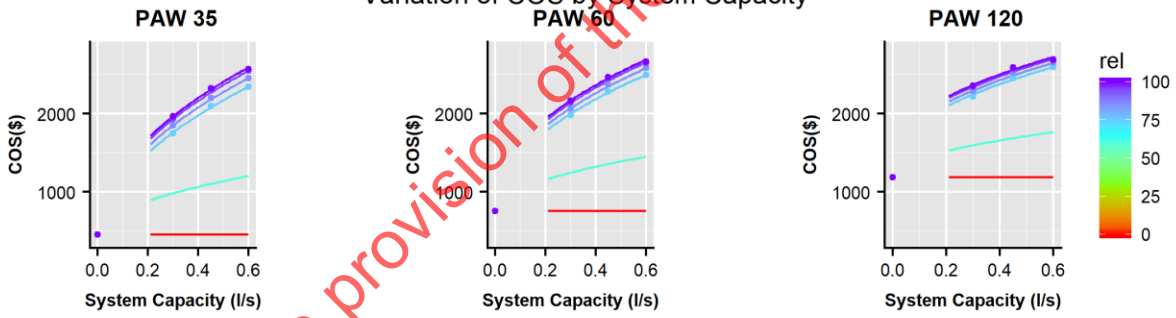


Modelled COS response surface

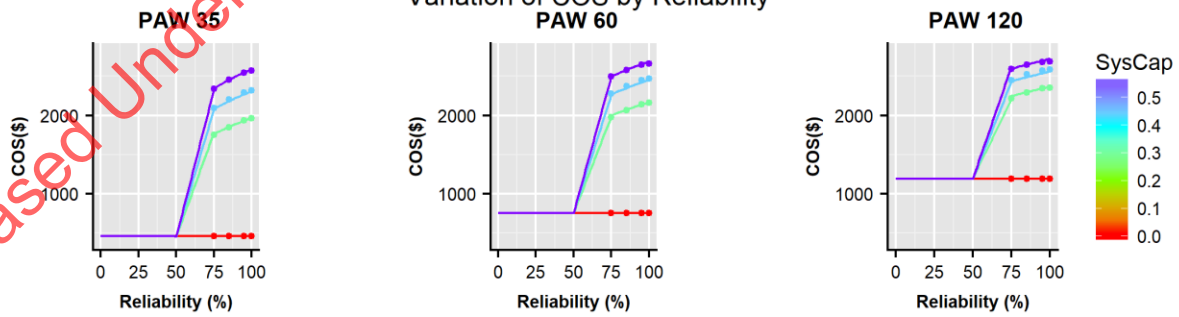
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

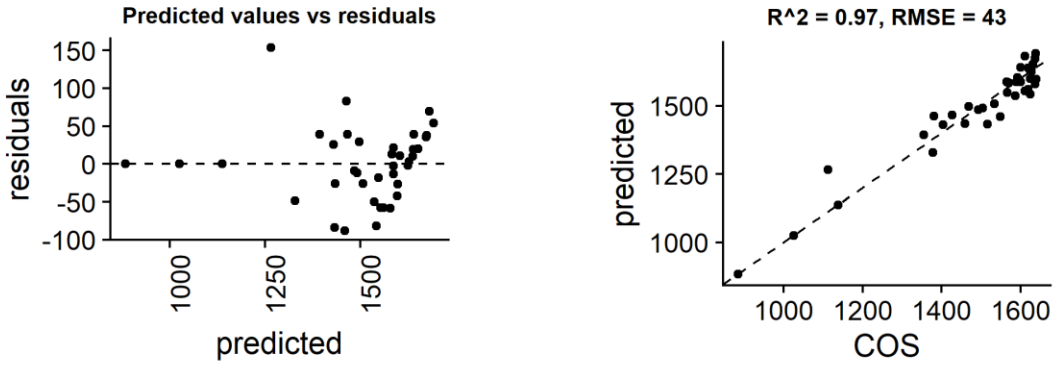


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

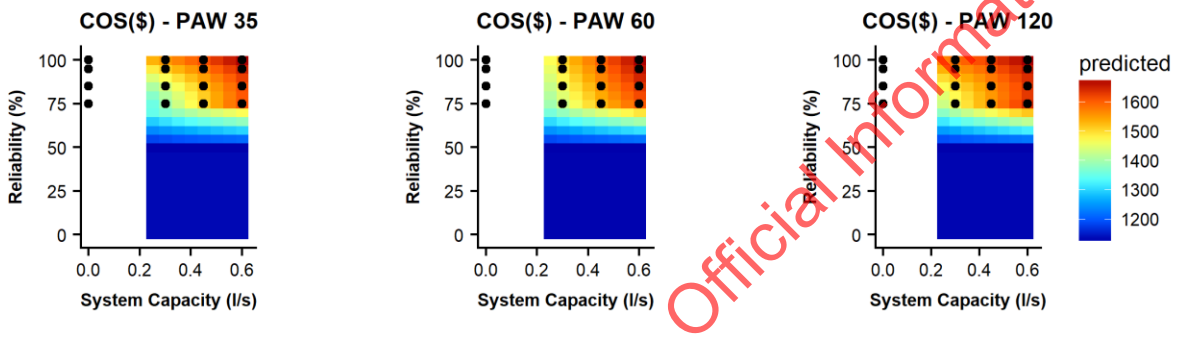
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South Island: Tasman; Sheep and Beef

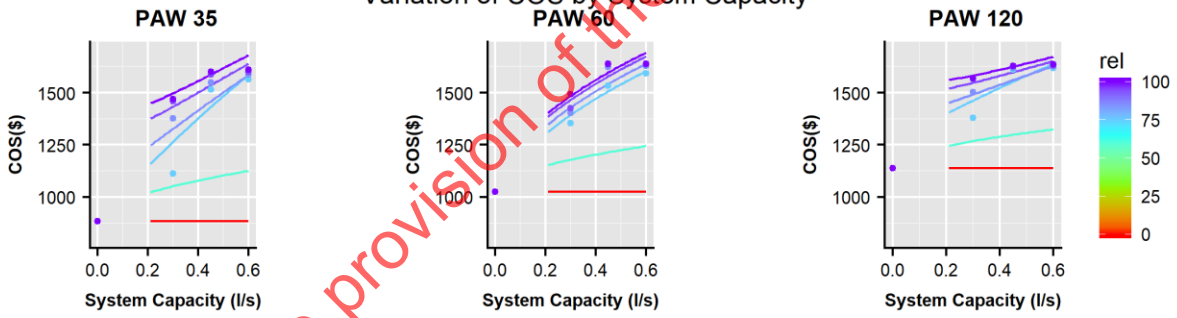


Modelled COS response surface

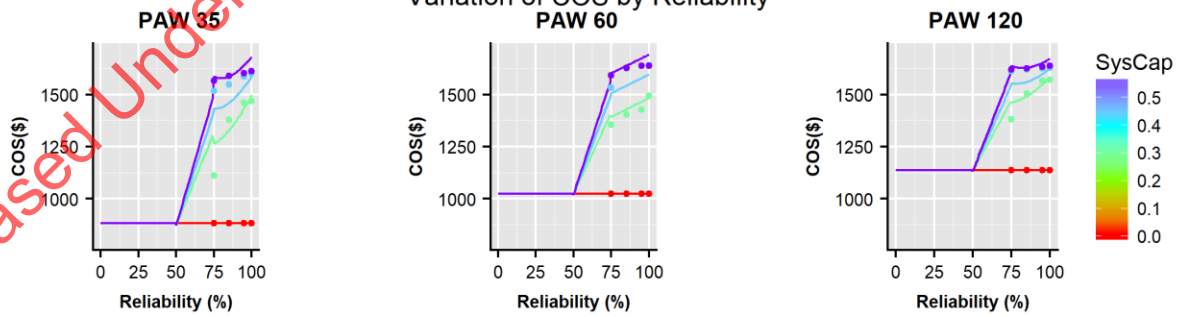
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

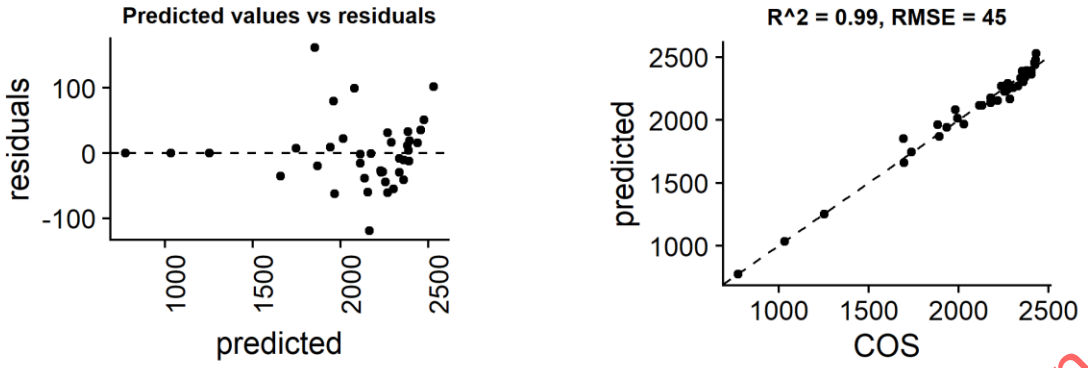


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

Released Under the provision of the Official Information Act 1982

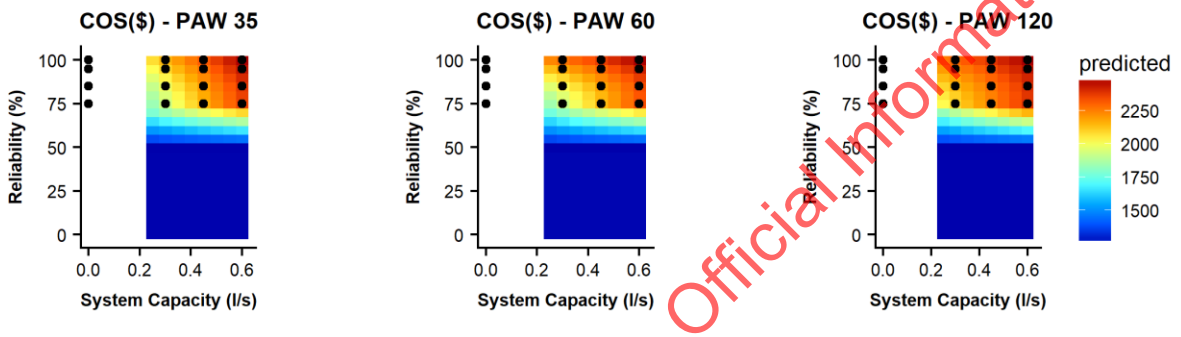
20-D-00014

South Island: Tasman; Dairy

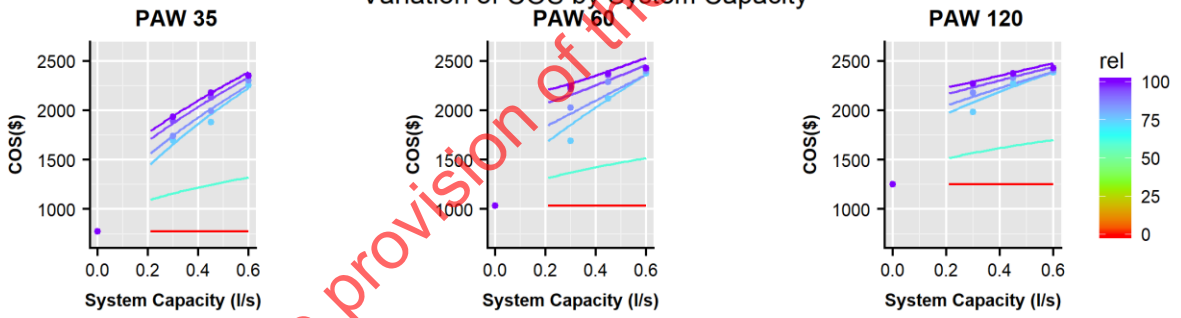


Modelled COS response surface

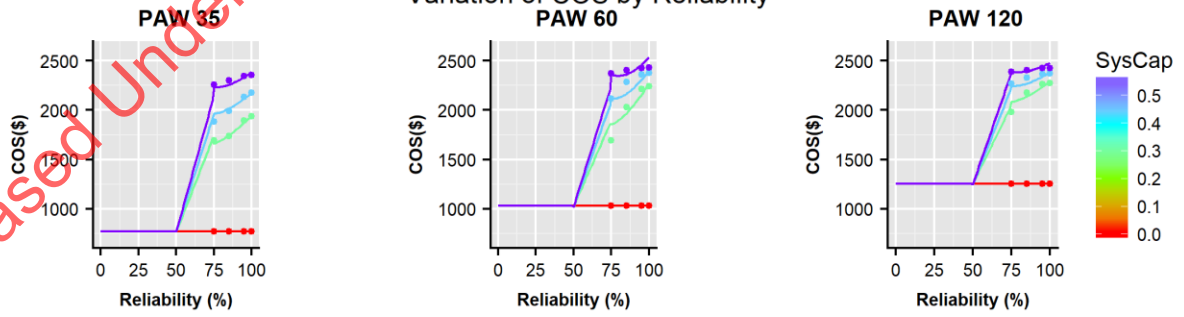
Black dots show actual sample points



Variation of COS by System Capacity



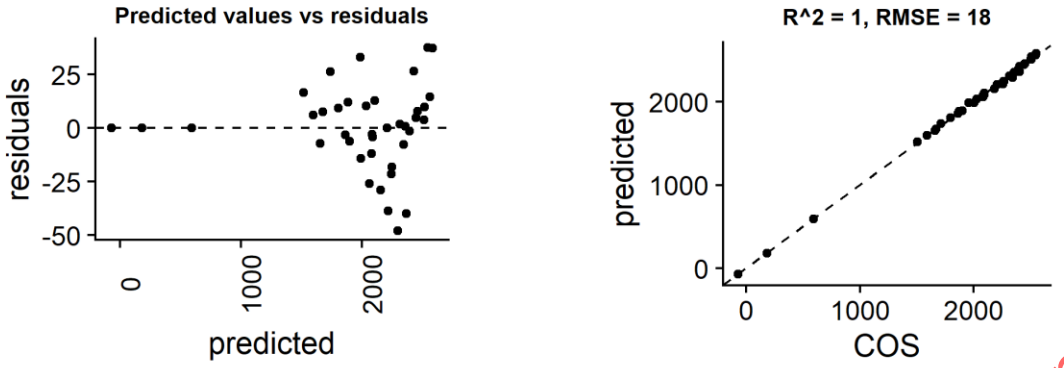
Variation of COS by Reliability



Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

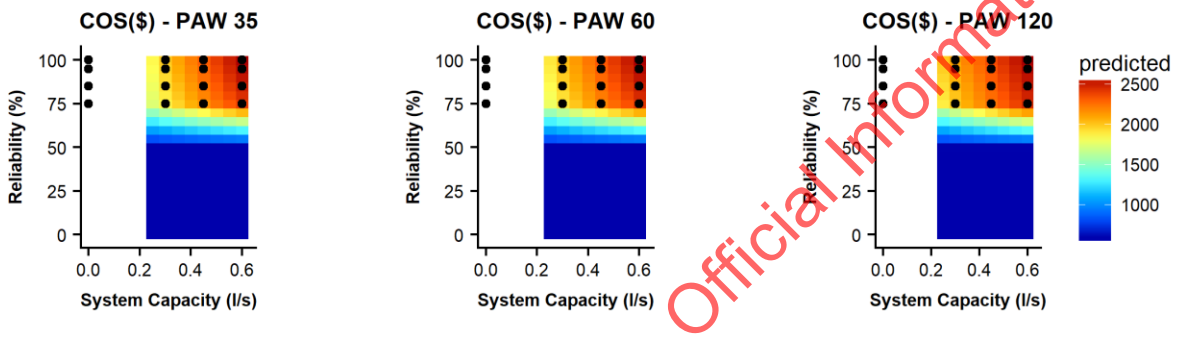
Released Under the provision of the Official Information Act 1982

South Island: Tasman; Arable

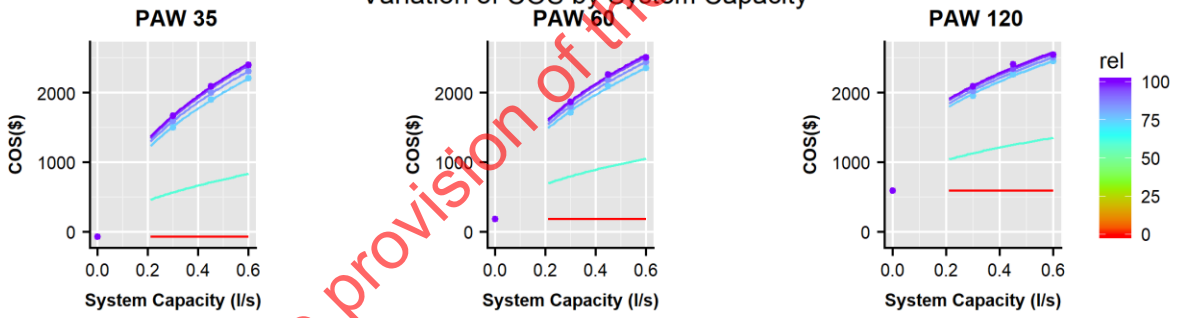


Modelled COS response surface

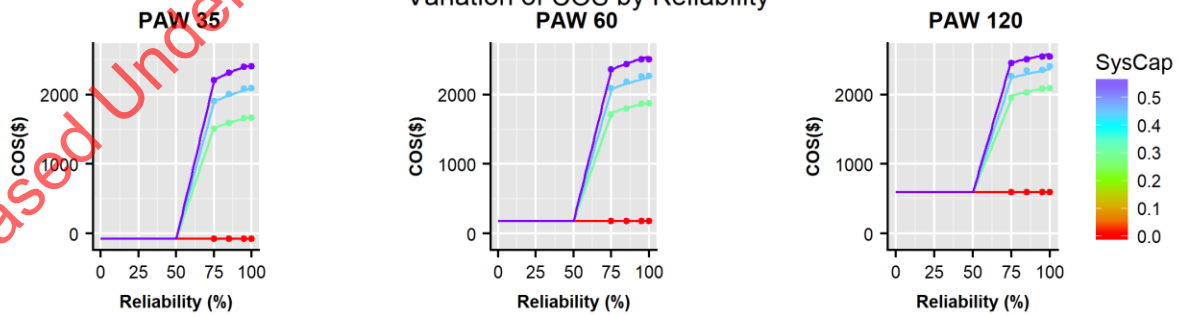
Black dots show actual sample points



Variation of COS by System Capacity



Variation of COS by Reliability

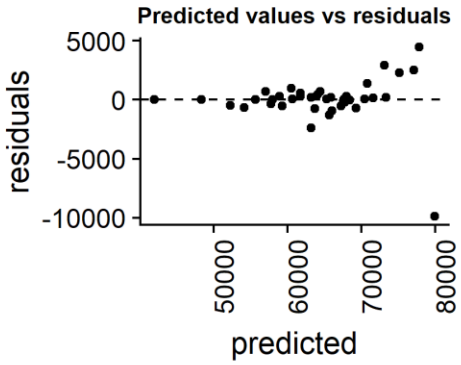


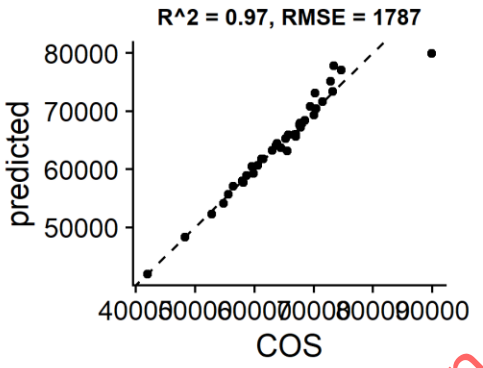
Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
COS ~ (SysCap^(1/2)*rel) + Int ~~ 50% < rel < 75% ~~~

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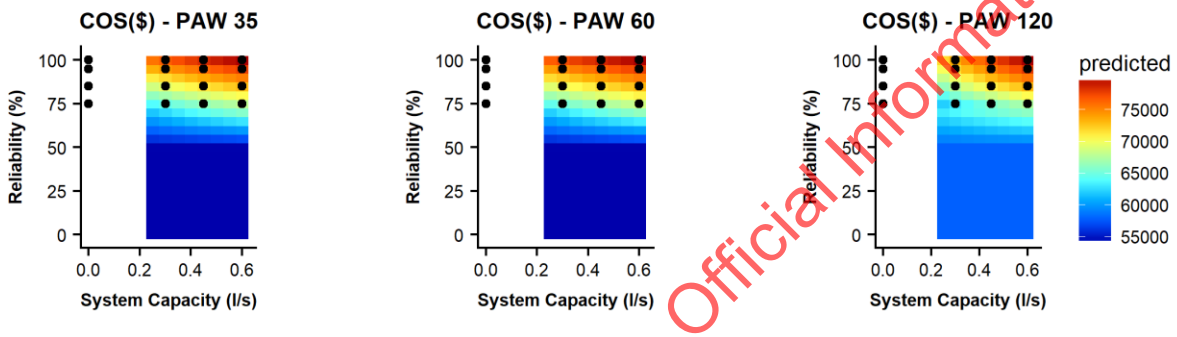
South Island: Tasman; Horticulture



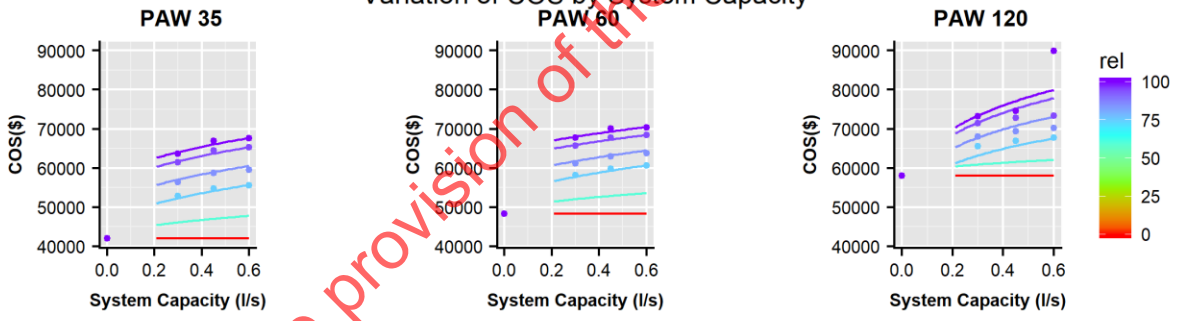


Modelled COS response surface

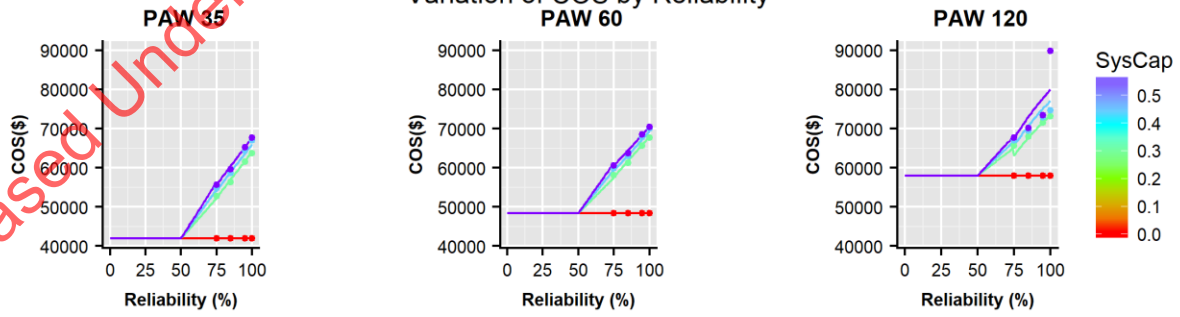
Black dots show actual sample points



Variation of COS by System Capacity



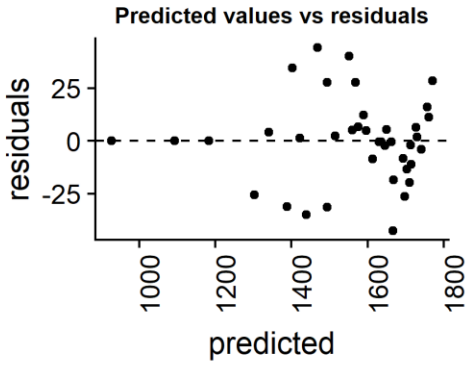
Variation of COS by Reliability

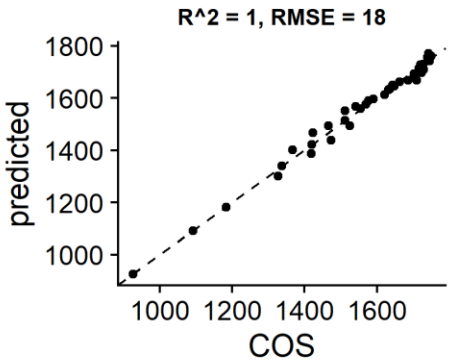


Model formula: COS ~ (SysCap*rel)^(1/3) + SysCap^(1/2) + Rel + Int ~~ rel > 75% ~~~
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Released Under the provision of the Official Information Act 1982

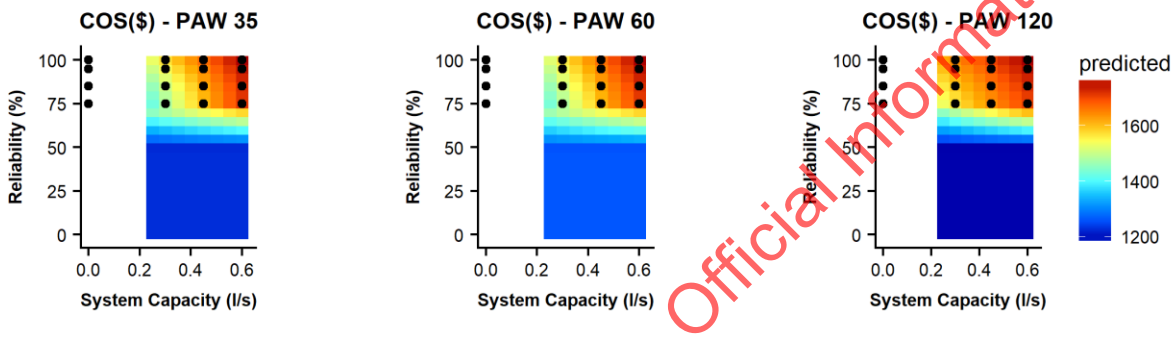
South Island: West Coast; Sheep and Beef



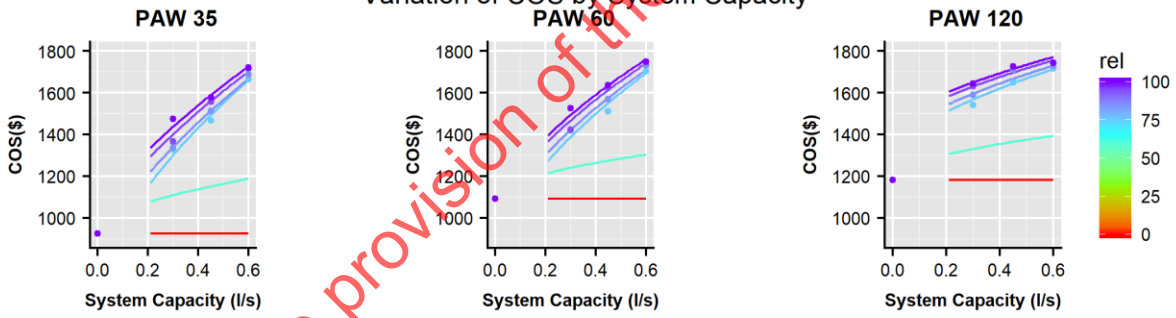


Modelled COS response surface

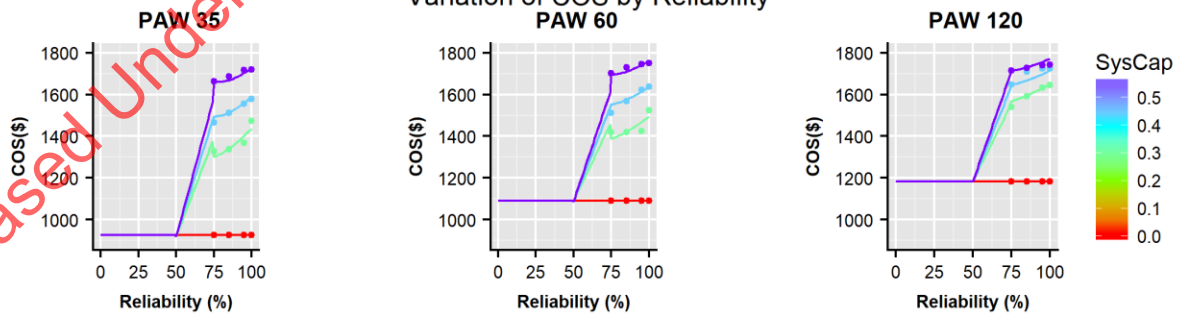
Black dots show actual sample points



Variation of COS by System Capacity



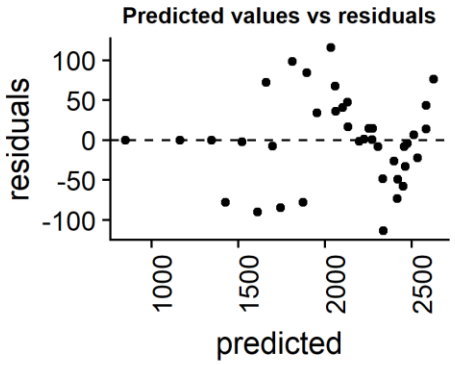
Variation of COS by Reliability

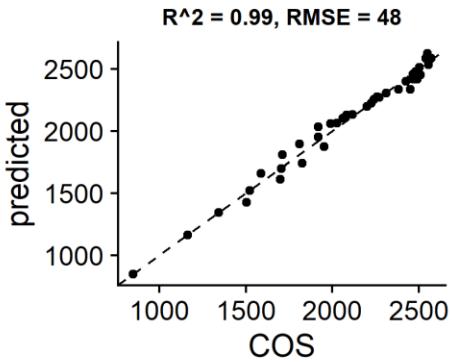


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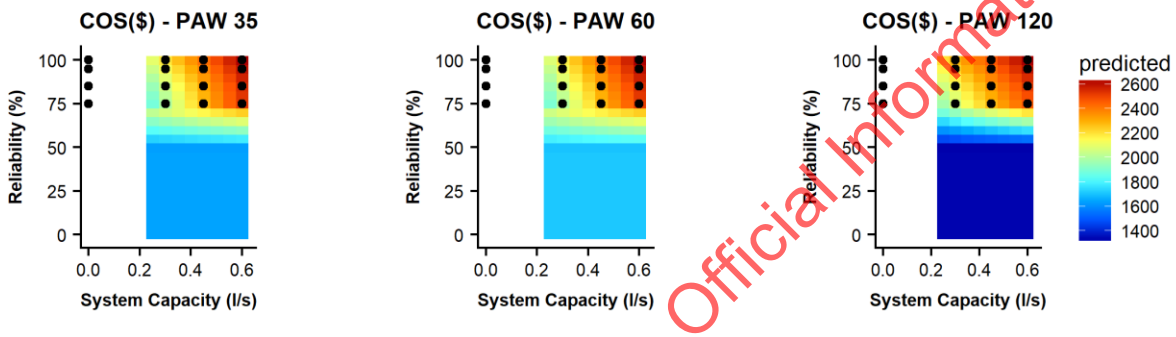
South Island: West Coast; Dairy



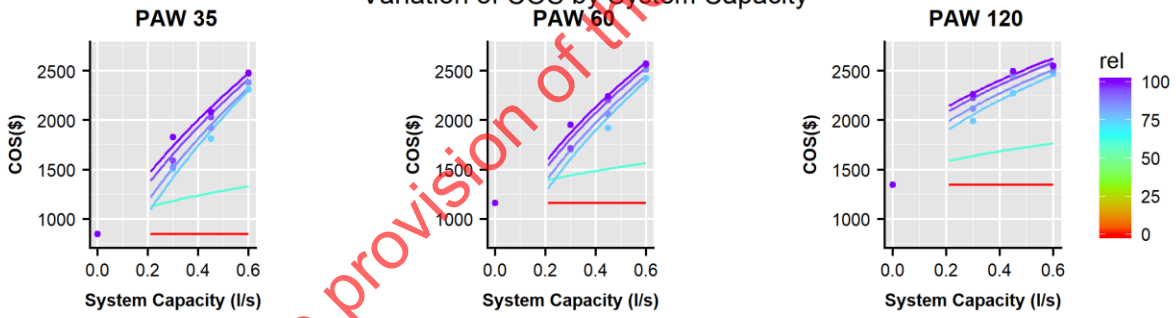


Modelled COS response surface

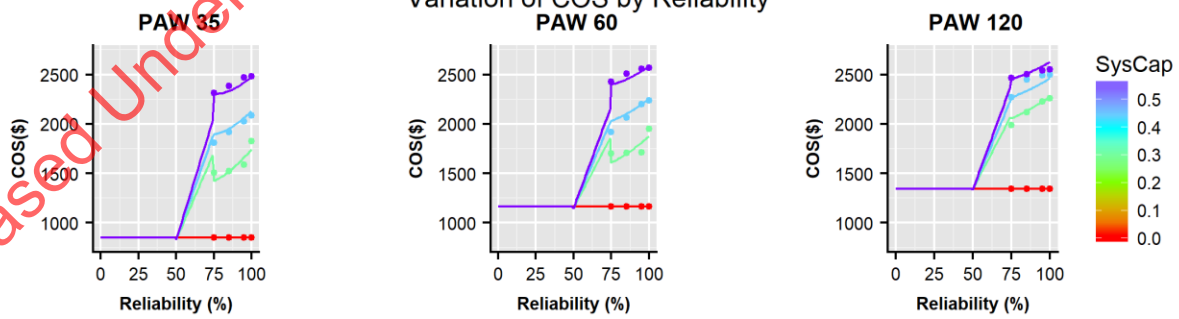
Black dots show actual sample points



Variation of COS by System Capacity



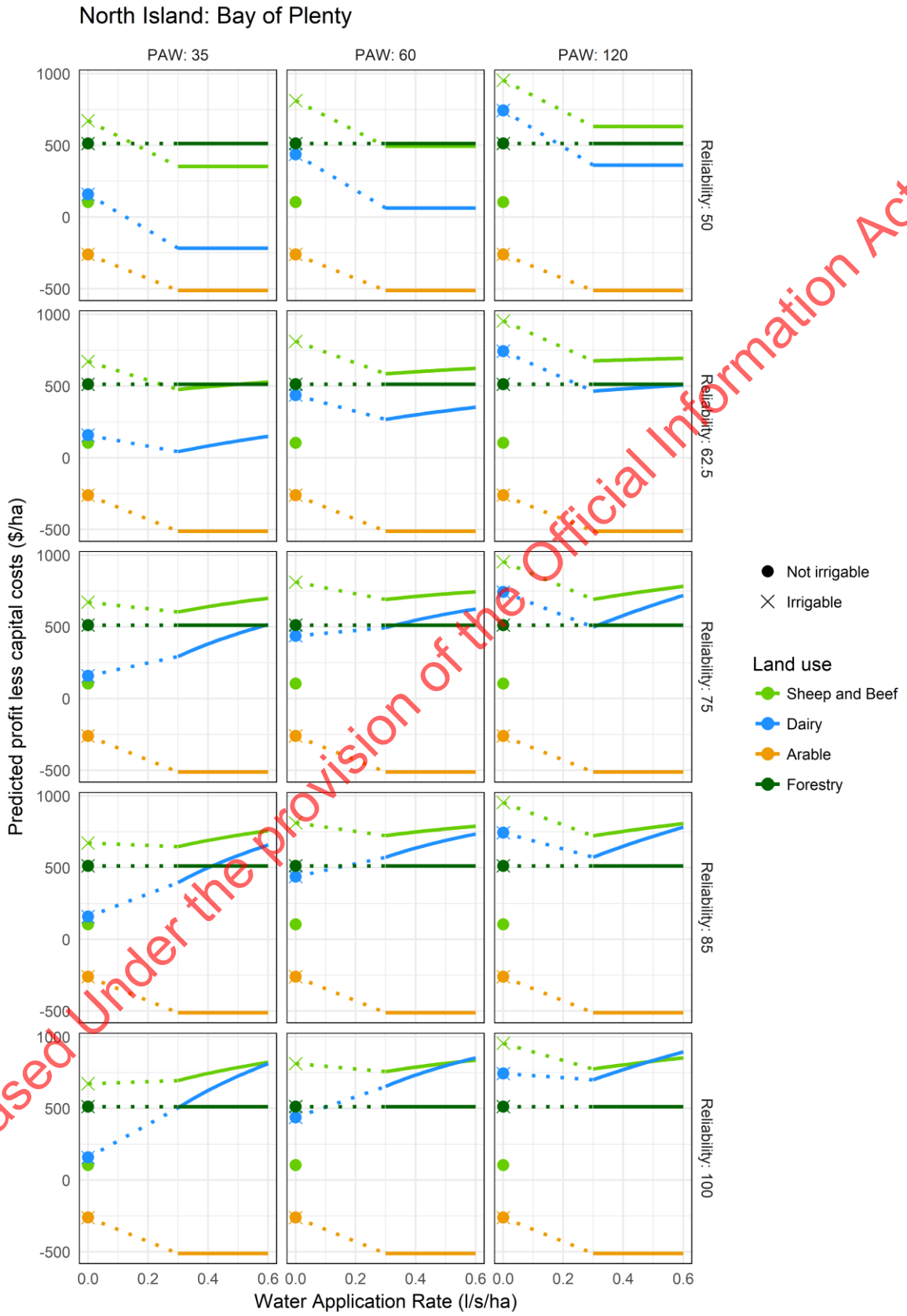
Variation of COS by Reliability



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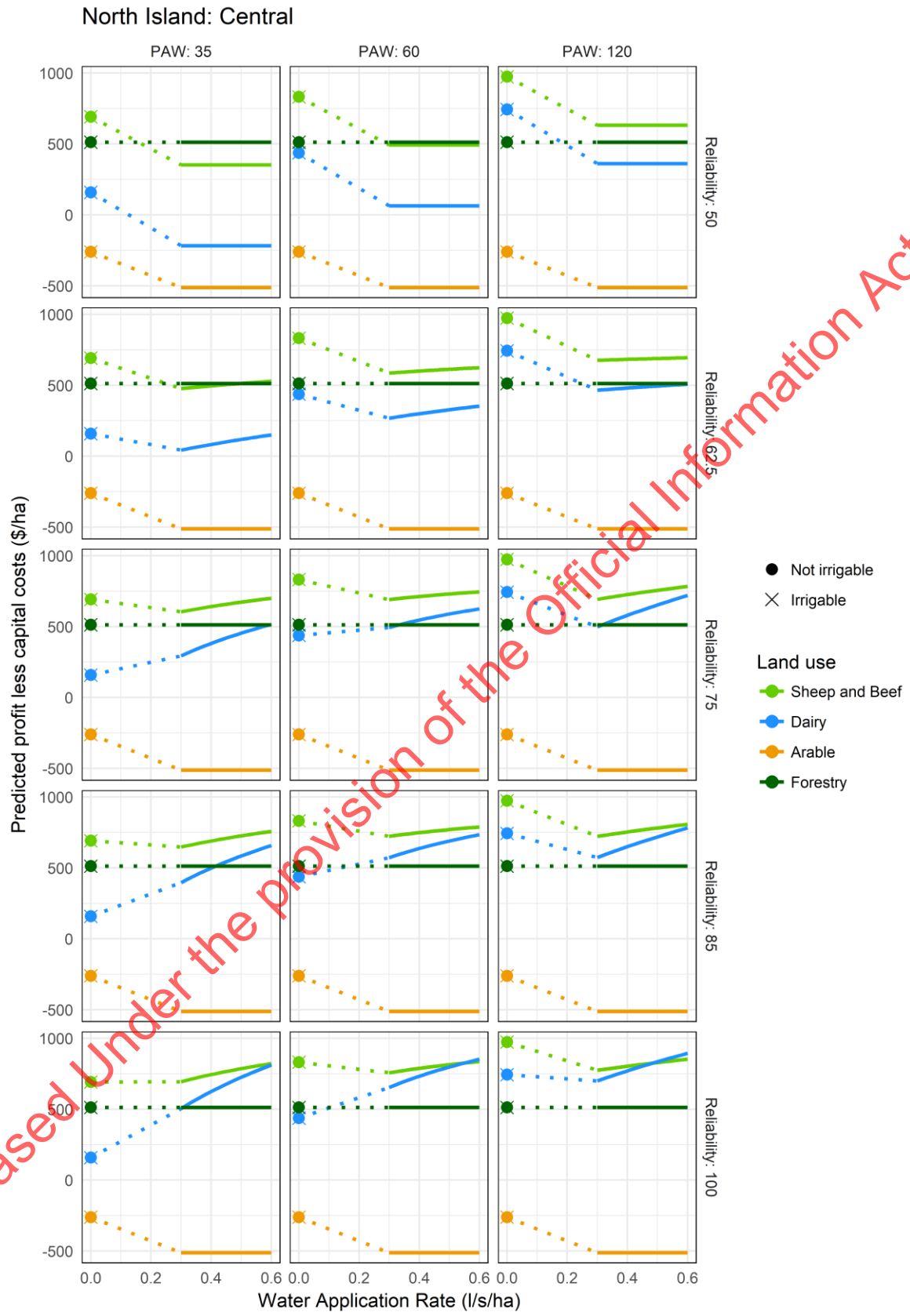
Released Under the provision of the Official Information Act 1982

Appendix E Summary Profit Curves by Region



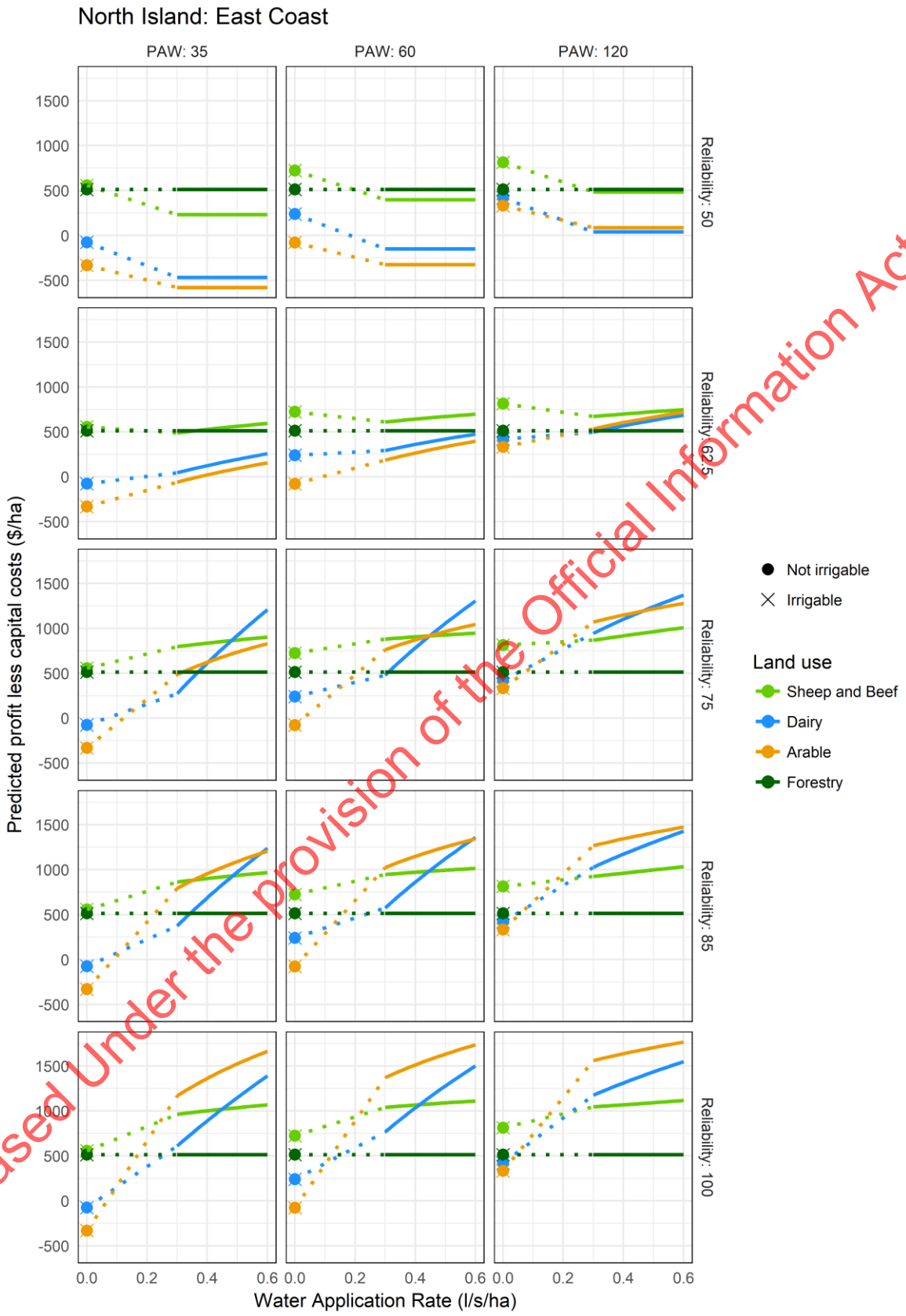
Released Under the provision of the Official Information Act 1982

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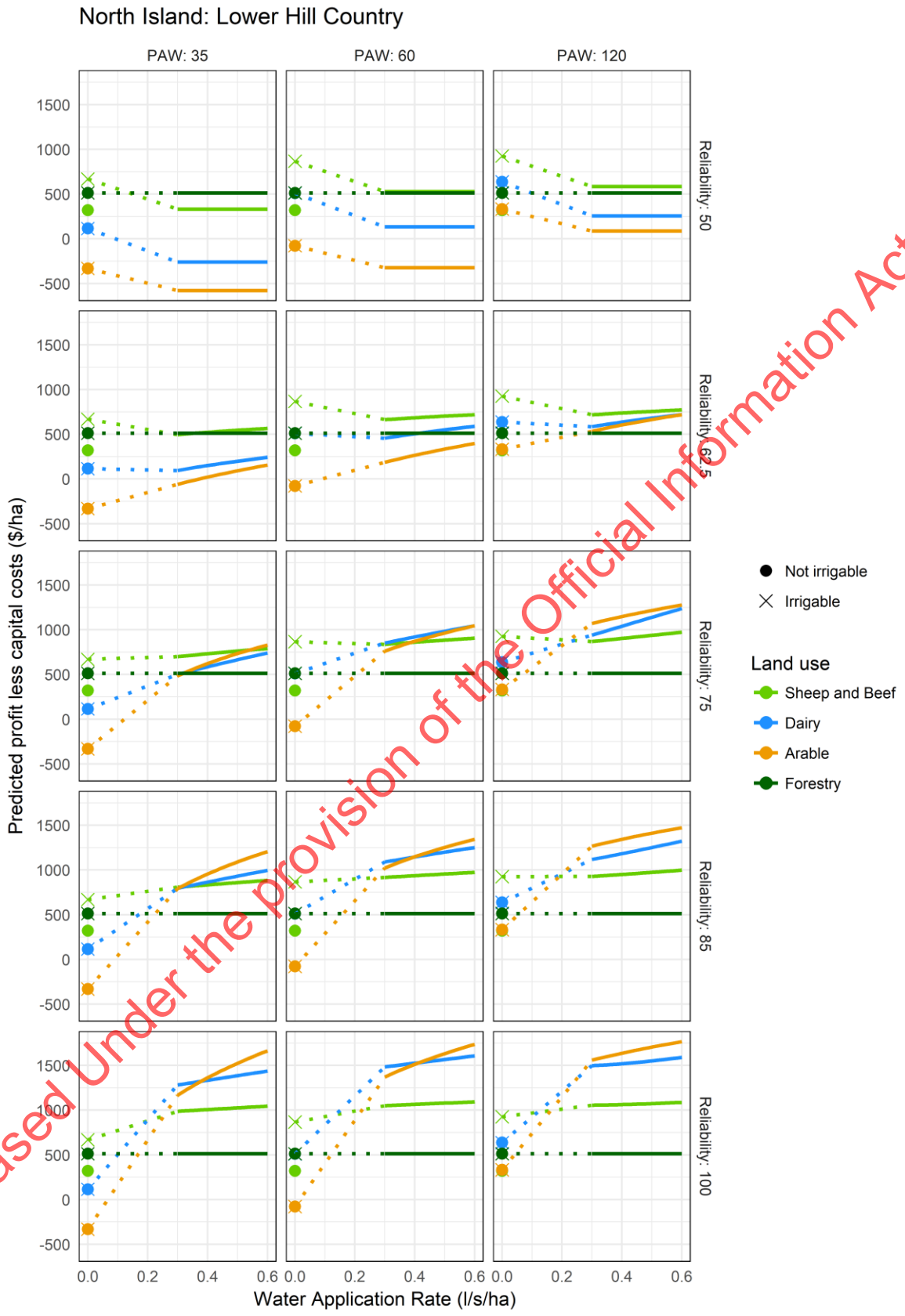
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20-D-00014



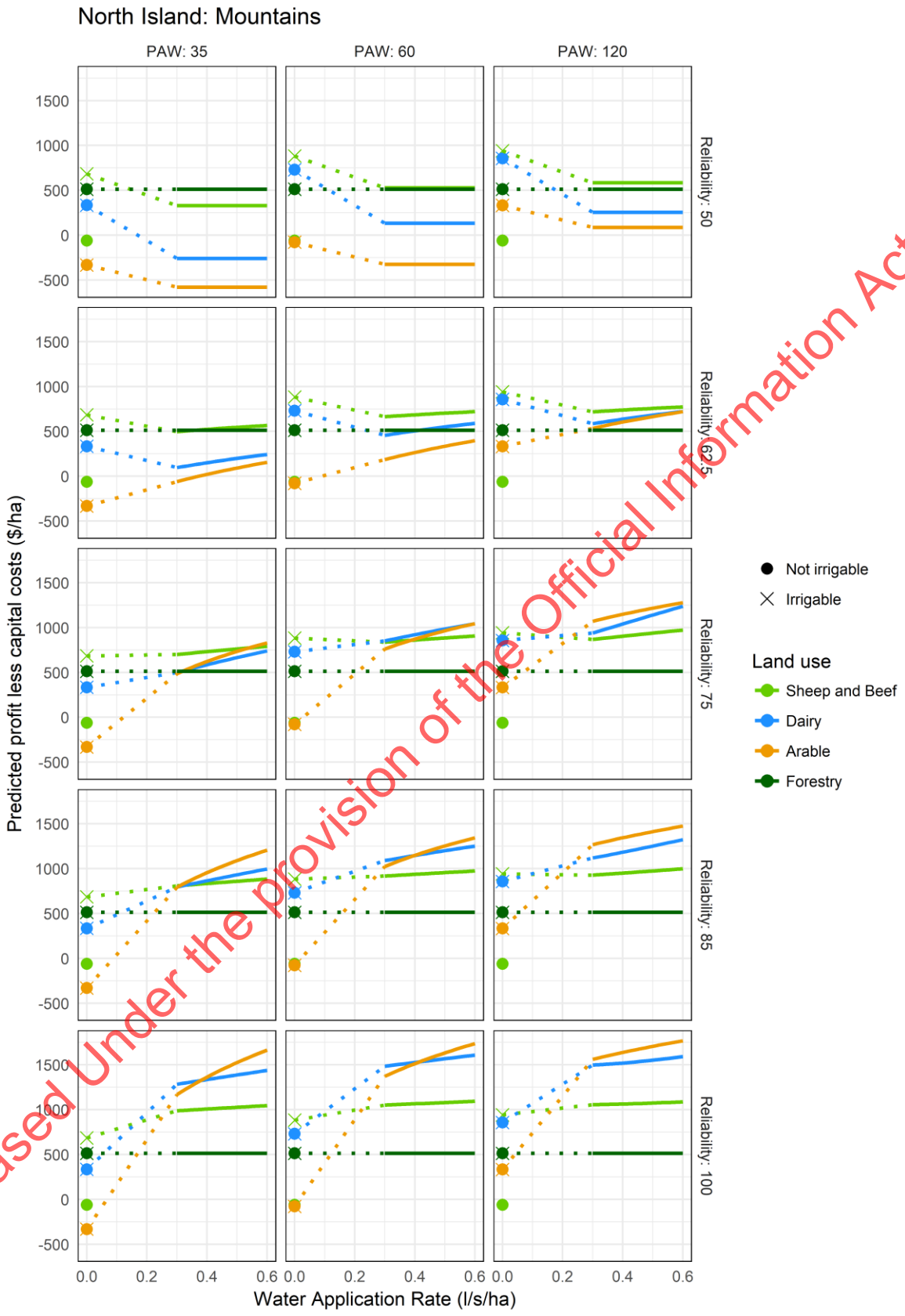
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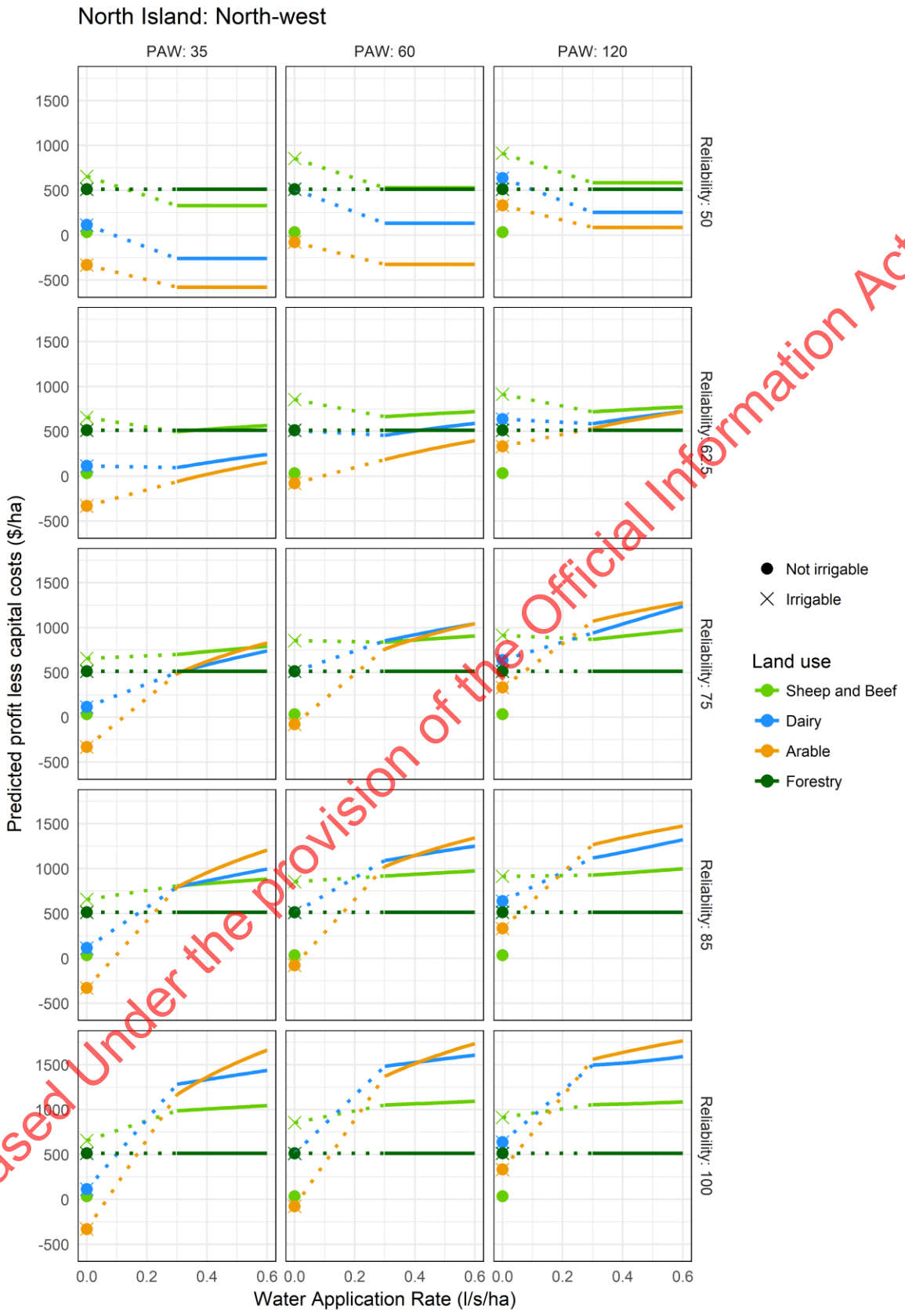
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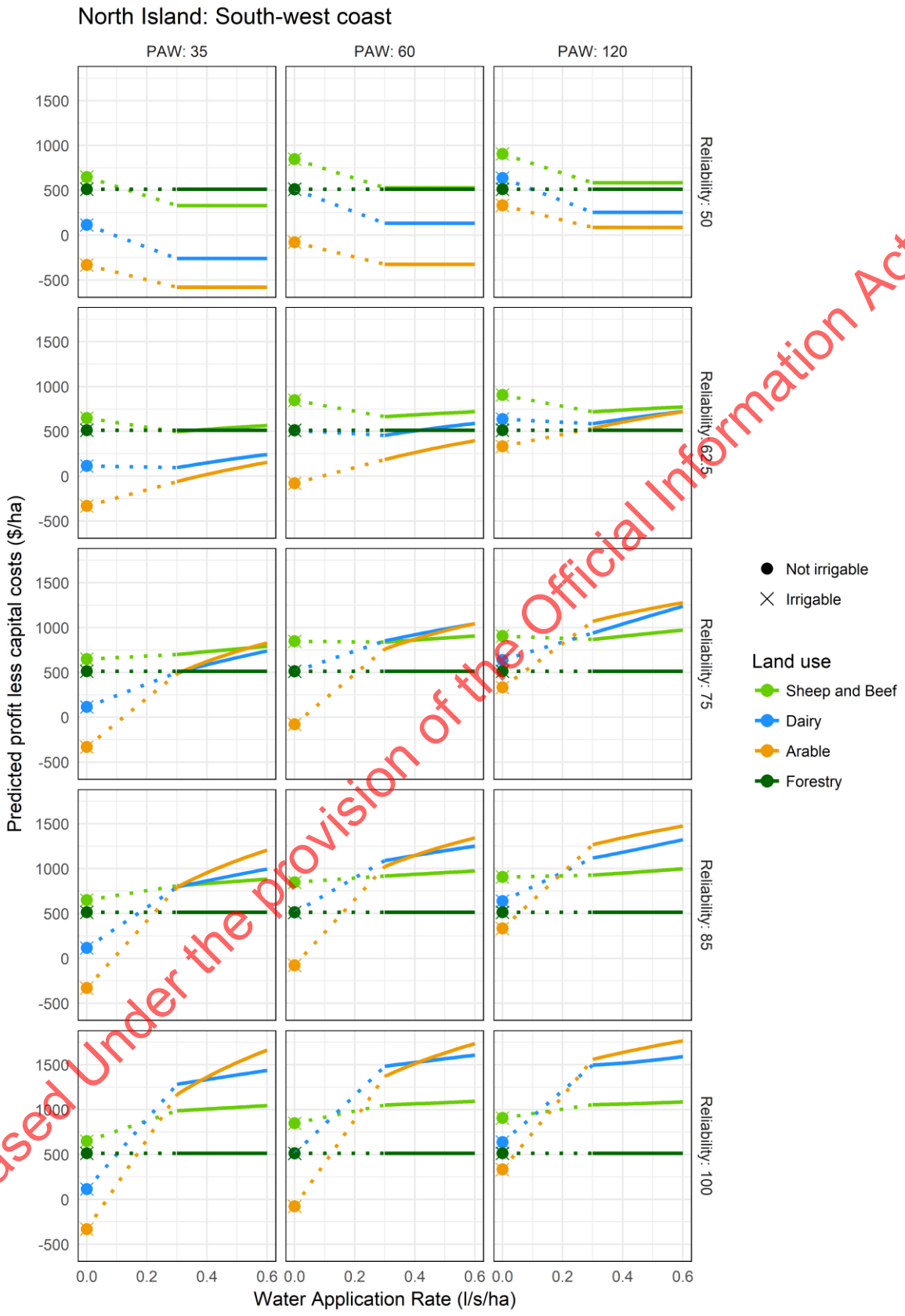
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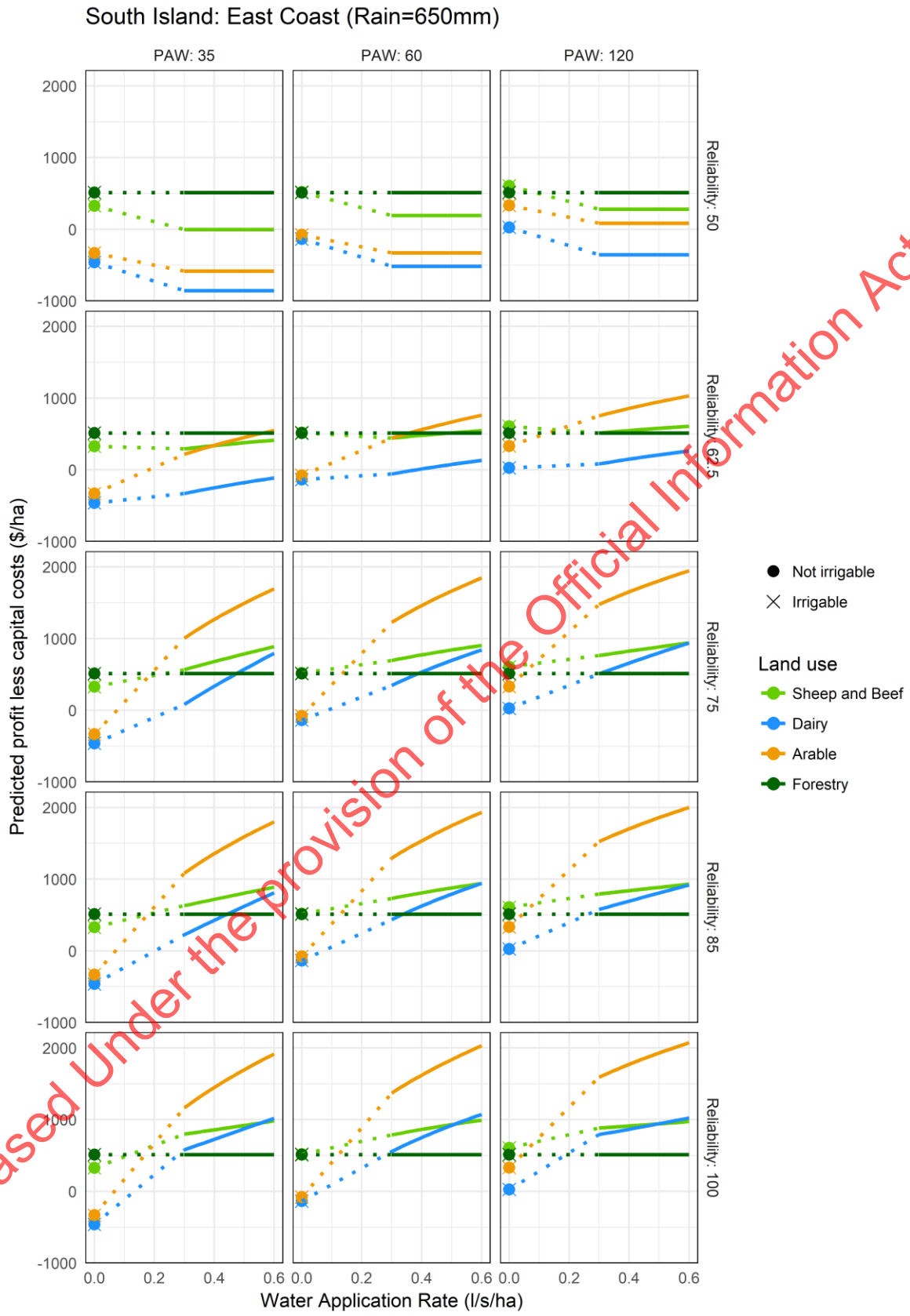
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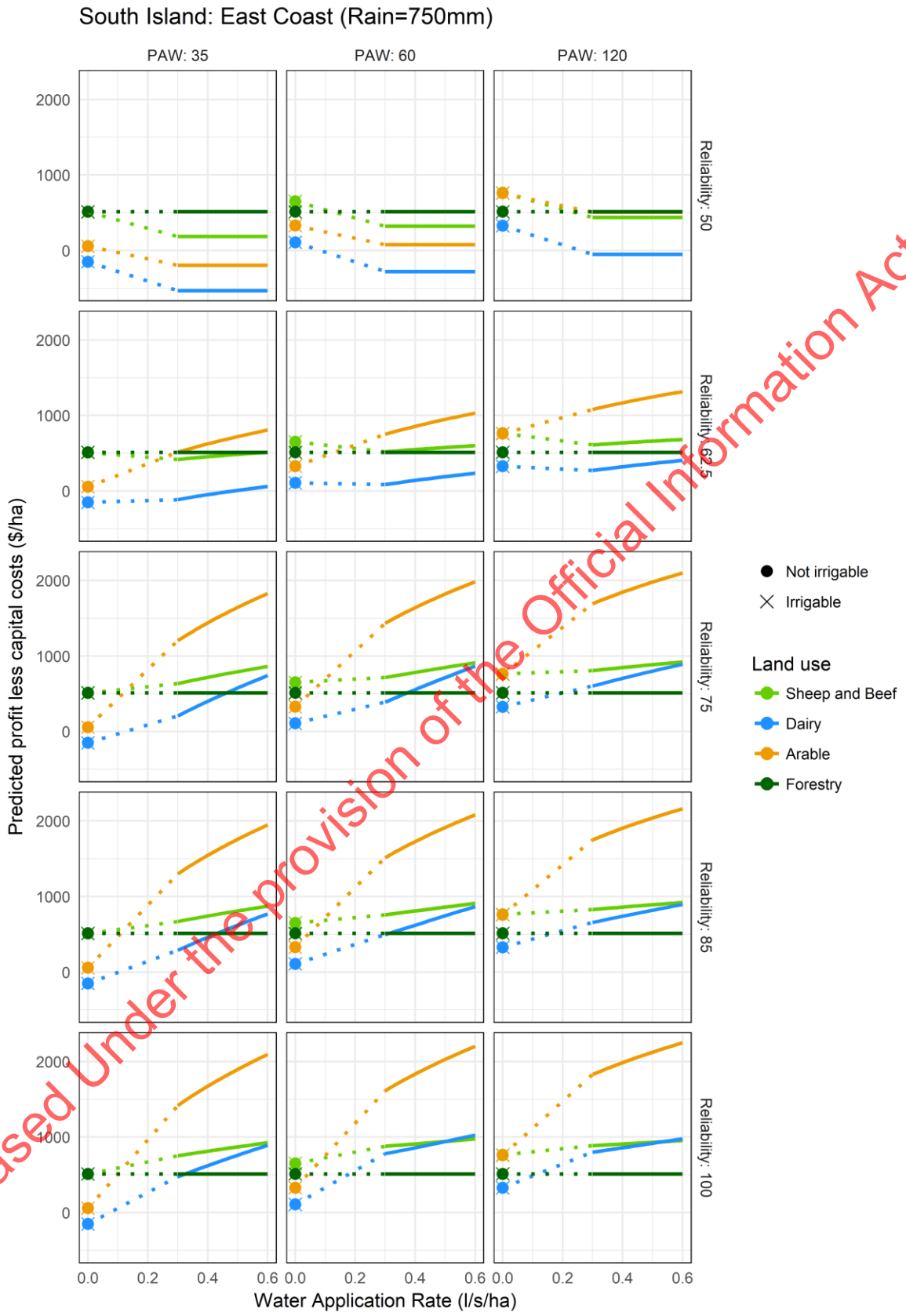
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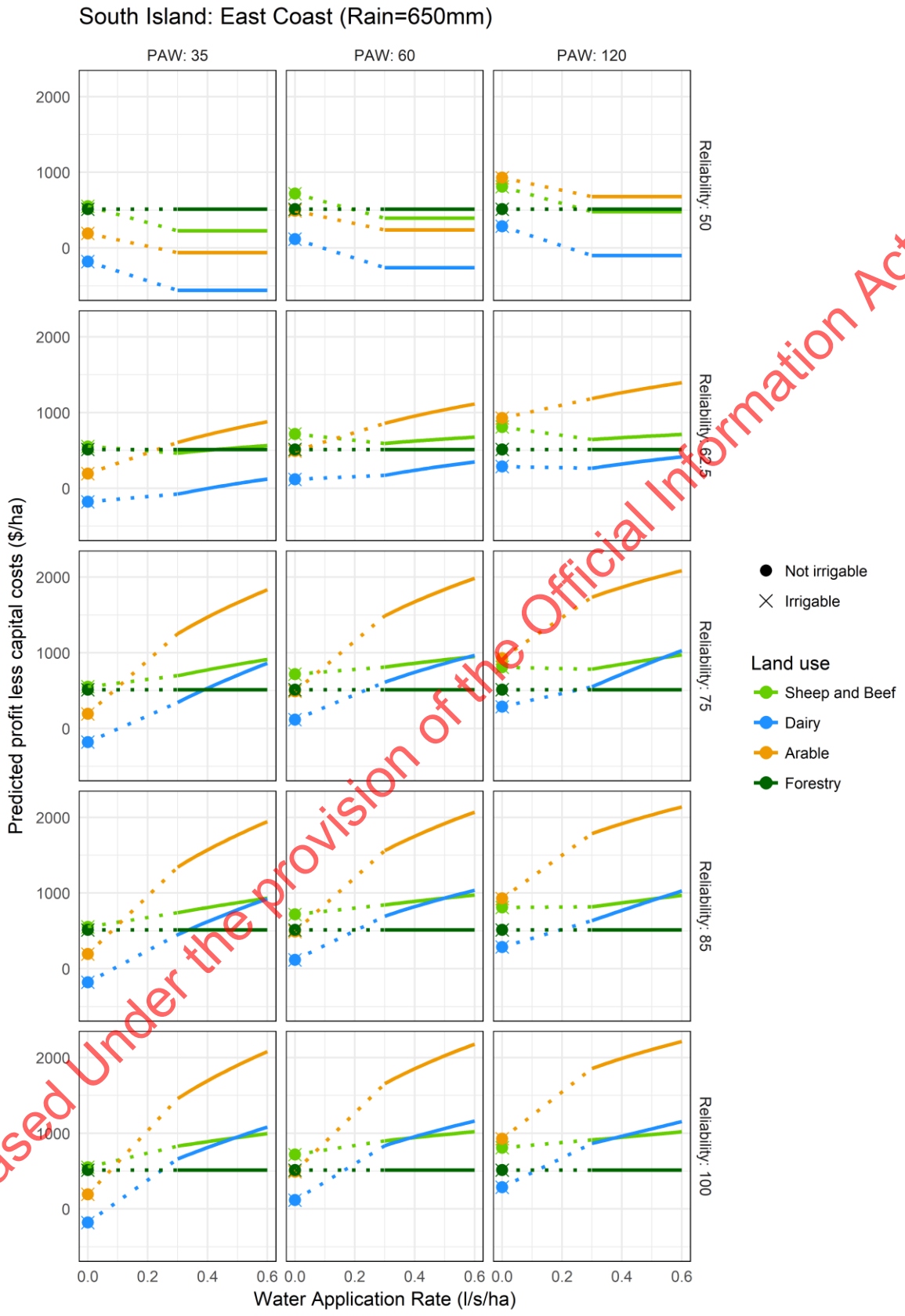
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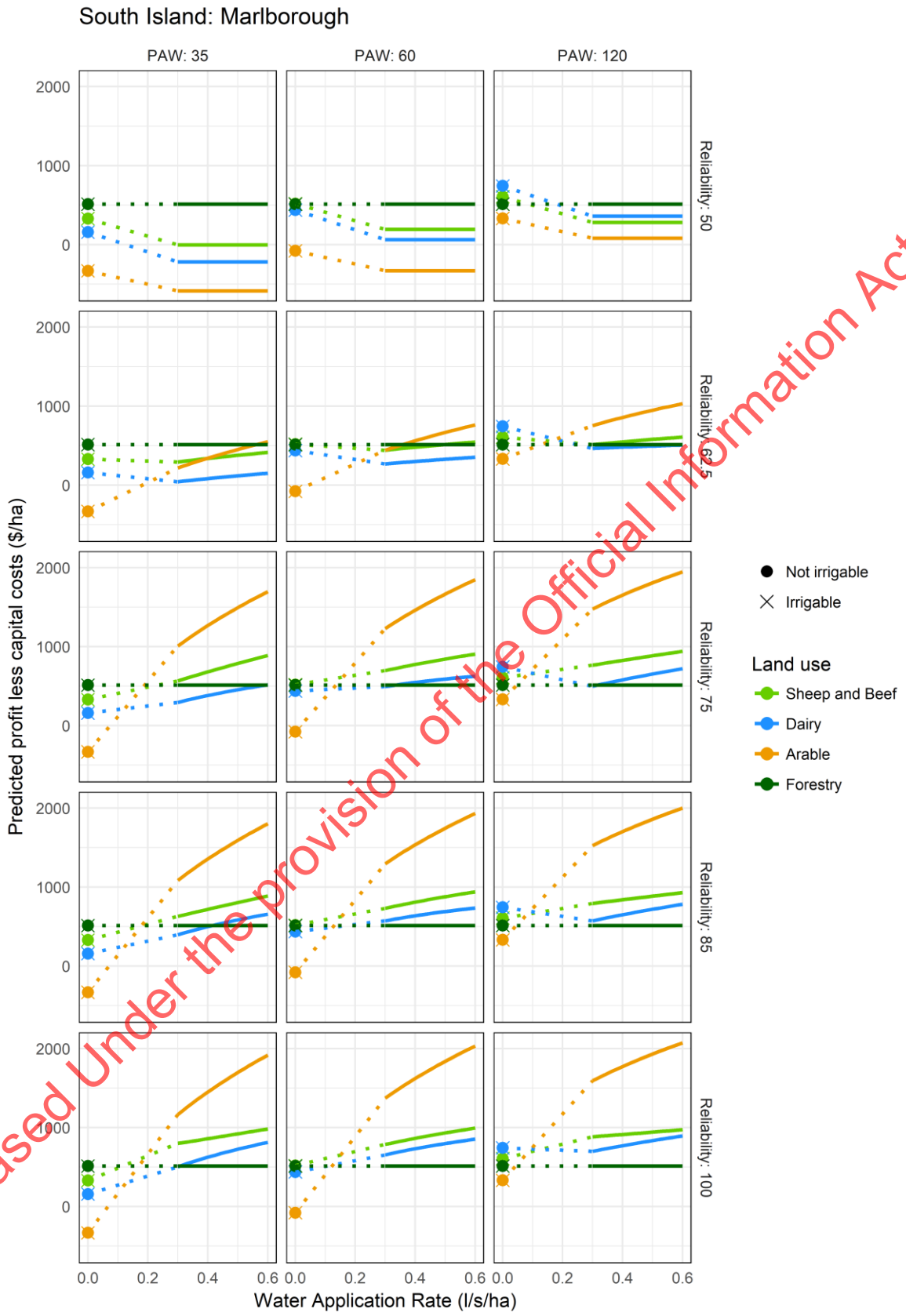
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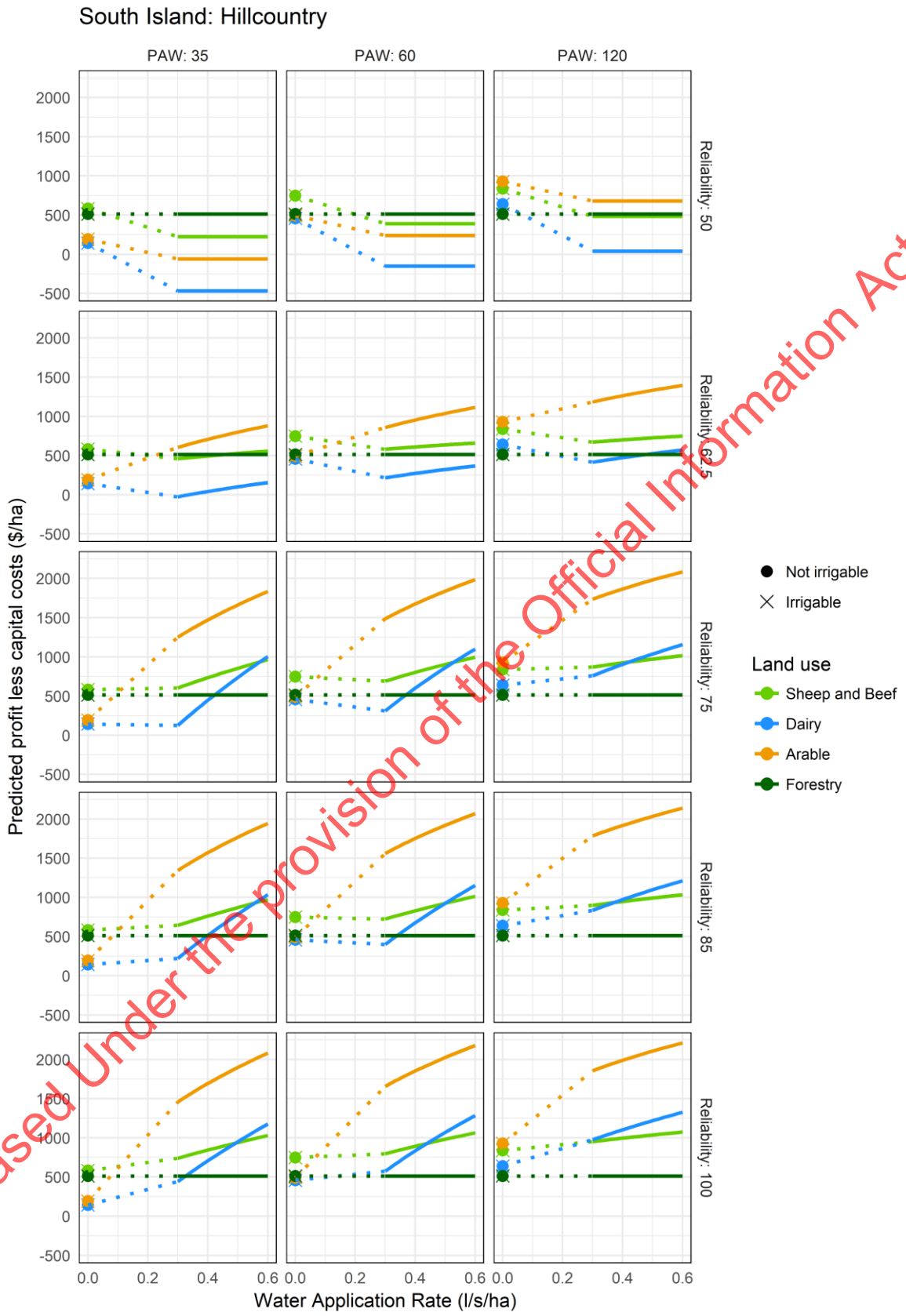
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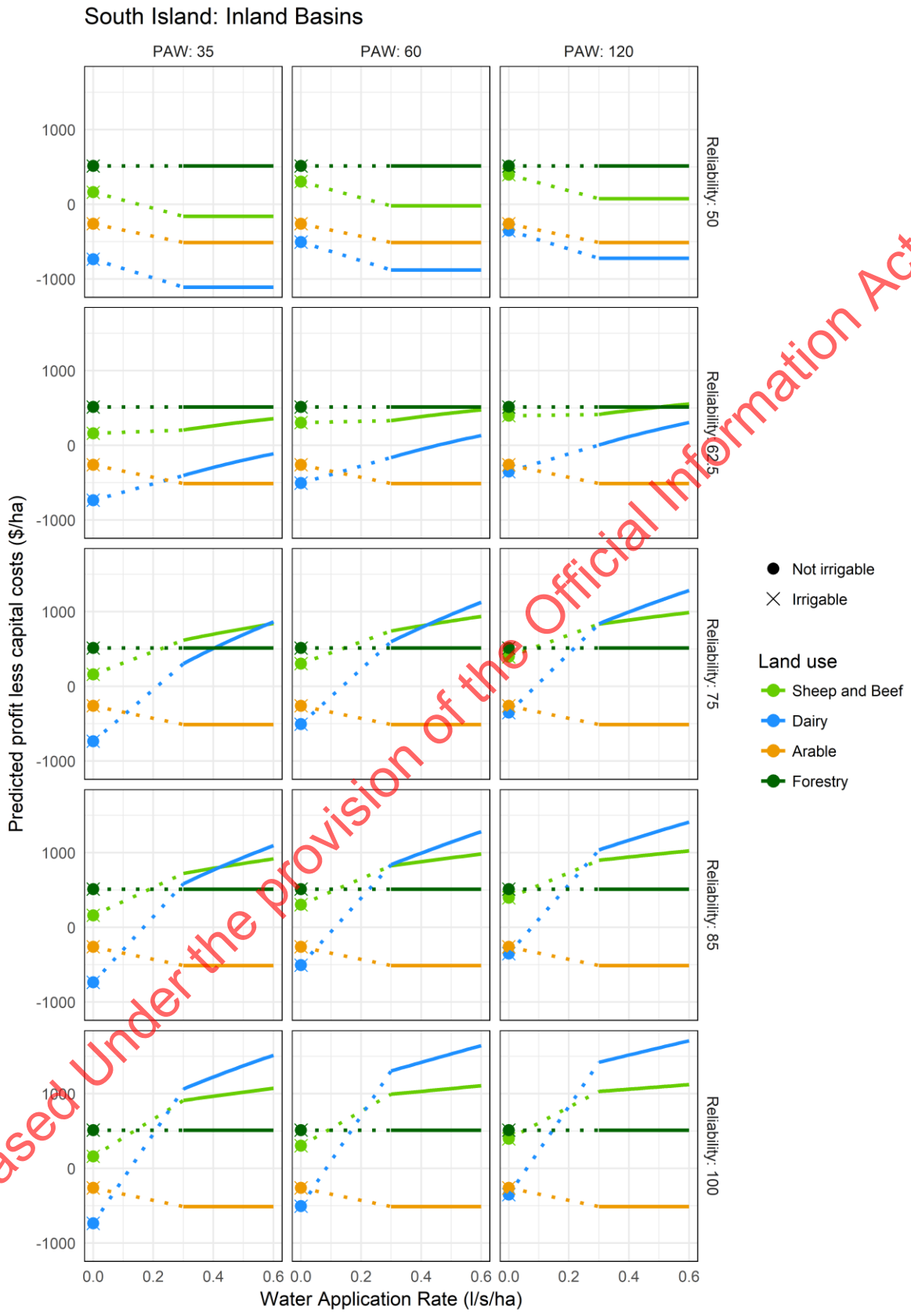
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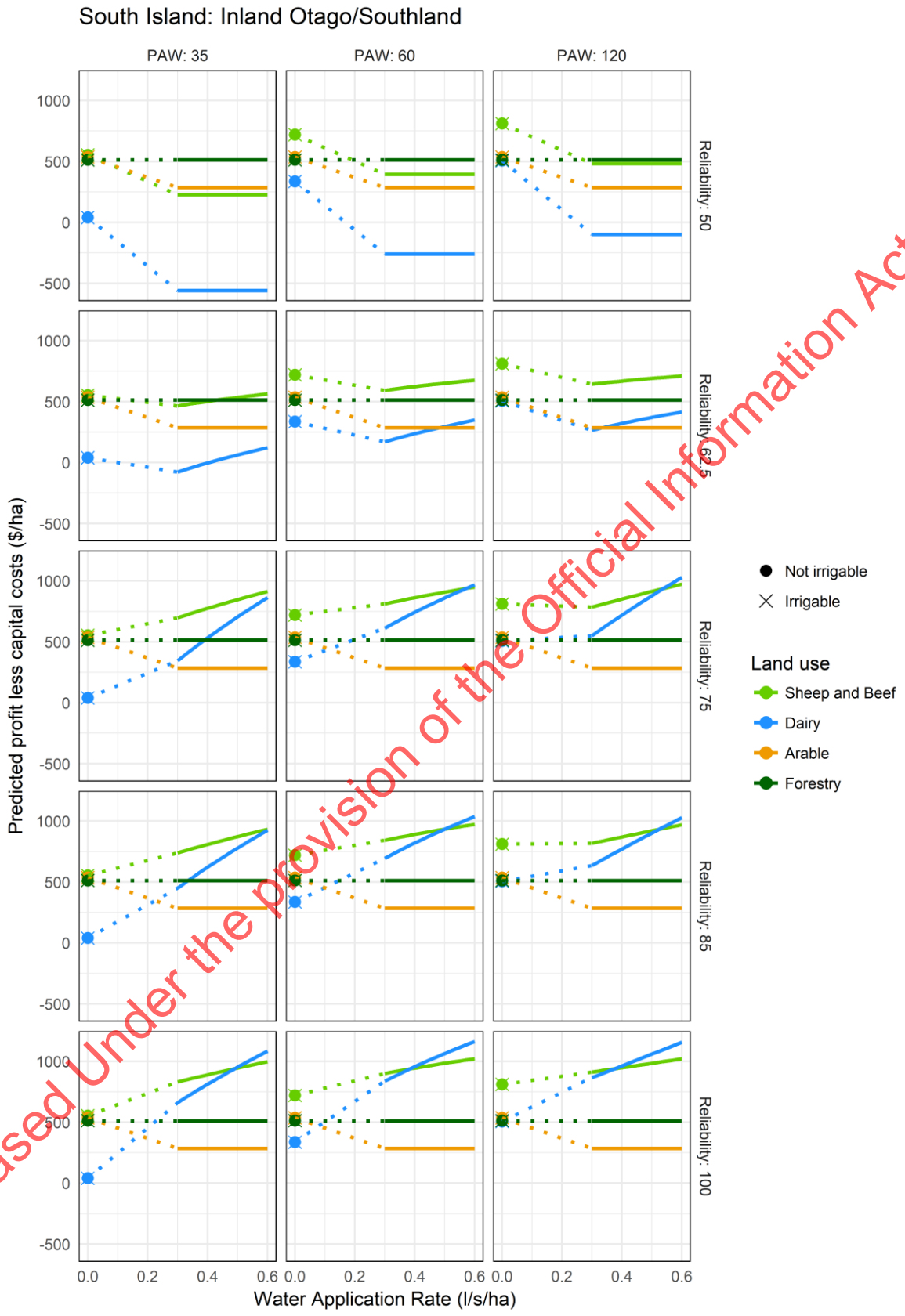
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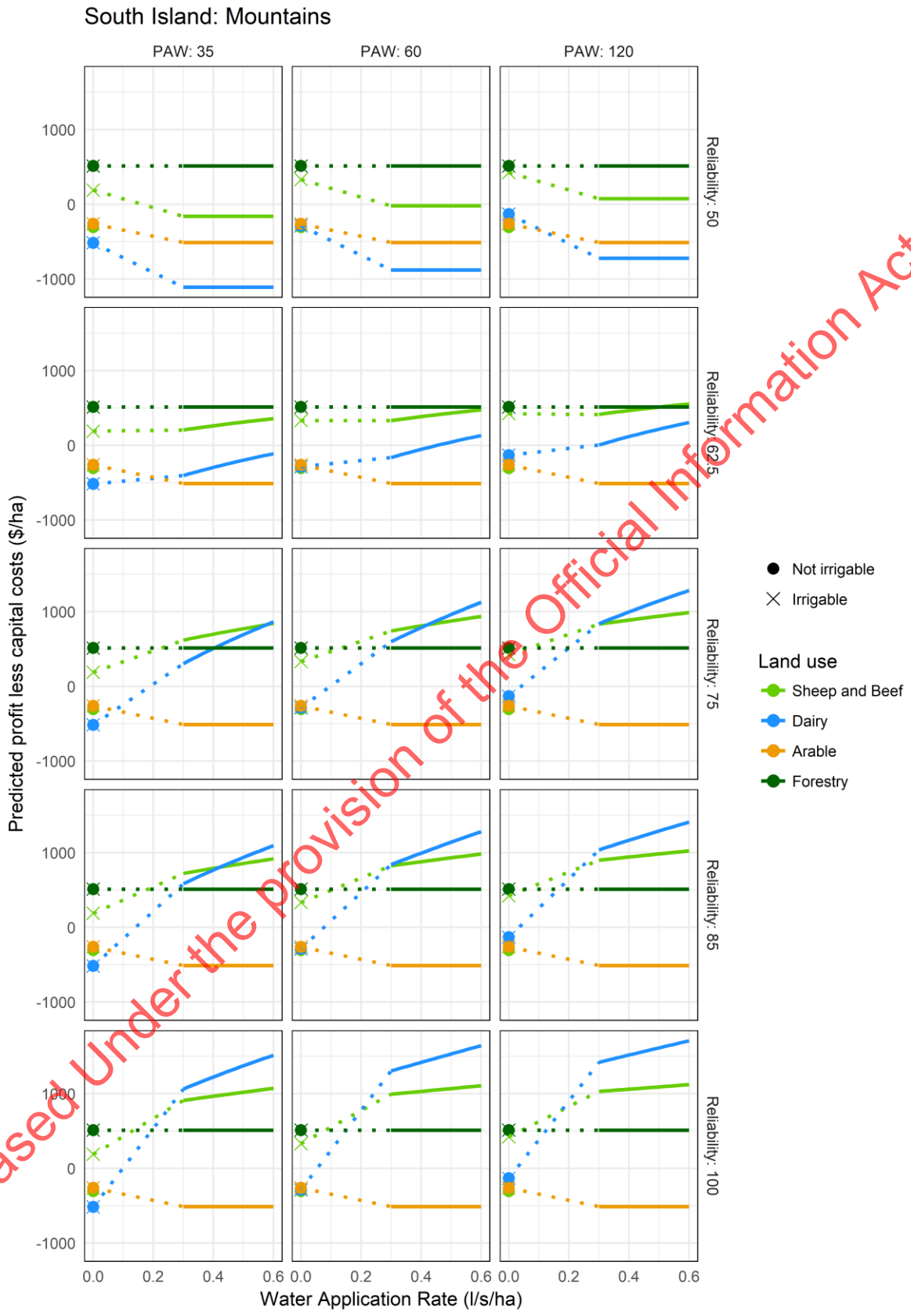
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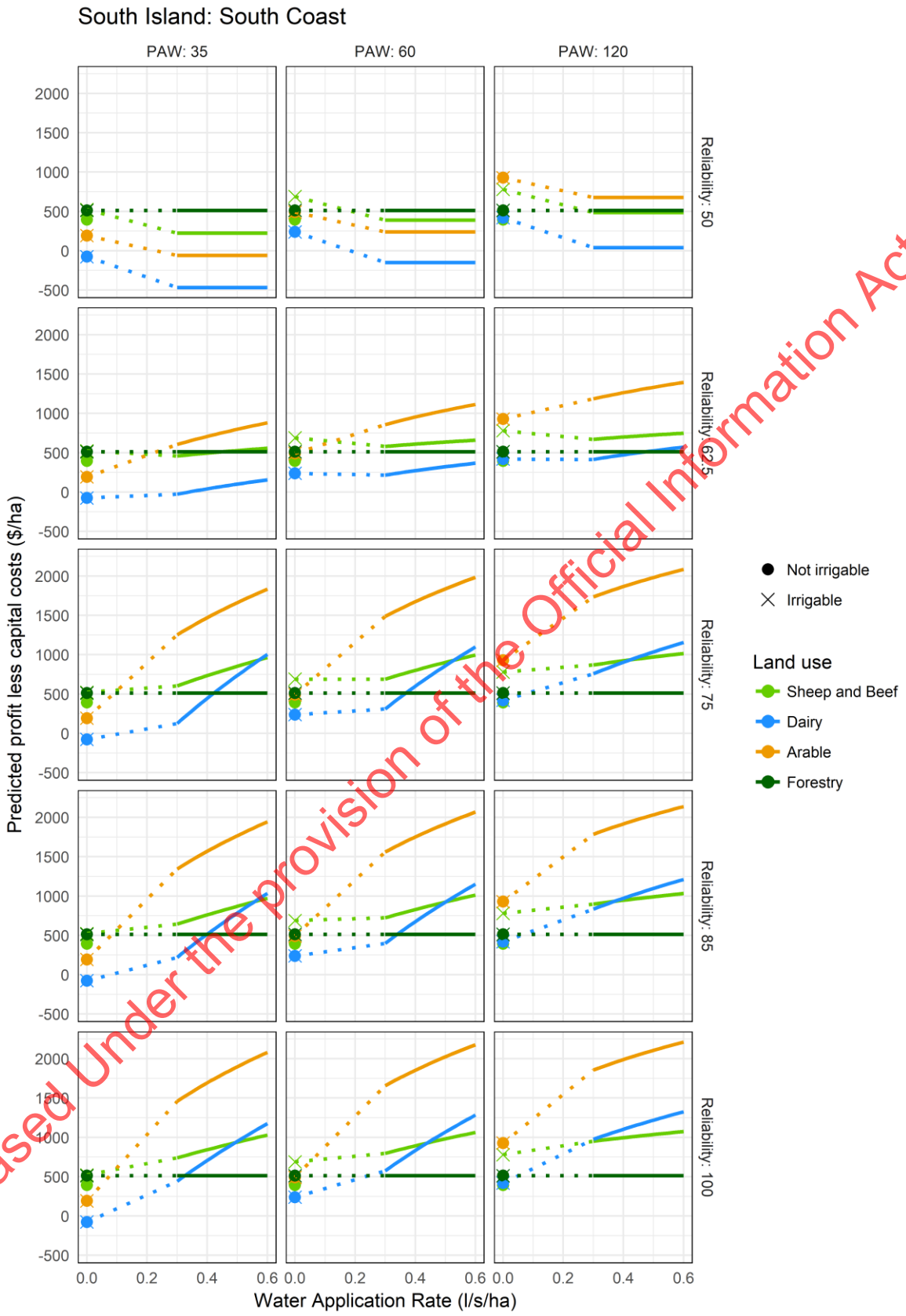
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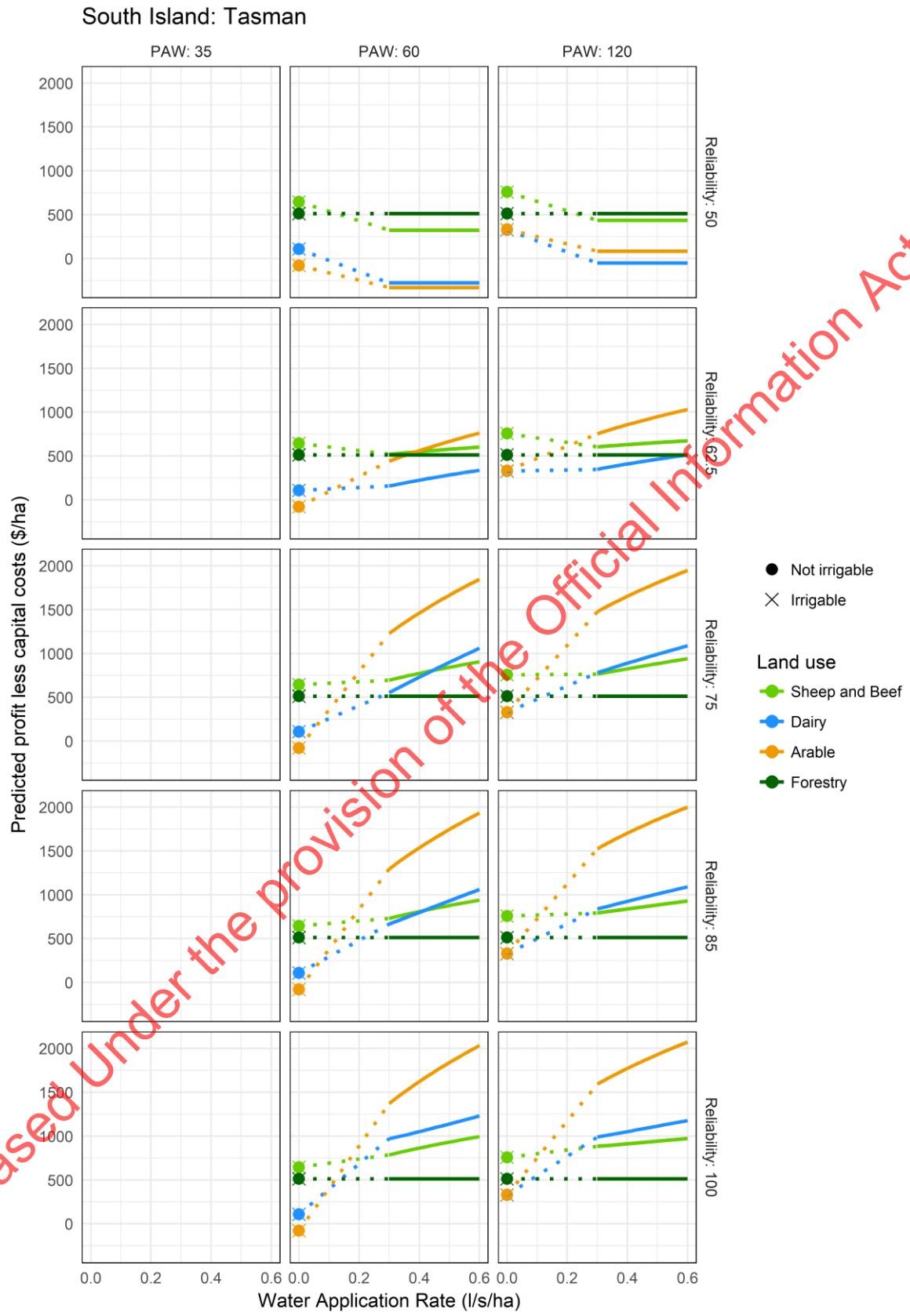
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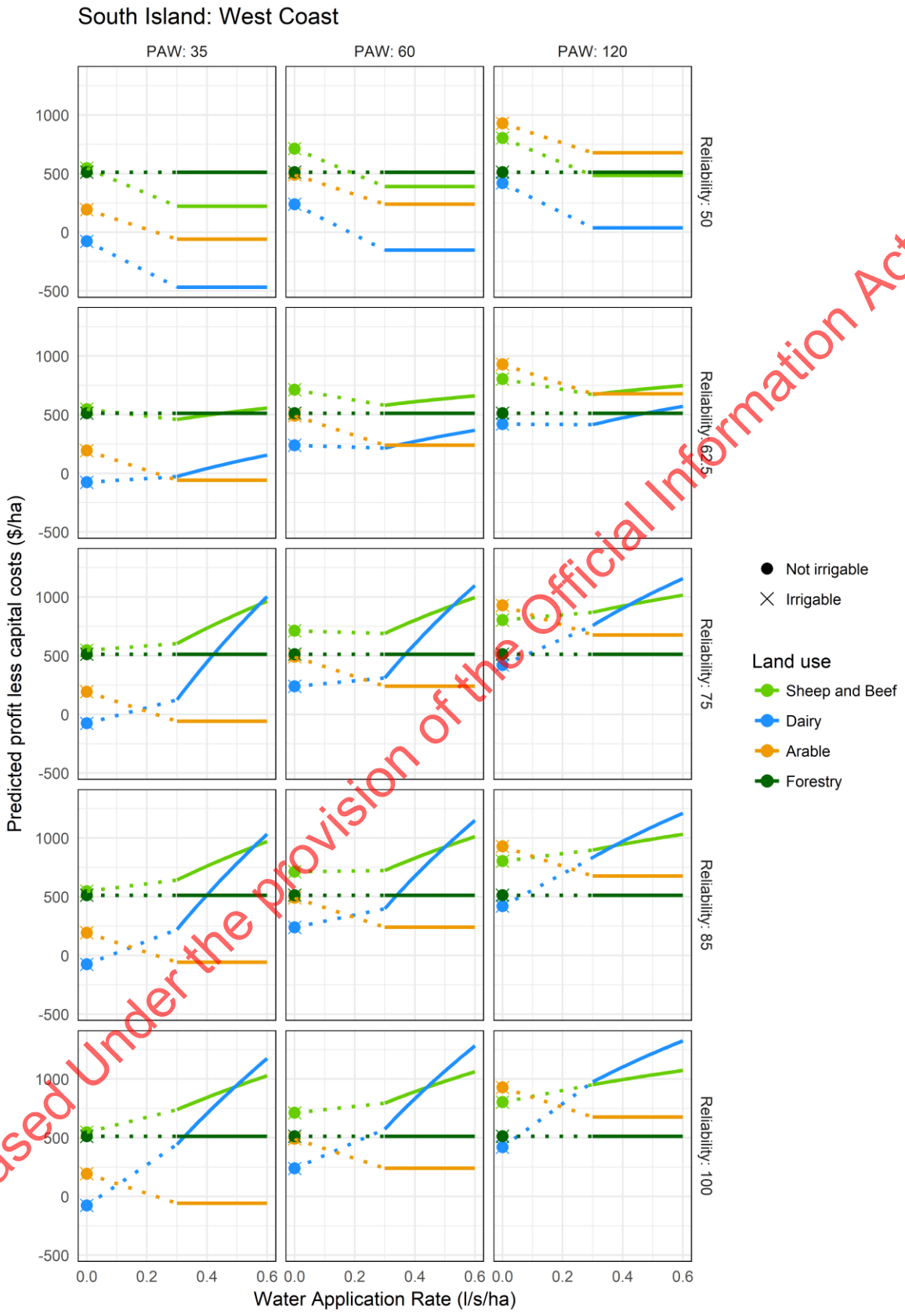
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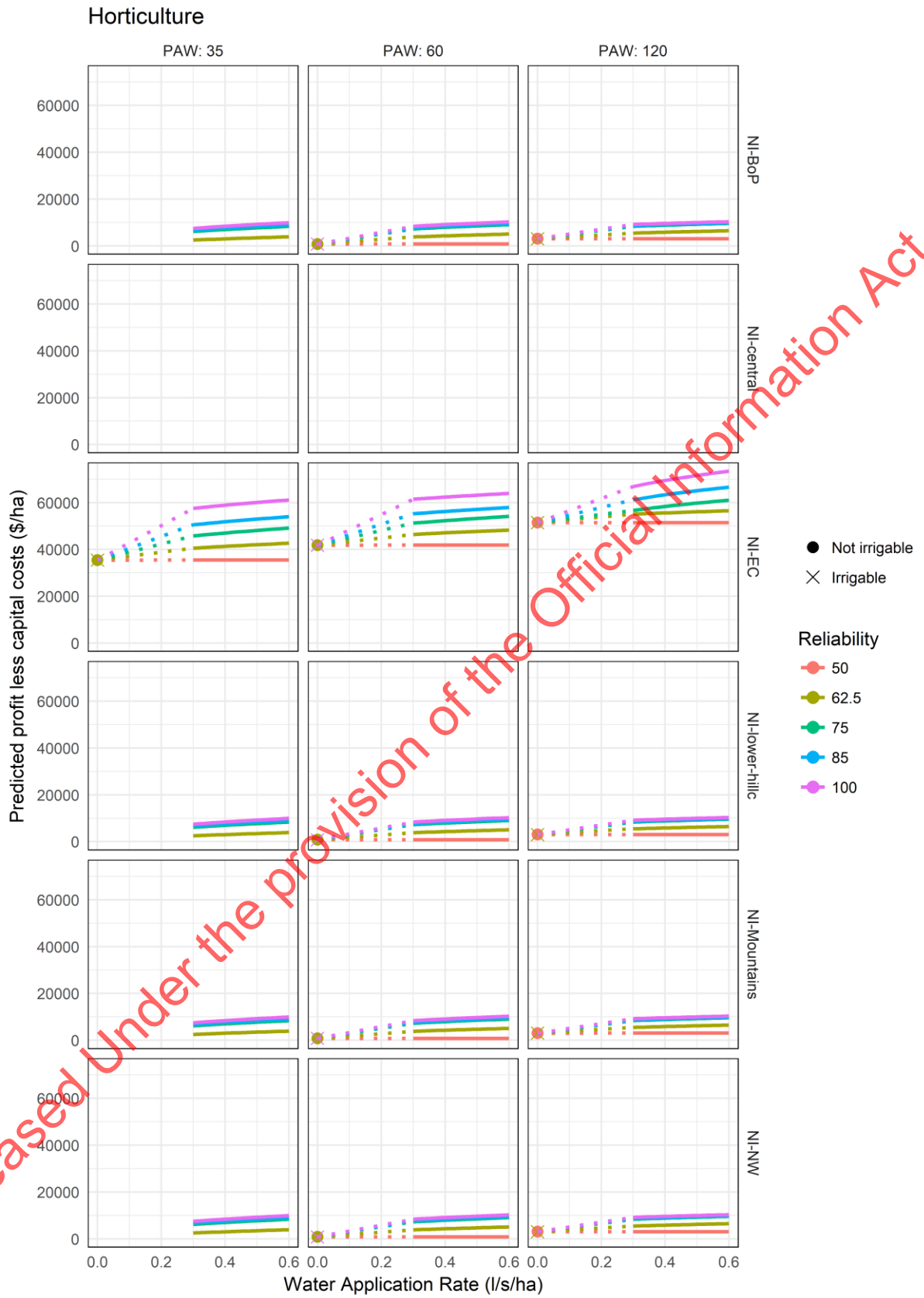
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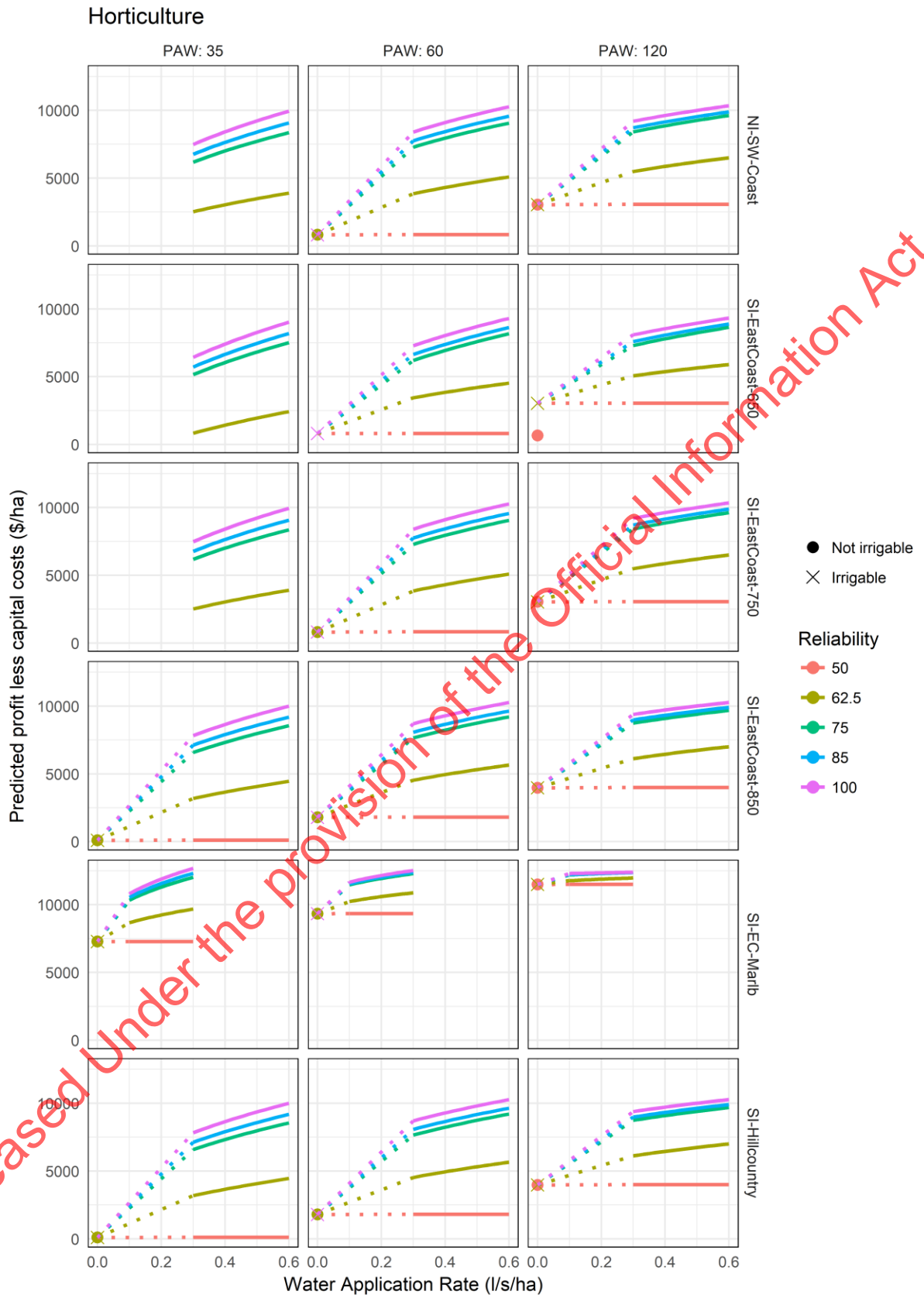
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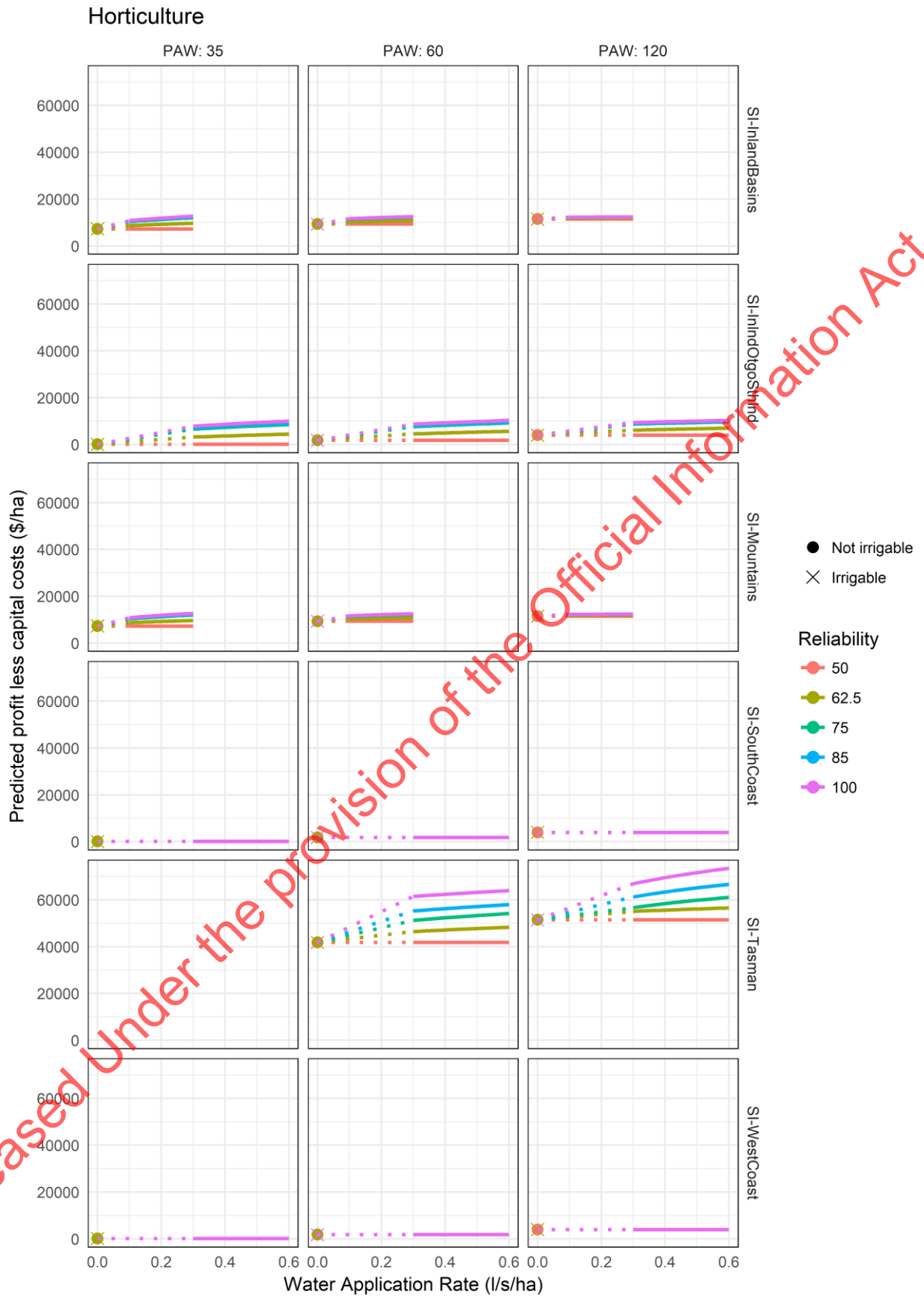
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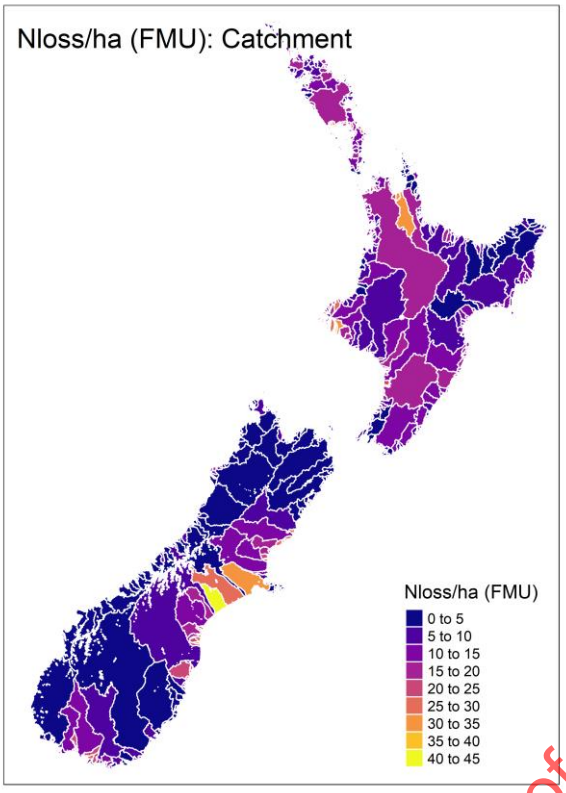
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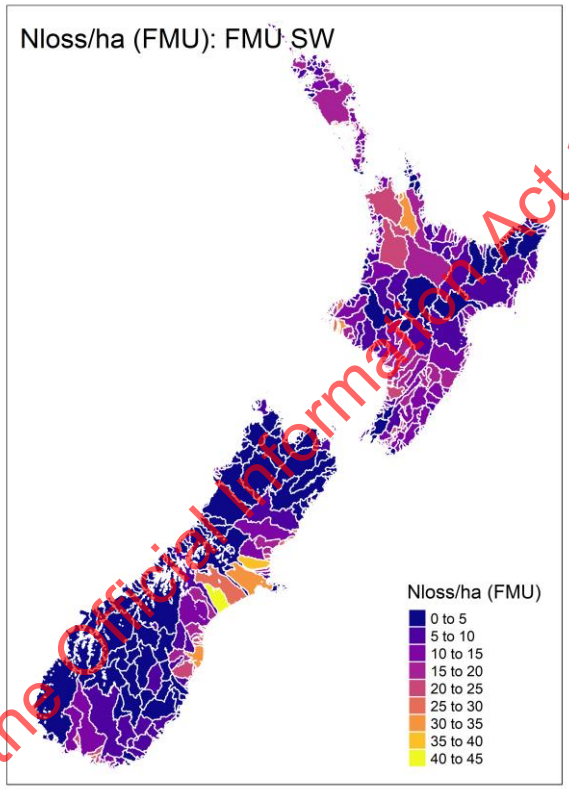
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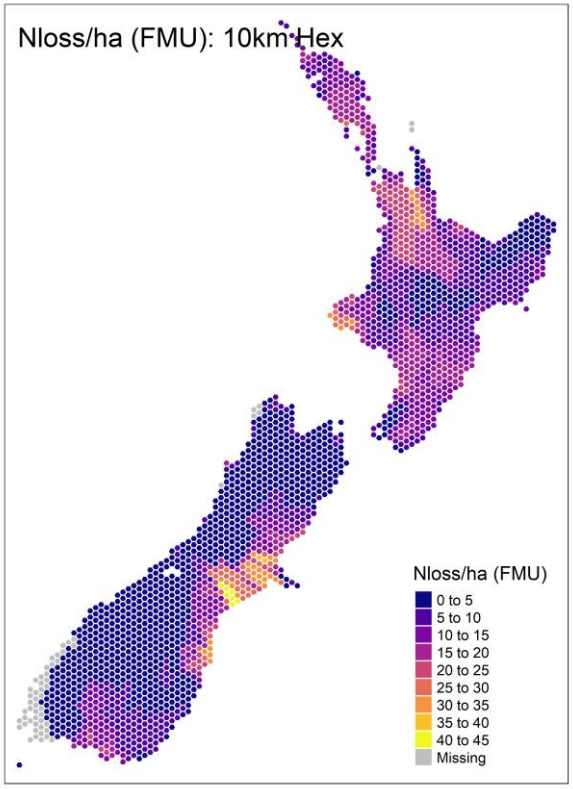
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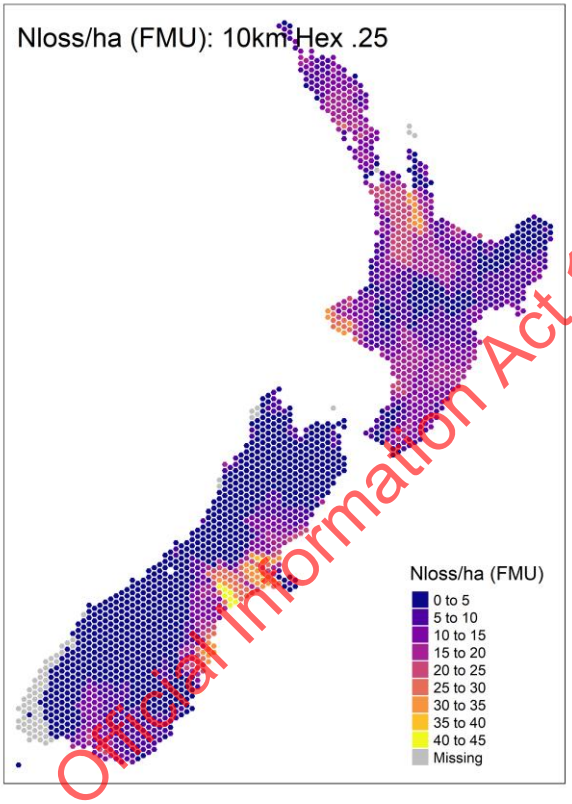
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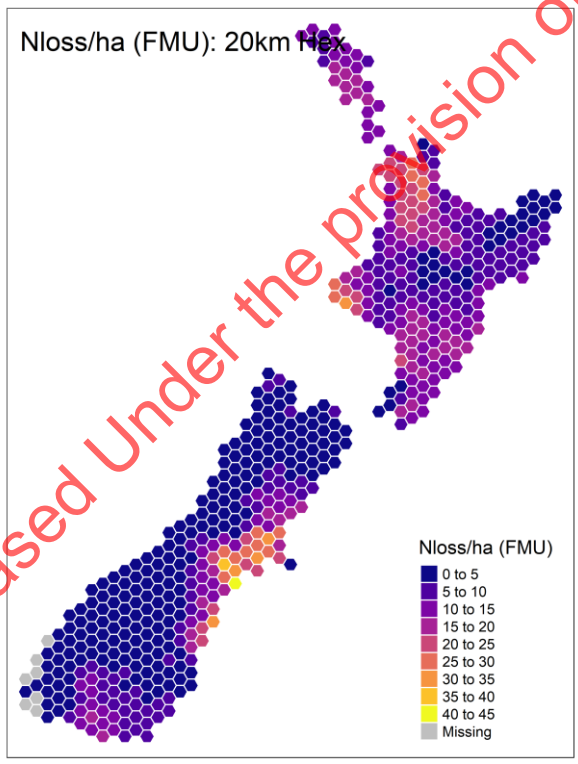


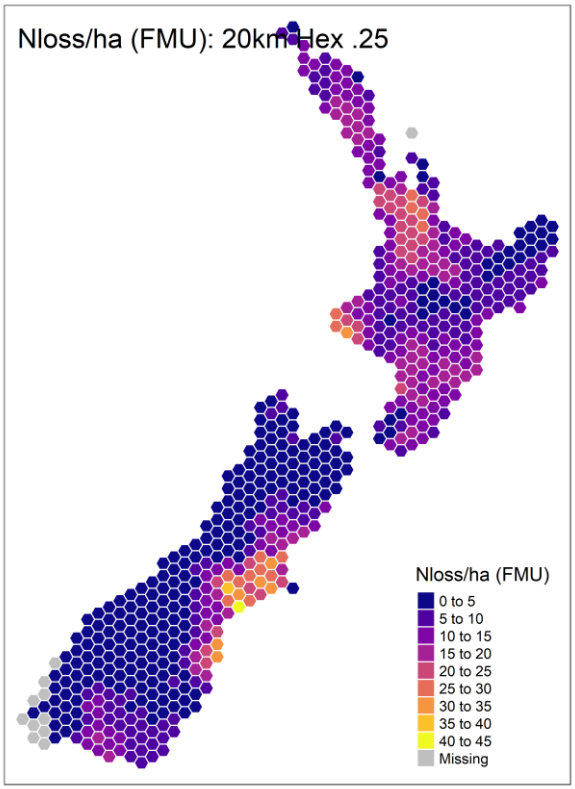


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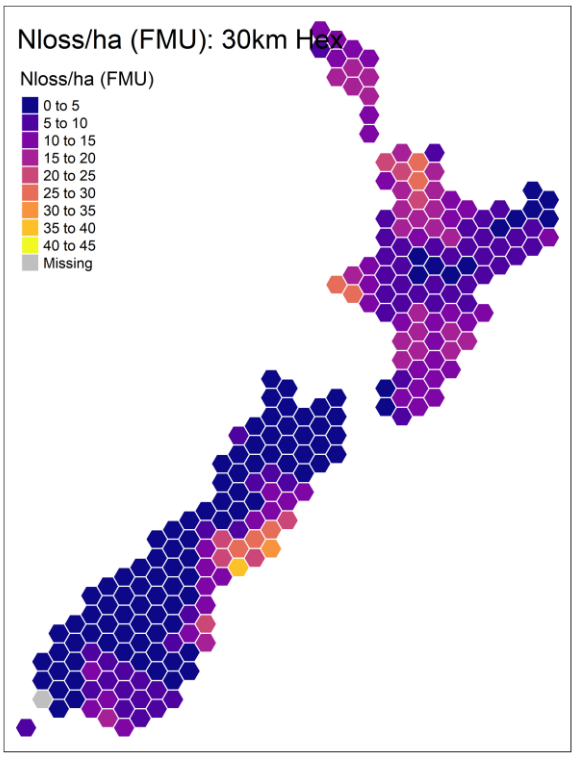


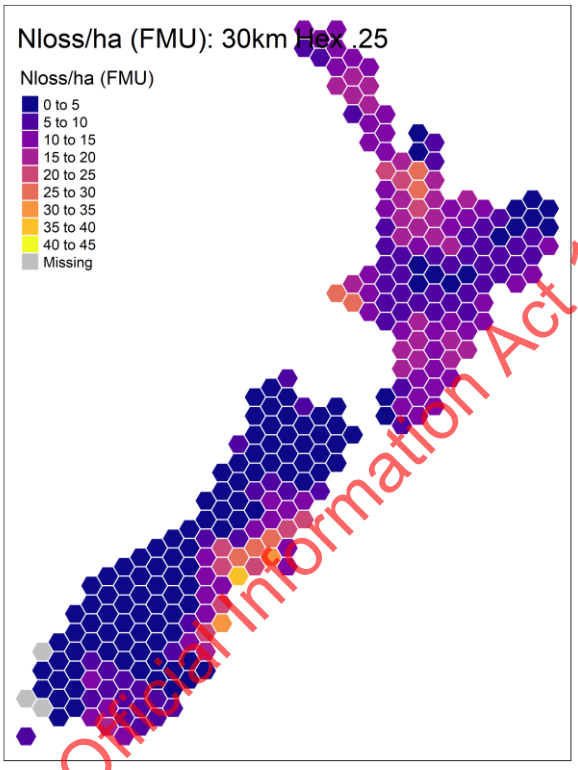


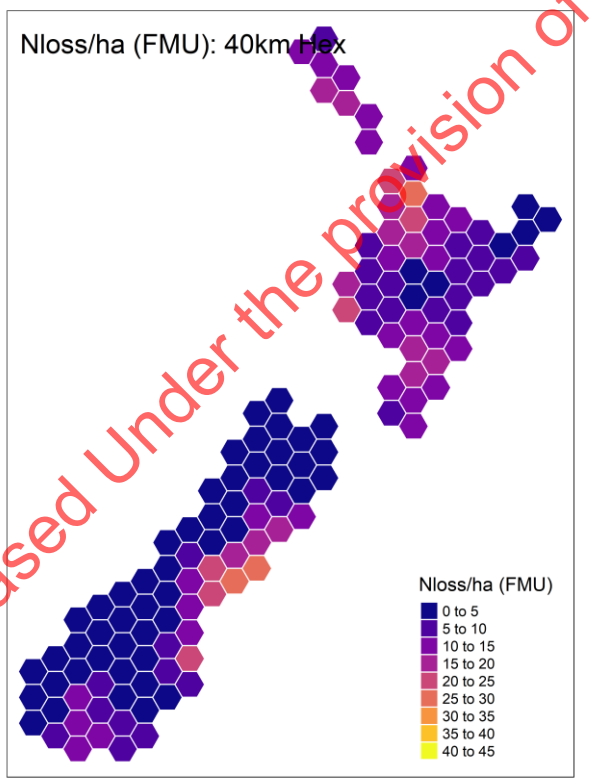


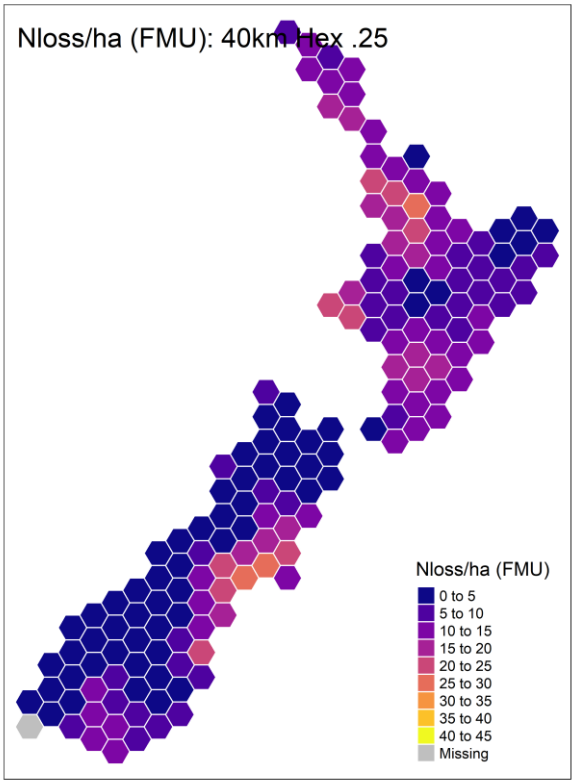


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National Allocation Model – Draft

Part 1 – Model Description and Results

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1 Introduction

MFE wishes to assess a range of potential policy options for allocation of rights to take water or discharge contaminants as part of a wider programme looking at the potential for national level intervention in this area. To do so it requires analysis of the economic implications of different policy options, and consequently a national scale model of allocation. The National Allocation Model is intended by MFE to be both detailed and comprehensive, both in terms of technical requirements and spatial coverage, and will deliver information to support the government in developing national level policy regarding water and nutrient allocation. It is intended to cover a range of uses and to provide information on the impact for Māori owned land.

This report describes the development and testing of the model for the national scale economic analysis, and outlines the results and their implications. The report follows on from a 2016 report (Harris, Fraser, & Dey, 2016) on the prototype model, which identified the availability and suitability of appropriate datasets and their interoperability, and demonstrated the types of outputs that can be produced from the modelling.

The analysis in this report is reliant on work undertaken by Aqualinc Research and the AgriBusiness Group in Part B of the project on profitability, water use and Nitrogen (N) loss across a range of water uses. This report should be read in conjunction with their report [REFERENCE].

This report assesses five allocation scenarios and the baseline. These are:

- Baseline (current land use and allocation)
- Current allocation approach – the current allocation projected forward to allow for land use change without reallocation of water or N.
- Land based allocation – the allocation of water and nutrients according to the relativity in the inherent requirements of a land parcel under full productivity.
- Māori land development – the reallocation of water and nutrients to Māori land to allow full development.
- Transfer markets – allowance for full transfer of water and nutrients within the constraints of hydrological integrity, to maximise profit from the resource use.
- Volumetric pricing – a charge on the use of water.

The report describes the development of the model to assess these scenarios, and provides information on the results generated together with some commentary on the implications of the outcomes. The report should be read in conjunction with the companion Appendices (Fraser, Harris, & Dey, 2017) which contains more detail on the method and a full set of results from the model.

There are five elements in our approach:

- Definition of FMUs
- Subdivision of the FMU into modelling agents
- Integration of profit function

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- Modelling the economic outcome of allocation
- Provision of outputs.

Each of these is discussed further in the following sections and an overview of the method is shown in Figure 1 below.

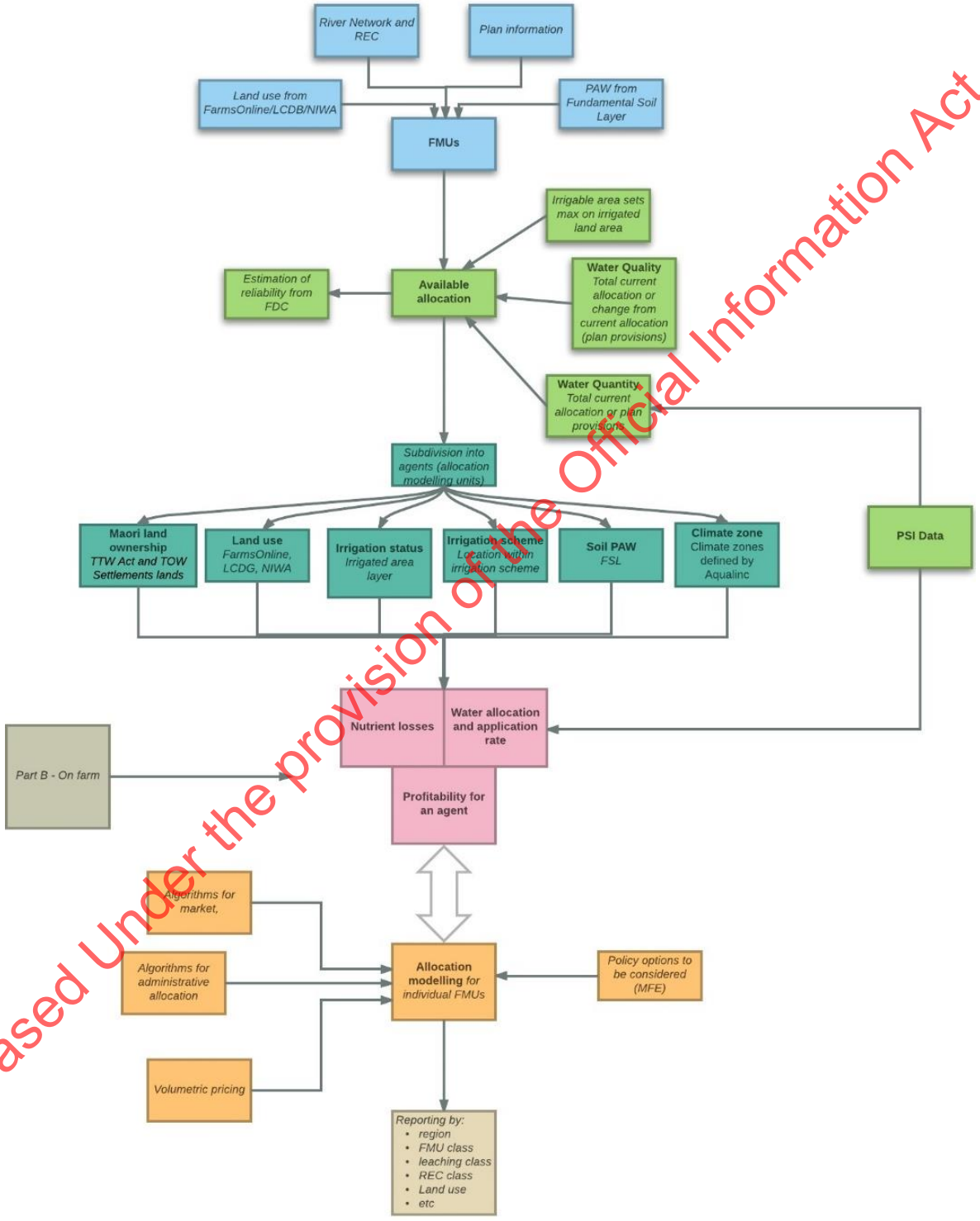


Figure 1: Overview diagram of proposed method

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1.1 Definition of Freshwater Management Units (FMU)

Our approach recognises that allocation of permits occurs within limits that are defined at the FMU level – FMU[1] are a subdivision of a catchment (or a whole catchment) which are sufficiently homogenous to ensure that a single set of policy requirements and regulations will deliver approximately the same outcomes from resource use. At a wider scale, the use of FMUs allows the analysis to recognise the reality of allocation in the New Zealand situation: there are many catchments of varying scale, with a high degree of fragmentation; there are upstream/downstream management constraints; and there are biophysical limitations to the operation of markets and other allocation mechanisms.

The model is based on catchments and FMUs which are defined through the digital river network (Snelder & Biggs, 2002). The digital river network defines all waterways (and their catchments) in the country as a connected network of reaches. Based on the digital river network there are ~11,500 sea draining catchments in New Zealand (see Table 1). We exclude any catchments with less than 100ha of horticulture or less than 200ha of other productive land uses, which leaves ~1,400 sea draining catchments.

Table 1: Number of catchments by area in New Zealand (Source: digital river network, NIWA)

Area (ha)	Number of catchments
1 - 10	3
10 - 100	6923
100 - 1,000	3391
1,000 - 10,000	825
10,000 - 100,000	177
100,000 - 1,000,000	46
1,000,000 - 10,000,000	3
Total	11,316

FMUs are defined through various mechanisms, primarily using the Landcare Research report (Daigneault et al, 2016). There were 19 major catchments that were subdivided into 2 or more surface water FMUs (excluding Northland, where most sea-draining catchments were subdivided into 2 FMUs). These sub-catchment FMUs are shown as coloured areas in the Figure 2 below. There were some FMUs for which more specific data, such as the Ruamahanga where the FMUs (with a minimum stream order of 3) are as derived for Greater Wellington Regional Council as part of their limit setting process under the NPS-FM (Snelder & Fraser, 2015). FMU definition issues are discussed further in the Appendices.

[1] Freshwater Management Units (FMU) are the administrative units for which regional councils are required, by the National Policy Statement for Freshwater Management 2014 (NPS-FM), to set plan objectives and management outcomes. As such we believe that the national scale model should be capable of being run at least this sub-regional scale. FMUs can be whole catchments, or parts of catchments.

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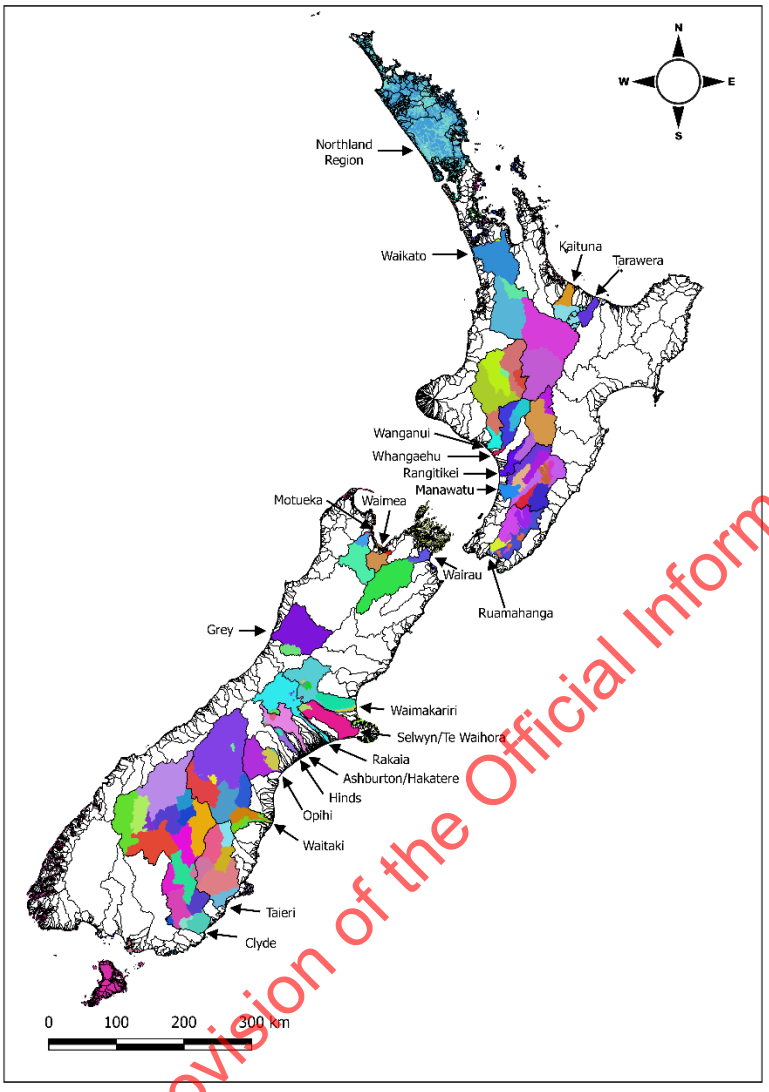


Figure 2: Freshwater management units

Most FMUs constitute an entire catchment as described in Daigneault et al (2016), but there are some, such on the West Coast, where the FMUs cover multiple catchments. In these cases the catchment becomes the primary allocation unit (see below).

1.1.1 Estimation of FMU available allocation

The FMU available allocation defines the quantum within which allocation can take place. The total consented allocation is derived from the PSI accumulation of consent takes down the catchment to the FMU management point(s) (the outlet point(s) of the FMU). Four approaches were modelled: (1) the sum of the instantaneous take rates; (2) the sum of the instantaneous take rates modified to take account of annual volume limits; (3) the sum of the annual volume limits converted to an instantaneous take rate and (4) the sum of the estimated baseline irrigated land uses system capacity.

The PSI consent data is summarised nationally in Table 2.

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Table 2: Estimated national consent allocation by use

Water use	Surface Water (m^3/s)	Groundwater (m^3/s)
Drinking	26.14	30.79
Industrial	75.31	7.73
Irrigation	202.27	153.48
Other	70.10	21.03
Hydro	576.25	0

It was determined that the consent information was not sufficiently reliable to use for estimating application rates and FMU allocation, because of significant mis-matches between the various consent based approaches to estimating allocation and that which was derived through estimations of likely actual use using irrigated land use and baseline system capacity. While it is probable that the actual allocation lies somewhere within these combined datasets, the approach adopted was based on baseline system capacity summed over all irrigated land uses in the catchment. This approach also eased the difficulties in assigning consents to land uses, and ensured that the individual and FMU allocations matched the current land use pattern. Note, this approach is only possible in the eight regions for which mapped irrigated area is currently available; for the other regions we have used a consents based approach. Further details are provided in the accompanying supplementary information report,

For ***water quality*** the Baseline available allocation is calculated from the applicable estimates of current N losses by land use, soil type, and irrigation status provided by Part B of the project (REF AQUALINC).

1.1.2 Estimation of FMU reliability

In order to estimate the profit of land uses in a catchment, it is necessary to have an estimate of the reliability of the water supply. The approach taken here is to estimate the bulk supply reliability for a FMU using the regionalised flow duration curves developed by Booker & Woods (2014). This requires an input of minimum flow and allocation for that FMU, and outputs a bulk supply reliability estimate that defines the proportion of time that the allocation is available. Booker (pers.comm.) supplied flow duration curves covering the irrigation season (September – May) only.

Minimum flow information is contained in the Jacobs' database for ~35% of catchments. However, these minimum flow monitoring points are not geolocated, which makes it very difficult to determine a supply reliability because the monitoring point may be quite distant from the FMU outlet. Therefore, the reliability calculated using the plan minimum flow may be quite erroneous if the plan minimum flow is applied to the local FMU flows (and FDC). The approach was taken therefore to use the proposed NES default minimum flows. For the baseline case the minimum flow was set as 0.8*MALF for FMUs categorised as LARGE (mean flow $>5m^3s^{-1}$) and 0.9*MALF for the remaining FMUs.

All groundwater consents were assumed to have 100% supply reliability and to have zero impact on surface water availability. Surface water consent reliabilities were assumed to be uniform across an FMU. FMU consent supply reliability was approximated by the frequency at which flows equal or exceeded the minimum flow plus half of the total (surface water)

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allocation at the FMU outlet(s). This allocation includes the local FMU allocation as well as any upstream allocations and is determined from the accumulated PSI allocation model. This approximation assumes flow ramping.

In the case of FMUs with more than one outlet, an allocation weighted average reliability was used. In the case that there are irrigation schemes present, estimates of the irrigation scheme reliabilities (from Brown 2012 and Brown pers. comm.) are used to develop an irrigated area weighted average reliability for the FMU. Figure 3 shows estimates of surface water FMU reliability based on the described methodology.

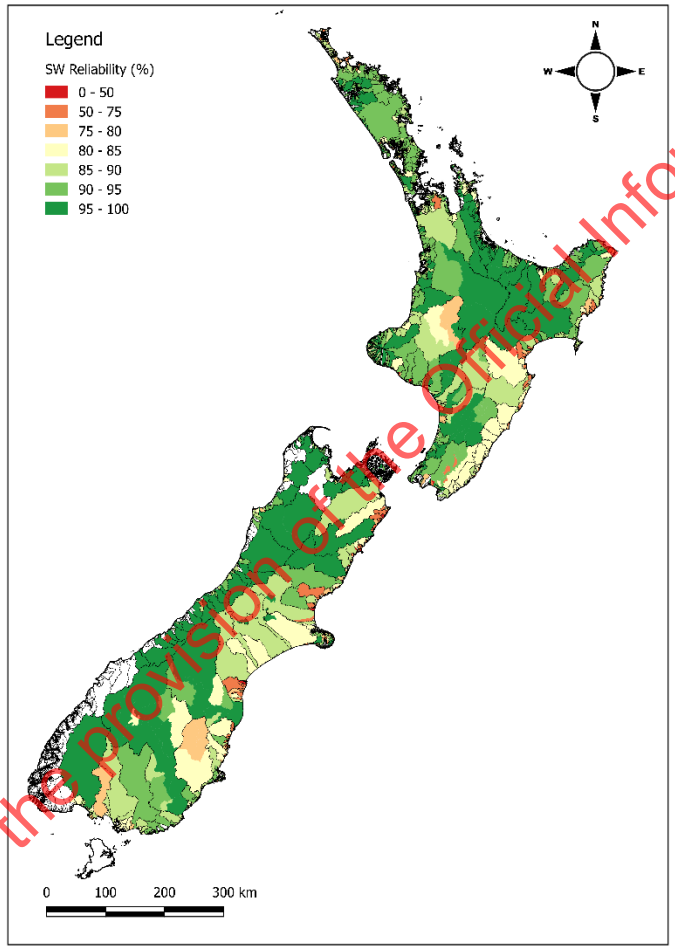


Figure 3: Map of estimated surface water reliability by FMU In cases where there is no surface water allocation, the reliability shown is the frequency that MALF is equalled or exceeded.

No individual storage is allowed for, which is likely to be problematic for catchments where there are a number of storage ponds present, largely on the east coast of the South Island (Marlborough and Canterbury). Storage ponds within irrigation schemes are accommodated through the assigned reliabilities of irrigation schemes. Banding of allocations based on different reliability was not provided for in this initial draft stage, but capacity is available in the model for it to be introduced at a later stage if desired.

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1.2 Managing problem FMU situations

The general model works on the following principles:

- Surface water allocations and nutrients accumulate through a surface water network.
- A sea draining catchment is the largest unit for surface water and nutrient accounting.
- A sea draining catchment may be divided into several smaller FMUs. These FMUs must have some hydrological basis, to allow for sensible accumulations to be calculated.
- Groundwater zones are used solely for water quantity accounting/trading.
- Nutrient allocations are based on surfacewater FMUs.
- A single groundwater FMU may cross several surface water catchments or FMUs.
- A sea draining catchment with multiple FMUs may also have multiple groundwater FMUs that are contiguous with the surface water FMUs.

There are three situations where there is a need to deviate from this general approach:

- Irrigation schemes that have a different profit structure for moving water around because of existing distribution infrastructure. Irrigation schemes allow for greater ease of transfer internally (within the scheme command area) because the infrastructure for water distribution is largely in place, and because the transfer is administratively much simpler. We intend to deal with the lower cost of transfer through an identification of all agents that are within irrigation schemes, and assign a lower capital cost of new irrigation associated with those agents. This assumption will not always hold because the irrigation infrastructure has a finite capacity, but it is likely that within the bounds of the other constraints imposed by the model that this will be sufficient to represent any transfer of water within or into an irrigation scheme.
- Cross-catchment transfers that transport water between surface water catchments, which may result in the irrigation experiencing different reliability from the catchment in which it is located. These are often associated with irrigation schemes. Cross catchment transfers with irrigation schemes are more problematic because in our model the FMU picks up characteristics from its source catchments such as location and reliability, whereas in reality, parcels of land can effectively transfer water and nutrients with both the source catchment and the catchment in which they are located. Because of sensitivity with the optimiser there is no capacity to create a third category of FMUs (alongside SW and GW FMUs) which would be able to cope with these complex sets of characteristics. Fortunately, the circumstances where significant cross catchment transfer occurs are largely limited to the Canterbury region, North Otago (from the Waitaki), and Marlborough. This allows some special case management of these situations so that they can work within the existing optimisation structure.
- FMUs that cover many finely dissected and poorly defined surface water catchments overlaid by a large groundwater FMU such as exist on the Canterbury Plains. The problem of finely dissected SW catchments is very similar to the cross catchment transfer issue, in that the location of irrigation is not well correlated with the take, and because the problem is limited in extent and primarily associated with

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Canterbury. Allocation and transfer within these catchments does not reflect the reality of how water is used in those areas.

After discussion amongst the project team and with the client, an approach was adopted which allows amalgamation of finely dissected streams and incorporation of cross catchment transfers within a single FMU. In addition, irrigation infrastructure was designated as a separate characteristic that defined agents. This solution has the following characteristics:

- It allows for transfer between different sources of water to the north and south of a major river source, which tend to form the basis of FMU boundaries. This occurs because the actual irrigated land is the basis of evaluating the FMU allocation (rather than the consents located within the FMU). By amalgamating several catchments into one FMU, optimisation of water use is possible across multiple surface water catchments, including the irrigation scheme agents and riparian water from major river catchments.
- The solution creates a problem for the RDR irrigation infrastructure and its associated schemes, which will be divided across two FMUs. This prevents transfer between the parts of the RDR and between other water sources, to the north and south of the Ashburton. Given the broad scope of the analysis we consider this error source to be acceptable.
- The definition of the irrigation scheme is contained within the agent characteristics, so that the infrastructure implications of transfer between, and in and out of the scheme can be easily accommodated.
- The reliability of the surface water allocation is based on a weighted average of the scheme (this information exists in previous ECAN studies) and local-river reliabilities (weighting based on the consented allocations).
- Locally sourced surface and groundwater is able to be traded locally and with the land in the irrigation scheme command area, subject to upstream trading constraints. Upstream trading will be constrained by the upstream distance parameter, but there is a possible error source in the potential for trading sideways in a catchment that could overload specific catchments. Given the aggregated nature of agents we consider it likely that the results will still represent a physically feasible solution provided the solution retains some spread across agent types.
- Nutrients are accumulated within a zone rather than within catchments. While this is not biophysically accurate, it does reflect the way the councils are managing their nutrient FMUs in a planning context.

The Part 2 report contains a detailed description of how these approaches were implemented.

1.3 Managing transfer of water within catchments

There is a need to control for hydrological integrity in a catchment to prevent transfers occurring that would overload parts of the catchment with takes or discharges that exceed the assimilative capacity of the environment. Typically this is done by creating a routing network that tracks allocations in a catchment and ensures that the allocations do not overload upstream areas.

Because of the large number of catchments assessed in this project the creation and tracking of these routing networks is problematic even with the river network. Furthermore, it requires the allocation model to undertake its allocations within a matrix of FMUs, which adds

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complexity and difficulty in solving the allocation problem. The approach adopted in the model uses a combination of some routing with indicators of hydrological integrity as follows:

- For allocation approaches where movement occurs between FMUs (Transfer market) and where downstream trading is allowed, the FMU total available allocation is set as the accumulation of all available upstream allocation.
- An indicator of location of water use was estimated based on distance from stream outlet. An indicator based on REC stream order was also considered during prototyping but was discarded as unnecessary and adding complexity without additional resolution.
- A weighted average distance from outlet is calculated based on all the consents/allocation in a catchment.
- The model is constrained so that the solution must maintain the weighted average distance. The constraints include a relaxation allowance, which can be user altered to test for sensitivity. For the simulations reported in this document, zero relaxation allowance has been used.

The use of this approach has enabled a simpler set up of transfer markets in a catchment, and still provides for provide some measures of hydrological integrity within a catchment. It does not prevent sideways trading which may overallocate in some parts of catchments, but this has proven to occur only in 3 catchments for N allocation (Figure 4 all less than 10% overallocated) and 3 catchments for water (Figure 5) only one of which is significant (>10%). In all bar one situations where it occurs the FMUs have a common node where the water exits the FMU. We therefore consider that the indicator based approach to maintaining hydrological integrity performs sufficiently well for the scale of the modelling.

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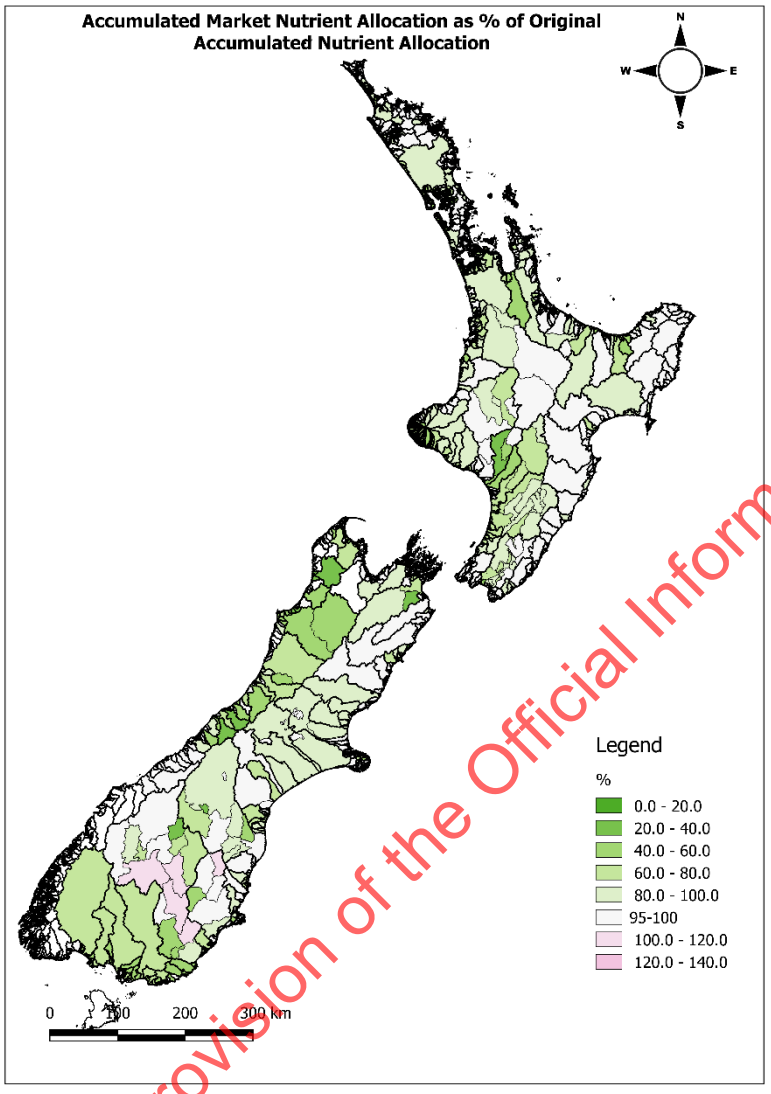


Figure 4: Water quality analysis - estimates of overallocation by FMU

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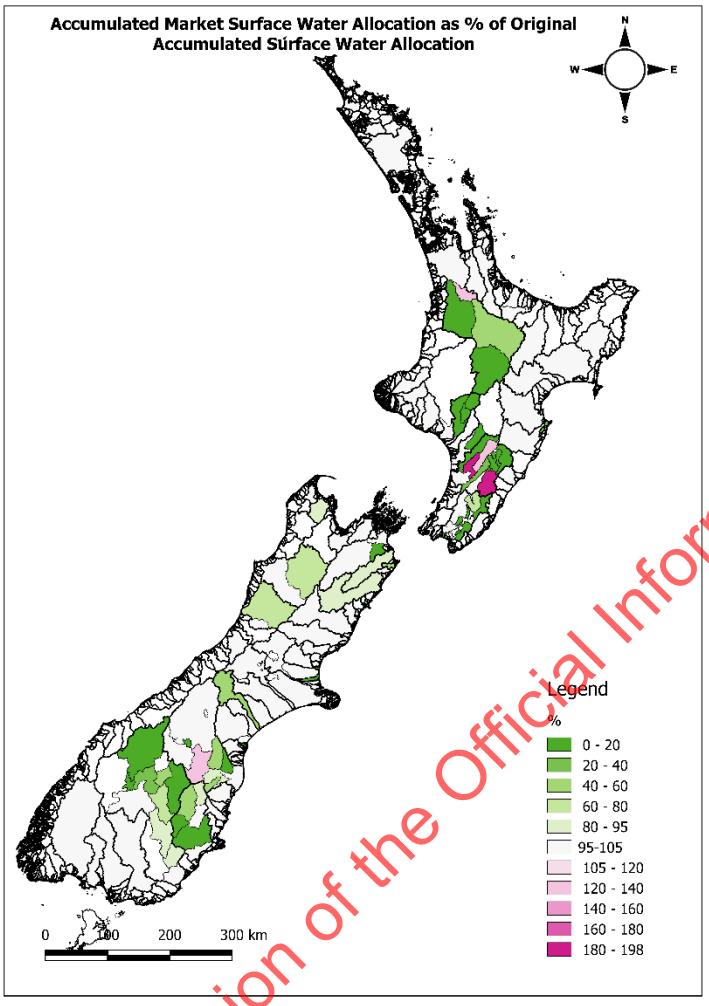


Figure 5: Water quantity analysis - estimates of overallocation by FMU

2 Agent Characteristics

Each FMU is further subdivided into a number of subunits that describe homogenous groupings of users of the resource, which we term 'agents'. Some caution is needed with the term agents since the term is used in different ways in different contexts – in this model it is used to refer to the units the model will manipulate to reflect the impact of changes to allocation. A simple reference point is to understand that the agent is the unit for which the Part B analysis calculated the profitability functions.

The agents are subdivided within the FMU using the following characteristics:

- Climate zone
- Soil type
- Irrigability of the land
- Initial land use
- Ownership by Māori entity

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- Location within irrigation scheme command area

2.1 Land use-

Land use is derived from the NIWA dataset used for CLUES and other modelling. The dataset is a combination of the LCDB 4.1, FarmsOnline and some NIWA internal analysis to further subdivide sheep and beef types (further details in the Part 2 appendices report)

Part B of the project (REF) provided a range of profitability curves for water quality and quantity across 5 land uses and 13 climate zones. The land use dataset was simplified to match the available land uses in that data, with all non-dairy pasture classified as “Sheep and Beef” and all non-productive land uses classified as “Other”. The land use distribution is demonstrated in Figure 6.

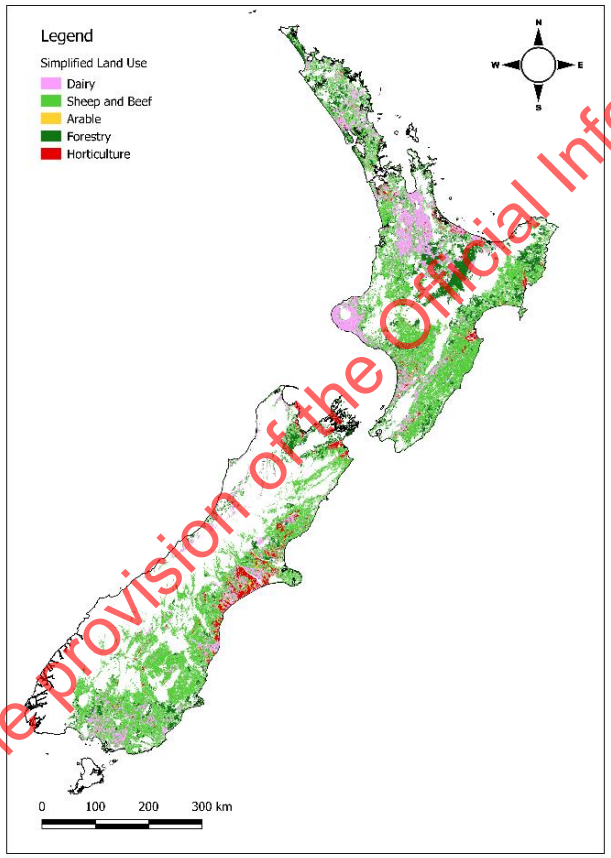


Figure 6: Simplified land use map used for modelling

Land uses which are not dairy, sheep and beef, horticulture or forestry are assumed to have no allocation or profit.

2.2 Estimation of Irrigable area

The irrigable area in the FMU is a constraint on the ability to increase the area of irrigated land and land uses that rely on irrigation (e.g. horticulture). Aqualinc provided the estimated irrigable area map used in the project (REF AQUALINC). The irrigable area constraint is estimated from a combination of slope (<15 degrees) and elevation (<600m). Land slopes of <15 degrees were identified through the NZLRI (Lynn, et al., 2009) as slope categories A, B or C. A 30 m DEM was used to determine elevation. Note, the delineated area is indicative only; it is possible that areas outside of these criteria may potentially be irrigated. The area

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does not take into the feasibility of irrigating these areas (i.e. accessibility, access to water etc), nor the need for irrigation, nor areas such as roads, dwellings or other areas that wouldn't be irrigated in practice; hence, it is likely that this is an upper estimate of likely irrigable area. The estimated irrigable area for the whole country using this method is 68,846 km^2.

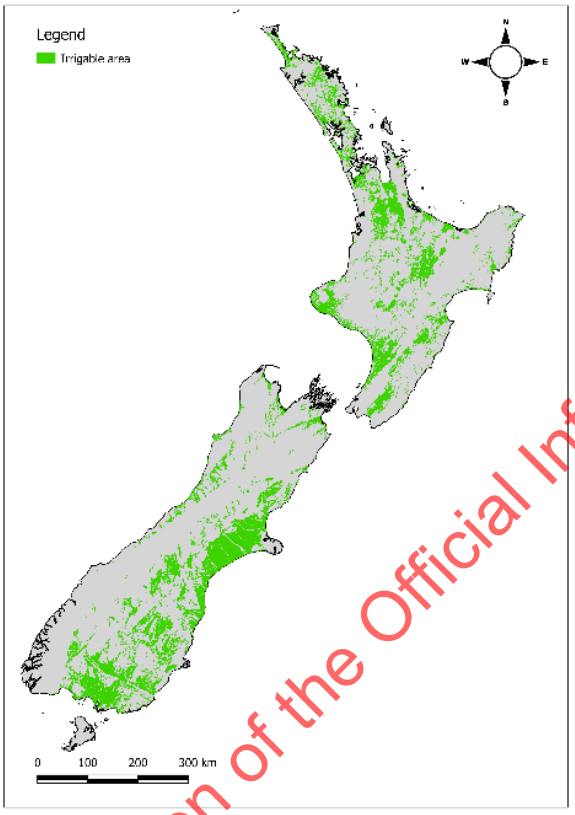


Figure 7: Estimate of irrigable area

2.3 Irrigated area and total allocation

The irrigated area for each agent was evaluated based on an irrigated land use layer provided by MFE, where this was available. The mapping was conducted by Aqualinc Research Ltd as part of an ongoing contract, and is yet to be fully documented. Although the dataset includes information about irrigation systems, we have only used irrigated area extent in our study. As of June 2017 irrigated area for eight regions was available as shown in Figure 8 and summarised in Table 3.

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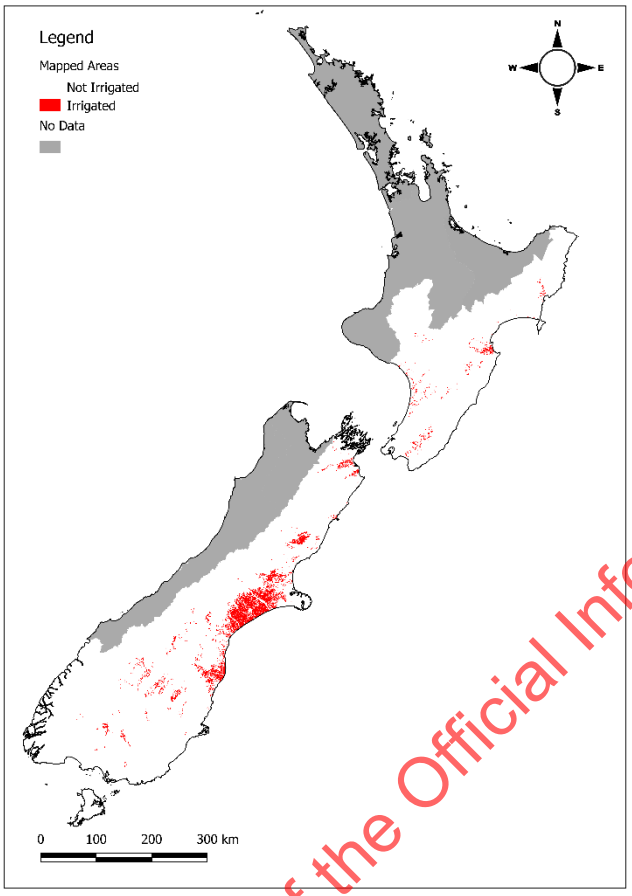


Figure 8: Map of Irrigated Area (Source: MFE)

Table 3: Summary of mapped irrigated area by region

Region	Area Irrigated (km2)	% Region Irrigated	% of Irrigable area Irrigated
Gisborne Region	16	0.19	2.78
Hawke's Bay Region	70	0.50	3.88
Manawatu-Wanganui Region	58	0.26	1.49
Wellington Region	44	0.56	3.48
Canterbury Region	1240	2.84	9.64
Otago Region	228	0.73	3.43
Southland Region	46	0.16	0.69
Marlborough Region	77	0.80	9.95

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In locations where mapped irrigated area was not available the irrigation undertaken in the baseline scenario was estimated by using the consent information. The consent information typically contains an instantaneous maximum rate and an annual volume. In this model we have used the maximum rate for all non-irrigation water takes and the smaller of the maximum rate or the annual rate over the irrigation season with the annual rate scaled by1/0.65 to account for typical requirement of actual use of an instantaneous take rate.

The comparison between the maximum rate and annual rate for the Ruamahanga catchment is shown in Figure 9 which shows that the actual outcomes are not very sensitive to the approach chosen.

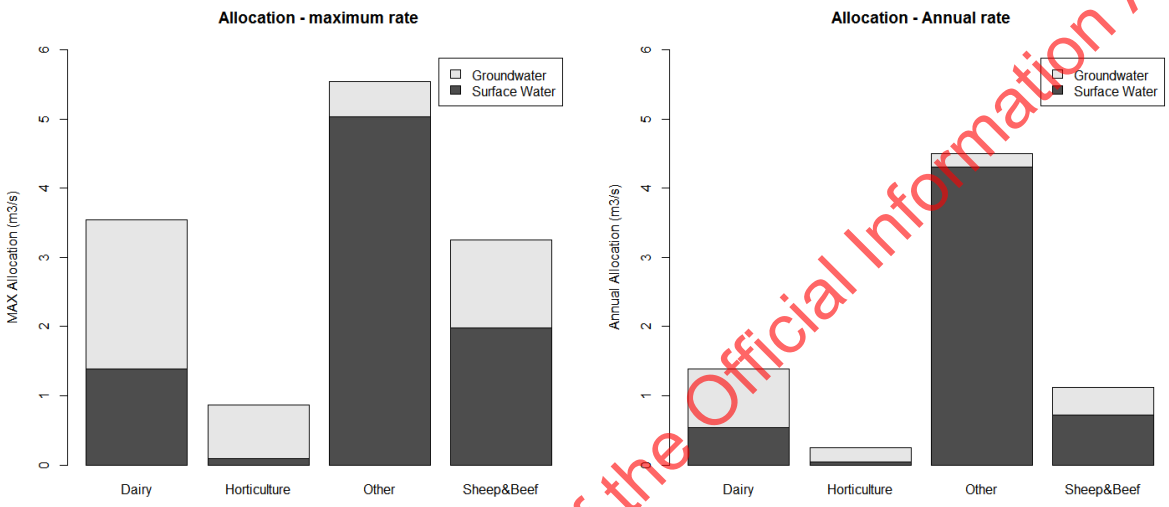


Figure 9: Comparison of allocations by land use for maximum instantaneous rate vs annual volume approaches (Ruamahanga catchment)

Figure 10 shows the location of ground and surface water consents broken down by consent type. These are summarised in Table 2.

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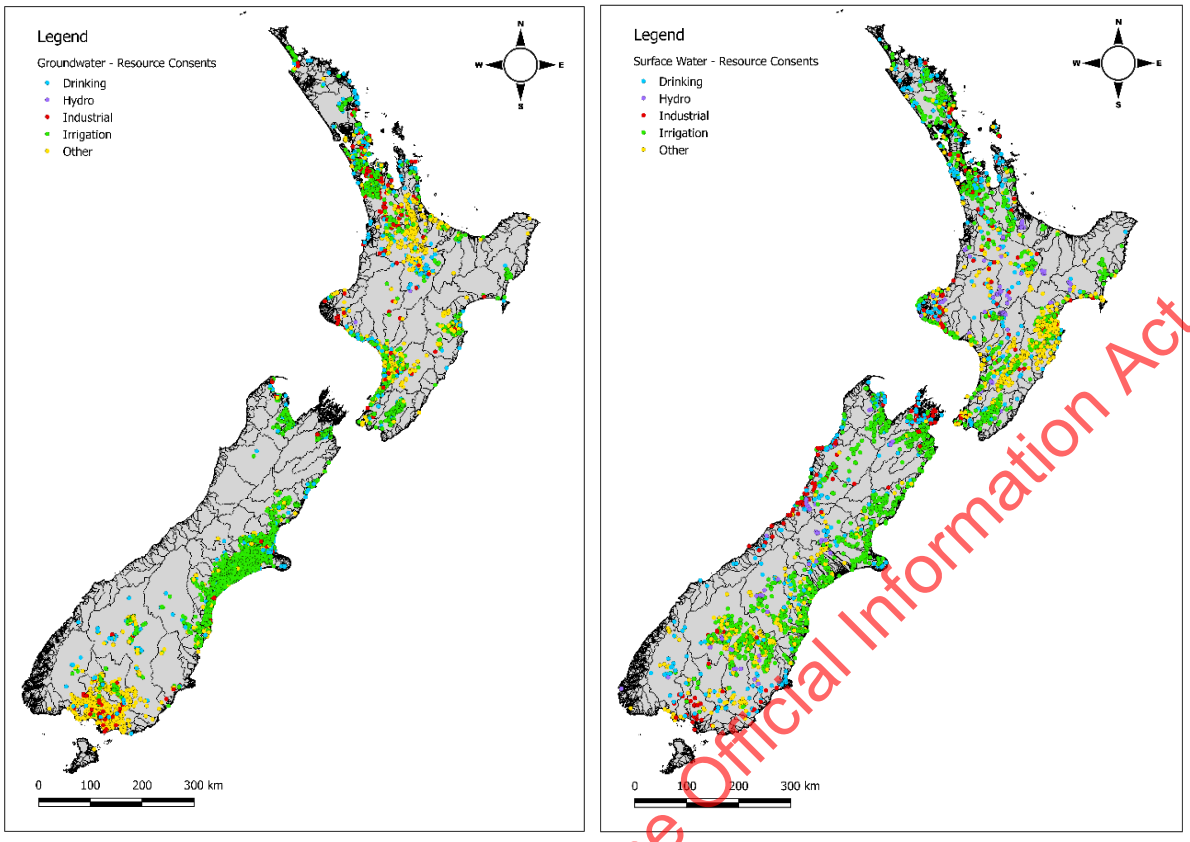


Figure 10 Breakdown of groundwater (a) and surface water (b) consents by water use

2.4 Soil type and Plant Available Water (PAW) –

The Fundamental Soil Layer (FSL) is used to provide soil information because of its national coverage and easy availability. The FSL contains a dataset that describes the Plant Available Water (PAW) for each soil type, which is the critical soil property used for the PART B modelling. The FSL is described in **https://soils.landcareresearch.co.nz/soil-data/fundamental-soil-layers** and the PAW dataset used in this modelling is available at **https://lris.scinfo.org.nz/layer/100-fsl-profile-available-water/**.

The PART B modelling has defined three PAW classes based on a 600mm depth: 0, 35mm, 60mm and 120mm. These were derived from the FSL PAW_Max attribute, adjusted to account for a 600mm rooting depth (rather than 900mm). More detail about the justification for these ranges are provided within the Aqualinc accompanying report. Figure 11 shows the map of these simplified soil classes.

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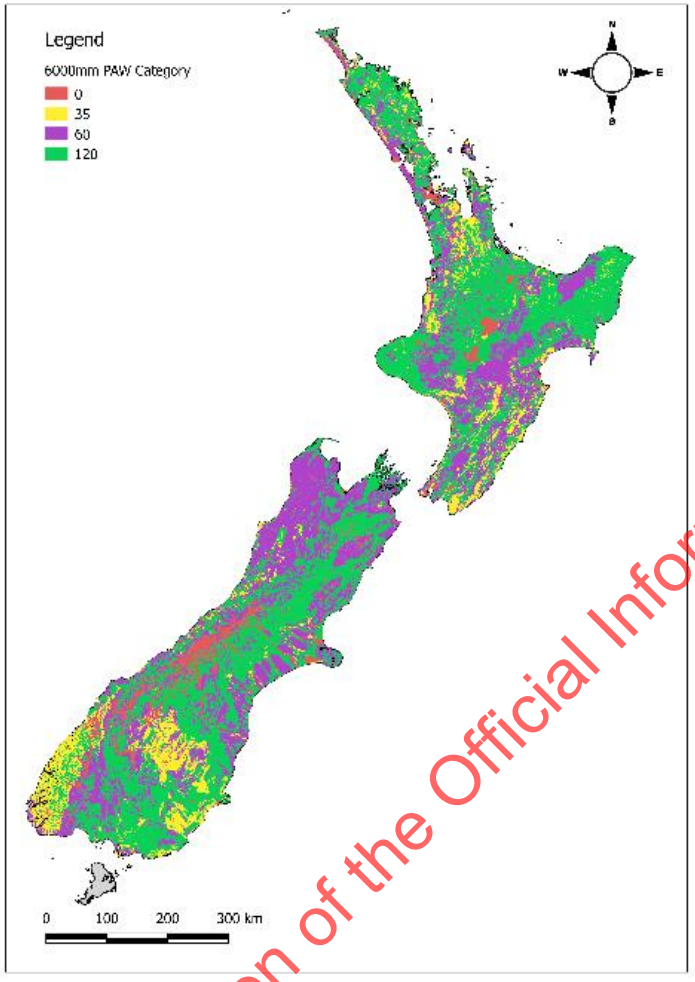


Figure 11: Simplified soil map

2.5 Māori land

MFE provided a GIS layer which defines land owned by Iwi related entities. These were defined as land held under the Te Ture Whenua Māori Act 1993 and returned Treaty Settlement land. This layer is not definitive and omits some land which is owned outside the defined entity types. However, it provides a basis from which to calculate impact on those entities as a result of different allocation approaches. Figure 12 shows the location of Māori owned land as provided by MFE.

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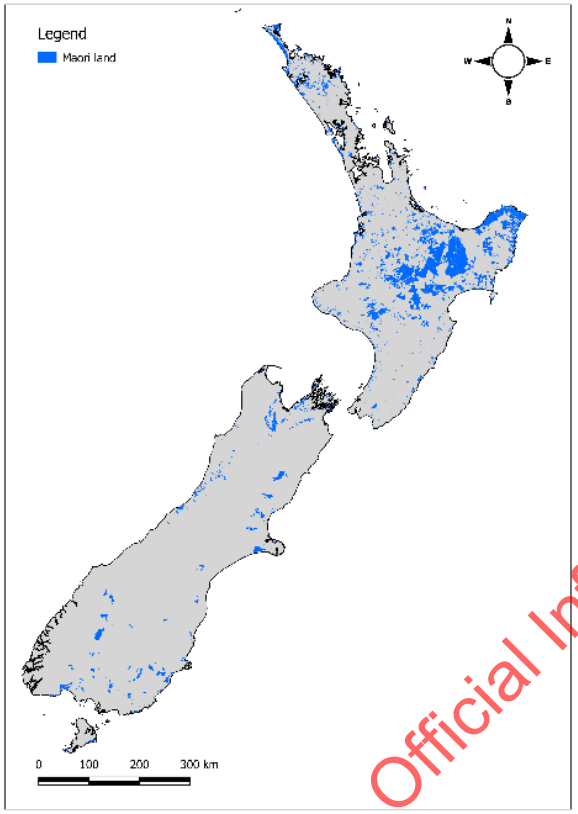


Figure 12: Location of defined Maori owned land (Source: MFE)

2.6 Irrigation schemes

The location of irrigation schemes was obtained for Canterbury (Brown, 2012). These are shown in Figure 13 below. Irrigation schemes exist outside Canterbury, but maps of these schemes were not available and given that, with a few exceptions, they are relatively small and do not cross catchment boundaries, are not likely to have a major impact on the outcomes.

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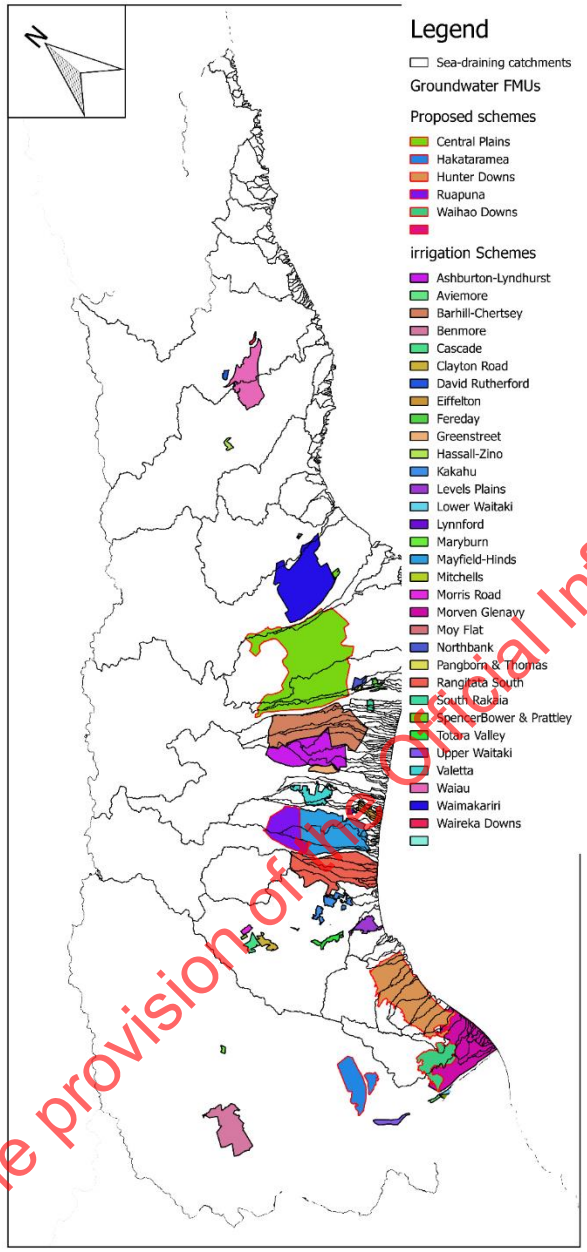


Figure 13: Location of irrigation schemes in Canterbury

2.7 Agent summary

Once all agent attributes were combined using the 4ha NZ grid cell, cells with common agent attributes were combined to identify the Agents. Based on this aggregation, total agent area was determined. Agents varied in size from 4ha to 278,924 ha, with a median area of 64ha. The distribution of the Agent areas is shown in Figure 14 and mapped in Figure 15.

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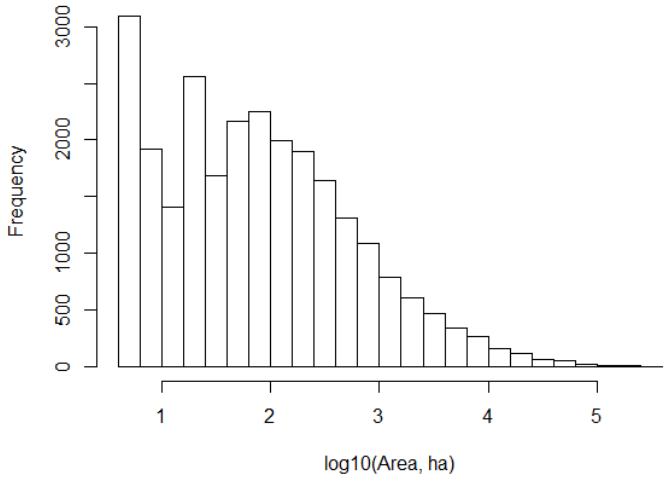


Figure 14: Distribution of Agent Areas



Figure 15: Map of all unique agents

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3 Water allocation, nutrient loss and profitability

3.1 Estimating profit functions

For each agent and land use the model must use water use and nutrient loss to estimate profitability. As noted above Part B of the project provided point estimates of the water use, N loss and profitability for a range of application rates and reliabilities for each land use and climate zone. These were used to estimate a continuous function that describes the estimated profitability at any given combination of soil type, application rate and reliability. The nutrient loss was provided for each baseline system capacity at 100% reliability, and a linear function used to describe the reduction in profitability with % reduction in nutrient losses.

Land use change is a de facto part of the profit function, because at a certain point it is more economical to change land use than to continue mitigating to accommodate a reduced allocation. Thus the profitability curve for any agent becomes a combination of mitigation within a land use, and conversion to alternate land uses once that becomes a more profitable option. In some models these two functions are combined into one curve, which ensures that the costs for landholders in an agent class are explicit. However it also hides the true extent of land use change that occurs as a result of a policy.

For this model each land use, soil type and climate zone combination has a single set of curves that covers the full range from 0% to 100% of maximum allocation. Implicit in this approach is an assumption that at extreme reductions in water quantity or nutrient losses, there will be a change in land use so that lower emitting or water using land uses substitute for the primary land use.

The profit curves for each land use and climate zone, at a range of reliabilities are shown in the Part 2 appendices report.

3.2 Estimation of the impact of capital costs on profitability

The profit data provided by AquaLinc was based on cash operating surplus and included no allowance for capital costs. Because capital costs are likely to be a significant issue in the decision on whether to convert between land uses, their inclusion is essential to correctly estimating potential long run land use change.

Several different approaches were attempted in order to address land use change, including the development of a transition matrix of capital costs for different combination of FROM/TO land uses represented in each change situation. However, these alternate options proved either too computationally difficult to implement on a large scale, or introduced discontinuities that prevented the model from solving. The approach used for this modelling adopts a long run approach that assumes that both existing and new land uses have to return sufficient profit to pay for the costs of capital invested. The capital costs invested in each land use were estimated by Stuart Ford (Agribusiness Group) and provided for both irrigated and dryland land uses. An assumption was made in the case of irrigated land uses within irrigate schemes command areas, that the cost of accessing water was $1000/ha less than for other irrigation sources.

The capital costs used for each land use are shown in the appendices. These were estimated for each situation of irrigated, irrigation within an irrigation scheme, and dryland, and then multiplied by a rate of return of 4.56% which is the average rate of return (excluding capital gains) for dairy properties from 2009/10 – 2014/15 (DairyNZ Economic Surveys).

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3.3 Managing land use change

The modelled profits discussed above may not fully represent the detail about the actual profitability of a land use in a location, which may be affected by a range of biophysical, infrastructural, labour related and other factors. Furthermore, individual landholders have non-profit related preferences that affect their decision making about the desirability of land uses in a location. This is reflected in the heterogeneity seen in land uses in any given catchment. Therefore, the absolute level of land use change also needs to be limited to ensure that it reflects the full range of preferences for a land use, which ensures that the model does not change all land parcels to the single most profitable land use in a location.

Several approaches to this were investigated, including representing some mechanism that would alter the profitability of land uses as occupancy of a catchment increased or decreased, which would act to change the desirability of further land use change. However, these proved difficult to implement at the scale required, and required untestable assumptions about the way in which the profitability would change. Therefore, a simpler system was adopted which reflected the historic rate of land use increase (previous 20 years) as a proportion of the remaining irrigable area. For decreases these change allowances were set as a proportion of existing area, and were allowed to alter on a larger scale in order to enable the model to make necessary adjustments to reach a solution. These land use change constraint estimates were calculated from district level data (Statistics NZ, DairyNZ and LIC), and then applied to catchments based on majority representation. The rates of land use change are shown in Table 4 (maximum increase) and Table 5 (maximum decrease) below.

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Table 4: Maximum rate of increase as a proportion of remaining irrigable area by land use (%)

Climate zone id	Climate zone name	Open Water (Inactive)	Non-productive land (Inactive)	Sheep and Beef	Dairy	Arable	Horticulture	Forestry	Urban	Drinking Water	Industrial	Other	Hydro
1	NI-BoP	0%	0%	80%	29%	0%	18%	80%	0%	0%	0%	0%	0%
2	NI-central	0%	0%	80%	29%	0%	0%	80%	0%	0%	0%	0%	0%
3	NI-EC	0%	0%	80%	29%	0%	0.1%	80%	0%	0%	0%	0%	0%
4	NI-lower-hillcountry	0%	0%	80%	0%	0%	0%	80%	0%	0%	0%	0%	0%
5	NI-Mountains	0%	0%	80%	0%	0%	0%	80%	0%	0%	0%	0%	0%
6	NI-NW	0%	0%	80%	29%	0%	0.1%	80%	0%	0%	0%	0%	0%
7	NI-SW-Coast	0%	0%	80%	29%	0%	0.1%	80%	0%	0%	0%	0%	0%
8	SI-EastCoast-650	0%	0%	80%	29%	20%	0.1%	80%	0%	0%	0%	0%	0%
9	SI-EastCoast-750	0%	0%	80%	29%	20%	0.1%	80%	0%	0%	0%	0%	0%
10	SI-EastCoast-850	0%	0%	80%	29%	20%	0.1%	80%	0%	0%	0%	0%	0%
11	SI-EC-Marlborough	0%	0%	80%	29%	0%	34%	80%	0%	0%	0%	0%	0%
12	SI-Hillcountry	0%	0%	80%	0%	0%	0%	80%	0%	0%	0%	0%	0%
13	SI-Hillcountry	0%	0%	80%	0%	0%	0%	80%	0%	0%	0%	0%	0%
14	SI-InlandBasins	0%	0%	80%	29%	0%	0.1%	80%	0%	0%	0%	0%	0%
15	SI-InlandOtagoSouthland	0%	0%	80%	29%	0%	0.1%	80%	0%	0%	0%	0%	0%
16	SI-Mountains	0%	0%	80%	0%	0%	0%	80%	0%	0%	0%	0%	0%
17	SI-SouthCoast	0%	0%	80%	29%	0%	0.1%	80%	0%	0%	0%	0%	0%
18	SI-Tasman	0%	0%	80%	29%	0%	0.1%	80%	0%	0%	0%	0%	0%
19	SI-WestCoast	0%	0%	80%	29%	0%	0.1%	80%	0%	0%	0%	0%	0%

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Table 5: Maximum decrease as a proportion of current by land use (%)

Climate zone id	Climate zone name	Open Water (Inactive)	Non-productive land (Inactive)	Sheep and Beef	Dairy	Arable	Horticulture	Forestry	Urban	Drinking Water	Industrial	Other	Hydro
1	NI-BoP	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
2	NI-central	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
3	NI-EC	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
4	NI-lower-hillcountry	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
5	NI-Mountains	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
6	NI-NW	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
7	NI-SW-Coast	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
8	SI-EastCoast-650	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
9	SI-EastCoast-750	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
10	SI-EastCoast-850	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
11	SI-EC-Marlborough	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
12	SI-Hillcountry	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
13	SI-Hillcountry	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
14	SI-InlandBasins	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
15	SI-InlandOtagoSouthland	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
16	SI-Mountains	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
17	SI-SouthCoast	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
18	SI-Tasman	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%
19	SI-WestCoast	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%

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4 Implementing policy scenarios

4.1 Description of policy scenarios

The five policy scenarios are discussed below, followed by a description of the way in which they have been implemented in the model.

4.1.1 Current approach projected forward

This scenario is intended to represent the situation where the current allocation of water and nutrients responds to the profitability signals that landholders are receiving over time. This reflects that farmers can change their use of land and water without necessarily trading, and indeed this naturally occurs over time.

What we want this scenario to do:

- Allow land use change within a parcel of land.

What we don't want it to do:

- Allow trading to occur.
- Allow land users to move to a lower capacity system, because they can't sell the water they save so there is no advantage to doing so. In doing so we assume that they are irrigating all their available land.

4.1.2 Market

This scenario represents a system where the allocation can be traded anywhere within biophysical constraints, and landholders move to the most efficient land use and use of their allocation.

What we want this scenario to do:

- Allow land use change to occur wherever it is suitable.

What we don't want it to do:

- Change in a way that doesn't reflect biophysical realities.

This is the least restrictive of the scenarios, and enables water and nutrients to move wherever they are needed. However, no mitigation is allowed for nutrients in the water quantity scenario, and no reduction of allocation rates are allowed for the water quality scenario. The scenario must meet all the high level constraints at the Run level (land use change), catchment level and FMU level (water and nutrients).

4.1.3 Māori land development

This scenario requires an increase in allocation to Māori land (both land held under the Te Ture Whenua Māori Act 1993 and returned Treaty Settlement land) sufficient to develop that land to its most profitable use. The most profitable use is assumed to be the higher of dairy farming or sheep and beef farming. This increase in both water and nitrogen allocation to Māori land is obtained by reducing allocation to other land within the FMU on a pro-rata basis.

What we want this scenario to do:

- Allow Māori land to develop to its most profitable use

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What we don't want it to do:

- Allow trading to occur.
- Allow land users to move to a lower capacity system than their *pro-rata* re-allocated amount, because they can't sell the water they save so there is no advantage to doing so. In doing so we assume that they are irrigating all their available land.

4.1.4 Land based-based allocation

This approach is intended to reflect a system that directs allocation to parcels of land in a way that reflects their need or efficiency of use. The chosen system involves a system based on need, with the allocation between agents reflecting the relativity in demands of water quantity and nutrient loss from a dairy operation on each soil type and climate zone.

What we want this scenario to do:

- Allow land use change within a parcel of land.
- Allow landholders to choose the most efficient use of their additional allocation.

What we don't want it to do:

- Allow trading to occur.
- Allow land users to use the water in a lower capacity system, to ensure we maintain comparability across scenarios.

It is difficult to determine whether the model is preventing trading internally within an agent – it may allow for the concentration of nutrients or water on a smaller area that can only be achieved on a practical scale by transfer of allocation between landholdings, but it cannot be represented here because the agents do not include landholdings as a characteristic.

4.1.5 Volumetric pricing

This scenario is intended to show the impact of pricing on profitability of water use. The model calculates the reduction in profitability associated with the water price, and the revenue collected. There are two approaches to pricing – based on allocation or use of the water.

- Basing pricing on allocation encourages efficiency in both allocation and use. It does not penalise use directly, and therefore has some potential losses in efficiency at an individual level. However, it has the advantage in that it frees up allocation for other users to develop infrastructure, which achieves greater efficiency in allocation of water at the catchment level.
- Basing pricing on use targets the actual use of water, and therefore encourages efficiency at the individual level. However, it does not ensure that individuals maintain the smallest allocation possible for their needs, and therefore does nothing to encourage efficient allocation of water at a catchment scale.

The approach adopted here is to base pricing on the allocation, with an allowance for volumetric limitations over a season[2]. The price for water is set at 1c/1000l, although this is adjustable.

The modelling does not allow for the impact of water pricing on behavioural change. This approach was adopted based on an assumption that the price would be so low as to not impact

[2] For irrigation this is set at 150 days of irrigation at the available system capacity.

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behaviour, and because MPI already has information on the impact of low pricing on behaviour. However, the price adopted in the final form is potentially of sufficient magnitude to affect behaviour, and it may be necessary therefore to assess the implications of price in terms of changes in land and water use.

4.2 Implementation of policy scenarios through Optimisation modelling

The policy scenarios have been implemented by an optimisation model that allocates land, water, and nitrogen to a variety of land uses under constraints that represent the various requirements of each policy scenario. This section discusses the allocation model, and the following section discusses the nature of the constraints used to represent the policy scenarios.

4.2.1 Optimisation Model and Algorithm

The allocation model has been formulated as a nonlinear constrained optimization problem. Nonlinear programming methods are frequently applied to the formulation and as a solution method to many real world economic, business and engineering problems. These are applied where one is interested in maximising or minimising some objective outcome within real world limitations or constraints, given a number of possible decisions (decision variables) which affect the objective outcome. The information obtained provides the set of optimal decisions which maximise the objective.

A nonlinear constrained optimization problem consists of a system of equality and inequality expressions, collectively termed constraints, in addition to an objective function which is to be either maximised or minimized. All the expressions and decision variables, and the objective being optimised may be nonlinear but all must be continuous variables and functions.

In the context of the allocation model, the objective is to maximise the total profits across all agents within a system of one or more catchments. The equality and inequality expressions represent the real-world limitations on the quantities of water, land and nutrients which can be allocated within various aggregations of land users. There are additionally constraint expressions to limit the change from the initial allocation of quantities. These also provide the information relating to the profits relating to different levels of water usage and nutrient reduction. The objective function represents the total profit of all agents in a system of catchments, which is desired to be maximised within the constraints imposed from both physical limitations and policies.

The two key solution algorithms employed for nonlinear optimisation are trust region or line search based algorithms. The employed algorithm uses a line searched base algorithm, which is proven to be efficient and robust in handling nonlinear optimisation problems with both convex and non-convex functional forms.

Alternative approaches to solving such allocation optimisation problems could include for example, the use of mixed-integer programming, or heuristic methods.

The nonlinear programming approach employed here is quite well suited for this application, as the constraints and functions describing profits for different levels of water usage and nutrient abatement. An extension application could be allowing for a combination of integer constraints or quantities within the model may allow for more realistic quantification of the real-world processes, and limitations. This would require the application and formulation of the model as a mixed integer programming model, which permits the use of both continuous and integer variables, which may allow for the imbedding of conditional or stepwise functional forms into the model.

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Aside from exact optimisation algorithms, heuristic based optimisation methods such as genetic algorithms, simulated annealing and ant colony optimization can provide significant advantages when faced with significantly complex problems, or problems which are intractable to be solved with exact mathematical programming approaches. The class of nonlinear programming algorithms applied can only guarantee a local optimum for a given problem is obtained, whereas heuristic based optimisation methods are suited to obtaining global optimal solutions.

A significant disadvantage of heuristic methods is that if a solution cannot be found, it cannot be determined whether it is because a feasible solution does not exist, or the chosen algorithm failed to determine an optimal solution. With exact optimisation algorithms, the feasibility of the solution is often known, and also when found the solution can be guaranteed to be at least a local optimum.

For this project, the open sourced software packages, Ipopt (Interior Point Optimizer), in conjunction with the linear solver MUMPS (a multifrontal massively parallel sparse direct Solver) has been employed. Ipopt is regarded as one of the most reliable open source nonlinear optimisation solver software available. Ipopt employs the use of an interior-point filter line-search algorithm, and is designed to find local solutions of mathematical optimization problems which may be both nonlinear and nonconvex, but all constraints and objectives must be twice continuously differentiable.

The direct interface for specifying the optimization problems uses the open sourced software Pyomo. Pyomo provides an open source, python based optimization modelling language, similar to other popular licensed algebraic modelling languages such as GAMS and AMPL.Further detail on the implementation of the model is shown in the appendices.

4.2.2 Implementation of policy scenarios through the use of constraints

The implementation of scenarios relies on setting constraints on variables within the optimiser model. The model is set up with a minimum of variables and constraints, to allow it to reliably solve for all catchment situations, but also to run through the large number of catchments in a manageable time frame. All constraints therefore must work for all catchment situations, and there can be no opportunity for bespoke modelling of specific catchments.

There are several constraints that act across all scenarios. These are:

- Weighted average water allocation distance to outlet is less than or equal to baseline weighted average water allocation distance.
- Weighted average nutrient allocation distance to outlet is less than or equal to baseline nutrient average water allocation distance.
- Catchment maximum surface water allocation is fixed as the baseline catchment surface water allocation.
- Groundwater FMU maximum water allocation is fixed as the baseline groundwater FMU water allocation.
- Catchment maximum nutrient allocation is fixed as the baseline catchment nutrient allocation.
- Land use change is limited to maximum rates of change, which is the same across all scenarios. The limitations on land use change have been implemented at a Run level, which is a collection of catchments and groundwater FMUs with common potential for water or nutrients to be moved amongst them. The application of land use change at this level is intended to be enabling, but may produce highly polarised

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land uses in some parts of the catchment as the model moves land uses to the most favourable locations.

In addition, the model sets constraints at more specific agent levels. These constraints are primarily implemented by setting minima and maxima on the application rate or nutrient loss rates and on the area for agents. The schema for all constraints is shown in Figure 16 below, and a summary of the issues and proposed solutions for implementing constraints by policy scenario is shown in Table 6. Greater detail is available in the appendices.

4.2.3 Model runs

There are a number of situations where multiple surface water catchments and groundwater catchments need to be modelled together because water is able to be transferred amongst them. These typically occur where there is a groundwater resource or an irrigation scheme that covers more than one catchment. To accommodate situations where this arises a high level collective designated a 'Run' was developed. This collective holds all the catchments and FMUS that must be simultaneously passed to the allocation model for solution.

The model iterates through each optimiser Run for each policy scenario sequentially, passing the input data and constraints for each scenario to the optimiser which generates a solution which maximises aggregate profitability within the constraints of that scenario. To execute the full set of scenarios for all Runs involves approximately requires approximately 5 – 8 hours.

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Table 6: Implementation of scenarios through constraints

Scenario name	Scenario description	Land use (Agent) System capacity, N loss	Allocation for each soil/climate combination (Agent type)	Maximum FMU allocation	Catchment constraints	Trading	Land use change	Offsetting (where one a reduction in intensity occurs to enable intensification elsewhere)
Current optimised	An optimisation of current to allow comparison with other scenarios. No trading	Fixed minimum and maximum at current	Fixed at current	No accumulation - allocation is fixed for a FMU, with no downstream movement allowed.	Upstream distance constraint to prevent upstream trading, and constraint on total N and water allocation.	Not allowed. Prevented by fixing system capacities and total allocation for an agent.	Allowed - within Agent type allocation and Run level land use change constraints. Implies existing farm can change, but the allocation can't be moved to other soil types.	Can occur within Agent type and the limits of land use change constraints. Depending on level of offsetting may be attributable to within farm offsetting, or trading between farms but within an agent type.
Transfer Market (Quantity – 1) (Quality – 2)	Market with hydrological and market imperfection constraints	1: Sys Cap– Minimum and maximum set by Aqualinc. Nloss: as per Baseline 2: SysCap – as per Current optimised Nloss: Minimum and maximum set by Aqualinc.	No limits	1. Accumulated water allocation, FMU only allocation for N 2. Accumulated nutrient allocation, FMU only allocation for water	Upstream distance constraint to prevent upstream trading, and constraint on total N and water allocation.	Allowed (but not conjunctive trading)	Allowed - within Run level change constraints.	Can occur within the limits of land use change constraints

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Scenario name	Scenario description	Land use (Agent) System capacity, N loss	Allocation for each soil/climate combination (Agent type)	Maximum FMU allocation	Catchment constraints	Trading	Land use change	Offsetting (where one a reduction in intensity occurs to enable intensification elsewhere)
Administrative reallocation - Reduction and redistribution to Māori land (Quantity – 1) (Quality – 2)	Redistribute sufficient allocation to Māori land to allow development to either dairy (can be changed to another land use in future). No trading	(1) System capacity is the larger of the minimum system capacity or the baseline system capacity times the prorata amount (see allocation column) for both Māori and non-Māori land Nloss is fixed at baseline (2) Mitigation percentages are the larger of the minimum possible percent N reduction (by land use) for mitigations, or the pro-rata amount. Mitigations are required from ALL land users. System capacity is fixed at baseline	(1) The smaller of all the allocation, or the water required to irrigate dairy is allocated to Māori land. Water allocation on non-Māori land is prorated down to account for reallocation. Reallocation done on a GW_FMUxSW_FMU basis and takes into account syscap reductions for Māori land. N allocation fixed as per baseline (2) The smaller of all the allocation less allocation required for the lowest nutrient using land use within he catchment, or the nutrients required to irrigate dairy is allocated to Māori land. Nutrient allocation on non-Māori land is prorated down to account for reallocation. (with a minimum allocation of losses for forestry). Water allocation as per baseline	No accumulation - allocation is fixed for a FMU, with no downstream movement allowed.	Upstream distance constraint to prevent upstream trading, and constraint on total N and water allocation.	Not allowed. Prevented by fixing system capacities and total allocation for an agent.	Allowed - within Agent type allocation and Run level land use change constraints. Implies existing farm can change, but the allocation can't be moved to other soil types.	Can occur within Agent type and the limits of land use change constraints. Depending on level of offsetting may be attributable to within farm offsetting, or trading between farms but within an agent type.

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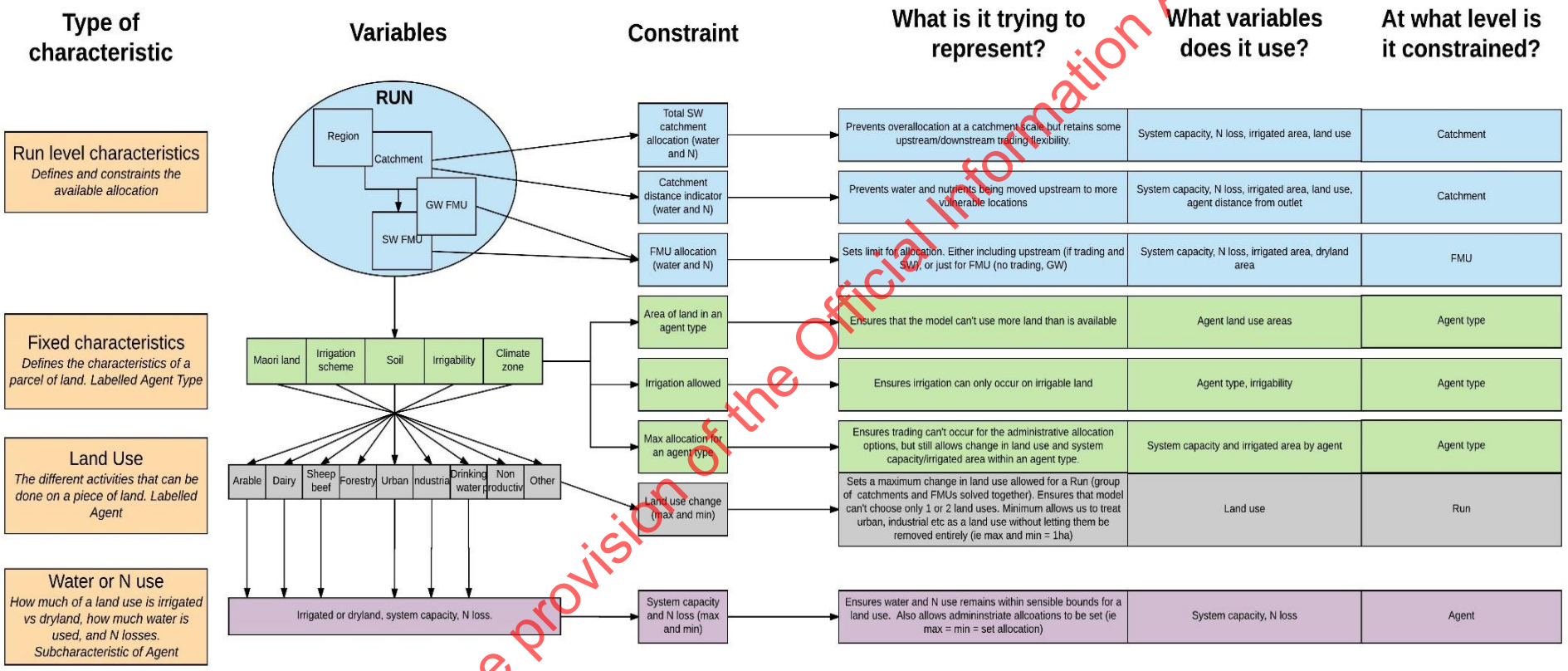
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Scenario name	Scenario description	Land use (Agent) System capacity, N loss	Allocation for each soil/climate combination (Agent type)	Maximum FMU allocation	Catchment constraints	Trading	Land use change	Offsetting (where one a reduction in intensity occurs to enable intensification elsewhere)
Land Based Allocation-based (Quantity – 1) (Quality – 2)	Remove all allocations and reallocate to assigned rates. No trading	The system capacity for any land use is set at baseline for that land use. Therefore the allocation for the agent type will have to be reassigned among land uses. No mitigations allowed.	(1) Total water allocation for an agent type is set at the sum of area times the allocation for dairy for climate zone and soil type, pro-rated down so that the FMU total allocation is met. Total nutrient allocation as per baseline (2) Total Nutrient allocation for an agent type is set at the minimum required Nloss plus the sum of area times the allocation for dairy (less minimum Nloss) for climate zone and soil type, pro-rated down so that the FMU total allocation is met. Water allocation is set at baseline	No accumulation - allocation is fixed for a FMU, with no downstream movement allowed.	Upstream distance constraint to prevent upstream trading, and constraint on total allocation.	Not allowed. Prevented by fixing system capacities and total allocation for an agent.	Allowed - within Agent type allocation and Run level land use change constraints. Implies existing farm can change, but the allocation can't be moved to other soil types.	Can occur within Agent type and the limits of land use change constraints. Depending on level of offsetting may be attributable to within farm offsetting, or trading between farms but within an agent type.
Volumetric pricing	Charge to all water users based on allocation with allowance for seasonal limits.	Fixed minimum and maximum at current	Fixed at current	No accumulation - allocation is fixed for a FMU, with no downstream movement allowed.	Upstream distance constraint to prevent upstream trading, and constraint on total allocation.	Not allowed. Prevented by fixing system capacities and total allocation for an agent.	No land use change allowed.	Cannot occur

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Figure 16: Relationship between variables and constraints



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5 Results

5.1 Interpreting the results

Any analysis that attempts to assess the impact of different policies is based on a model of how various parameters interact, and the outcomes are dependent on the way in which the model is set up and the beliefs about the way in which relationships between different parts of the model behave and should be modelled. Because many parts of the model are essentially unknown or have to be described through generalised relationships, models are always imperfect representations of the real situation they attempt to assess.

In the case of this analysis the modelling is further circumscribed by the need to represent the outcomes nationally. While the model does this catchment by catchment, the input data is necessarily generalised, and the model itself has to be sufficiently generic to represent all catchments regardless of their various complexities. The problems encountered in modelling at this scale while representing each catchment manifest themselves in three ways:

- The level of necessary simplifying assumptions required to develop the input data and the parameterise the model
- The modelling framework itself must be sufficiently robust to accept data from a wide range of catchments and to represent the interactions occurring within each catchment at a comparable level of detail and robustness.
- The model must be capable to being run in a reasonable time frame to allow for iteration and testing, and to allow a range of policy approaches to be assessed.

These limitations have meant that approaches which may be practical when modelling a single catchment are not possible on a national scale. The analysis presented here is therefore not a prediction of a state that will occur under different scenarios of allocation, because the representation of the catchments, the land uses, their profitability, and the behaviour of land managers under different scenarios cannot be considered sufficiently comprehensive to allow predictions to be made. For example, only five land uses are included, each of which is an amalgamation of a range of different farms and farm types. Similarly, the climate zones cover large parts of the country and do not allow for the range of different outcomes within those climate zones.

These caveats place limitations on the level of detail at which it is appropriate to consider the results. Because of the broad scale nature of some of the input data, there are likely to be errors in specific catchments and regions that are not readily understood using the mechanisms that are available for error checking, and there will be differences between the model assumed plan and estimated flow conditions and the actual. Therefore, the outcomes for specific catchments and even regions may not be comparable with the actual on the ground situation, and this makes very detailed comparisons and analysis at that level inappropriate. However, when aggregated to a multi-region and national level the error levels become more acceptable.

These limitations are important to understand but are not fatal to the purpose of the modelling. What the model does do successfully is allow for comparative analysis of the differences that might be achievable under different policy options. The analysis presented here is an assessment of the potential for each approach, and it is most appropriate to compare the potential of each policy option with the other rather than any given real-world state.

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For the purposes of this comparative analysis, presentation of results has generally used the Current allocation approach as the main point of comparison. The projection of the Current allocation approach is used rather than actual current situation (Baseline) because the Current allocation approach scenario outcomes is a set of land and resource use that is achieved under the same modelling conditions as the other policy scenarios, whereas the Baseline reflects a whole host of other factors that are not able to be modelled accurately. The Current allocation approach represents the profitability that can conceptually be achieved without trading or reallocation of water or nutrients from the current rights holders.

The combined outputs from the model amount to more than 800,000 rows of data with 40+ columns (>32 million data points). The possibilities for exploring the results are numerous, and this report necessarily picks out a few key points and issues for discussion to illustrate the general tenor of the outcomes. A fuller set of results is represented both geographically and graphically in the appendices.

5.2 Results

5.2.1 Quantity scenarios

The analysis of the quantity scenarios considers situations where the available water is allocated in different ways. For the administrative approaches (Māori land development and Land based allocation), neither water nor nutrients are not allowed to be transferred, but in the Market transfer scenario water can be traded at any rates, but nutrients can only be traded at baseline nutrient losses (i.e. agents cannot mitigate their nutrient use below standard baseline loss rates).

In aggregate (Figure 17) the Current Approach achieves the highest profit of the policy options considered other than the Market transfer. The Māori land development scenario generates approximately the same as the Current approach, and the Land based allocation the least profitable in aggregate of the policy options considered.

The range of changes in profit/ha (Figure 18) is relatively constant across scenarios for land uses, although agents that were originally arable experience a major increase in profitability which is likely to be associated with a shift out of arable and into horticulture. The major changes in horticulture are driven by rearrangement of horticultural land to different soil types, which in turn is driven by the cap on land use change which drives the model to maximise returns from horticulture within a set area of land. The graph is also somewhat skewed because it has not been weighted, so although there are major changes in arable and horticulture these are very minor land uses and the majority of land lies within a much smaller range – changes of the magnitude shown by arable and horticulture would represent outliers for the major land uses, which have been deleted from this plot.

There do not appear to be substantial differences between soil types in respect of the changes made in land use, with some movement of irrigation from the lighter soils to the heavier soils across the board, and most markedly in the Market transfer scenario. However, there are major changes to the distribution of land uses (Figure 19). For the administrative allocation scenarios (Current approach, Land based, Māori land development) there is a reduction in dairy and small reduction in sheep and beef, and an increase in arable, horticulture and forestry. For the market scenario the reduction in dairy is not as large relative to baseline as the other policy options, and there is a slightly greater increase in arable, and a smaller increase in forestry. It appears that the low post capital returns from dairy in the input data means that the historic rates of increase in dairy land are not replicated in this model.

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These changes in land use are reflected in the changes in profits by land use, with increases in profit from sheep and beef, arable, horticulture and forestry, with decreases in dairy profit from baseline apart from in the Market transfer scenario. In general the administrative scenarios perform in a very similar manner to the Current approach, with the Māori land development scenario slightly better for all land uses than the Land based allocation.

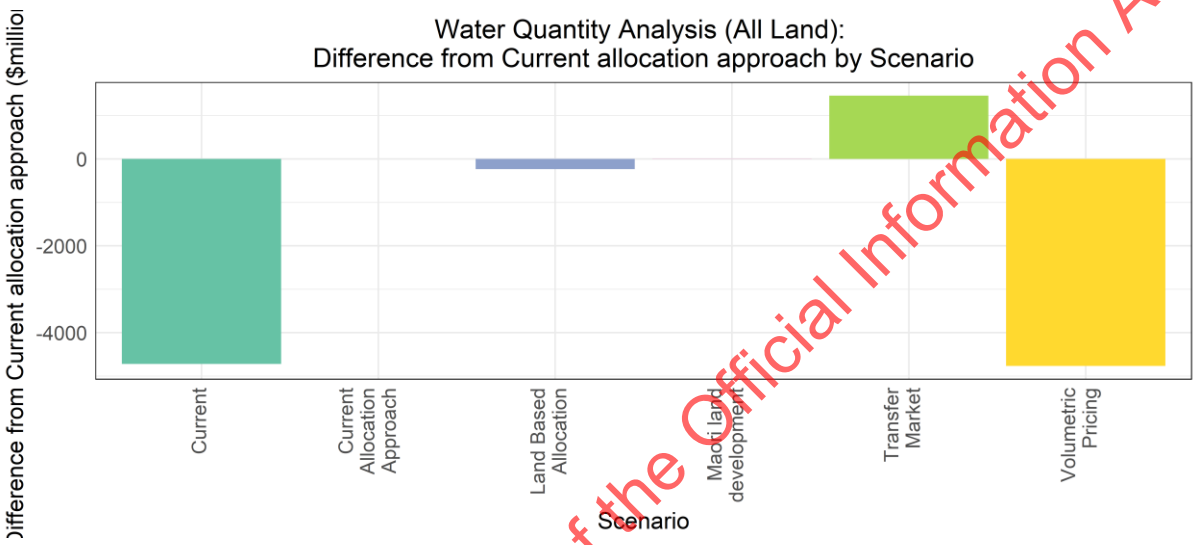


Figure 17: Water quantity analysis - policy scenario represented as difference from Current Approach

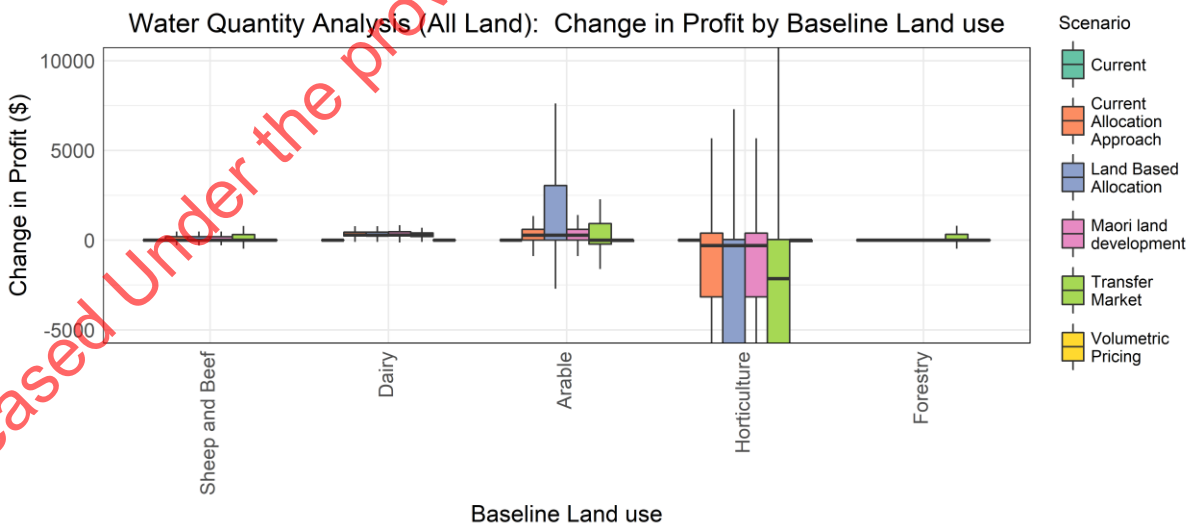


Figure 18: Water quantity analysis – change in profit/ha by baseline land use and scenario.

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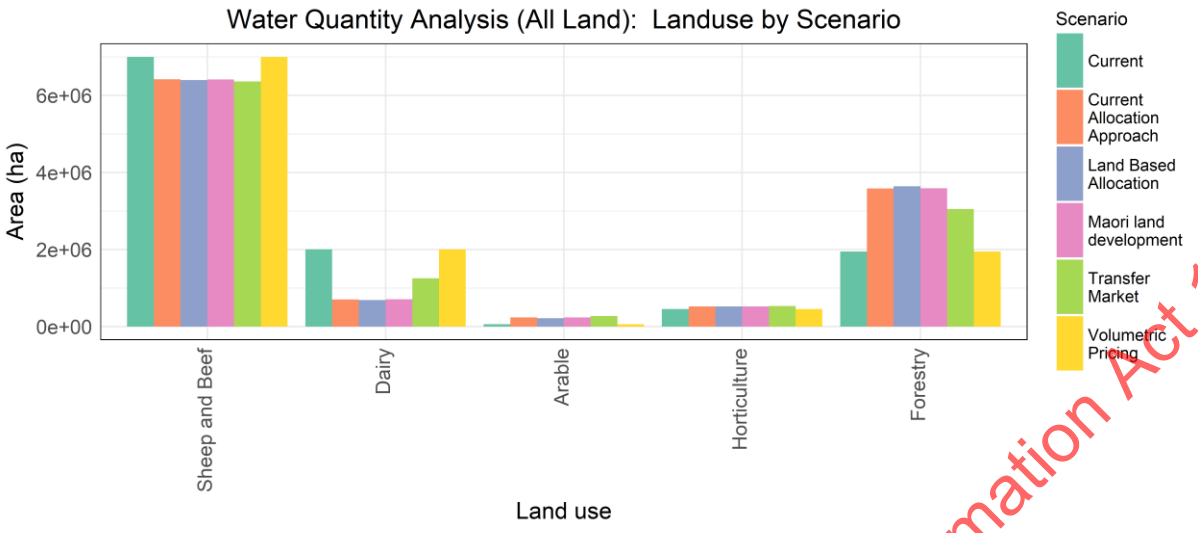


Figure 19: Water quantity analysis – Land use by policy scenario

All scenarios (other than Volumetric pricing) increase the returns per l/s of water used relative to baseline and relative to the Current Approach, and this is true at the land use level as well apart from horticulture under Land based allocation. The spread of returns per l/s increases slightly under both Māori land development scenario and Transfer Markets relative to Current Approach, and all scenarios have slightly greater variability than the baseline (Figure 20).

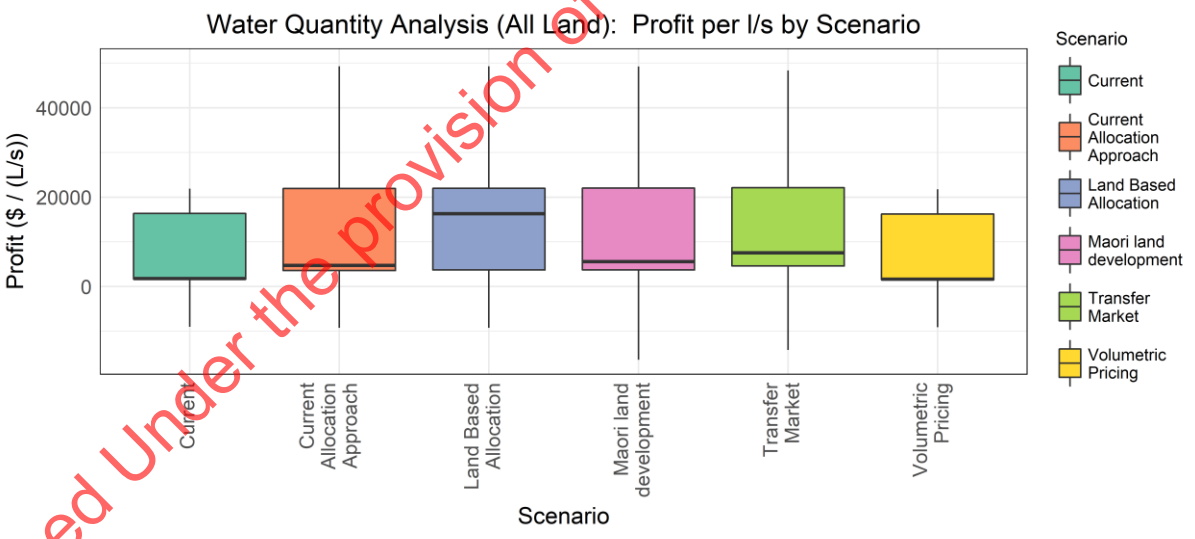


Figure 20: Water quantity analysis – variability in water use efficiency (profit/(l/s) water) by scenario

Dairy, sheep and beef and arable land uses which appear to increase their efficiency of water use (Figure 21under the Transfer market scenario, with dairy increasing markedly so for groundwater where it appears the high reliability is enabling land users to reduce the application rate and increase returns to water used. The effect is present for surface water, but is not as marked.

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It is interesting to note that there appears to be a general increase in variability in profit per l/s for all land uses in the Transfer market scenario. However the results for other policy scenarios are more land use dependent. There is an increase from baseline for dairy in both surface and groundwater, but arable shows a decrease in variability apart from Transfer market and Māori land development. Sheep and beef shows relatively stable variability in returns per l/s across land uses and scenarios, but horticulture shows significantly lower variability for groundwater from baseline, and similar for surface water which suggests greater changes in groundwater allocation to maximise profitability across the catchment.



Figure 21: Water quantity analysis – variability in water use efficiency (profit/(l/s) water) by Land use (a) non-horticulture land uses (b) horticulture

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5.2.2 Quality scenarios

The analysis for scenarios run under nutrient allocation (water quality) parameters tells a similar story to the quantity scenarios (Figure 22), with the exception that Māori Land Development performs significantly worse than the other scenarios, and the Transfer Market scenario does not outperform the other scenarios to quite the same extent. There appears to be relatively little difference in the range of increases and decreases in profit (Figure 23) apart

from horticulture. However the horticulture results, as with the Quantity scenarios, are driven by rearrangement of horticulture across soil types to maximise returns from that land use. Analysis of individual sets of results suggests that this is likely because of the limits on maximum system capacity and nutrient losses that were allowed under the Māori Land Development scenario, as well as the lack of water available to develop land under all scenarios which meant that water was not able to be used as effectively. This is highlighted by the fact that in some scenarios there are areas of the country (Figure 24) which have large proportions of Māori owned land, and which are water short, that result in Māori owned land being worse off under the Māori Land Development scenario.

Even in the transfer market scenario the limitations on minimum system capacity meant that water was not able to be spread further, which appears to have limited the gains that could be made by reallocating nutrients. These and other results appear to point to the need for conjunctive allocation of water and nutrients if maximum gains are to be made from different approaches to allocation.

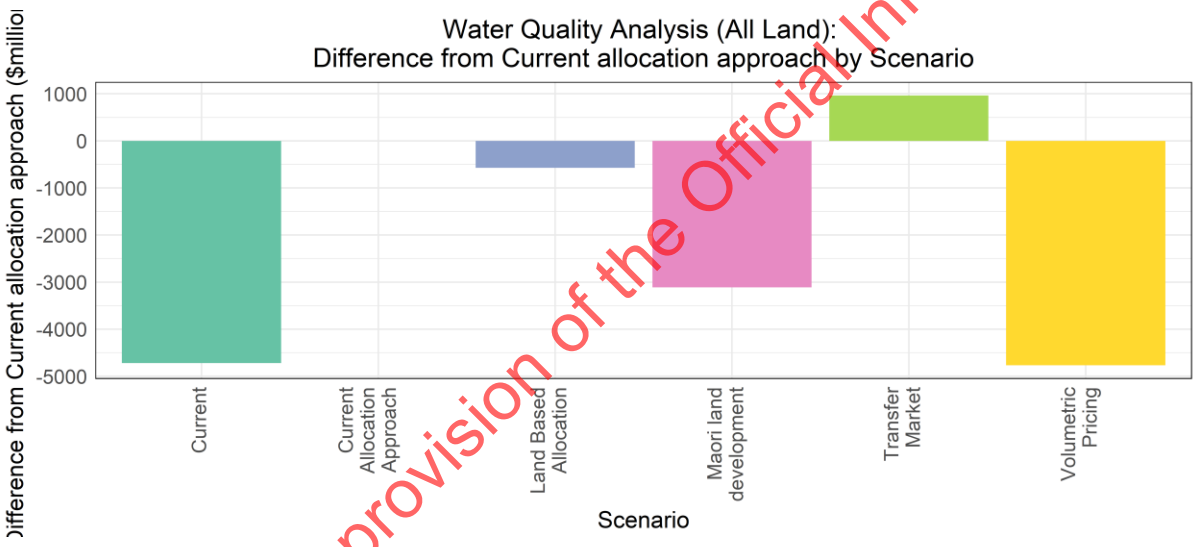
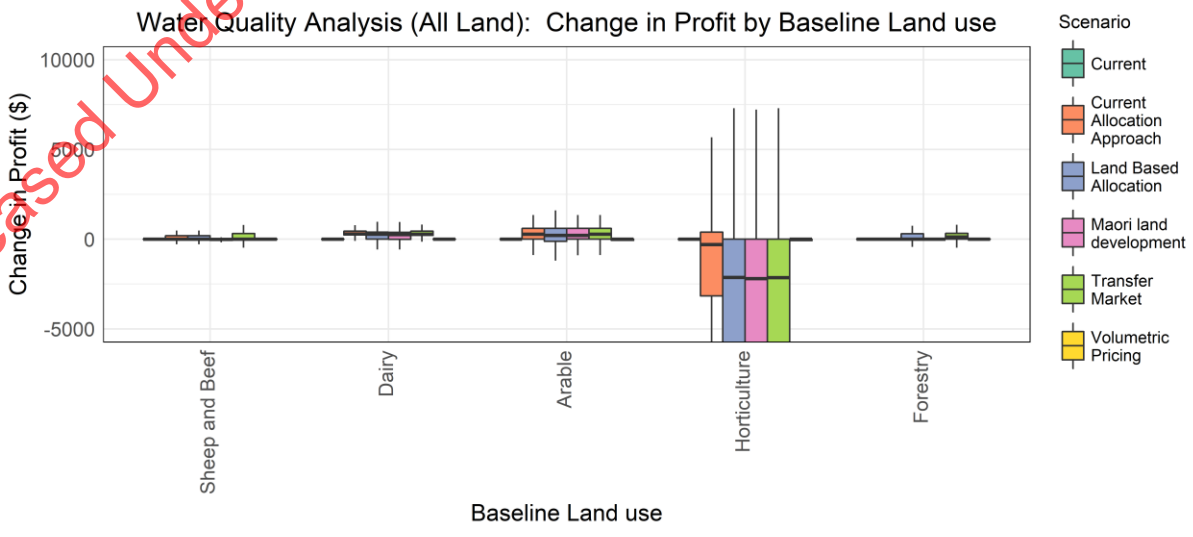


Figure 22: Water quality analysis – difference from Current Approach in profit by scenario



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Figure 23: Water quality analysis – change in profit by baseline land use and by scenario

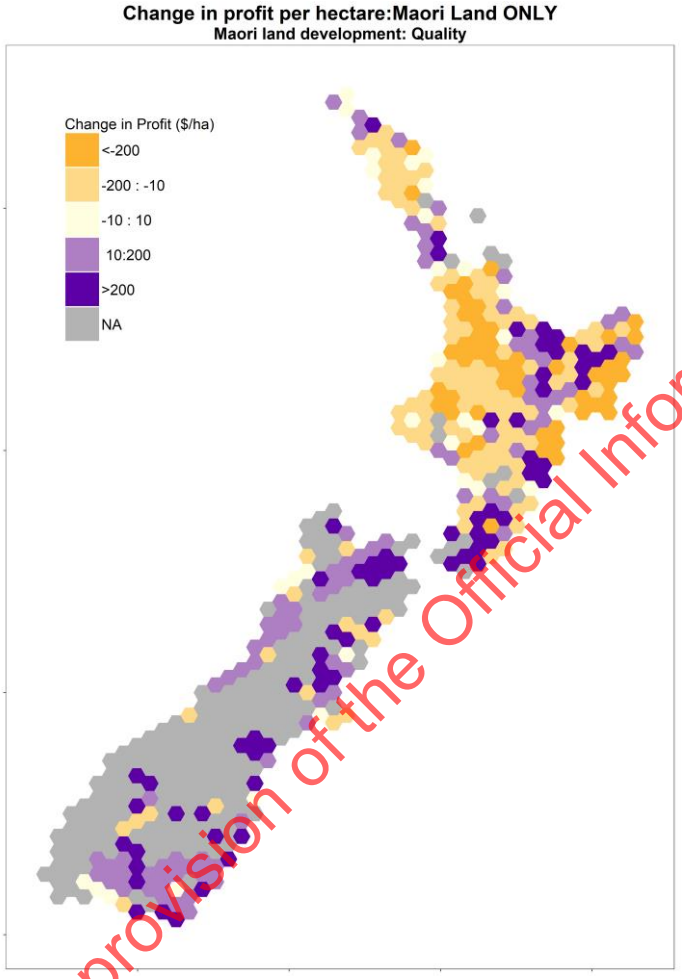


Figure 24: Water quality analysis – change in profit/ha from Current Approach to Māori Land Development scenario, for Māori owned land

In terms of land use (Figure 25) the Quality administrative scenarios (Land based allocation and Māori land development) result in more land in dairy than do the same scenarios for Quantity. This appears to be primarily at the expense of sheep and beef, which was relatively constant across the Quantity scenarios but declines for the Quality administrative scenarios. The reasons for this are possibly related to the relatively lower profitability of dairying under reduced system capacities in the Quantity scenarios, whereas the reduced N allocation in the Quality scenarios does not appear to have reduced dairy profitability in relative terms to the same extent. Put simply it appears that based on the input data used, a reduction in water hurts dairy relative to sheep and beef more than a reduction in nutrients.

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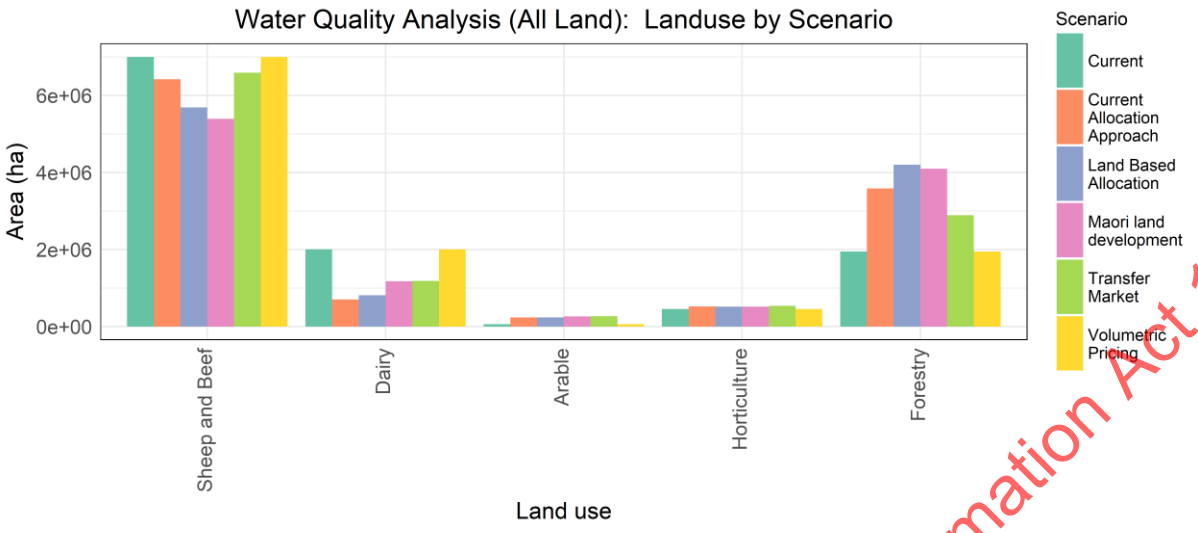


Figure 25: Water quality analysis- Land use by scenario

In terms of irrigated land (Figure 26), the Quality scenario has some interesting features when compared with the Quantity scenarios. While the relative use of irrigated land is not markedly different, the Transfer Market scenario does not result in the same relative increase in irrigated land when compared with the Quantity scenario. This is likely to be because the fixed system capacity in the Quality scenario does not result in the more efficient use of water that is encouraged in the Quantity scenario under Transfer Market conditions.

A further interesting feature of the Quality scenario is the relative increase in irrigation under Māori land development, which suggests that availability of nutrients may have been constraining use of available irrigation in the equivalent Quantity scenario.

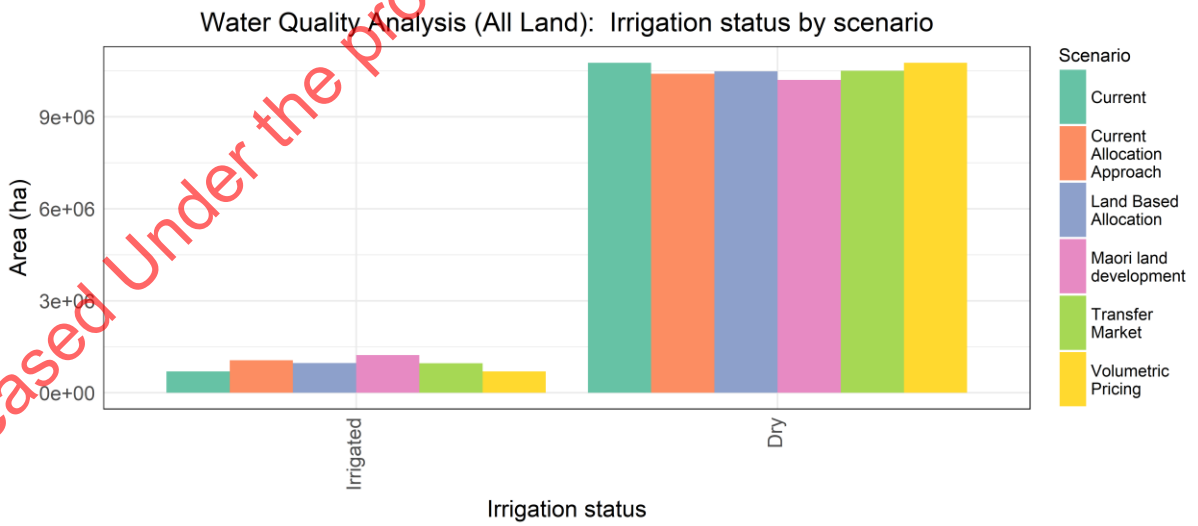


Figure 26: Water quality analysis - irrigated area by scenario.

The amount of nutrient use does not appear to change significantly across under Quality allocation for the administrative scenarios (Current Approach, Land based allocation, and Māori land development) which implies a reduced efficiency of nutrient use in the Land based

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allocation and Māori land development scenario. Nutrient use increases in the Transfer Market relative to Current allocation approach, and when combined with the higher profit the nutrient use efficiency (profit/kgN) increases. None of the scenarios uses all the available nutrients, which is likely to be driven by the move to higher profit/lower leaching land uses – particularly horticulture – being favoured.

There is also a clear reduction in the efficiency of water use under the Quality scenarios for the Land based allocation and Māori land development. It appears that this is driven by a reduction in the efficiency of water use in horticulture, but the source of this is unclear at present (see Figure 27 and Figure 28).

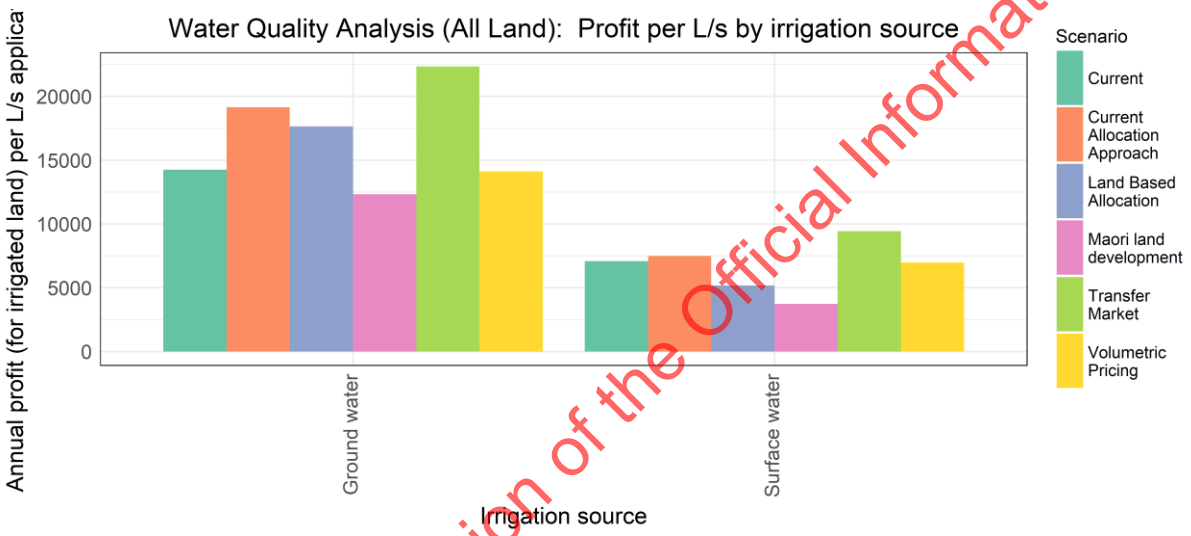


Figure 27: Water quality analysis - profit per l/s by irrigation source

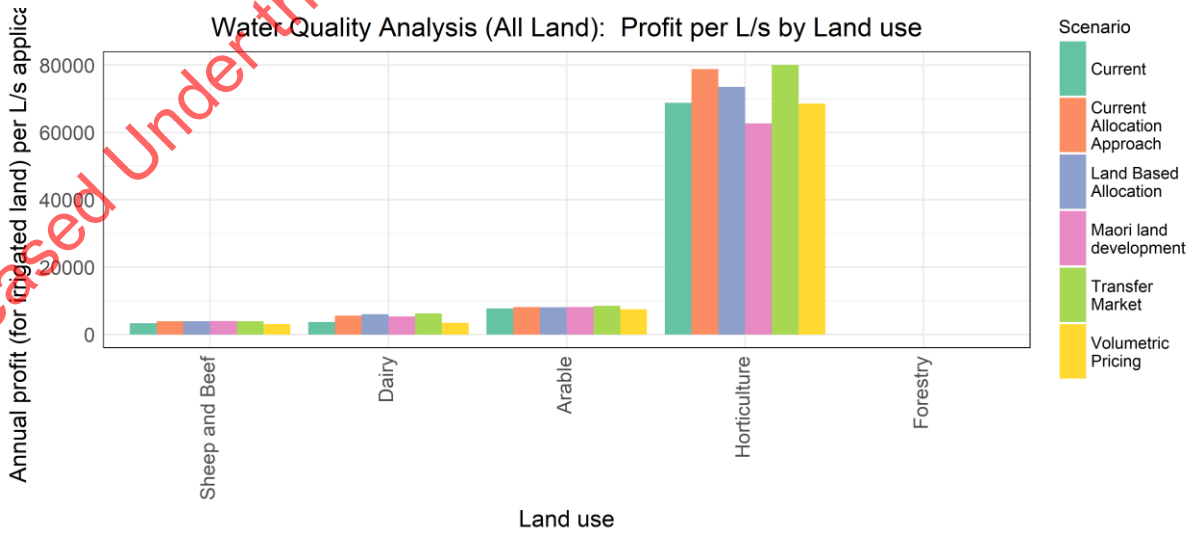


Figure 28: Water quality analysis - profit per l/s by land use

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The spread of profit per l/s as measured by standard deviation is relatively constant across scenarios and within the margins of error for the analysis, with the major differences being an increase in variance relative to baseline.

5.2.3 Volumetric pricing

The volumetric pricing scenario assesses the cost of introducing a charge per litre of water. This scenario was based on the incidence upon baseline land uses, which allows a better reflection of the impact for current land uses. For this reason the plots for the Volumetric pricing scenarios match the baseline scenario closely, generally with slightly lower profits. The incidence of this charge (Figure 29) is largest on Dairy and sheep and beef land uses, with forestry not affected and arable only slightly affected. Drinking water, industrial and other water uses experience a similar magnitude of aggregate charges to the horticulture, dairy and sheep and beef land uses.

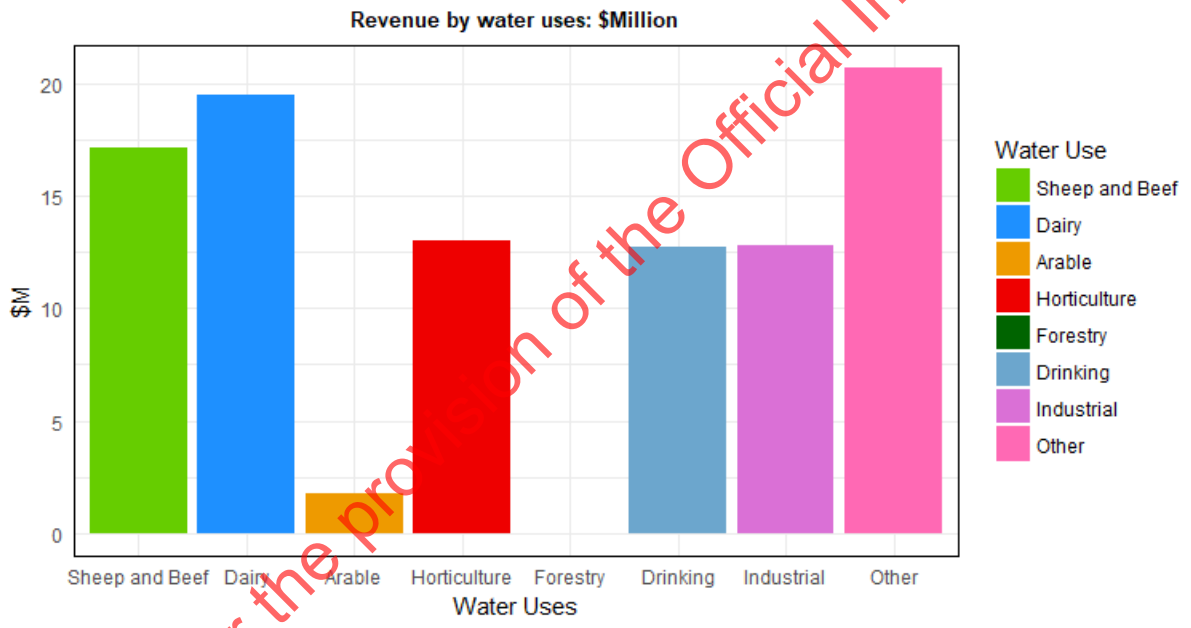


Figure 29: Volumetric pricing - incidence of the costs relative to Baseline

5.2.4 Implications for Māori

Under the Quantity scenario Māori land experiences increases in profit under the Māori land development scenario (Figure 30) but under the Quality scenario it experiences a decrease (Figure 31). As discussed above this is likely to be largely attributable to the combination of limits on the maximum nutrient losses and the unavailability of additional water for development. Interestingly the situations with the land based allocation is the opposite – Māori land experiences a decrease in aggregate profit under the Quantity scenario, but an increase for the Quality scenario relative to the Current approach.

It appears that there is also an increase in the profit per l/s of water allocation for Māori land under the Quantity scenario, which appears reasonably consistent across land uses and is

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particularly apparent with groundwater (Figure 33). The range of profits for Māori landholders also increases in the Quantity scenarios, although it is likely that this is a result of the upper bounds increasing (ii.e. greater gains for some landholders) rather than a decrease in the lower bounds (ii.e. some landholder experiencing reducing profits. This is not the case for the Quality scenario (Figure 33where the range tends to decrease with an associated lower profit in line with the reducing profitability for Māori in this scenario.

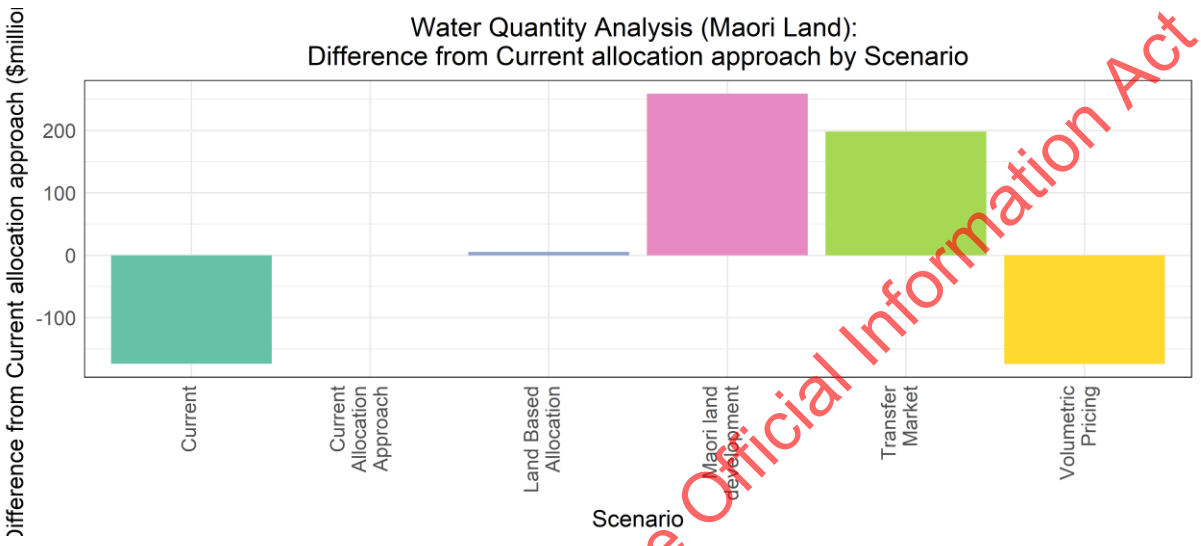


Figure 30: Water Quantity analysis - change in profit from Current allocation approach for Māori land

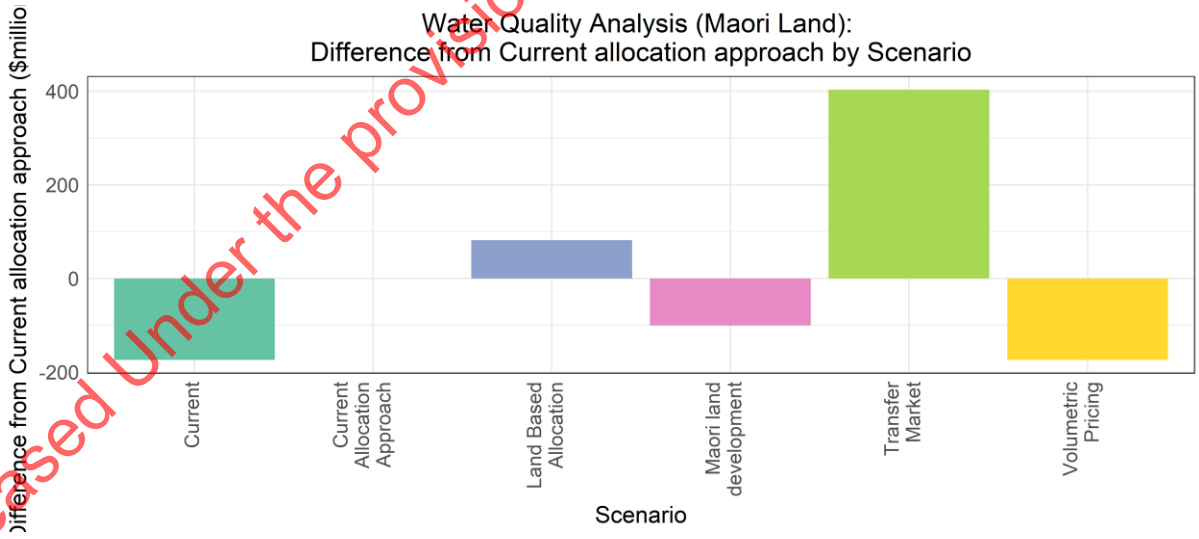


Figure 31: Water Quality analysis - change in profit from Current allocation approach for Māori land

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Figure 32: Water Quantity analysis – variability in profit by land use for Māori land

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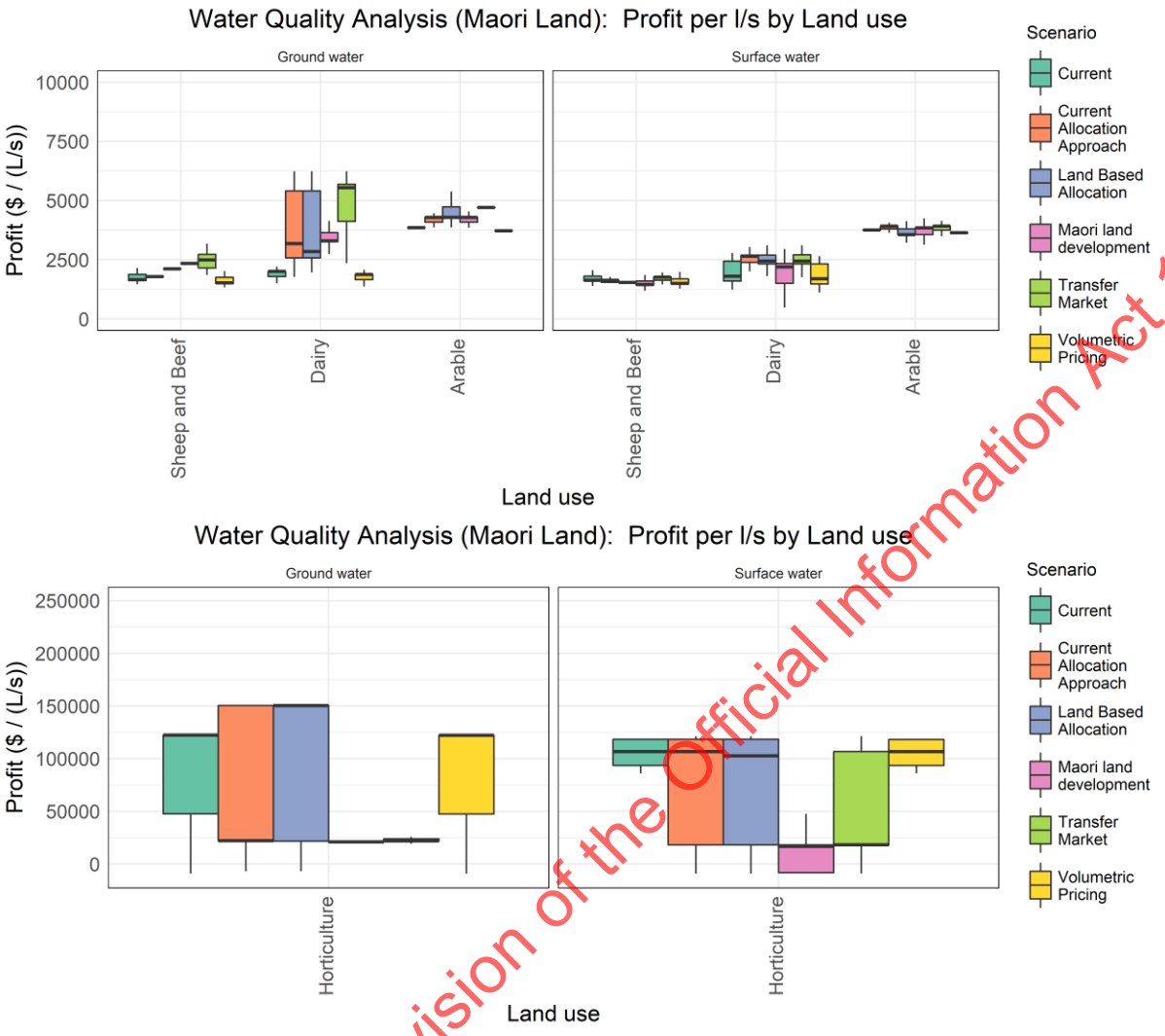


Figure 33: Water Quality analysis – variability in profit by land use for Māori land

5.3 Issues

The analysis is based on a set of input data and parameters which are based on the best available information, but the combination of input data and parameters have created a set of issues that may not reflect the way in which land use change is expected to occur, or the way in which scenarios are expected to operate. These issues are highlighted here and potential implications for Stage 2 development noted.

5.3.1 Overestimation of total profitability

The analysis suggests a total profit from agriculture, hortiuclture and forestry in the order of $12 billion, which is likely to be an overestimate. The primary contribution to this overestimate is the horticultural sector, which appears to be overestimated in size by the baseline land use layer. Statistics NZ indicates approximately 128,000 ha in horticulture in the last AgCensus (2012), while the baseline land use layer estimates approximately 457,000 ha. This contributes $5.8 billion in profit under baseline, and is likely to be a substantial contributor to the total overstimate of profitability.

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A secondary problem is that horticulture is a highly variable activity, and the operating profit from vegetable production is orders of magnitude less than from pipfruit production. However only one option is able to be selected due to aggregation in the land use layer – and while the option selected is the most prevalent horticultural use in that climate zone, the potential for error in the estimation of returns from all horticultural land uses is high.

It should also be noted that there is relatively little differentiation in the capital costs associated with horticulture, and so when these are subtracted from the profitability estimates it is likely to aggravate the size of errors – being either too high or too low for the actual land use model used to represent a climate zone.

5.3.2 Profitability curves and capital cost data

The profitability curves have been modified to include capital costs for each farm system. Because the capital costs for some systems, particularly dairy, are a large part of the total expenses, the net profit has become highly sensitive. For example in many of the South Island east coast areas dairy profit after capital costs is close to or less than that of sheep and beef. When combined with the flatter response of sheep and beef to reducing system capacity and reliability, it appears that there is a strong driver to move out of dairy and into sheep and beef.

Similarly forestry has higher profitability under the information used here than might be apparent from land use trends across the country. This is exacerbated by the use of a single set of returns nationally, which does not differentiate between returns in the same way that sheep and beef returns do. The implications of this is that there are some signfiicant drivers from sheep and beef, and in some cases dairy, into forestry. There may need to be adjustments to the capital costs and profit curves in order to better represent the relative profitabilities of these land uses.

5.3.3 Impacts of system capacity limits

The setting of a fixed system capacity ensures there is no incentive to reduce the use of water and spread it further across land area available in an agent. This fixed system capacity approach is used in Current allocation approach and Māori land development as a tool to prevent trading of water, since agents are an amalgamation across more than one landholding. The Land based allocation was set up in the same way, in order to ensure that the results were appropriately comparable across land uses.

The use of minimum system capacity in this way has resulted in some unexpected outcomes, and may contribute to the reduced profit for Māori landholdings in the Māori land development scenario. This approach may therefore need to be revisited to determine whether there is a more appropriate mechanism for preventing the gains that can be made from trading within an agent.

5.3.4 Profitability change in horticulture

Horticulture as a land use is highly constrained in its ability to increase within the model. This was intended to reflect the reality that horticulture tends to be limited by the avialability of profitable markets for product more than the availability of land or water for conversion into a horticultural crop. In the model the area under horticulture changes relatively little, but the profit increases substantially which is driven by a switch from dryland to irrigated (Figure 34).

It is likely that the switch between dryland and irrigated horticulture is driven by the shape of the profit curves. In some climate zones there is relatively little difference between dryland and irrigated horticluture, but in other climate zones there is a greater difference and this sets up

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a strong driver for installation of irrigation. In reality the likelihood is that dryland horticulture only occurs in areas where it is close to or as profitable as irrigation – ie irrigation is not really necessary. This is because the capital and input costs associated with horticulture mean that the costs of irrigation are relatively minor, and therefore where irrigation is a necessary part of growing a hortucultural crop it would normally be installed. The conclusion to draw is that the existing dryland horticulture is either non-existent, or that it is close to equally profitable to irrigated horticulture. The massive overestimate of the area in horticulture suggest that much of the dryland horticulture has been mis-labelled.

If appears questionable therefore whether the gains represented by this land use change are likely to be realised.

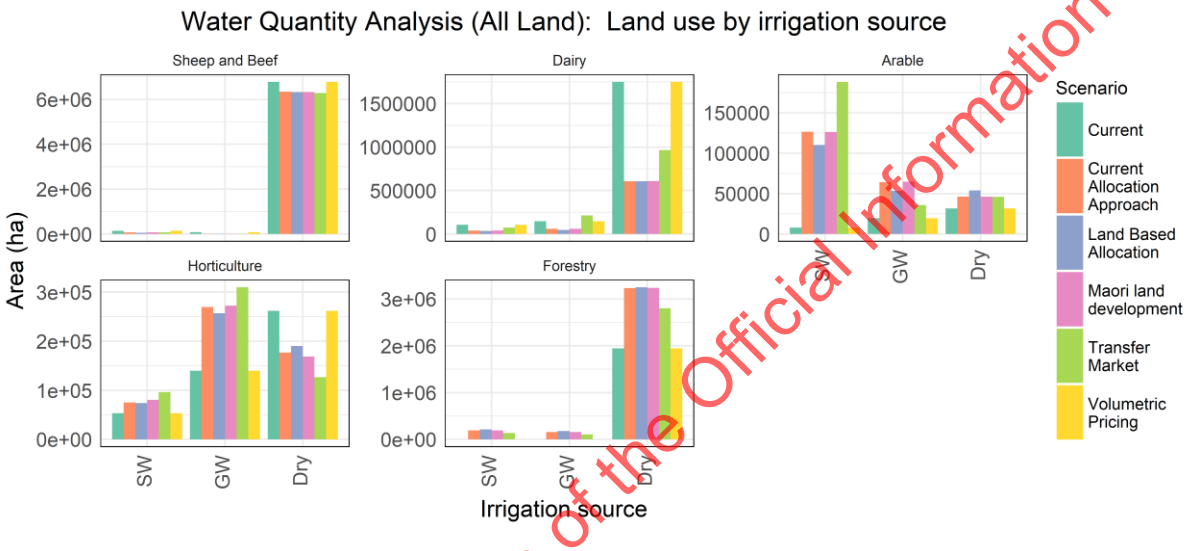


Figure 34: Water quantity analysis - land use by irrigation source

5.3.5 Transfer markets

The transfer market approach assumes freely available and costless transfer between agents. In practice there are a range of obstacles to the achievability of the gains that have been outlined here. These include transaction costs, omissions of full costs of land us change, greater variability in returns than is indicated in the inputs, and cultural reluctance to trade water. However it is worth noting that the point of comparison, the Current allocation approach, makes some other assumptions that may not be supported in practice. In particular there are a range of reasons why landholders may not change their land use to the highest possible value option. These include market reasons, infrastructure, suitability, personal and cultural issues, lack of capital, lack of expertise, risk etc, and the range of other factors that come into play in making management decisions. In reality land use change often only occurs alongside change of ownership or generational change on farms, and these occur sporadically and over long periods of time which may exceed our modelling horizon.

As with other issues in this modelling the problems arise not so much from the modelling but the interpretation of the modelling. The gains from neither the Transfer market nor the Current allocation approach are likely to be realised, so they represent the potential of these allocation approaches rather than predictions. Policy makers will need to take into account both the potential gains and the likely obstacles when making decisions on options, together with other factors such as the potential for the Transfer market to achieve the outcomes over a shorter

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time horizon that the equivalent gains could be achieved under the Current allocation approach..

5.3.6 Conjunctive allocation

The results presented here analyse scenarios that allocate water and nutrient separately. However it is clear that in the administrative allocation options there are significant problems with allocating one of these in the absence of the other. Allocated nutrients may not be usable in some locations if water is not available for development, and similarly unavailability of nutrients may prevent the full development of water resources.

Assessment of administrative options that allocate both of these together should be undertaken at the next stage of this project.

5.3.7 Payments in a market

The market transfer approach represents a market where there are buyers and sellers for the allocation. The outcomes presented here show the raw outcomes in terms of change in operating profit after capital. The aggregate outcomes for the catchment and nationally are accurate, but the outcomes for individual agents should also include the payment made from buyers to sellers for the allocation. The inclusion of this payment would reduce the apparent range of individual outcomes and affect the numbers of agents which experienced a reducing profit. The price at which the trade occurs is theoretically calculable, although is complex to determine in the context of multiple constraints and may be appropriate to consider in Stage 2 of the project.

5.3.8 Land use change constraints

The constraints on land use change have an impact on all scenarios as at least one of the land use constraints is generally binding in all catchments and in all scenarios. This suggests that the major barrier to most efficient use of resources is the management decisions made about the most appropriate land use. However because of institutional, infrastructural, and capital costs implications associated with land use and land use change, the actual land use mix always lags the ideal, and often significantly. Other modelling approaches (e.g. NZFarm) attempt to address this using an elasticity associated with land use change that reflects these lags, and then time stepping the model to demonstrate the way in which land use changes over time. Such approaches are not appropriate given the scale of this model, and it is accepted that the designation of limits on land use change does results in some arbitrary outcomes.

Of greater significance is the occurrence of some trading of *de facto* rights to undertake a land use. In order to maximise the returns from the catchment within the land use change constraint the model transfers land uses from locations where it is less profitable to others where it is more profitable, which can reduce the profit for those agents where the land use transferred from. This is unlikely to occur in reality because the landholder would not be willing to reduce their profit in order to benefit another landholder, and is an artefact of the need to impose constraints on the change overall. It is difficult however to prevent without introducing further artefacts into the results, and is acceptable in the context of the results representing potential from an allocation approach relative to other allocation approaches using the same modelling constraints.

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5.3.9 Volumetric Pricing

The Volumetric pricing scenario is calculated from the baseline land uses. This allows a clearer definition of the likely impact of the charge for current users of water. Furthermore it is calculated on consented rather than actual use, so those users with large takes which effectively reserve a quantity of water for potential future needs are penalised more heavily. There are two issues associated with this approach:

The charge itself is likely to have some impact on behaviour. When the scenario was set up it was considered likely that users would not be affected, but the actual charge on a per ha basis is likely to be sufficient to alter the long term relative profitability of some land uses. It may be appropriate therefore to consider the additional implications of this charge on land use change in the Current allocation approach, which would involve altering the profitability curves to reflect the change implied by the price, then rerunning the scenario to estimate the impact on land use and total profitability.

The charge could also be based on actual use, which would reflect both the availability of water (lower reliability water is used less often) and the demand. Land uses in wetter parts of the country and with takes from lower reliability water sources would experience lower costs as a result. The need to take this approach will depend on the policy objectives of the pricing regime.

5.4 Summary

The results are preliminary and should be seen in the context of potential further developments and re-specification of the model to better reflect the intent of the policy options. Furthermore the results are critically dependent on the input data, of which the land use (particularly horticulture) and the profit curves require some examination.

The approaches to allocation all produce higher net profit than the baseline. This suggests that there is further room for development and change of land use nationally regardless of the allocation approach adopted.

The Land based allocation does not produce higher outcomes overall than the Current approach for either the Quantity or Quality scenario. However the results for Māori land show improvements for the Māori land development in the Quantity scenario but reducing outcomes in the Quality scenario. Although these differences may be caused by modelling parameters, these parameters were set up to represent what was thought to be a reasonable approach to the allocation, so the clear conclusion is that any administrative allocation approach will need to be very carefully designed if they are to achieve their intended outcome. The difficulties in setting up the model reflect the real world problems in designing allocation systems. As the results for the Māori land development scenarios show, the potential for unintended consequences are high.

The results for Māori land development also show that conjunctive allocation of nutrient and water should be considered. It has also been assumed in the model that no capital, skill or other constraints exist to the development of this land, which may not be the case. Therefore design of the allocation system would need to provide for nutrients and water for development, but also ensure that the full range of resources is available otherwise the reallocation would impose costs to existing allocation holders without any concomitant benefits for Māori, and society would be worse off overall. It may be that the Land based allocation system is similarly constrained by unavailability of either water or nutrients for development, and that conjunctive allocation would show gains for this approach too.

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A Transfer market appears to be the only approach that has reliably increased overall profit relative to the Current allocation approach. The extent to which these gains could be achieved in real life are not demonstrated by the model, but it is clear that transfer markets enable the potential for gains over and above what could be achieved through the Current allocation approach. Furthermore the element of time is not taken into account and the Transfer markets may achieve their gains faster than the Current allocation approach because of greater fluidity in the mix of capital, skills, entrepreneurship, land and resource allocation.

6 Glossary

Baseline	Base 'Current' scenario which assumes the sum of the current consents as the available allocation.
FDC	Flow Duration Curve – which provides an estimate of the proportion of time a given flow will be exceeded.
FMU	Freshwater Management Unit – the management unit to which plan provisions apply.
FMU Class	A grouping of similar FMUs such that
FSL	Fundamental Soil Layer – a Landcare Research national database of the underlying soil types.
NZLRI	NZ Land Resources Inventory – a classification of NZ into classes of land according to soils, slope, climate etc and provides an indication of its suitability for different uses.
PSI	Pressure – State – Impact model developed by NIWA. It models consent information in a digital river network format.
REC	River Environment Classification system, which is a classification of all river reaches based on the characteristics of the upstream catchment. It is based on the digital river network.
PAW	Plant available water, which provides an estimate of the water stored in the soil profile.

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Acknowledgements

The authors wish to thank MFE staff for their input and assistance, Doug Booker for his help with the PSI database and observations on data issues with the consents, and John Bright and Stu Ford for their continued help on the project. We also wish to thank our spouses, without whom none of us could continue, and our children who drive us to want to work more.

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Waimea water allocation economic modelling – first tranche

Purpose

This paper updates the TAG on economic analysis that Professor Graeme Doole has helped the water allocation team with. This work will test some of the allocation policy options discussed during this process in the Waimea catchment in Tasman district. This work is intended to develop our understanding of the water quantity allocation options being considered by the TAG and ultimately minsters.

The modelling builds on modelling completed in 2015[1] but focuses more sharply on the current policy options (and less on the Waimea Community Dam). Further scenarios will be run in coming weeks based on feedback from the TAG.

Farm and orchard economics

The first underpinning step was to build a detailed picture of the economics of water use in the catchment. Plant and Food Research, Landcare Research, and local horticultural consultants Fruition analysed profitability and water use for apples, grapes, dairy farming, and a vegetable cropping rotation including pumpkins, lettuce and cabbage.

For each land use, water use was constrained by the maximum weekly rate of water abstraction allocated and the supply reliability of this allocation. Irrigation system capacity is developed to align with the maximum weekly rate of water abstraction. Seven levels of water allocation and two levels of water supply reliability were modelled. Water supply reliability was estimated using 40 years of historic river flow data and the minimum flow triggers in the current Tasman District Council plan. Crop or pasture water demand and production responses were generated using 40 years of evapotranspiration and sunshine data.

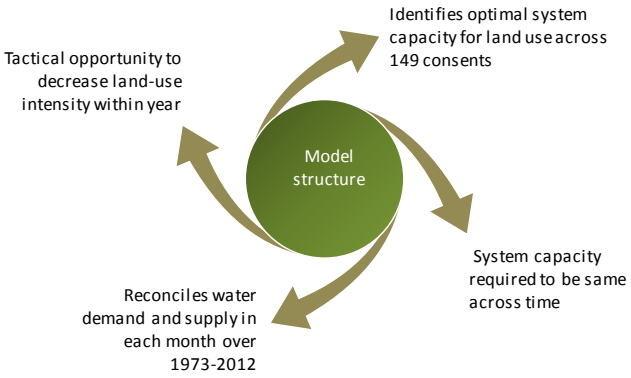
Catchment economics

Within Professor Doole's modelling, in this updated piece of work, 149 consents within the Waimea catchment were assigned an area, land use, and water allocation based on the council's consent database (checked against land mapping and local knowledge). Consents were placed within one of the 9 water management zones within the catchment.

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[1] Detailed reports on the previous modelling present the economic modelling results and the underpinning farm and orchard economics.

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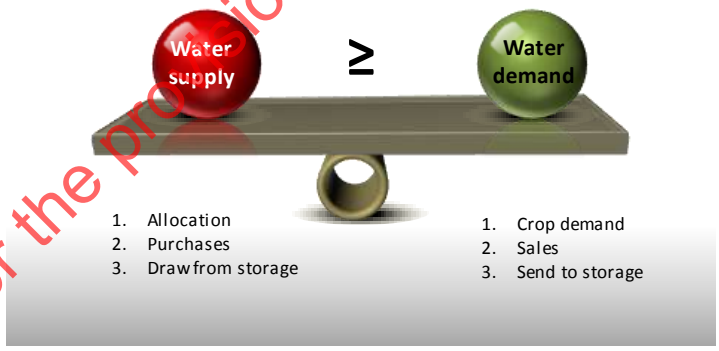


Water demand is reconciled with water supply within each of the 9 zones in each month. The allocation available is governed by the 40 years of minimum flow restrictions. The crop water demand is governed by monthly evapotranspiration.

Within the trading scenarios, sales and purchases of water are a decision variable that can modify the amount of water available. On-farm storage is included as an additional option to mediate differences in water demand and water supply.

Water use

Defined for each consent, month, and year

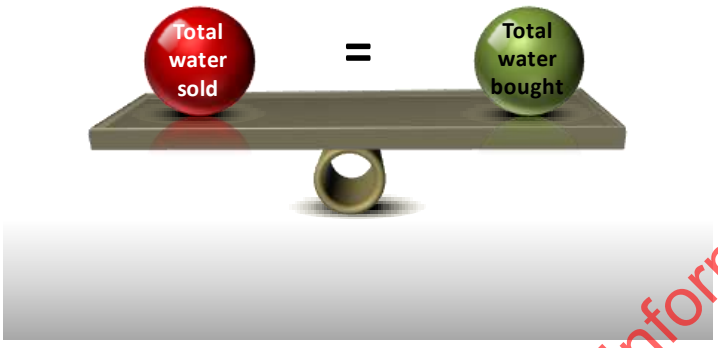


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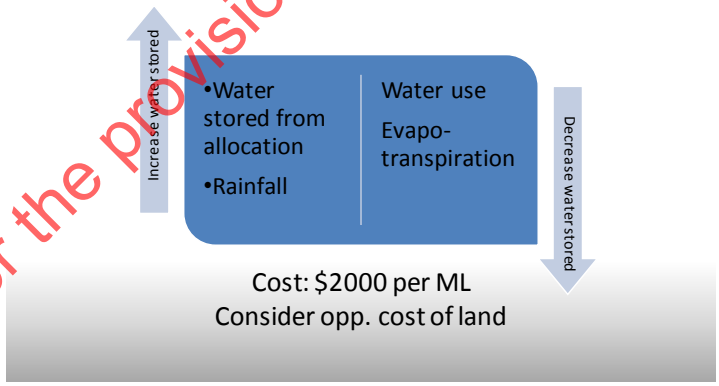
In the trading scenarios, within each of the 9 water management zones, for each month in the 40 years, the volumes of water bought and sold are reconciled.

Water market
Defined for each zone, month, and year



On-farm storage is enabled as a decision variable to manage temporal differences in water supply and demand. This form of storage is much more expensive than the Waimea Community Dam.

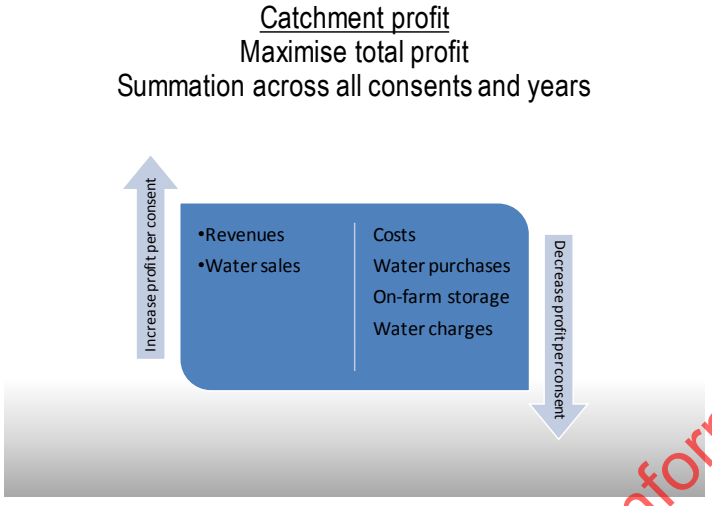
On-farm storage
Defined for each consent, month, and year



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The model maximises total profit across these decision variables to simulate the impact of policy.



Policy analysis

7 of the 9 zones within the Waimea catchment are over-allocated. The council currently has a policy of reducing allocations to 'bona fide' use which is a level of allocation sufficient to meet crop water demands in 9 out of 10 years. This reduction to 'bona fide' use, while getting rid of some paper over-allocation (particularly amongst the grape growers), does not eliminate all over-allocation in the catchment. Further reductions in allocation are required to address over-allocation.

The 'bona fide' use level of allocation forms the starting point for this analysis. In this paper, two methods of clawing back to full allocation are considered before moving on to analyse the impact of short term trading in the aftermath of clawback.

The **flat rate cut scenario** reduces allocations across all consents, regardless of crop type or land use, within a water management zone by the same percentage to eliminate over-allocation.

The **stringent bona fide use scenario** reduces the sufficiency of allocations below 9 out of 10 years (to say 7 out of 10 years) until over-allocation is eliminated in the relevant water management zone. Different crops or land uses on different soil types receive different percentage reductions depending on plant demand.

Trading, as described above, is introduced in the aftermath of both of these clawback methods.

In coming weeks further scenarios will be tested including **volumetric water levies**, **auctions**, and administratively set **water scarcity pricing**.

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Results

Comparing the two clawback methods, the flat rate cut is more costly than the stringent bona fide use. This is because the stringent bona fide use more closely matches crops needs.

The introduction of trading results in increased catchment income in both cases. These gains primarily occur in the driest years.

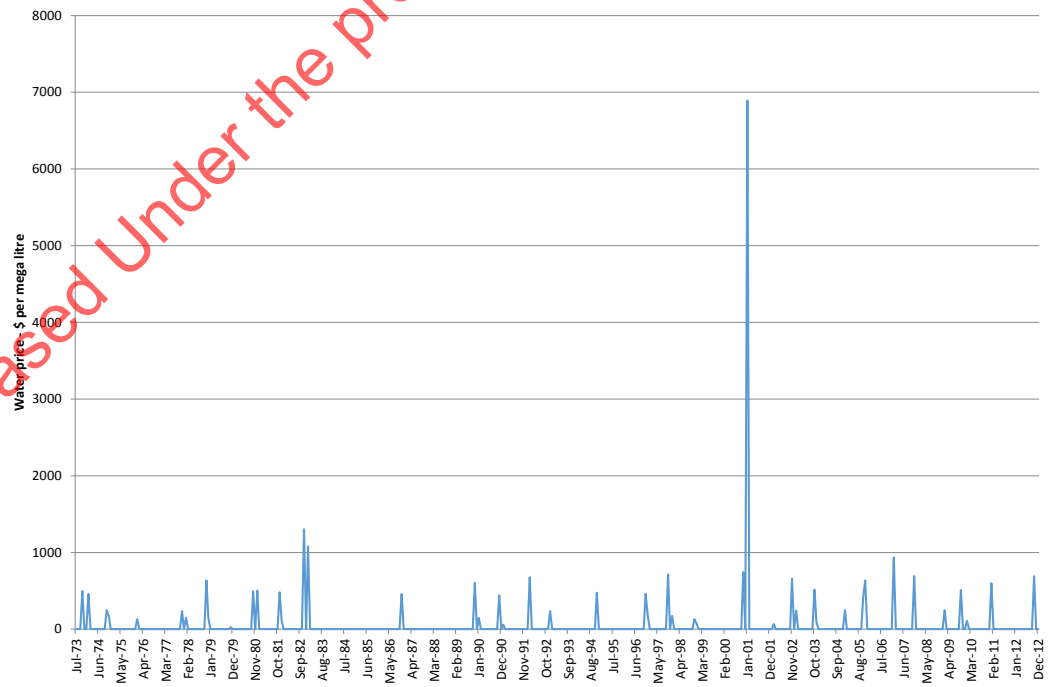
Following a flat rate cut, trading increases catchment income on average by 11 percent, and by 39 percent in the driest year.

Table 1: Summary results

	Average annual profit ($m)	Minimum profit ($m)	Maximum profit ($m)	Average annual water use (ML)
Bona fide use	15.4	8.6	21.3	6,926
Flat rate cut	13.6	6.7	19.3	4,906
Stringent bona fide use cut	14.2	7.7	20.1	5,354
Flat rate cut and trade	15.3	9.3	21.1	5,480
Stringent bona fide use cut and trade	15.3	9.3	21.1	5,411

The equilibrium water price estimated in the modelling is highly variable. Most months there is no scarcity, there is no trade, and the water price is zero. During summer, in the drier years, crops are thirsty, and minimum flow restrictions are triggered. At this time trading is highly beneficial and the water price shoots up.

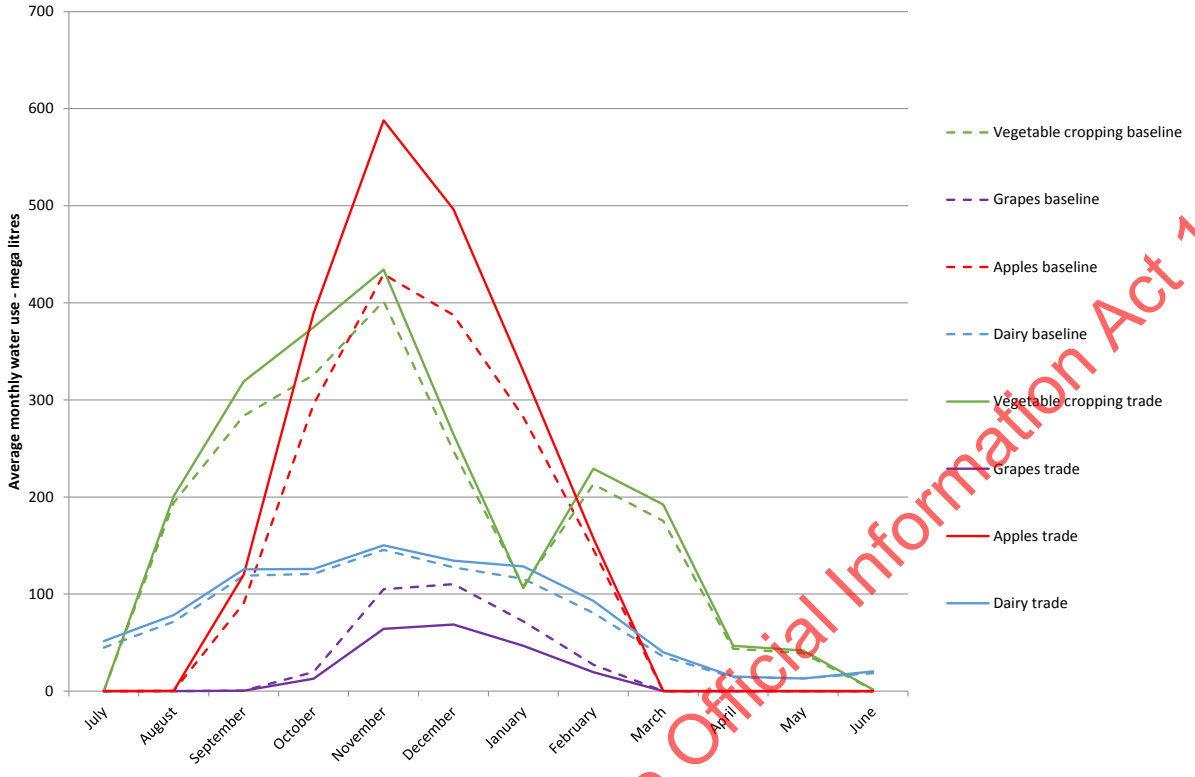
Figure 1: Monthly water price, Delta water management zone, flat rate cut and trade



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Figure 2: Average aggregate monthly water use by land use – flat rate cut baseline



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Ministry for the Environment
Manatū Mō Te Taiao

Ministry for Primary Industries
Manatū Ahu Matua

To: Ken Taylor and Brett Painter

Date: 13 March 2015

Subject: **ECONOMICS OF MANAGING WITHIN WATER QUANTITY LIMITS: WAIMAKARIRI DISTRICT**

Executive Summary

1. The Environmental Economics Unit[1] in the Ministry for Primary Industries has undertaken projects at the catchment level to consider three questions in detail:

    a) What are the costs of clawing back water quantity over-allocation?
    b) What is the potential for economic gain by trading water?
    c) What are the social and behavioural barriers to achieving this potential economic gain in practice?

2. This memo provides a detailed assessment of the economics of managing within water quantity limits in the Waimakariri catchment.

3. This analysis takes the setting of quantity and quality limits as given and focuses on managing within those bounds.

Key findings: Clawbacks

4. Analysis of groundwater consents revealed a range of allocation levels relative to modelled water demand.

    A. 7 of the 94 consents in the zone are unlikely to be fully utilised during even the driest years and a portion of allocated water could be clawed back with no direct cost;
    B. A further group of 33 consents fall short in 1 year out of 4 or fewer. The direct cost of clawing back a portion of allocated water for these consents would be low;
    C. 54 of the 94 consents fall short more frequently than 1 year out of 4 and any clawback on these users would be costly.

5. The method of clawback had a significant impact on costs, depending on how it affects the three groups described above. Flat rate cuts are costly because they impact group C. Reasonable use tests are cheaper because they primarily affect groups A and B. In aggregate, clawing back groundwater allocation by 10% would cost between 0.6 and 2.7% of income.

[1] The Unit is jointly funded by MPI and MfE and is part of the cross-agency Water Directorate based at MfE.

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Key findings: Gains from trade

6. Under the current level of infrastructure, benefits of 3% can be gained from water trading. When the water distribution system is extended, the benefits from trading are 17% as unirrigated land becomes available for development. This expansion of water distribution overcomes the fragmentation of the district's water resource into 22 separate groundwater and surface water zones.
7. Nitrogen limits could constrain economic development more than quantity limits:
   a) If nitrogen losses are capped at current levels, mitigation creates room for around two-thirds of the potential irrigation expansion;
   b) If nitrogen losses are reduced by 20%, irrigation expansion is essentially halted within the district.
8. Without trading, water storage schemes are the only way to access additional water within the catchment and the storage scheme generates benefit net of the capital costs.

Key findings: Attitudes to trade

9. A survey of water users revealed that most were in favour of trading, particularly temporary transfer of water rights. However, there were concerns around the impact of trading on equity and rural society. Most viewed the current council process as too time-consuming and complicated.

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Economics of managing within water quantity limits: Waimakariri District

What are the costs of clawing back water quantity over-allocation?

10. Councils are required by the National Policy Statement for Freshwater Management to phase out over-allocation where it exists. To ensure efficiency and consistency in how this is done, the Land and Water Forum recommended national guidance should be given to regional councils on the suite of methods for managing over-allocation (Recommendation 49).

11. In the Waimakariri District, a clawback analysis was undertaken to look at the impact of hypothetically reducing the annual allocation of the Eyre groundwater[2] zone by 10%. In reality over-allocation in the Eyre groundwater zone was resolved with an increase in allocation limit in January 2014 when better hydrological modelling showed the limit could be safely lifted.

12. Because clawing back allocations will affect some water users more than others, it is important to look beyond aggregate impacts to the distribution of losses to get an insight into how the methods will be perceived.

13. 58% of the Eyre Zone's annual allocation limit is spread among 94 agricultural consent-holders covering 10,138 hectares. The remainder is allocated to municipal, industrial, and other users and is excluded from this analysis.

Clawback methods: flat rate and reasonable use

14. There are many potential clawback methods. To illustrate how a clawback might work this study focuses on variations of two methods: flat rate and reasonable use.

15. Flat rate cuts decrease each consent holder's annual allocation by the same percentage without regard for irrigation demand, land use, or any other factors.

16. Cuts based on reasonable use tests compare each farm's current allocation to estimated irrigation demand. Irrigation demand is estimated for each farm based on a number of parameters including land use, climate zone, and soil type. The majority of regional councils are using this method when issuing or reviewing allocations.

17. As groundwater is generally not subject to minimum flow restrictions[3], consent holders are able to fully utilise their annual volume. Climate-driven variation in irrigation water demand means that a farm's allocation might be insufficient in some dry years.

[2] Groundwater resources do not have seasonal flow restrictions provided that each consent's annual volume allocation is not exceeded.

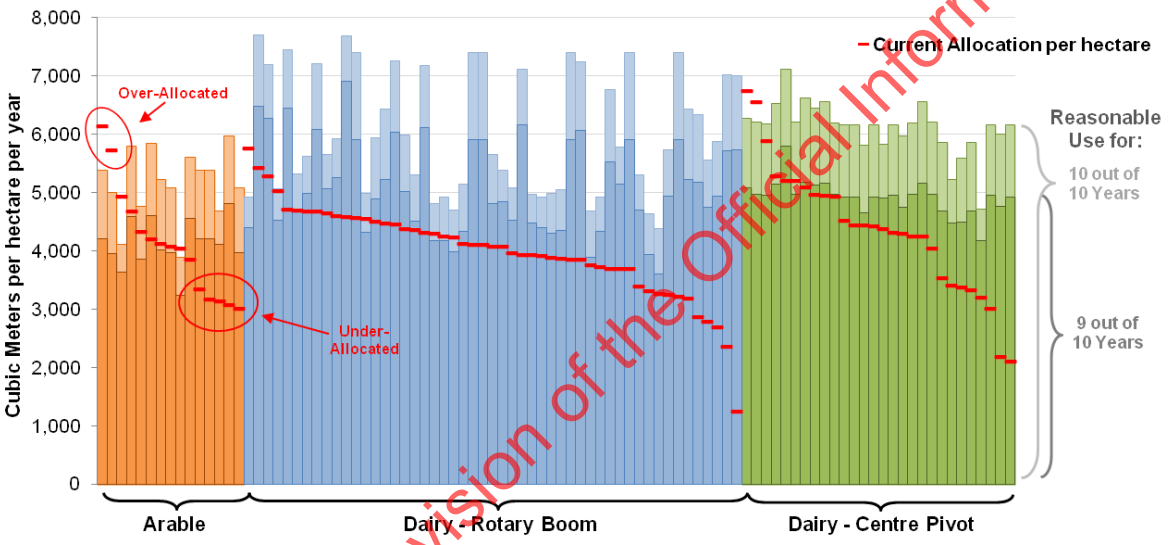
[3] 7 out of the 94 consents are deemed to be hydrologically connected to a surface water body and face minimum flow restrictions in addition to their annual volume constraint.

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18. Reasonable use is defined here as the amount of allocation needed to satisfy a farm's irrigation demand in a specific number of years in a decade. This study looks at three levels: 10, 9, and 7.5 years out of 10. Consent holders were held to their current allocation or their reasonable use level, whichever was lower. After applying the reasonable use test, a flat rate cut was applied to achieve the target 10% reduction if necessary.

19. Figure 1 illustrates the variation in reasonable use and current allocation across the 94 consent holders in the Eyre zone. The consent data shows that only 7 of 94 consents have a higher allocation than modelled irrigation demand in even the driest year. Many allocations are even lower; 54 consents are allocated less water than needed in 7.5 years out of 10.

Figure 1: Current Groundwater Allocations vs Reasonable Use



20. Water use data was considered as a basis for clawback in the analysis. However, as the data covers 54 of the 94 consents in 2013-14 and goes back in time less than 4 years, the coverage is not complete enough to do the analysis.

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Key Results: impacts are low; reasonable use has lower, less concentrated costs

21. Table 1 shows that the overall cost of a flat 10% allocation cut has a relatively small direct impact, ranging between 0.6% and 2.7% of annual operating income.

Table 1: On-farm impacts of 10% clawback in Eyre groundwater zone

Clawback Method	Annual Allocation		Annual operating income		Number of consents affected (by % of lost operating income)				
	million m³	*change*	*$ million*	*change*	*0%*	*0 to 1%*	*1 to 2%*	*2 to 5%*	*5 to 10%*
Current Allocation (excluding non-irrigators)	42.7	0%	$23.5	0%	94				
Flat 10% cut	38.4	-10%	$22.9	-2.7%	5	14	16	37	22
Reasonable use for 10 years out of 10, then flat 8.6% cut	38.4	-10%	$22.9	-2.2%	0	22	23	36	13
Reasonable use for 9 years out of 10, then flat 4.4% cut	38.4	-10%	$23.2	-1.3%	0	49	24	21	0
Reasonable use for 7.5 years out of 10	38.4	-10%	$23.3	-0.6%	54	17	21	2	0

22. Flat rate cuts have a larger impact on farm operating income and these costs disproportionately affect a number of consent holders whose current allocations are below reasonable use thresholds.

23. This finding is primarily driven by the uneven current distribution of allocations as shown in Figure 1. Flat rate cuts have a minimal impact on farms with surplus water allocation and a larger impact on farms whose allocations fall well short of demand.

24. In contrast, reasonable use scenarios have a smaller overall impact on farm operating income and tend to distribute those losses across a larger group. This is because reasonable use tests fine-tune clawbacks in proportion to each farm's modelled irrigation demands.

25. Across all scenarios, farm systems with higher water demands have more to lose from the tested clawback methods. For example, dairy farms tend to lose more than arable farms, and light soils more than heavy soils.

26. Allocations may have value beyond that directly generated through irrigation. Excess allocation gives the consent holder the option to use it in the future by intensifying production. Resource consents are also tied to land values, so clawbacks might reduce farmers' net worth.

27. Accuracy of the input data is an important consideration, not just for this analysis but also for councils to consider when implementing clawbacks. In particular, the area irrigated has been identified as potentially inaccurate in the council's database, which has a significant impact when estimating a farm's reasonable use.

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What is the potential for economic gain by trading water?

28. An economic model was built to test the potential for economic gain from allowing water to be freely traded. The model optimises total average earnings expected across the 41 years of climatic outcomes subject to constraints on land availability, the supply of water from groundwater and surface water, and nitrate leaching limits.

29. Transactions costs and other impediments to trading are not modelled but will prevent the achievement of high economic returns. These barriers and transaction costs are discussed in the next section.

30. Scenarios representing the development of infrastructure within the district and different nitrate leaching limits are progressively introduced.

31. Water transfer was represented as the long-term permanent transfer of access to groundwater volumes and surface water flows. The temporary movement of water was not modelled.

Results: value of trading limited by extent of distribution infrastructure

32. Gains of $4m (or a 3% increase) can be achieved through trading within the current irrigable area if water is utilised more efficiently. This involves dairy farmers operating their systems at a lower level of water use, down to 0.4 litres per second per hectare. Arable farms do not reduce water allocation from 0.6 litres per second per hectare in this scenario.

33. The trading of water has significant economic benefits if distribution systems expanding the irrigable area are constructed. Freeing the trading of water allocation increases water availability, and allows the expansion of irrigable area generating a benefit of $17m annually (a 13% increase).

Gains from storage and distribution infrastructure

34. In the absence of water trading, there are economic gains of $11m (a 9% increase) associated with the development of central storage. Without trading, storage is the only way that sufficient water can be accessed to allow the expansion of irrigation development across the 16,000 ha of unirrigated sheep and beef land. These gains occur after the capital costs associated with developing central storage, converting dryland, and extending irrigation infrastructure are borne.

35. With the introduction of water trading the emphasis of infrastructure development may swing more towards wider distribution systems at the expense of storage volumes as buying water permits can be cheaper.

36. On-farm storage was included in the modelling but was not economic under any of the scenarios considered.

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Table 2: Trading and storage scenarios – no nitrogen cap

Unconstrained N case	Total Operating Income ($m)	Irrigation Expansion (ha)	Total N leaching (t)	Capital costs* ($m)
Baseline	$129	0	2,194	$0
Trading	$133	0	2,111	$0
Expanded distribution with trading	$146	15,877	2,511	$15
Expanded distribution and storage without trading	$141	15,877	2,605	$23
Expanded distribution and storage with trading	$144	15,877	2,512	$23

*Annualised storage, distribution, and farm development capital costs

Nitrogen limits constrain development

37. Three nitrogen limits set at the catchment level were explored: no cap set on leaching, leaching held at current levels, and leaching 20% below current levels.

38. The Waimakariri zone committee is working towards setting water quality objectives and nutrient limits for the district. The current situation falls short of the community's aspirations for water quality and a nutrient load limit is likely to emerge from the zone's collaborative process.

39. In the absence of a set nitrogen cap, leaching tends to increase with irrigation expansion within the catchment as more intensive agricultural practices replace unirrigated land that has much lower loadings to the environment. For example, converting a hectare of unirrigated sheep and beef to dairy production increases leaching losses by around 30 kg N per ha (a 350% increase).

40. Maintaining nitrogen losses at current levels decrease the possible extent of irrigation expansion and reduces the benefits of both trading and storage. Around 10,000 of a possible 16,000 hectares is converted to irrigated dairy. Nitrogen mitigation through irrigation efficiency creates the space for expansion within this scenario's fixed nitrogen budget.

41. A target to reduce nitrogen losses by 20% essentially precludes any irrigation expansion within the district.

42. On existing farms, significant nitrogen mitigation is deployed to meet the target. Most dairy farms use stand-off pads in these scenarios complemented by reductions in water allocation when water trading is modelled. In the arable sector, water allocation drops below 0.6 litres per second per hectare to reduce nitrogen loss. Enabling water quantity trading helps offset the high economic costs of stringent nutrient limits.

43. Mitigation of nitrogen leaching was represented more simply than has been the case in nutrient focused studies. The inclusion of a more comprehensive set of nitrogen mitigations in these scenarios could increase the amount of irrigation expansion possible with nitrogen budget limits.

Table 3: Nitrogen limit scenarios

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Maintain total N leaching at baseline	Total Operating Income ($m)	Irrigation Expansion (ha)	Total N leaching (t)	Dairy farms using stand-off
Baseline	$129	0	2,194	0%
Expanded distribution with trading	$141	10,859	2,194	0%
Expanded distribution and storage without trading	$130	3,759	2,194	1%
Expanded distribution and storage with trading	$139	10,743	2,194	0%

Reduce total N leaching 20%	Total Operating Income ($m)	Irrigation Expansion (ha)	Total N leaching (t)	Dairy farms using stand-off
Baseline	$92	0	1,755	100%
Expanded distribution with trading	$103	9	1,755	72%
Expanded distribution and storage without trading	$93	357	1,755	100%
Expanded distribution and storage with trading	$102	726	1,755	76%

What are the barriers to achieving this potential economic gain in practice?

44. A range of barriers may prevent any gains identified by the optimisation model from being realised. To get a sense of these practical barriers, the Water Directorate contracted Landcare Research to survey water users about their attitudes to transferable water permits. This research was conducted through interviewing 16 water users in both the Waimakariri District in Canterbury, and the Waimea plains in Tasman.

45. The research aimed to gain insight into water users' attitudes to transferable water permits and factors influencing farmers' decisions whether or not to transfer water permits.

46. Key findings of this research are that almost all water users are generally receptive to transferable water permits, but this support was conditional.

    a) Farmers identified benefits from water transfers, including increased flexibility of land use through increased access to water, and the win/win nature of transfers for both buyers and sellers - "…at the end of the day nobody's forced to transfer their water, are they?...";
    b) Most respondents were concerned that water permit trading would have negative effects on the distribution of wealth and opportunity in the community;
    c) Some respondents were sceptical that a transfer regime could be implemented effectively or that it was appropriate for the conditions in their community.

47. While this research is qualitative, and provides information on water users' opinions on transfers, it does not show how prevalent these views are.

Some respondents concerned about equity effects and impacts on rural society

48. Support for temporary transfer was much stronger than for permanent transfer, primarily because of concerns about permanent transfer's effect on land values.

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49. Concerns were expressed that water would move out of agriculture, and that non-rural users would bid up the price of water to the point that agriculture becomes uncompetitive in the area. Some suggested that non-landowners, speculators, and urban users should not be allowed to engage in water trading.

50. Some felt that trading systems should have local and regional benefits at their core including economic, social and environmental.

51. There was concern that for-profit water trading would unfairly exclude new farmers and small scale operators.

52. There was a belief expressed that the initial allocation needs to be fair from the start, otherwise some people will get windfall profits.

Some respondents discouraged by complexity and uncertainty

53. Some respondents believe that the process is too complicated, expensive and takes too long.

    a) A formal transfer with the council takes up to 2 years, according to some respondents;
    b) However, there was some optimism about ways to bypass council: trading within an irrigation scheme or farmer-run water user group is far easier.

54. There was concern that trading puts one at risk of scrutiny by council and neighbours; and there is no way to know that council will continue to recognise permits that are invested in and transferred.

55. It was noted there was a lack of information about potential trading partners or hydrological data in the area.

56. A feeling was expressed that water permit trading is unnecessary in under-allocated catchments and inappropriate for over-allocated catchments.

57. There was concern that lack of reliability creates uncertainty as to whether or not they should trade a water permit.

Next steps

58. A number of assumptions underpinning this analysis are being worked on further and additional scenarios will likely be run. A more technical report will be put together in future to capture this work and some of the technical detail not included in this memo.

59. This work will add to the evidence base for further central government work on managing over-allocation and improving the flexibility of water management in New Zealand.

60. There would be considerable value in robustly testing the modelling and assumptions with well-informed stakeholders and updating the results if this process changes the conclusions.

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61. A further detailed catchment study in the Waimea catchment in Tasman will be completed by April 2015.

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Appendix 1: Description of Waimakariri District

62. The Waimakariri District was chosen because it is broadly representative of Canterbury, which as a region accounts for 64% of New Zealand's irrigated area. The Waimakariri District has a mix of irrigated dairy and irrigated arable farming drawing on a combination of ground and surface water, with some dryland sheep and beef remaining. There is significant lifestyle farming in the district. The district has about 5% of New Zealand's irrigated area.

Fragmented water resources limit trading potential

63. Water resources within the Waimakariri District are highly fragmented and complex with overlapping surface and groundwater zones. Maps showing the layout of the Waimakariri District can be found in Appendix 1.

64. The Waimakariri Irrigation Limited scheme further complicates the picture with a surface water distribution network that sprawls across multiple surface and groundwater zones. The scheme delivers water to 18,000 hectares.

65. These areas define the extent to which water can move to its highest value use and, without new infrastructure, limit the potential gains from trade.

66. The Eyre groundwater zone accounts for 80% of all groundwater allocations in the district. The Waimakariri River accounts for 75% of all surface water allocations in the district, half of which is allocated to Waimakariri Irrigation Limited.

Groundwater and surface water are managed quite differently.

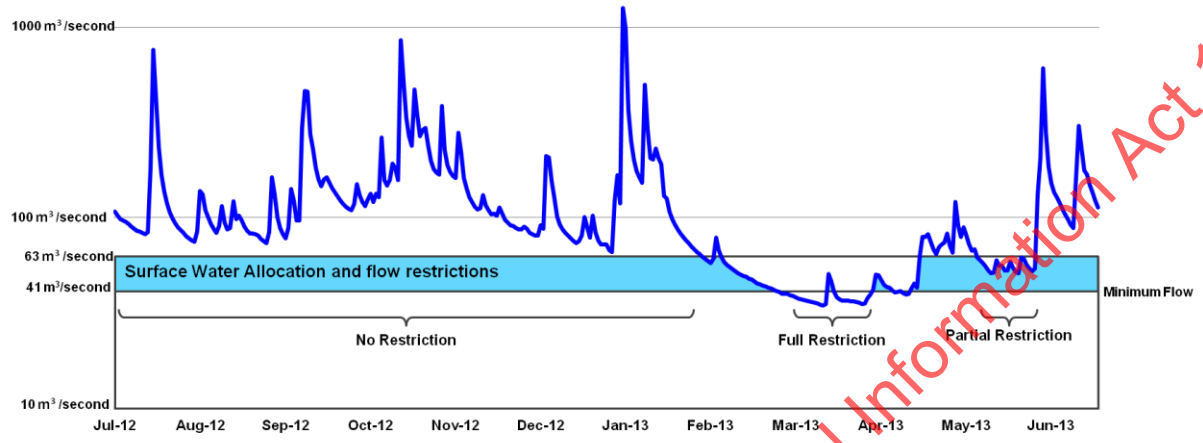
67. Groundwater resources are like a bucket that gets filled each winter. Regional councils set an annual allocation limit on each groundwater zone expressed in cubic meters per year. There are no flow restrictions provided that each consent's annual allocation is not exceeded. (Some wells are hydrologically connected to rivers or streams and are exceptions to this rule.)

68. Surface water resources are flows in a river, a portion of which can be abstracted for productive uses. Regional councils specify allocation limits and minimum flows for each surface water zone expressed in litres per second. Figure 2 shows how allocation limits and minimum flows interact with the variable flow of the Waimakariri River on a daily basis.

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69. The clawback analysis covers groundwater only. The optimisation analysis covers both groundwater and surface water.

Figure 2: Surface Water Flow in the Waimakariri River 2012-13



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Appendix 2: Farm Level Analysis

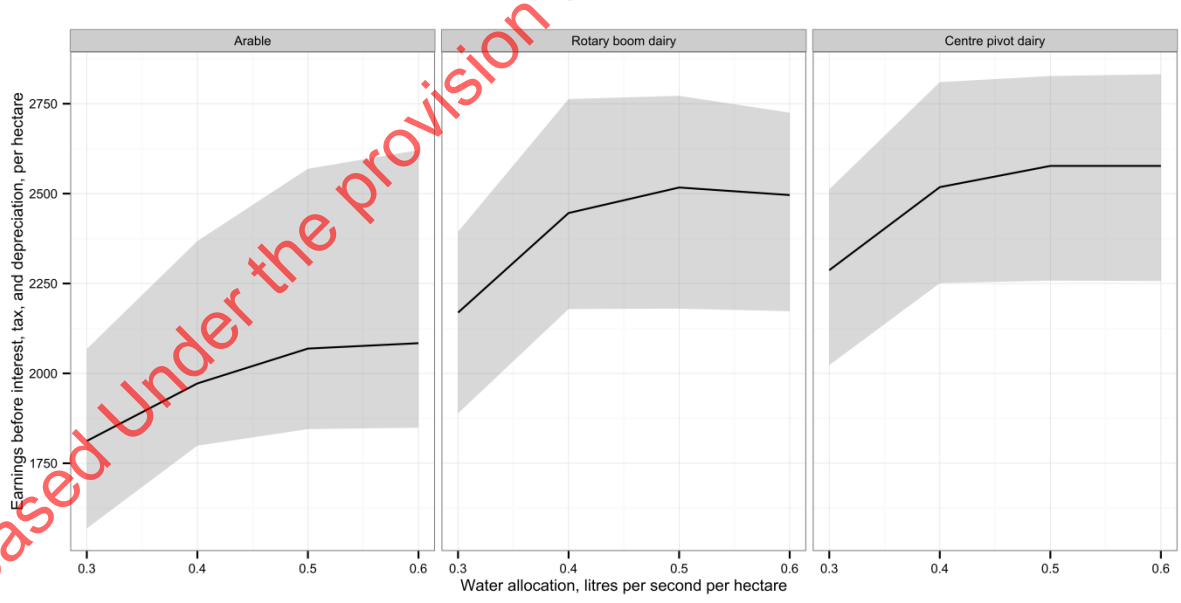
70. To underpin the analysis, Aqualinc Research was commissioned to model farm water demand and profitability in the Waimakariri zone. A range of irrigation systems, soil types, rainfall bands, and nitrogen mitigation measures were modelled over 41 years of climatic data.

71. Regional councils typically allocate water at rate of 0.6 litres per second per hectare. As allocation is reduced the ability of an irrigation system to keep up with evaporation and plant water demand in dry years is diminished and eventually profitability falls.

72. The farm level modelling, illustrated in Figure 3, shows that:

    a) At the $6.30[1] payout used for this analysis, dairy farms are more profitable than arable farms;
    b) Solely varying the climate data, the farm level modelling generates significant variability in profitability (represented by the grey area in figure 3);
    c) As allocation is reduced from 0.6 to 0.5 litres per second per hectare, in this modelling there is no major impact on mean or variability of profit per hectare in the dairy systems.
    For all farm systems, moving down to 0.3 litres per second per hectare reduces profit more significantly.

Figure 3: Farm earnings and water allocation, median and 9 out 10 year range

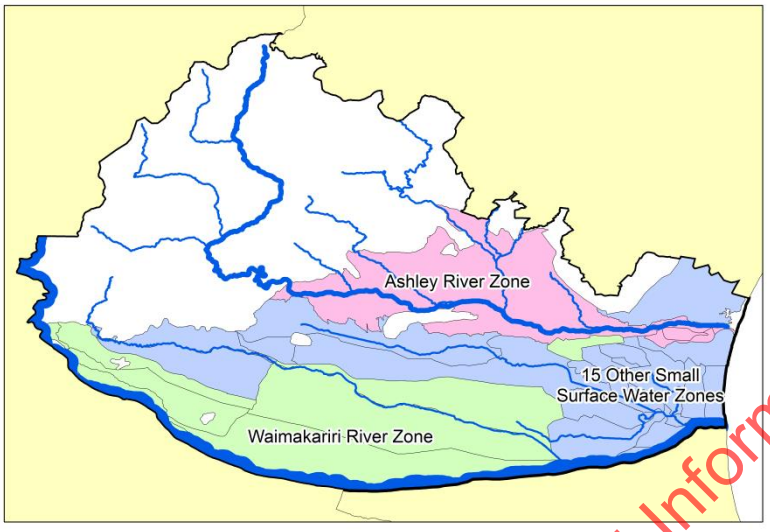


[1] For 2012/13 and similar to the 5-year average payout.

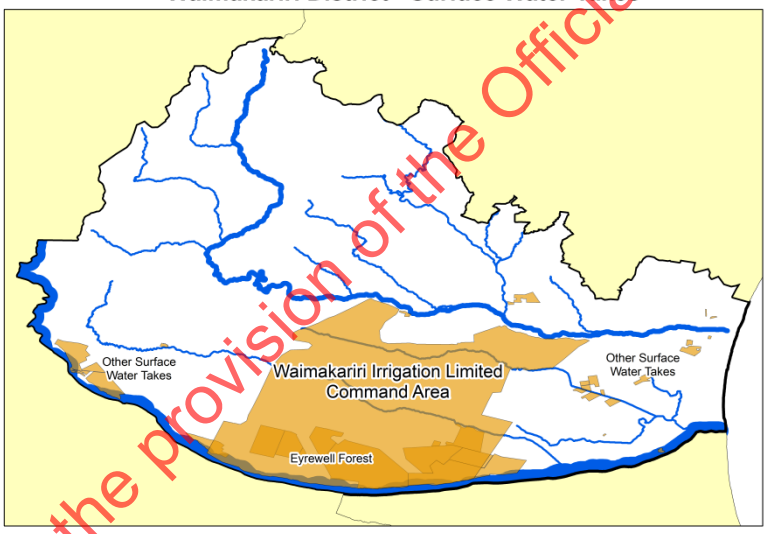
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Appendix 3: Waimakariri District Maps

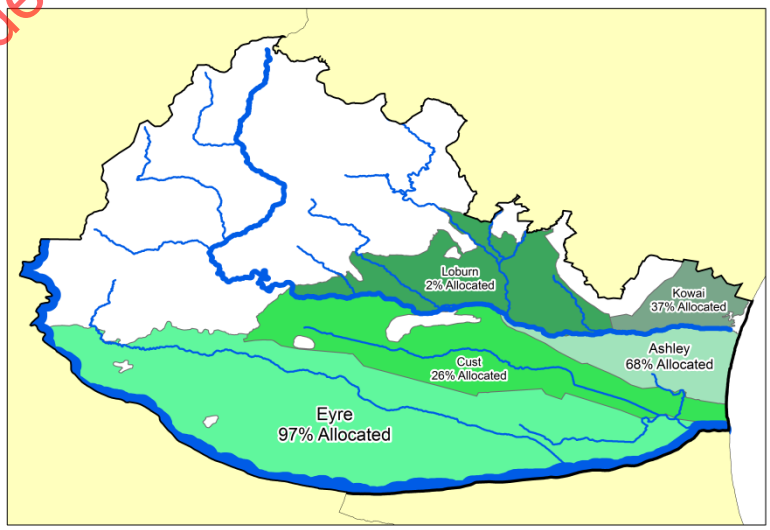
Waimakariri District - Surface Water Zones



Waimakariri District - Surface Water Takes



Waimakariri District - Groundwater Zones



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Maori Land Project – Phase Two Analysis of Water Quality data on a National Scale.

Presentation of findings to the Rights and Interests Advisory Group Meeting – 5 March 2015

Approach of the analysis of water quality data

This is a national scale analysis based on national scale datasets. It provides broad scale information, but should not be relied on for fine scale information about whether a particular catchment or land parcel is, or is not, constrained or suitable for agricultural development.

There are multiple constraints on the potential development of land for agricultural use. This analysis estimates the area of New Zealand that, with "advanced mitigation[1]", might support agricultural development within these natural and made-made constraints.

Examples of natural constraints to agricultural use include slope, soil type, drainage and water availability. Examples of man-made constraints include the current management (eg, conservation, agriculture, urban) and the ability of our activities to occur within acceptable effects on our environment (eg, pollution levels in rivers and lakes, river flows remaining after abstraction).

This analysis uses estimates of these constraints to identify areas that are potentially suitable for agricultural development based on:

- natural land capabilities
- current land management
- the ability of advanced agricultural mitigation techniques to enable agricultural development within national water quality bottom lines and maintaining current water quality
- the availability of water.

The analysis also looks for any differences in the level of natural or man-made constraints between the total land in New Zealand and Maori-owned land[2] to understand if agricultural activities on Maori-owned land might be disproportionately affected by water quality national bottom lines.

Conclusions

Mitigation is likely to enable agricultural activities to continue in most places, but is unlikely to create widespread headroom for expansion or intensification. Parts of Waikato, Horizons, Taranaki, Canterbury and Southland are unlikely to achieve national bottom lines even with advanced mitigation.

Creating headroom for agricultural expansion will require high degrees of innovation.

Setting water quality bottom lines does not disproportionately affect Maori-owned land in comparison to the land base of New Zealand.

The lower levels of current development and higher proportion of low capability Maori-owned land mean that the use of allocation mechanisms based on current land use or land capability (eg, grandfathering, land use capability) could disadvantage agricultural development opportunities for Maori-owned land.

[1] Mitigations comprise bundles of land management practices. For example, for dairying, advanced mitigation includes a combination of practices such as stock exclusion from streams, effluent best practices, fertiliser and crop management and so on.
[2] Maori owned land as defined by the Te Ture Whenua – Maori Act, 1993.

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Distribution
Minister
Minister's Advisor
Minister's Office

Ministry for Primary Industries
Manatū Ahu Matua

Ministry for the Environment
Manatū Mō Te Taiao

4 December 2014

Document Number: **MPI B14-214**
MfE 14-B-01879

Economics of managing within water quantity limits: Waimakariri District

Purpose:

This briefing presents the results of MPI's economic analysis and modelling of different opportunities to get more economic benefit from water and the costs of managing the over-allocation of water using the Waimakariri water management zone. The findings have the potential to inform the development of guidance for regional councils and discussions with iwi.

Minister	Action Required:	Minister's Deadline
Minister for Primary Industries **Minister for the Environment**	**Agree** to forward this briefing to the Minister of Finance and to meet with officials and economists to discuss further.	When convenient.
CC Associate Minister for Primary Industries		

Contact for telephone discussion (if required**)**

	Name	Position	Work	After Hours
Responsible Manager	Mike Hayward	Manager, Environmental Economics Unit	04 8194778	027 6793158
Principal Author	Darran Austin	Principal Advisor	04 8940630	

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Key Messages

1. This briefing describes the results of a detailed economic analysis of water allocation in the Waimakariri District. This analysis complements the information recently reported back to you under the managing within limits work (briefing 14-B-01655/B14-143 refers). The results support the approach of catchment-by-catchment decision making. The model and data could be used in other catchments decisions however the most time consuming part is collecting data.

Key findings: Clawbacks

2. Analysis of groundwater consents revealed a range of allocation levels relative to modelled water demand.
   a) 7 of the 94 consents in the zone are unlikely to be fully utilised during even the driest years and a portion of allocated water could be clawed back with no direct cost;
   b) A further group of 33 consents fall short in one year out of four or less. The direct cost of clawing back a portion of allocated water for these consents would be low;
   c) 54 of the 94 consents fall short more frequently than 1 year out of 4 and any clawback on these users would be costly.

3. The method of clawback had a significant impact on costs, depending on how it affects the three groups described above. Flat rate cuts are costly because they impact group C. Reasonable use tests are cheaper because they primarily affect groups A and B. In aggregate, clawing back groundwater allocation by 10% would cost between 0.6 and 2.7% of income.

Key findings: Gains from trade

4. Under the current level of infrastructure benefits of 3% can be gained from water trading. When the water distribution system is extended, the benefits from trading are 17% as unirrigated land becomes available for development. This expansion of water distribution overcomes the fragmentation of the district's water resource into 22 separate groundwater and surface water zones.

5. Nitrogen limits could constrain economic development more than quantity limits.
   a) If nitrogen losses are capped at current levels, mitigation creates room for around two- thirds of the potential irrigation expansion;
   b) If nitrogen losses are reduced by 20%, irrigation expansion is essentially halted within the district.

6. Without trading, water storage schemes are the only way to access additional water within the catchment and the storage scheme generates benefit net of the capital costs.

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Key findings: Attitudes to trade

7. A survey of water users revealed that most were in favour of trading, particularly temporary transfer of water rights. However, there were concerns around the impact of trading on equity and rural society. Most viewed the current council process as too time consuming and complicated.

Implications for further work

8. The modelling results indicate that further modelling and policy work would be useful in the following areas:
   a) Reducing barriers to transfer and trade given the gains in the Waimakariri catchment;
   b) Better understanding of the interaction between water quality and quantity limits, given the reduction in irrigation expansion caused by nitrogen limits;
   c) Increasing support for councils and resource users to manage water quality and encouraging mitigation, given that the economic gains are highly dependent on nitrogen mitigation;
   d) The impact of water storage and distribution infrastructure in catchments where water trading markets may not be effective;
   e) Tools for councils to address over-allocation that consider the distribution of costs on water users across a catchment, and are adaptable to local circumstances.

9. These findings are based on one catchment. The findings from a further study in the Waimea catchment in Tasman are due in April 2015. This additional catchment will enable a comparison between two different regional councils and a different land use mix.

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Recommendations

10. MPI recommends that you:

a) **Agree** to forward this briefing to the Minister of Finance

Agreed / Not Agreed

b) **Agree** to meet with officials and economists to discuss further

Agreed / Not Agreed

c) **Agree** to share this analysis with Iwi Leaders

Agreed / Not Agreed

d) After this, **agree** to share and test this analysis with other stakeholders

Agreed / Not Agreed

Hon Dr Nick Smith
Minister for the Environment

Deborah Roche
Deputy Director-General
Policy and Trade
for Director-General

Hon Nathan Guy
Minister for Primary Industries

/ / 2014

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Background

11. This briefing is a follow up report to the "Managing within limits, pressures and opportunities briefing" [B14-143] and provides a detailed assessment of the economics of managing within water quantity limits from the Waimakariri catchment.

12. This analysis takes the setting of quantity and quality limits as given and focuses on managing within those bounds.

13. The Environmental Economics Unit[1] in the Ministry for Primary Industries has undertaken projects at the catchment level to consider three questions in detail:

    a) What are the costs of clawing back water quantity over-allocation?
    b) What is the potential for economic gain by trading water?
    c) What are the social and behavioural barriers to achieving this potential economic gain in practice?

What are the costs of clawing back water quantity over-allocation?

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16. Because clawing back allocations will affect some water users more than others, it is important to look beyond aggregate impacts to the distribution of losses to get an insight into how the methods will be perceived.

17. 58% of the Eyre Zone's annual allocation limit is spread among 94 agricultural consent-holders covering 10,138 hectares. The remainder is allocated to municipal, industrial, and other users and is excluded from this analysis.

Clawback methods: flat rate and reasonable use

18. There are many potential clawback methods. To illustrate how a clawback might work this study focuses on variations of two methods: flat rate and reasonable use.
19. Flat rate cuts decrease each consent holder's annual allocation by the same percentage without regard for irrigation demand, land use, or any other factors.

[1] The Unit is jointly funded by MPI and MfE and is part of the Water Directorate which is based at MfE.
2 Groundwater resources do not have seasonal flow restrictions provided that each consent's annual volume allocation is not exceeded.

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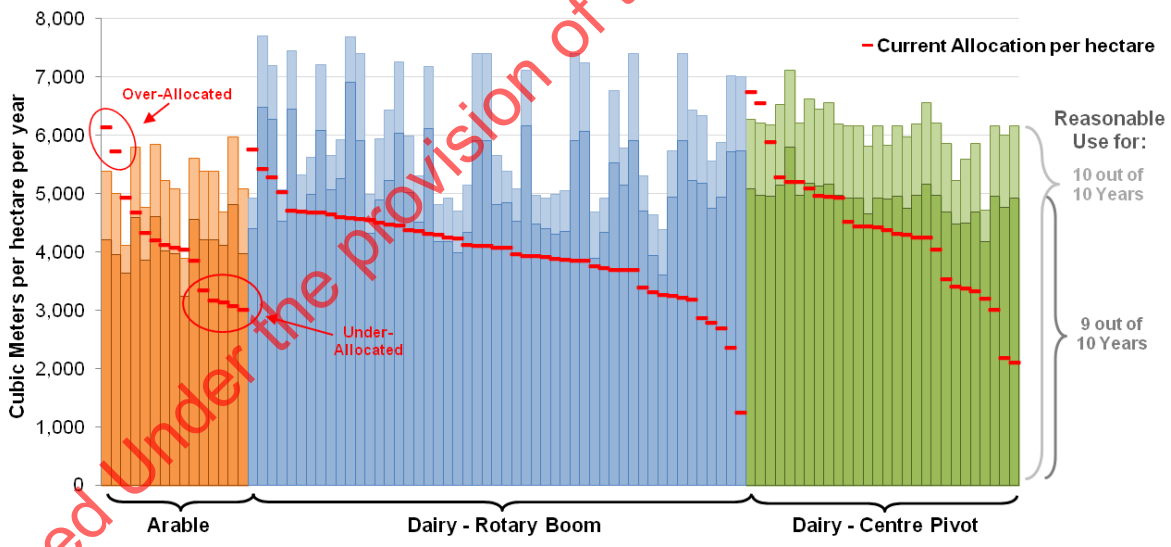
20. Cuts based on reasonable use tests compare each farm's current allocation to estimated irrigation demand. Irrigation demand is estimated for each farm based on a number of parameters including land use, climate zone, and soil type. The majority of regional councils are using this method when issuing or reviewing allocations.

21. As groundwater is generally not subject to minimum flow restrictions[3], consent holders are able to fully utilize their annual volume. Climate-driven variation in irrigation water demand means that a farm's allocation might be insufficient in some dry years.

22. Reasonable use is defined here as the amount of allocation needed to satisfy a farm's irrigation demand in a specific number of years in a decade. This study looks at three levels: 10, 9, and 7.5 years out of 10. Consent holders were held to their current allocation or their reasonable use level, whichever was lower. After applying the reasonable use test, a flat rate cut was applied to achieve the target 10% reduction if necessary.

23. Figure 1 illustrates the variation in reasonable use and current allocation across the 94 consent holders in the Eyre zone. The consent data shows that only 7 of 94 consents have a higher allocation than modelled irrigation demand in even the driest year. Many allocations are even lower; 54 consents are allocated less water than needed in 7.5 years out of 10.

Figure 1: Current Groundwater Allocations vs Reasonable Use



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[3] 7 out of the 94 consents are deemed to be hydrological connected to a surface water body and face minimum flow restrictions in addition to their annual volume constraint.

24. Water use data was considered as a basis for clawback in the analysis. However, as the data covers 54 of the 94 consents in 2013-14 and goes back in time less than 4 years the coverage is not complete enough to do the analysis.

Key Results: impacts are low; reasonable use has lower, less concentrated costs

25. Table 1 shows that the overall cost of a 10% allocation cut has a relatively small direct impact, ranging between 0.6% and 2.7% of annual operating income.

Table 1: On-farm impacts of 10% clawback in Eyre groundwater zone

Clawback Method	Annual Allocation		Annual operating income		Number of consents affected (by % of lost operating income)				
	million m³	*change*	*$ million*	*change*	*0%*	*0 to 1%*	*1 to 2%*	*2 to 5%*	*5 to 10%*
Current Allocation (excluding non-irrigators)	42.7	0%	$23.5	0%	94				
Flat 10% cut	38.4	-10%	$22.9	-2.7%	5	14	16	37	22
Reasonable use for 10 years out of 10, then flat 8.6% cut	38.4	-10%	$22.9	-2.2%	0	22	23	36	13
Reasonable use for 9 years out of 10, then flat 4.4% cut	38.4	-10%	$23.2	-1.3%	0	49	24	21	0
Reasonable use for 7.5 years out of 10	38.4	-10%	$23.3	-0.6%	54	17	21	2	0

26. Flat rate cuts have a larger impact on farm operating income and these costs disproportionately affect a number of consent holders whose current allocations are below reasonable use thresholds.

27. This finding is primarily driven by the uneven current distribution of allocations as shown in Figure 1. Flat rate cuts have a minimal impact on farms with surplus water allocation and a larger impact on farms whose allocations fall well short of demand.

28. In contrast, reasonable use scenarios have a smaller overall impact on farm operating income and tend to distribute those losses across a larger group. This is because reasonable use tests fine-tune clawbacks in proportion to each farm's modelled irrigation demands.

29. Across all scenarios, farm systems with higher water demands have more to lose from the tested claw back methods. For example dairy farms tend to lose more than arable and light soils more than heavy soils.

30. Allocations may have value beyond that directly generated through irrigation. Excess allocation gives them the option to use it in the future by intensifying production. Resource consents are also tied to land values, so clawbacks might reduce farmers' net worth.

31. Accuracy of the input data is an important consideration not just for this analysis, but also for councils to consider when implementing clawbacks. In particular, the area irrigated has been identified as potentially inaccurate in the council's database, which has a significant impact when estimating a farm's reasonable use.

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What is the potential for economic gain by trading water?

32. An economic model was built to test the potential for economic gain from allowing water to be freely traded. The model optimises total average earnings expected across the 41 years of climatic outcomes subject to constraints on land availability, the supply of water from groundwater and surface water, and nitrate leaching limits.

33. Transactions costs and other impediments to trading are not modelled but will prevent the achievement of high economic returns. These barriers and transaction costs are discussed in the next section.

34. Scenarios representing the development of infrastructure within the district and different nitrate leaching limits are progressively introduced.

35. Water transfer was represented as the long term permanent transfer of access to groundwater volumes and surface water flows. The temporary movement of water was not modelled.

Results: value of trading limited by extent of distribution infrastructure

36. Gains of $4m (or a 3% increase) can be achieved through trading within the current irrigable area if water is utilised more efficiently. This involves dairy farmers operating their systems at a lower level of water use, down to 0.4 litres per second per hectare. Arable farms do not reduce water allocation from 0.6 litres per second per year in this scenario.

37. The trading of water has significant economic benefits if distribution systems expanding the irrigable area are constructed. Freeing the trading of water allocation increases water availability, and allows the expansion of irrigable area generating a benefit of $17m annually (a 13% increase).

Gains from storage and distribution infrastructure

38. In the absence of water trading, there are economic gains of $11m (a 9% increase) associated with the development of central storage. Without trading, storage is the only way that sufficient water can be accessed to allow the expansion of irrigation development across the 16,000 ha of unirrigated sheep and beef land. These gains occur after the capital costs associated with developing central storage, converting dryland, and extending irrigation infrastructure are borne.

39. With the introduction of water trading the emphasis of infrastructure development may swing more towards wider distribution systems at the expense of storage volumes as buying water permits can be cheaper.

40. On-farm storage was included in the modelled but was not economic under any of the scenarios considered.

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Table 2: Trading and storage scenarios – no nitrogen cap

Unconstrained N case	Total Operating Income ($m)	Irrigation Expansion (ha)	Total N leaching (t)	Capital costs* ($m)
Baseline	$129	0	2,194	$0
Trading	$133	0	2,111	$0
Expanded distribution with trading	$146	15,877	2,511	$15
Expanded distribution and storage without trading	$141	15,877	2,605	$23
Expanded distribution and storage with trading	$144	15,877	2,512	$23

*Annualised storage, distribution, and farm development capital costs

Nitrogen limits constrain development

41. Three nitrogen limits set at the catchment level were explored: no cap set on leaching, leaching held at current levels, and leaching 20% below current levels.

42. The Waimakariri zone committee is working towards setting water quality objectives and nutrient limits for the district. Given that water quality does not currently meet aspirations due to nutrient losses from land uses, some kind of nutrient load limit combined with a suite of management approaches is expected to emerge from the collaborative process.

43. In the absence of a set nitrogen cap, leaching tends to increase with irrigation expansion within the catchment as more intensive agricultural practices replace unirrigated land that has much lower loadings to the environment. For example, converting a hectare of unirrigated sheep and beef to dairy production increases leaching losses by around 30 kg N per ha (a 350% increase).

44. Maintaining nitrogen losses at current levels decrease the possible extent of irrigation expansion and reduces the benefits of both trading and storage. Around 10,000 of a possible 16,000 hectares is converted to irrigated dairy. Nitrogen mitigation through irrigation efficiency creates the space for expansion within this scenario's fixed nitrogen budget.

45. A target to reduce nitrogen losses by 20% essentially precludes any irrigation expansion within the district.

46. On existing farms significant nitrogen mitigation is deployed to meet the target. Most dairy farms use stand-off pads in these scenarios complemented by reductions in water allocation when water trading is modelled. In the arable sector, water allocation drops below 0.6 litres per second per hectare to reduce nitrogen loss. Enabling water quantity trading helps offset the high economic costs of stringent nutrient limits.

47. Mitigation of nitrogen leaching was represented more simply than has been the case in nutrient focused studies. The inclusion of a more comprehensive set of nitrogen mitigations in these scenarios could increase the amount of irrigation expansion possible with nitrogen budget limits.

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Table 3: Nitrogen limit scenarios

Maintain total N leaching at baseline	Total Operating Income ($m)	Irrigation Expansion (ha)	Total N leaching (t)	Dairy farms using stand-off
Baseline	$129	0	2,194	0%
Expanded distribution with trading	$141	10,859	2,194	0%
Expanded distribution and storage without trading	$130	3,759	2,194	1%
Expanded distribution and storage with trading	$139	10,743	2,194	0%

Reduce total N leaching 20%	Total Operating Income ($m)	Irrigation Expansion (ha)	Total N leaching (t)	Dairy farms using stand-off
Baseline	$92	0	1,755	100%
Expanded distribution with trading	$103	9	1,755	72%
Expanded distribution and storage without trading	$93	357	1,755	100%
Expanded distribution and storage with trading	$102	726	1,755	76%

What are the barriers to achieving this potential economic gain in practice?

48. A range of barriers may prevent any gains identified by the optimisation model from being realised. To get a sense of these practical barriers, the Water Directorate contracted Landcare Research to survey water users about their attitudes to transferable water permits. This research was conducted through interviewing sixteen water users in both the Waimakariri District in Canterbury, and the Waimea plains in Tasman.

49. The research aimed to gain insight into water users' attitudes to transferable water permits and factors influencing farmer's decisions whether or not to transfer water permits.

50. Key findings of this research are that almost all water users are generally receptive to transferable water permits, but this support was conditional.

    a) Farmers identified benefits from water transfers, including increased flexibility of land use through increased access to water, and the win/win nature of transfers for both buyers and sellers - "…at the end of the day nobody's forced to transfer their water, are they?...";
    b) Most respondents were concerned that water permit trading would have negative effects on the distribution of wealth and opportunity in the community;
    c) Some respondents were sceptical that a transfer regime could be implemented effectively or that it was appropriate for the conditions in their community.

51. While this research is qualitative, and provides information on water users' opinions on transfers, it does not show how prevalent these views are.

Some respondents concerned about equity effects and impacts on rural society

52. Support for temporary transfers was much stronger than permanent transfers, primarily because of concerns about permanent transfer's effect on land values.

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53. Concern were expressed that water would move out of agriculture, and that non-rural users would bid up the price of water to the point that agriculture becomes uncompetitive in the area. Some suggested that non-landowners, speculators, and urban users should not be allowed to engage in water trading.

54. Some felt that trading systems should have local and regional benefits at their core including economic, social and environmental.

55. There was concern that for-profit water trading would unfairly exclude new farmers and small scale operators.

56. Belief that initial allocation the allocation needs to be fair from the start, otherwise some people will get windfall profits.

Some respondents discouraged by complexity and uncertainty

57. Some respondents believe that the process is too complicated, expensive and takes too long.

    a) A formal transfer with the council takes up to 2 years, according to some respondents;
    b) However, there was some optimism about ways to bypass council: trading within an irrigation scheme or farmer-run water user group is far easier.

58. Concern that trading puts one at risk of scrutiny by council and neighbours; and there is no way to know that council will continue to recognise permits that are invested in and transferred.

59. Lack of information about potential trading partners or hydrological data in the area.

60. Feeling that water permit trading is unnecessary in under-allocated catchments and inappropriate for over-allocated catchments.

61. Concern that lack of reliability creates uncertainty as to whether or not they should trade a water permit.

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Next steps

62. This work will add to the evidence base for further central government work on managing over-allocation and improving the flexibility of water management in New Zealand.
63. More detailed advice on these themes will be delivered following discussions at Waitangi in February 2015. This timing allows for the continued development of policy options for managing within limits alongside the development of options to address iwi/hapū rights and interests in fresh water.
64. There would be considerable value in robustly testing the modelling and assumptions with well informed stakeholders and updating the results if this process changes the conclusions.
65. A further detailed catchment study in the Waimea catchment in Tasman will be completed by April 2015.

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Appendix 1: Description of Waimakariri District

66. The Waimakariri District was chosen because it is broadly representative of Canterbury, which as a region accounts for 64% of New Zealand's irrigated area. The Waimakariri District has a mix of irrigated dairy and irrigated arable drawing on a combination of ground and surface water with some dryland sheep and beef remaining. There is significant lifestyle farming in the district. The district has about 5% of New Zealand's irrigated area.

Fragmented water resources limit trading potential

67. Water resources within the Waimakariri District are highly fragmented and complex with overlapping surface and groundwater zones. Maps showing the layout of the Waimakariri District can be found in Appendix 1.
68. The Waimakariri Irrigation Limited scheme further complicates the picture with a surface water distribution network that sprawls across multiple surface and groundwater zones. The scheme delivers water to 18,000 hectares.

69. These areas define the extent to which water can move to its highest value use and, without new infrastructure, limit the potential gains from trade.

70. The Eyre groundwater zone accounts for 80% of all groundwater allocations in the District. The Waimakariri River accounts for 75% of all surface water allocations in the District, half of which is allocated to Waimakariri Irrigation Limited.

Groundwater and surface water are managed quite differently.

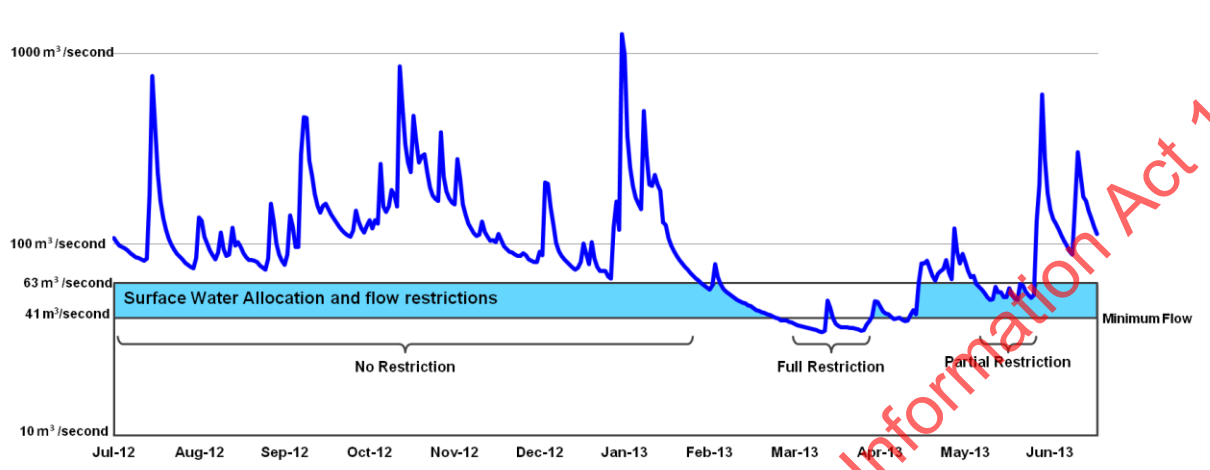
71. Groundwater resources are like a bucket that gets filled each winter. Regional councils set an annual allocation limit on each groundwater zone expressed in cubic meters per year. There are no flow restrictions provided that each consent's annual allocation is not exceeded. (Some wells are hydrologically connected to rivers or streams and are exceptions to this rule.)

72. Surface water resources are flows in a river, a portion of which can be abstracted for productive uses. Regional councils specify allocation limits and minimum flows for each surface water zone expressed in litres per second. Figure 2 shows how allocation limits and minimum flows interact with the variable flow of the Waimakariri River on a daily basis.

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73. The clawback analysis covers groundwater only. The optimisation analysis covers both groundwater and surface water.

Figure 2: Surface Water Flow in the Waimakariri River 2012-13



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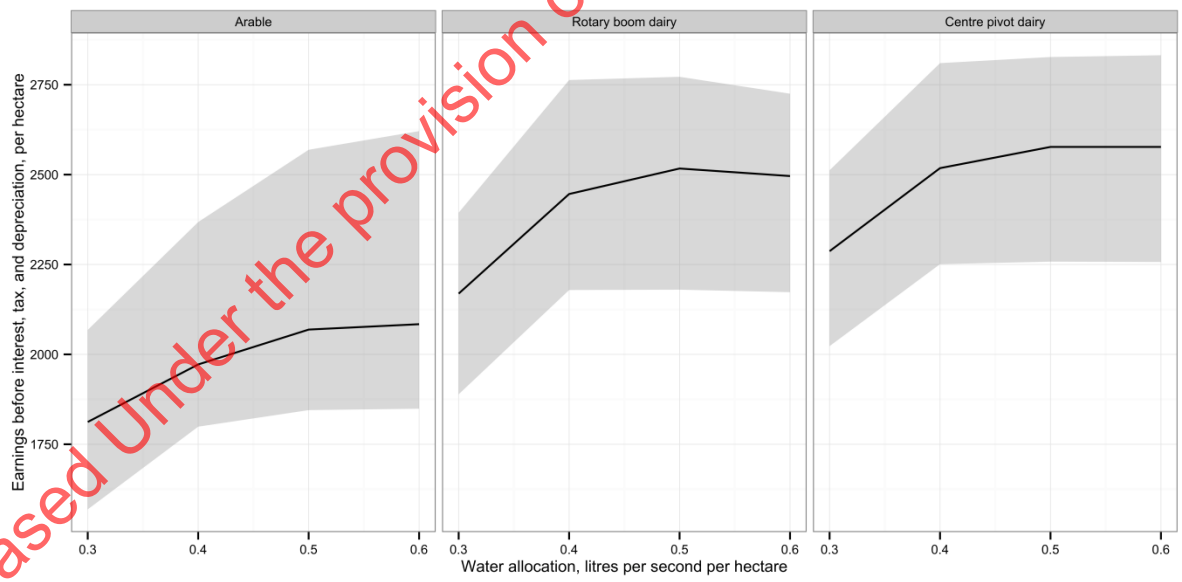
Appendix 2: Farm Level Analysis

74. To underpin the analysis, Aqualinc Research was commissioned to model farm water demand and profitability in the Waimakariri zone. A range of irrigation systems, soil types, rainfall bands, and nitrogen mitigation measures were modelled over 41 years of climatic data.
75. Regional councils typically allocate water at rate of 0.6 litres per second per hectare. As allocation is reduced the ability of an irrigation system to keep up with evaporation and plant water demand in dry years is diminished and eventually profitability falls.

76. The farm level modelling, illustrated in Figure 3, shows that:

    a) At the $6.30[1] payout used for this analysis, dairy farms are more profitable than arable farms;
    b) Solely varying the climate data the farm level modelling generates significant variability in profitability (represented by the grey area in figure 3);
    c) As allocation is reduced from 0.6 to 0.5 litres per second per hectare, in this modelling, there is no major impact on mean or variability of profit per hectare in the dairy systems.
    For all farm systems, moving down to 0.3 litres per second per hectare reduces profit more significantly.

Figure 3: Farm earnings and water allocation, median and 9 out 10 year range

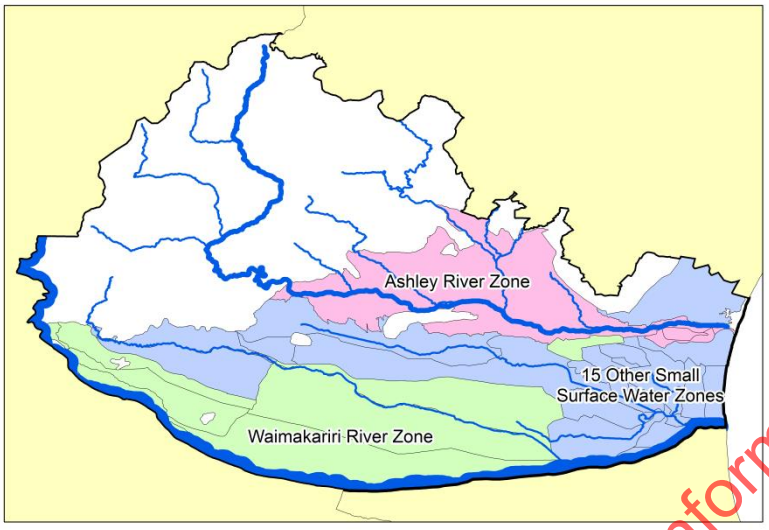


[1] For 2012/13 and similar to the 5 year average payout.

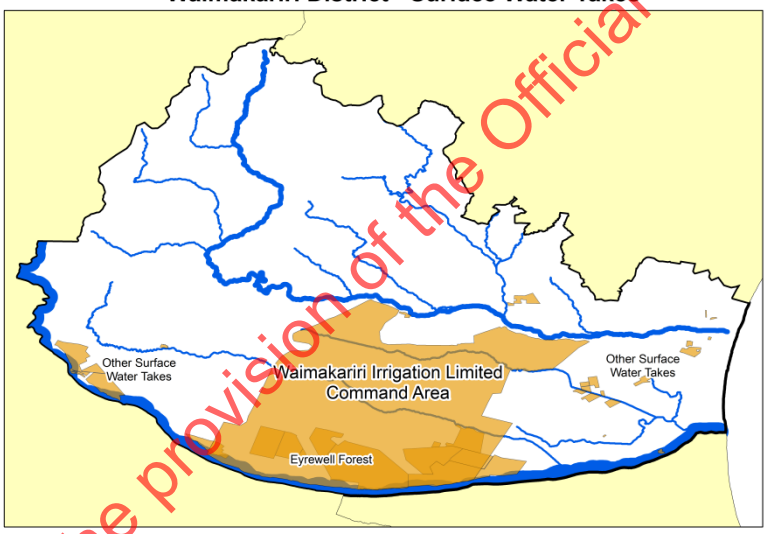
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Appendix 3: Waimakariri District Maps

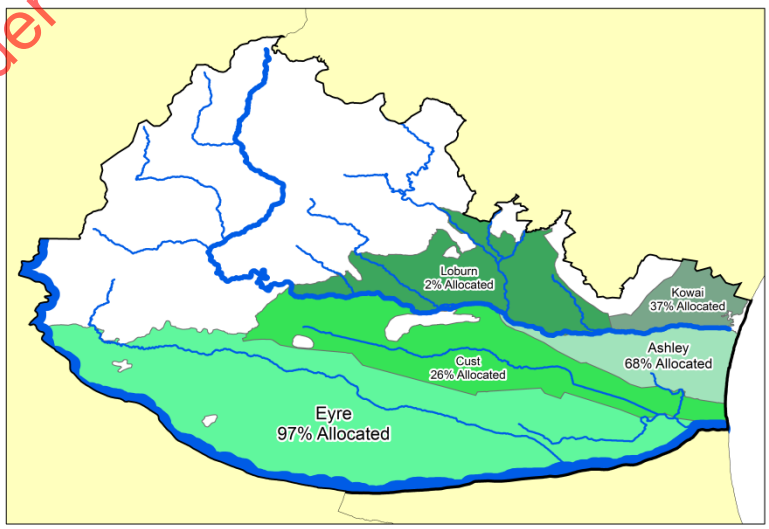
Waimakariri District - Surface Water Zones



Waimakariri District - Surface Water Takes



Waimakariri District - Groundwater Zones



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Waimea water allocation economic modelling – first tranche

Purpose

This paper updates the TAG on economic analysis that Professor Graeme Doole has helped the water allocation team with. This work will test some of the allocation policy options discussed during this process in the Waimea catchment in Tasman district. This work is intended to develop our understanding of the water quantity allocation options being considered by the TAG and ultimately minsters.

The modelling builds on modelling completed in 2015[1] but focuses more sharply on the current policy options (and less on the Waimea Community Dam). Further scenarios will be run in coming weeks based on feedback from the TAG.

Farm and orchard economics

The first underpinning step was to build a detailed picture of the economics of water use in the catchment. Plant and Food Research, Landcare Research, and local horticultural consultants Fruition analysed profitability and water use for apples, grapes, dairy farming, and a vegetable cropping rotation including pumpkins, lettuce and cabbage.

For each land use, water use was constrained by the maximum weekly rate of water abstraction allocated and the supply reliability of this allocation. Irrigation system capacity is developed to align with the maximum weekly rate of water abstraction. Seven levels of water allocation and two levels of water supply reliability were modelled. Water supply reliability was estimated using 40 years of historic river flow data and the minimum flow triggers in the current Tasman District Council plan. Crop or pasture water demand and production responses were generated using 40 years of evapotranspiration and sunshine data.

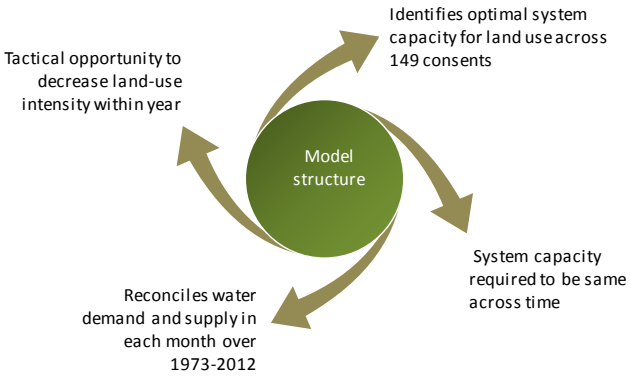
Catchment economics

Within Professor Doole's modelling, in this updated piece of work, 149 consents within the Waimea catchment were assigned an area, land use, and water allocation based on the council's consent database (checked against land mapping and local knowledge). Consents were placed within one of the 9 water management zones within the catchment.

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[1] Detailed reports on the previous modelling present the economic modelling results and the underpinning farm and orchard economics.

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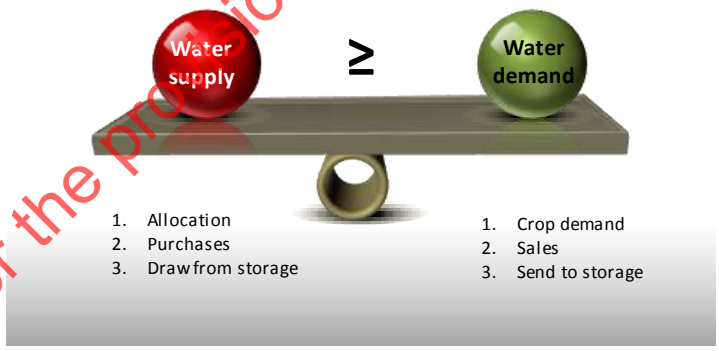


Water demand is reconciled with water supply within each of the 9 zones in each month. The allocation available is governed by the 40 years of minimum flow restrictions. The crop water demand is governed by monthly evapotranspiration.

Within the trading scenarios, sales and purchases of water are a decision variable that can modify the amount of water available. On-farm storage is included as an additional option to mediate differences in water demand and water supply.

Water use

Defined for each consent, month, and year

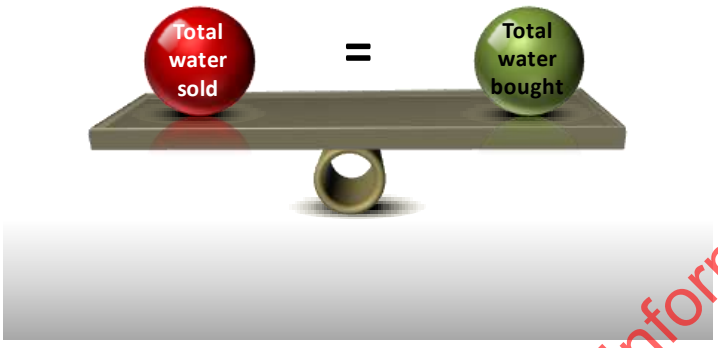


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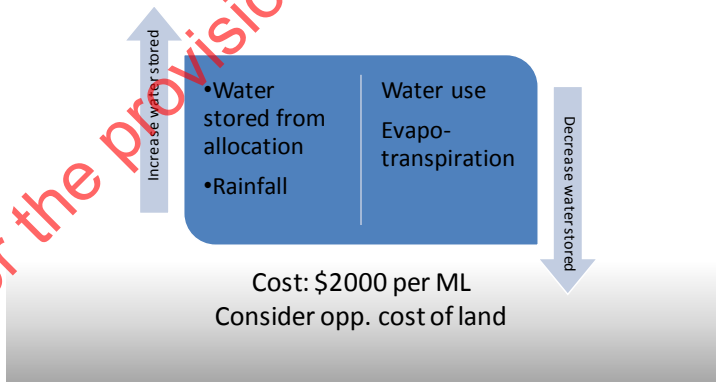
In the trading scenarios, within each of the 9 water management zones, for each month in the 40 years, the volumes of water bought and sold are reconciled.

Water market
Defined for each zone, month, and year



On-farm storage is enabled as a decision variable to manage temporal differences in water supply and demand. This form of storage is much more expensive than the Waimea Community Dam.

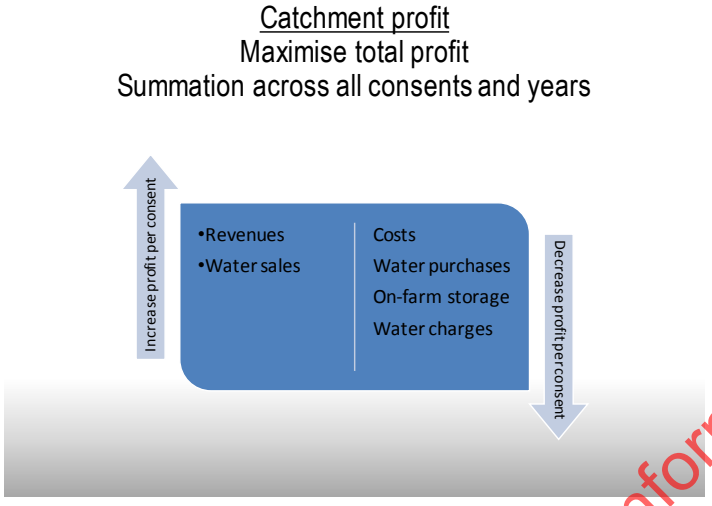
On-farm storage
Defined for each consent, month, and year



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The model maximises total profit across these decision variables to simulate the impact of policy.



Policy analysis

7 of the 9 zones within the Waimea catchment are over-allocated. The council currently has a policy of reducing allocations to 'bona fide' use which is a level of allocation sufficient to meet crop water demands in 9 out of 10 years. This reduction to 'bona fide' use, while getting rid of some paper over-allocation (particularly amongst the grape growers), does not eliminate all over-allocation in the catchment. Further reductions in allocation are required to address over-allocation.

The 'bona fide' use level of allocation forms the starting point for this analysis. In this paper, two methods of clawing back to full allocation are considered before moving on to analyse the impact of short term trading in the aftermath of clawback.

The **flat rate cut scenario** reduces allocations across all consents, regardless of crop type or land use, within a water management zone by the same percentage to eliminate over-allocation.

The **stringent bona fide use scenario** reduces the sufficiency of allocations below 9 out of 10 years (to say 7 out of 10 years) until over-allocation is eliminated in the relevant water management zone. Different crops or land uses on different soil types receive different percentage reductions depending on plant demand.

Trading, as described above, is introduced in the aftermath of both of these clawback methods.

In coming weeks further scenarios will be tested including **volumetric water levies**, **auctions**, and administratively set **water scarcity pricing**.

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Results

Comparing the two clawback methods, the flat rate cut is more costly than the stringent bona fide use. This is because the stringent bona fide use more closely matches crops needs.

The introduction of trading results in increased catchment income in both cases. These gains primarily occur in the driest years.

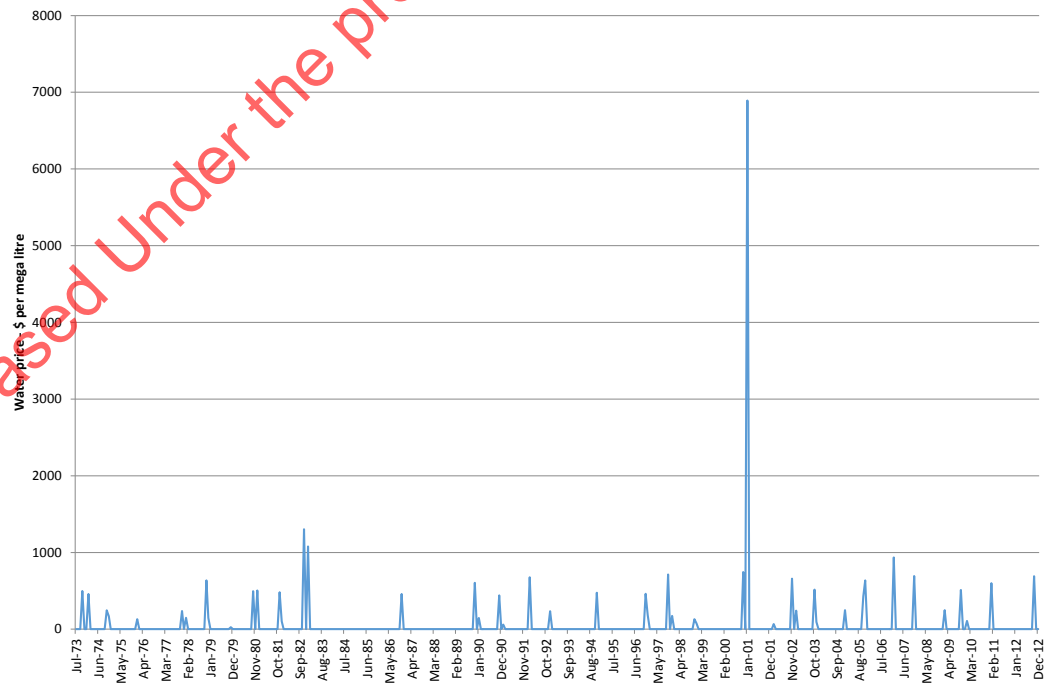
Following a flat rate cut, trading increases catchment income on average by 11 percent, and by 39 percent in the driest year.

Table 1: Summary results

	Average annual profit ($m)	Minimum profit ($m)	Maximum profit ($m)	Average annual water use (ML)
Bona fide use	15.4	8.6	21.3	6,926
Flat rate cut	13.6	6.7	19.3	4,906
Stringent bona fide use cut	14.2	7.7	20.1	5,354
Flat rate cut and trade	15.3	9.3	21.1	5,480
Stringent bona fide use cut and trade	15.3	9.3	21.1	5,411

The equilibrium water price estimated in the modelling is highly variable. Most months there is no scarcity, there is no trade, and the water price is zero. During summer, in the drier years, crops are thirsty, and minimum flow restrictions are triggered. At this time trading is highly beneficial and the water price shoots up.

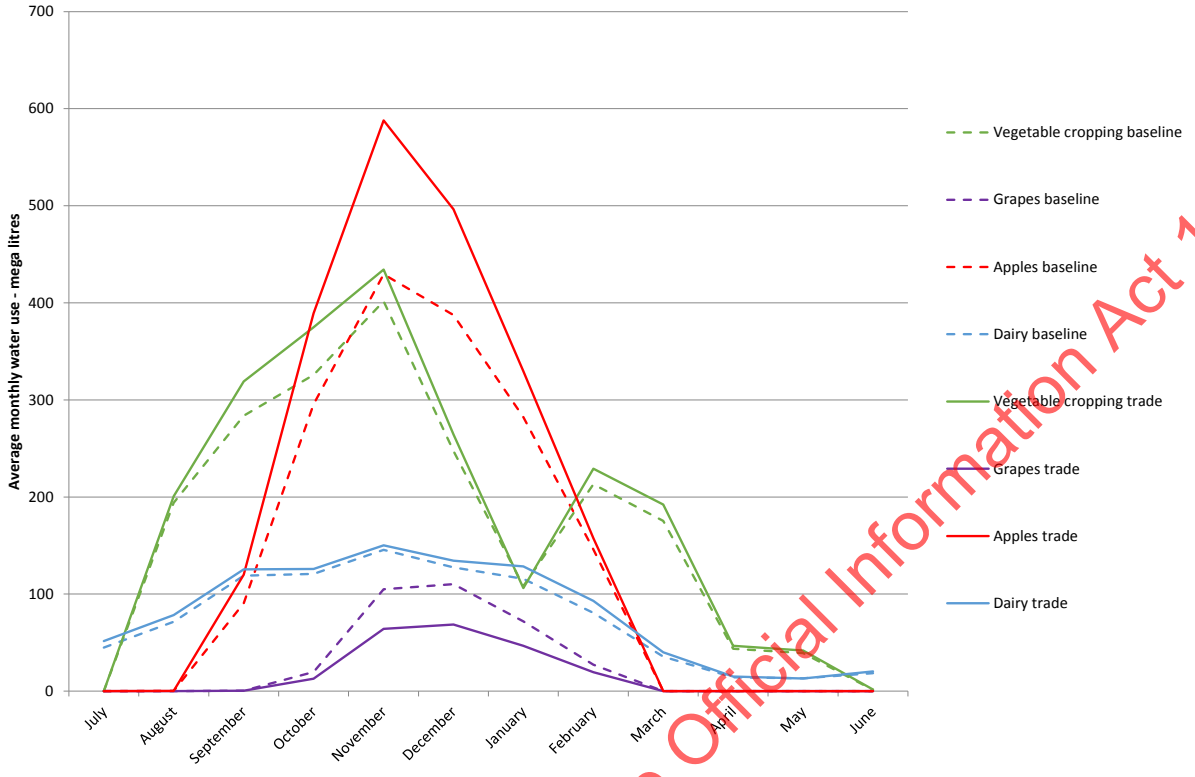
Figure 1: Monthly water price, Delta water management zone, flat rate cut and trade



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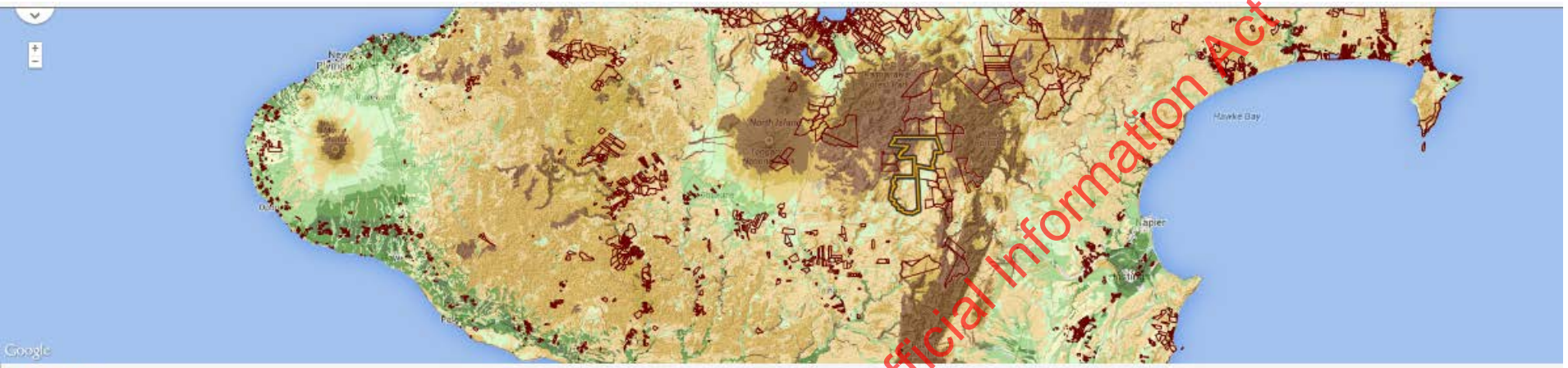
Figure 2: Average aggregate monthly water use by land use – flat rate cut baseline



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http://whenuaviz.landcareresearch.co.nz

2010-00014



Land Capability

This layer shows the general capability and versatility of the land, and incorporates the degree of physical resource limitation to agriculture, by interpreting and colour coding each of the original eight land-type classes of Land Use Capability (LUC) within the New Zealand Land Resource Inventory(NZLRI).

- Unclassified
- Best
- Excellent
- Occasional crops, pasture, and forest
- Pasture and forest
- Moderately limited
- Extremely limited

Land potential | Land cover | Climate | Soil properties

Land Potential

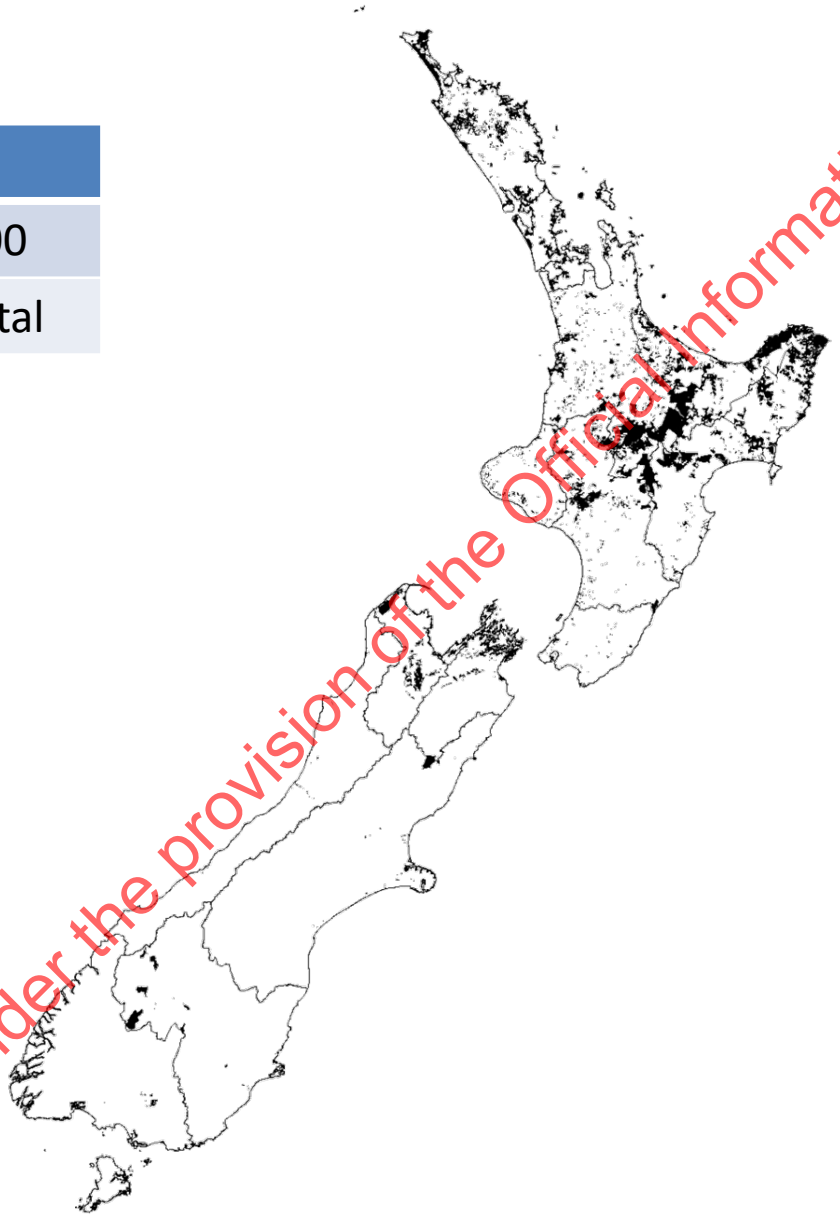
What is the potential of this land?

Class	Area	Description
6	40% 6679.36 ha	**Not suited to cropping but good for pastoral and forestry** Non-arable land with moderate limitations for use under perennial vegetation such as pasture or forest.
8	29% 4922.74 ha	**Extreme limitations** Land with very severe to extreme limitations or hazards that make it unsuitable for cropping, pasture or forestry.
7	23% 3892.24 ha	**Marginal for pastoral and forestry** Non-arable land with severe limitations to use under perennial vegetation such as pasture or forest.
4	8% 1297.11 ha	**Significant limitations for cropping and horticulture** Land with moderate limitations for arable use, but suitable for occasional cropping, pasture or forestry.

Learn more about land use classes...

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NZ	ML
26,500,000	1,830,000
	7% of total

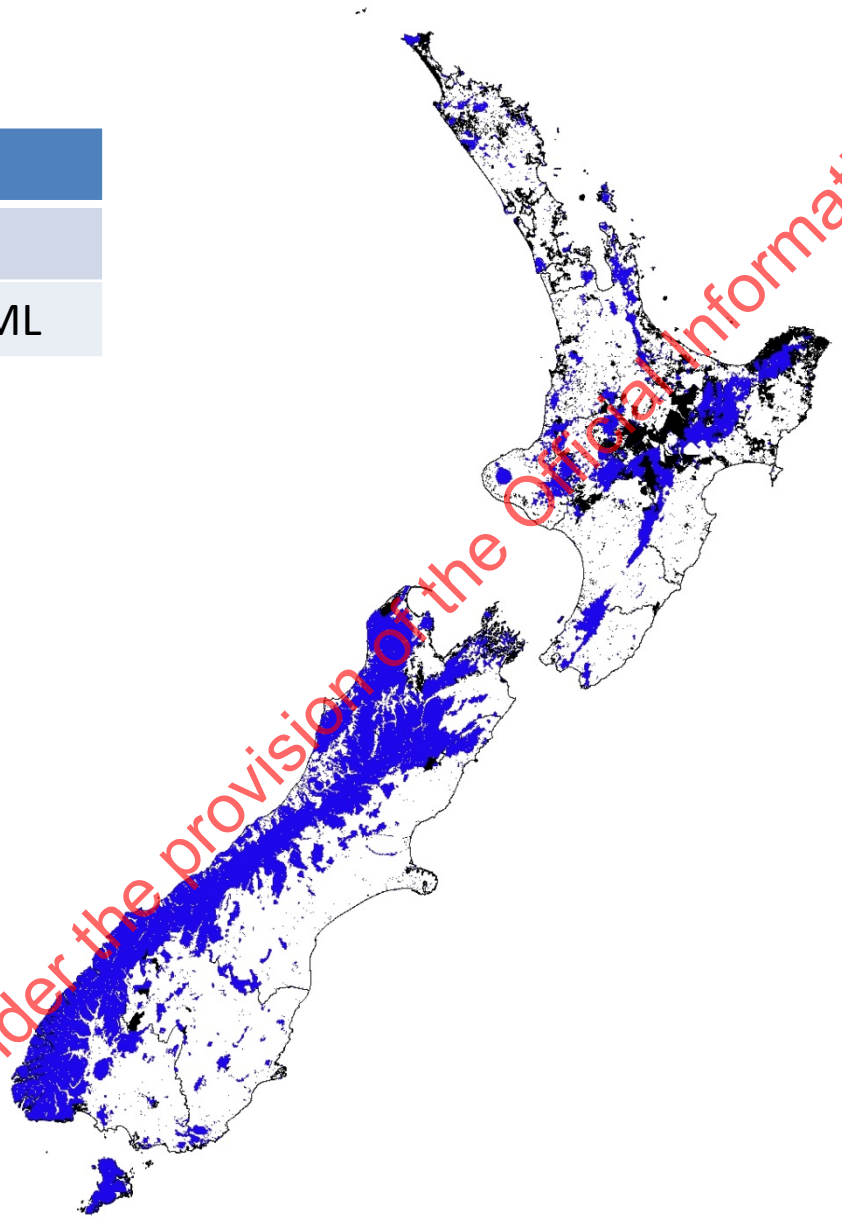


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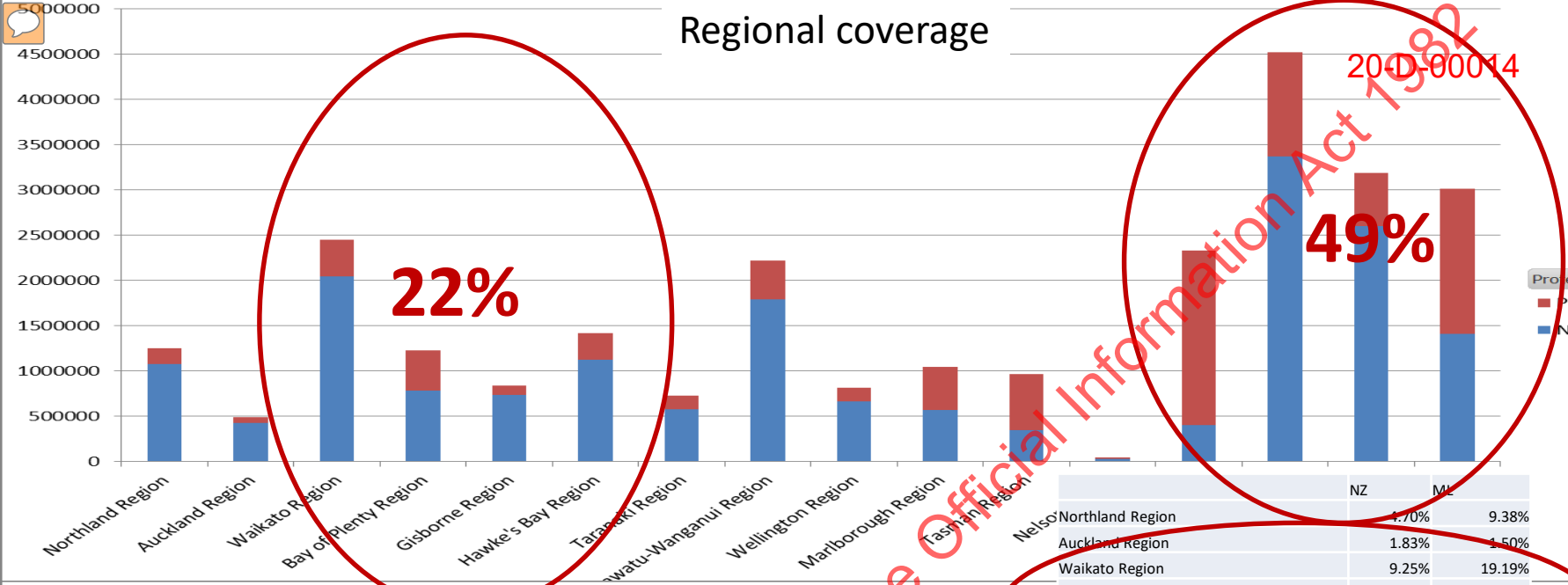
NZ	ML
8,597,000	230,000
32% of NZ	13% of ML



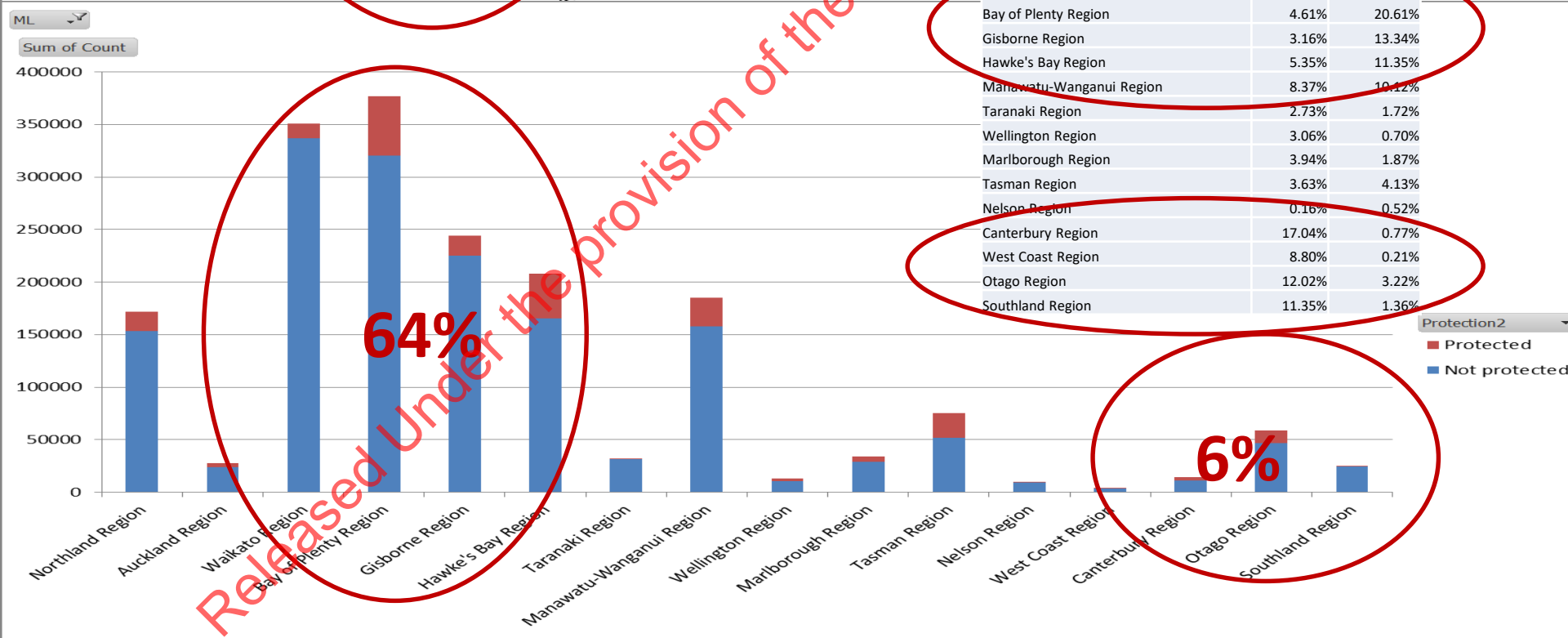
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Regional coverage

20-D-00014

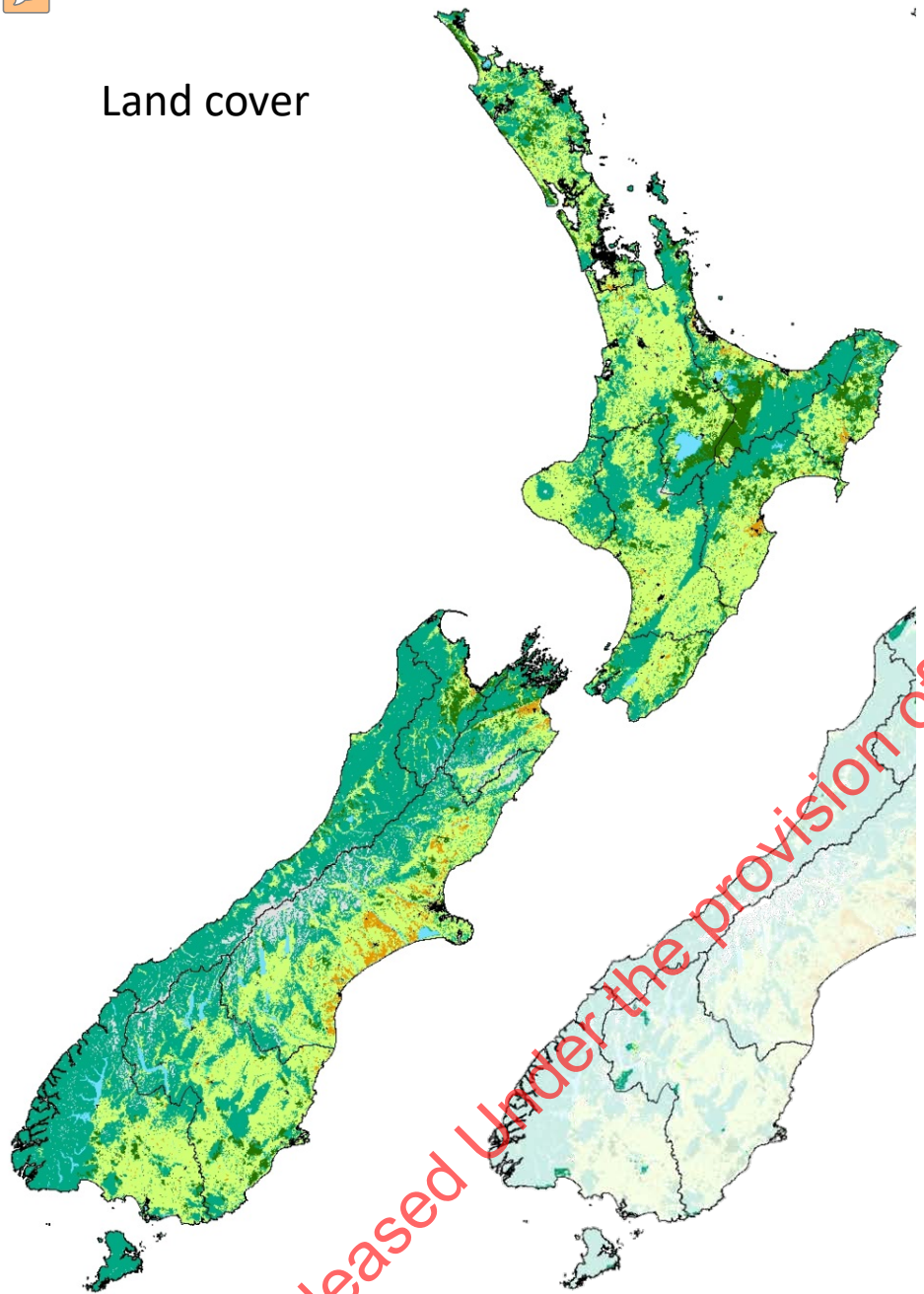


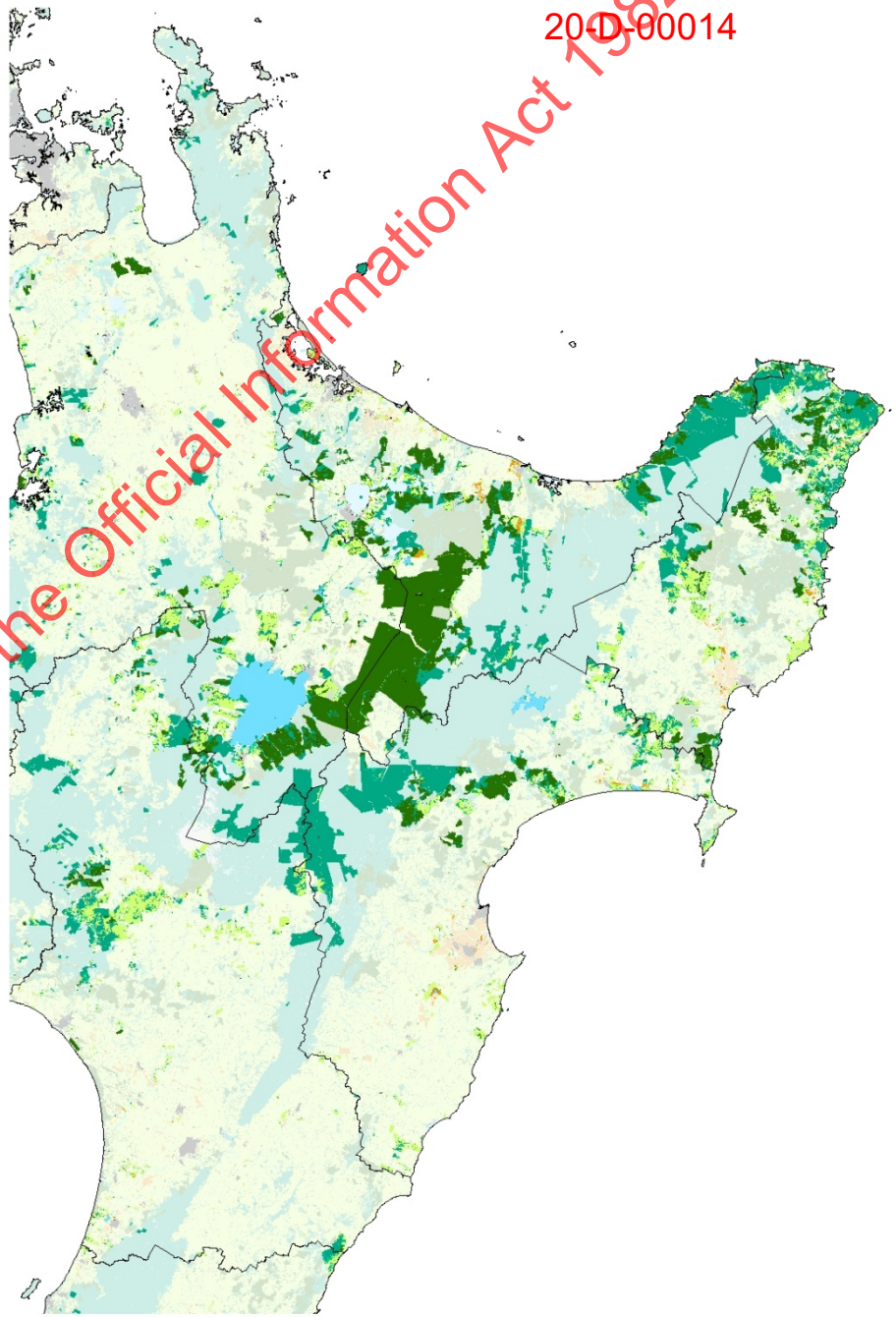
	NZ	ML
Northland Region	4.70%	9.38%
Auckland Region	1.83%	1.50%
Waikato Region	9.25%	19.19%
Bay of Plenty Region	4.61%	20.61%
Gisborne Region	3.16%	13.34%
Hawke's Bay Region	5.35%	11.35%
Manawatu-Wanganui Region	8.37%	19.12%
Taranaki Region	2.73%	1.72%
Wellington Region	3.06%	0.70%
Marlborough Region	3.94%	1.87%
Tasman Region	3.63%	4.13%
Nelson Region	0.16%	0.52%
Canterbury Region	17.04%	0.77%
West Coast Region	8.80%	0.21%
Otago Region	12.02%	3.22%
Southland Region	11.35%	1.36%



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Land cover



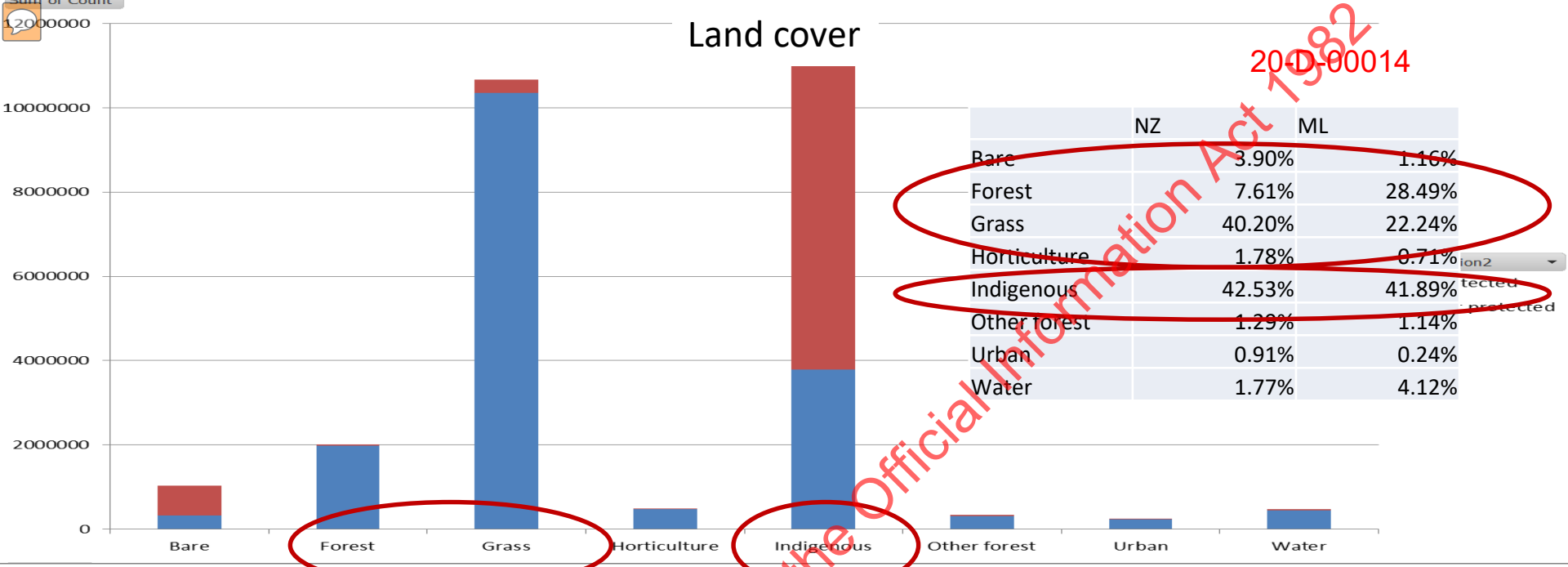


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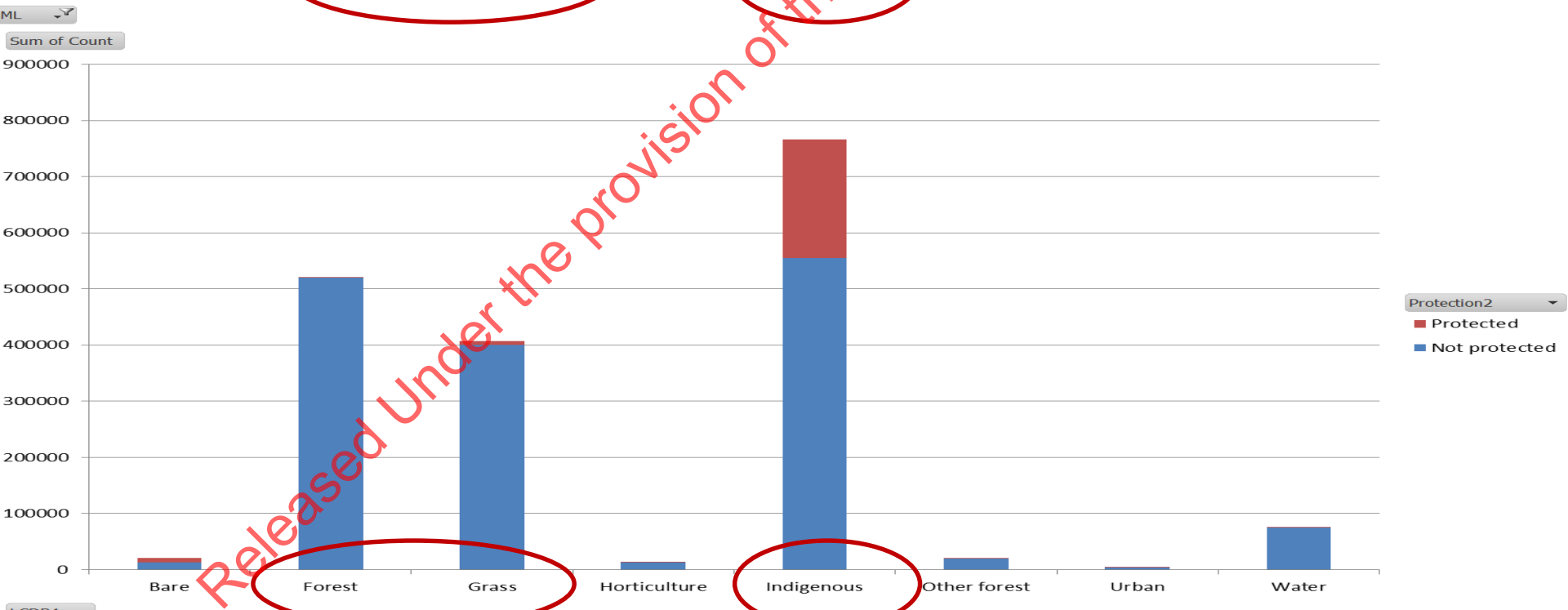
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Land cover

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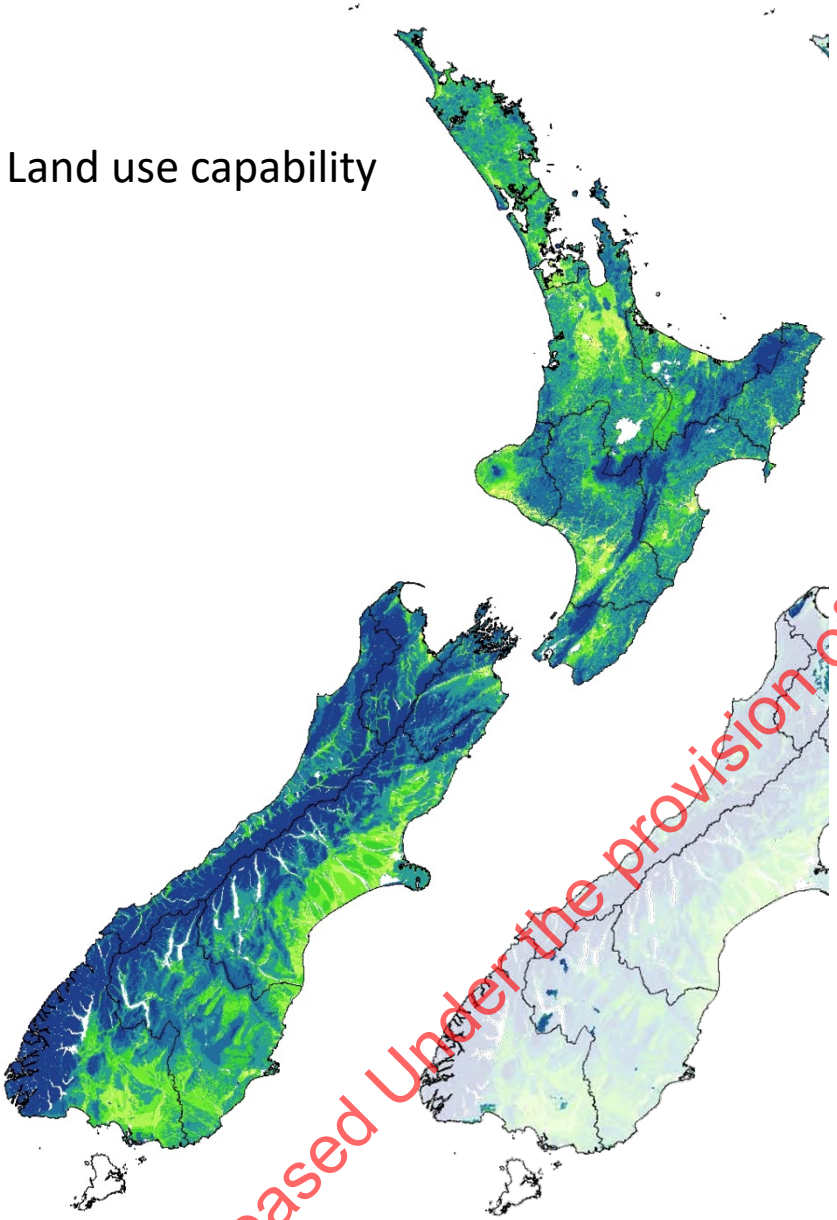


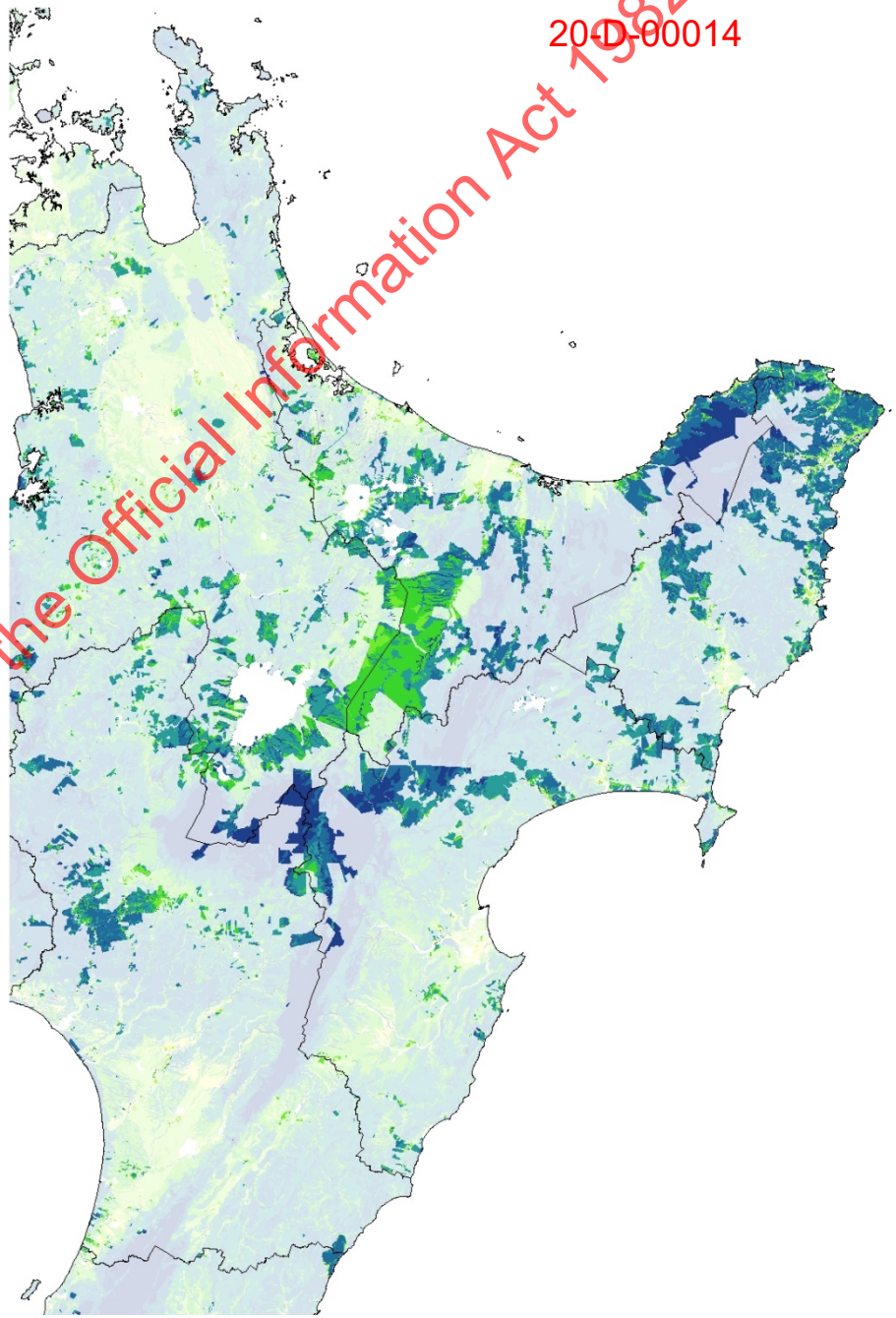
	NZ	ML
Bare	3.90%	1.16%
Forest	7.61%	28.49%
Grass	40.20%	22.24%
Horticulture	1.78%	0.71%
Indigenous	42.53%	41.89%
Other forest	1.29%	1.14%
Urban	0.91%	0.24%
Water	1.77%	4.12%



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Land use capability





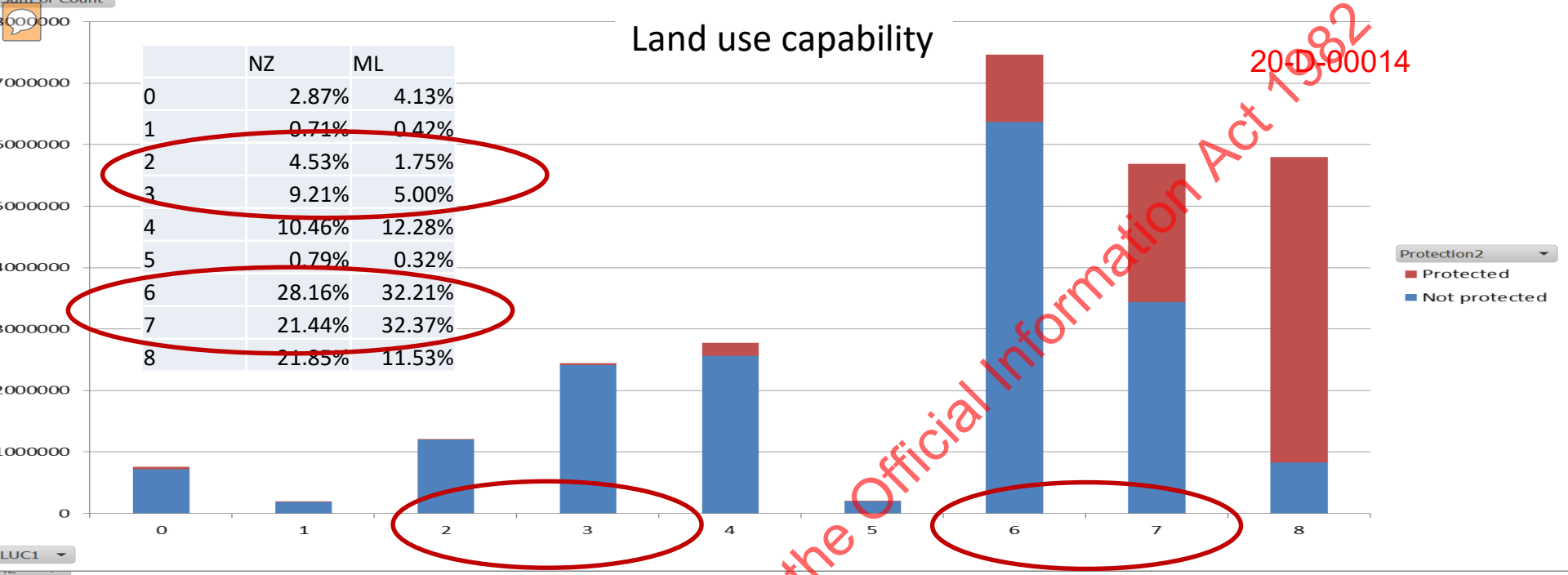
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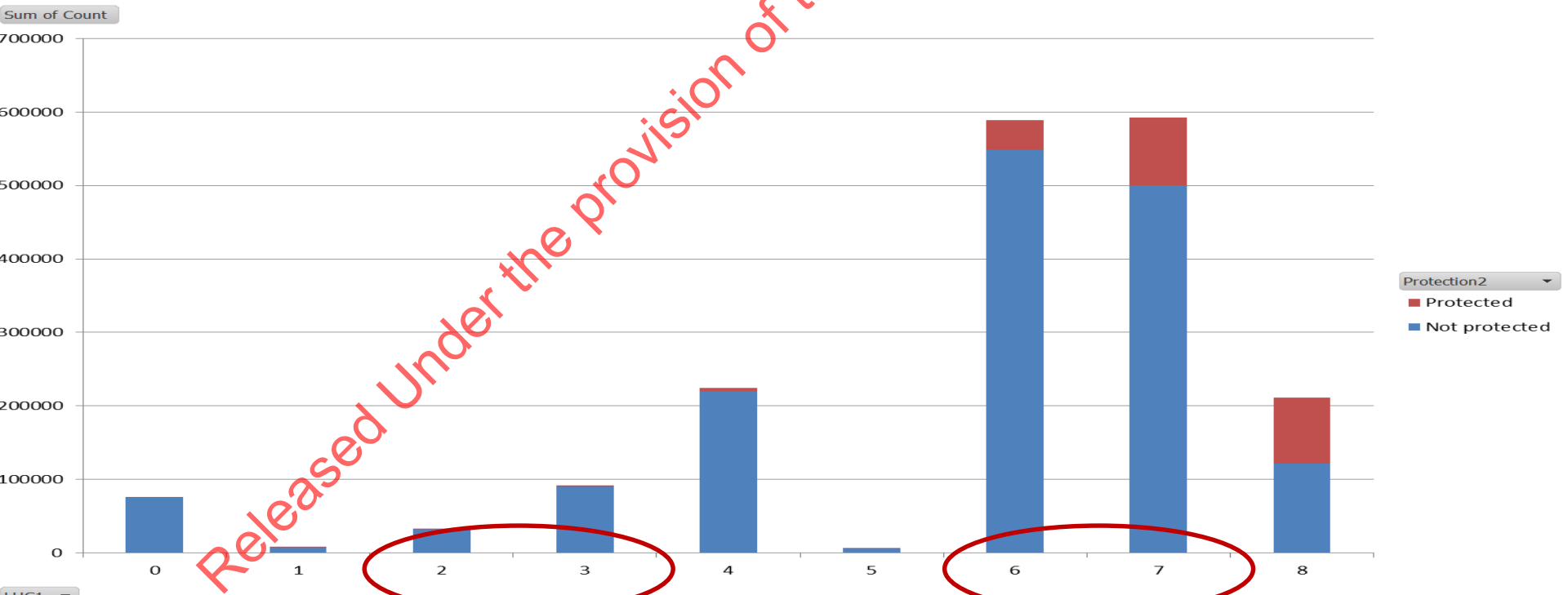
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Land use capability

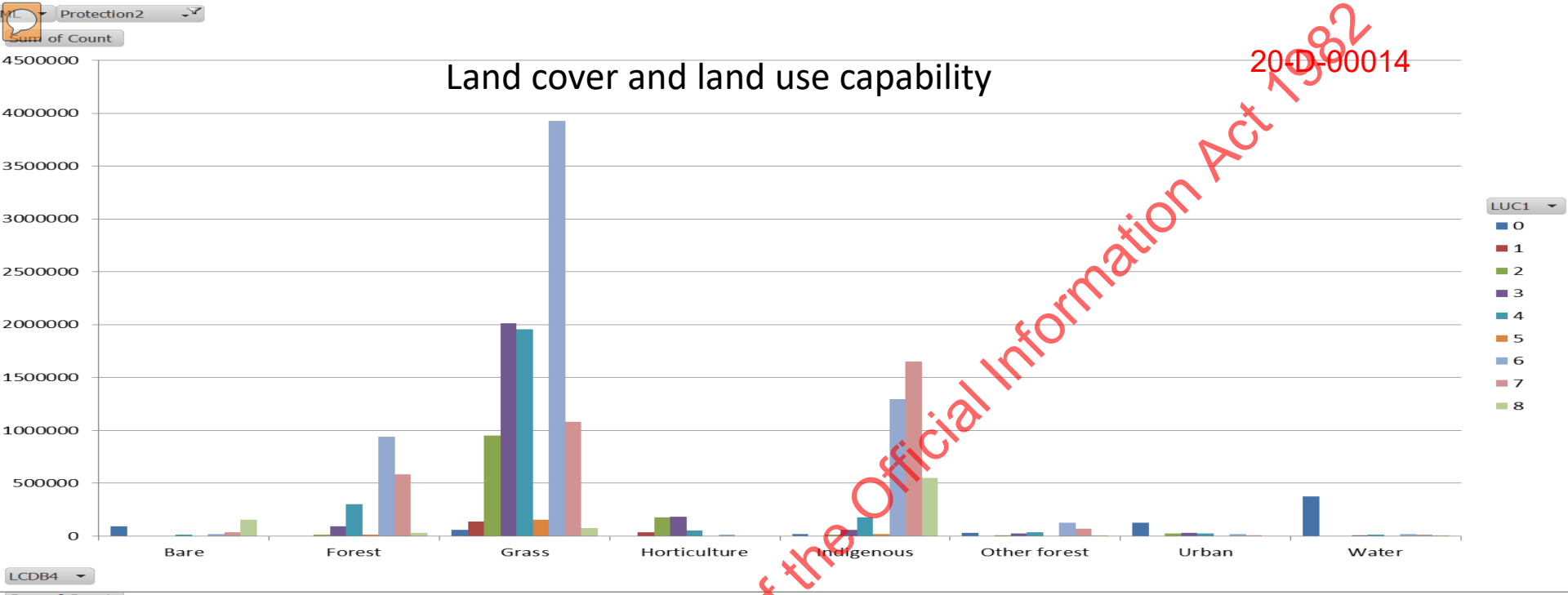
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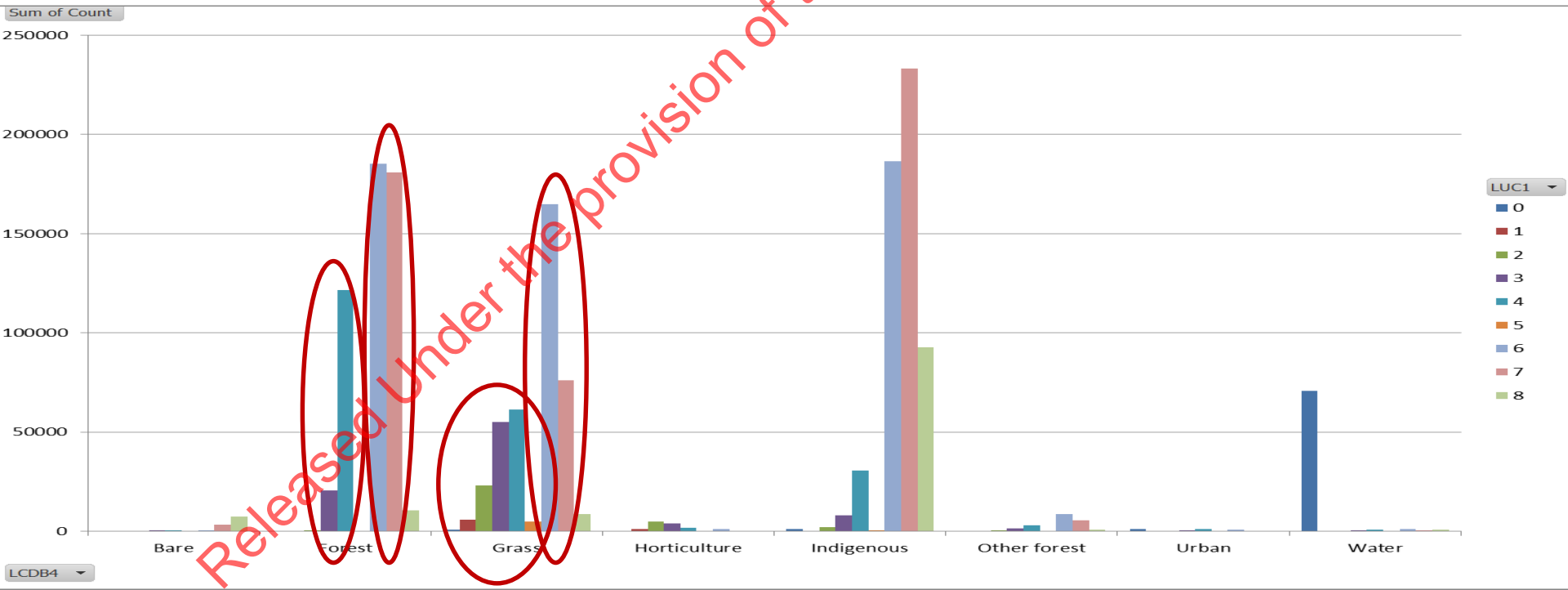
	NZ	ML
0	2.87%	4.13%
1	0.71%	0.42%
2	4.53%	1.75%
3	9.21%	5.00%
4	10.46%	12.28%
5	0.79%	0.32%
6	28.16%	32.21%
7	21.44%	32.37%
8	21.85%	11.53%





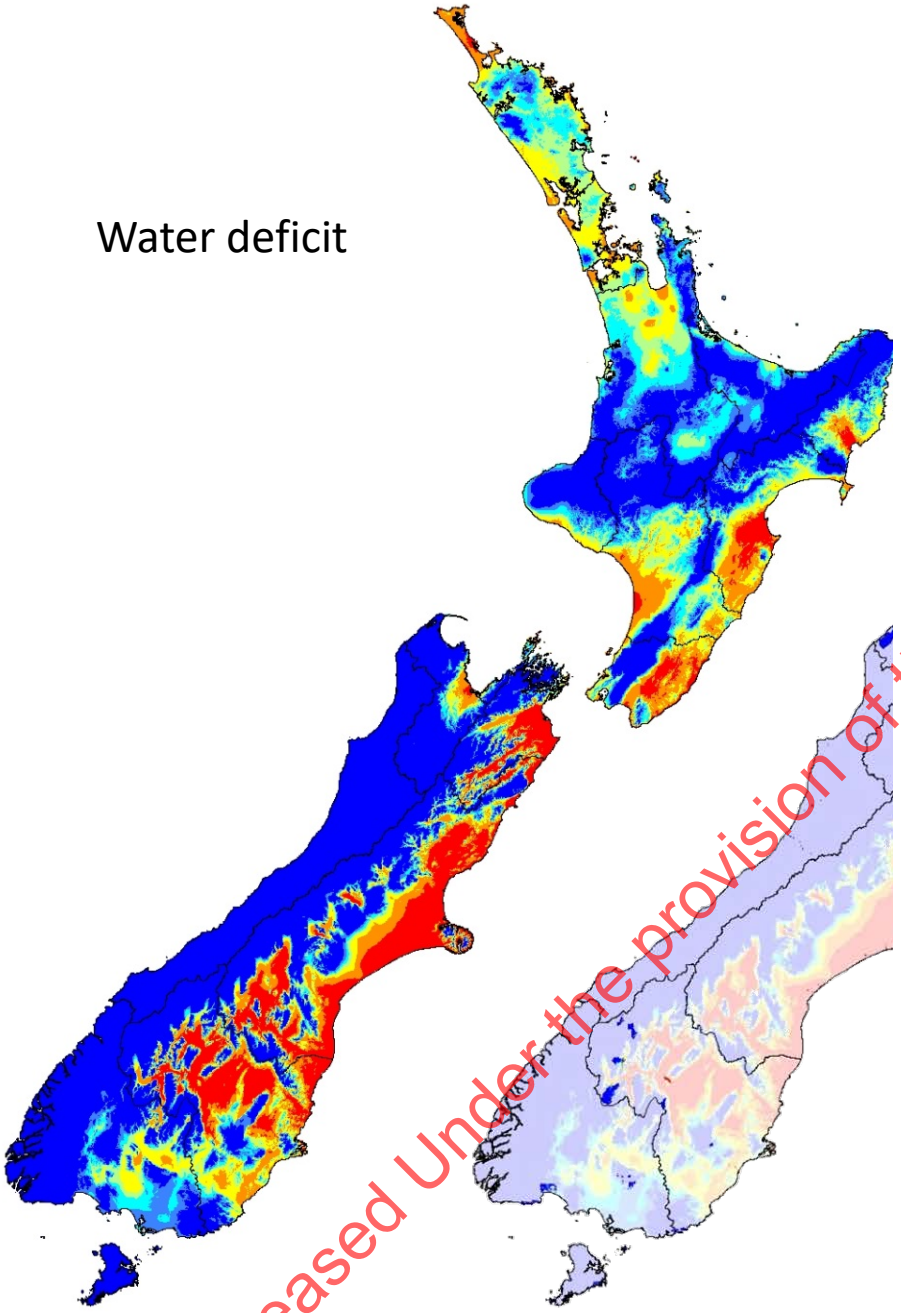
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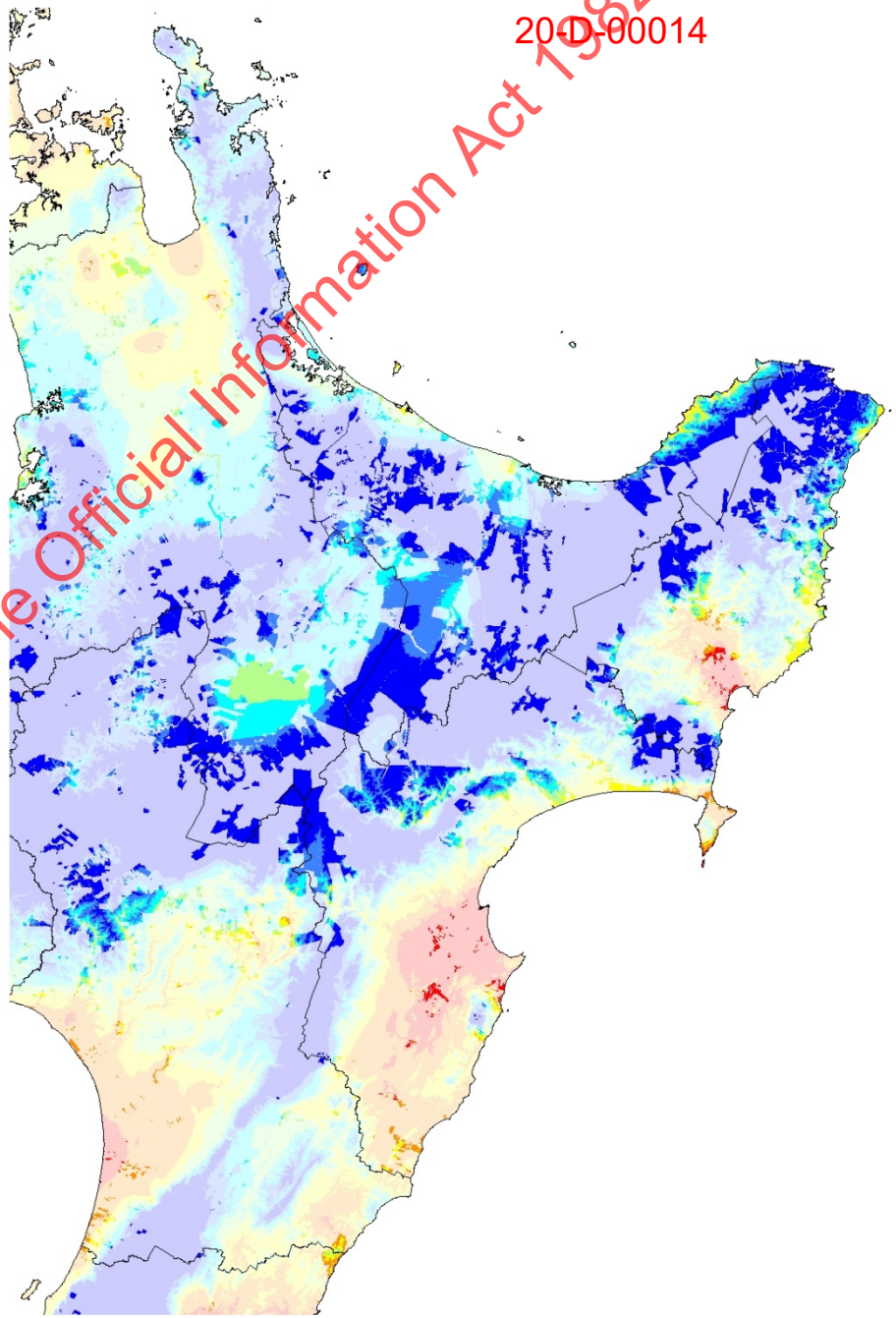




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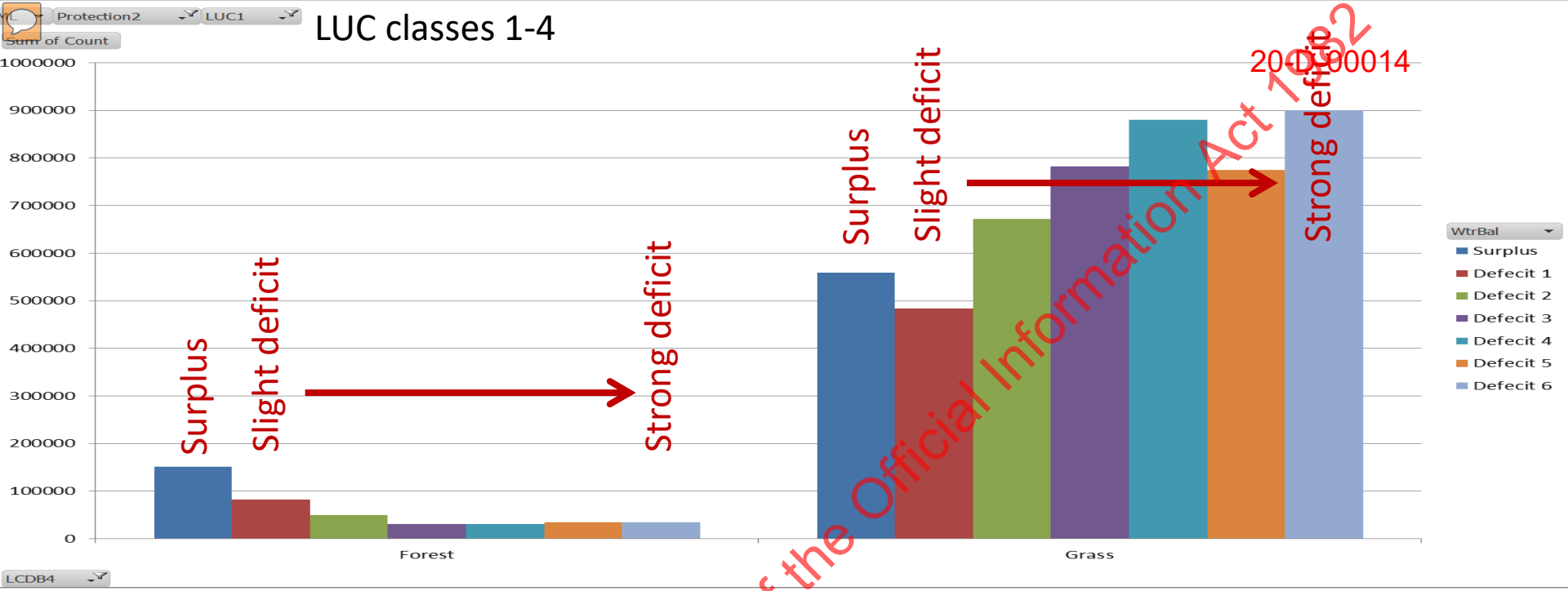
Water deficit

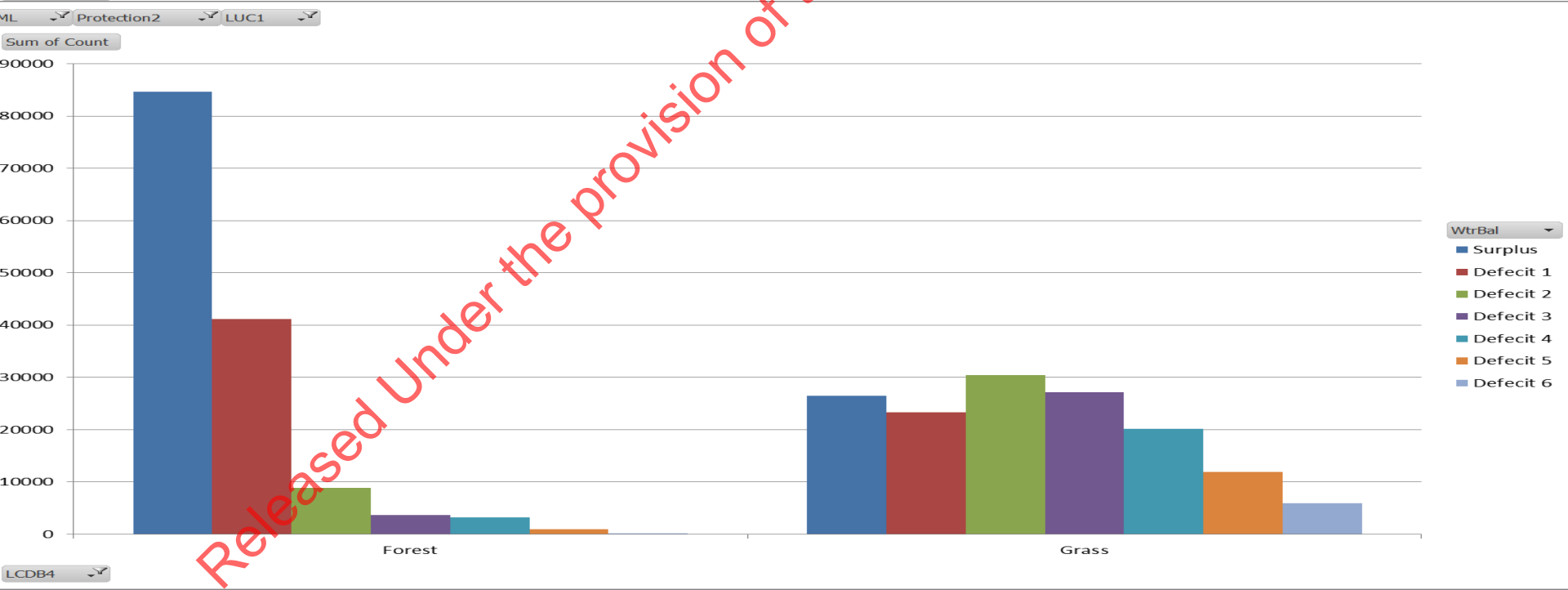




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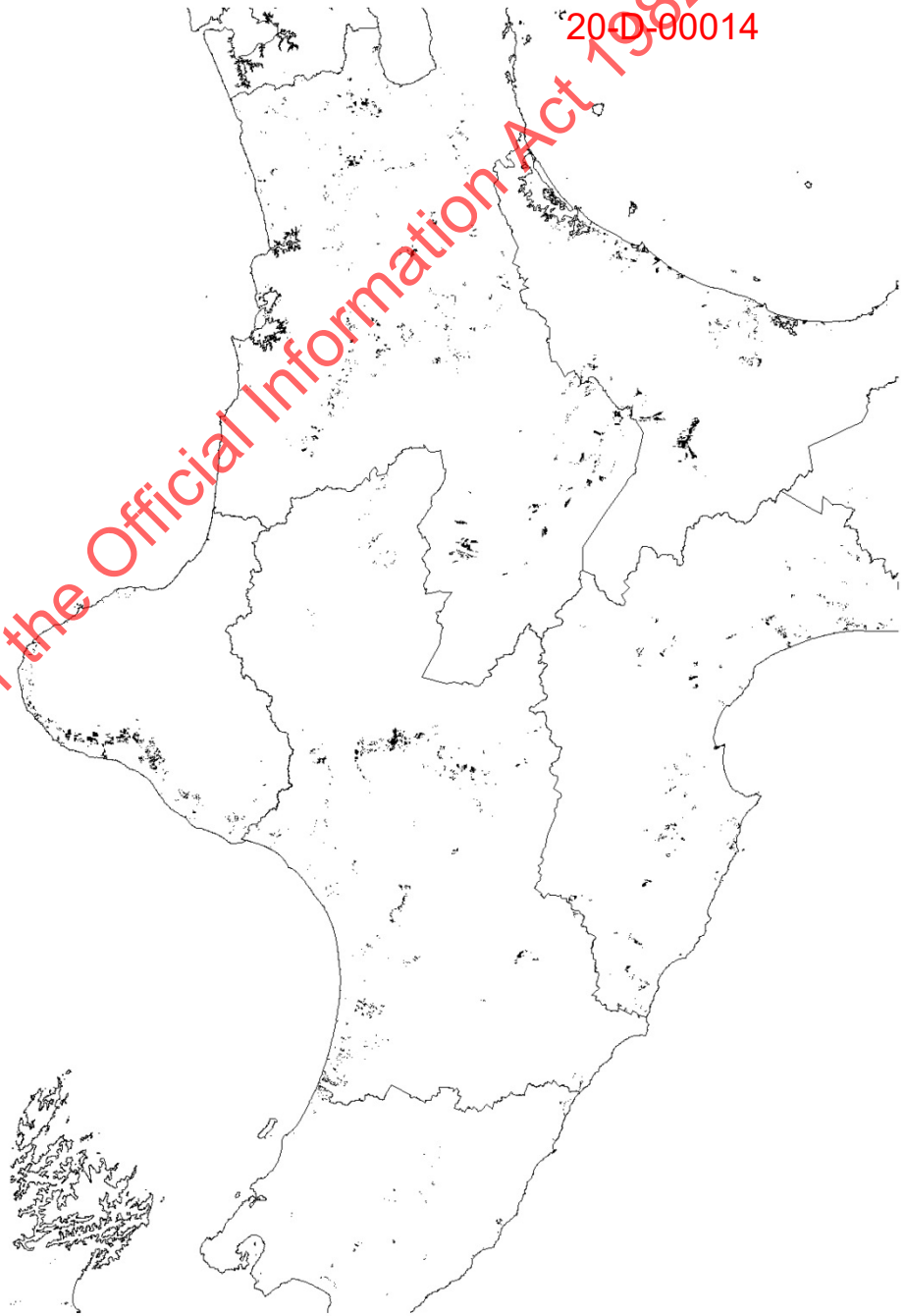




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Versatile forest or grassland in areas v



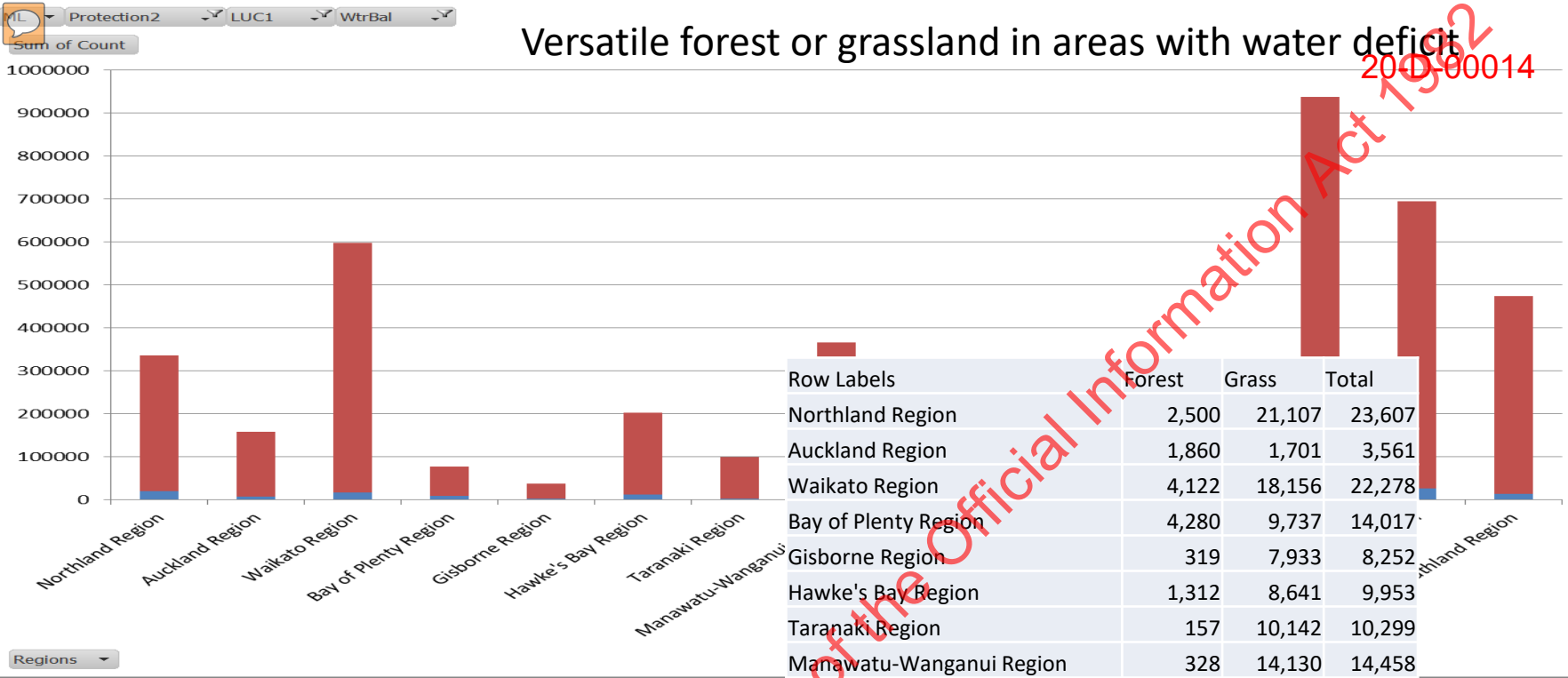


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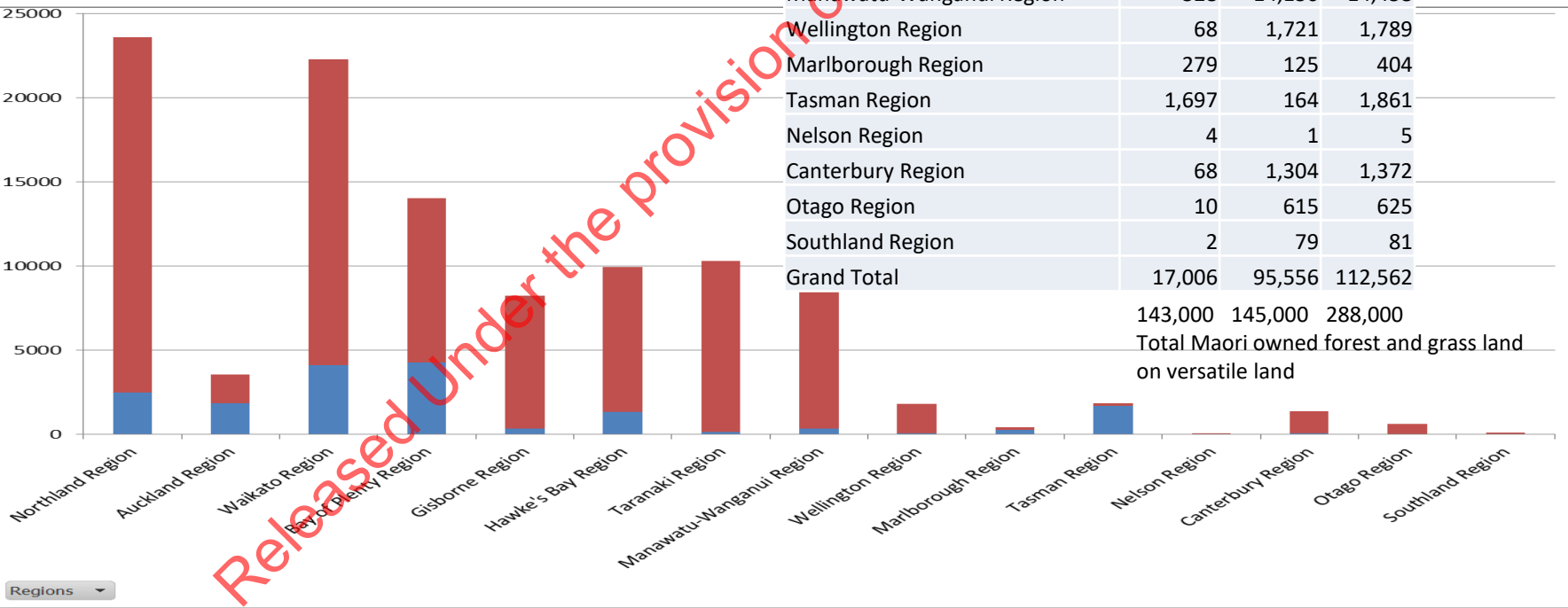
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Versatile forest or grassland in areas with water deficit

2020-00014



Row Labels	Forest	Grass	Total
Northland Region	2,500	21,107	23,607
Auckland Region	1,860	1,701	3,561
Waikato Region	4,122	18,156	22,278
Bay of Plenty Region	4,280	9,737	14,017
Gisborne Region	319	7,933	8,252
Hawke's Bay Region	1,312	8,641	9,953
Taranaki Region	157	10,142	10,299
Manawatu-Wanganui Region	328	14,130	14,458
Wellington Region	68	1,721	1,789
Marlborough Region	279	125	404
Tasman Region	1,697	164	1,861
Nelson Region	4	1	5
Canterbury Region	68	1,304	1,372
Otago Region	10	615	625
Southland Region	2	79	81
Grand Total	17,006	95,556	112,562

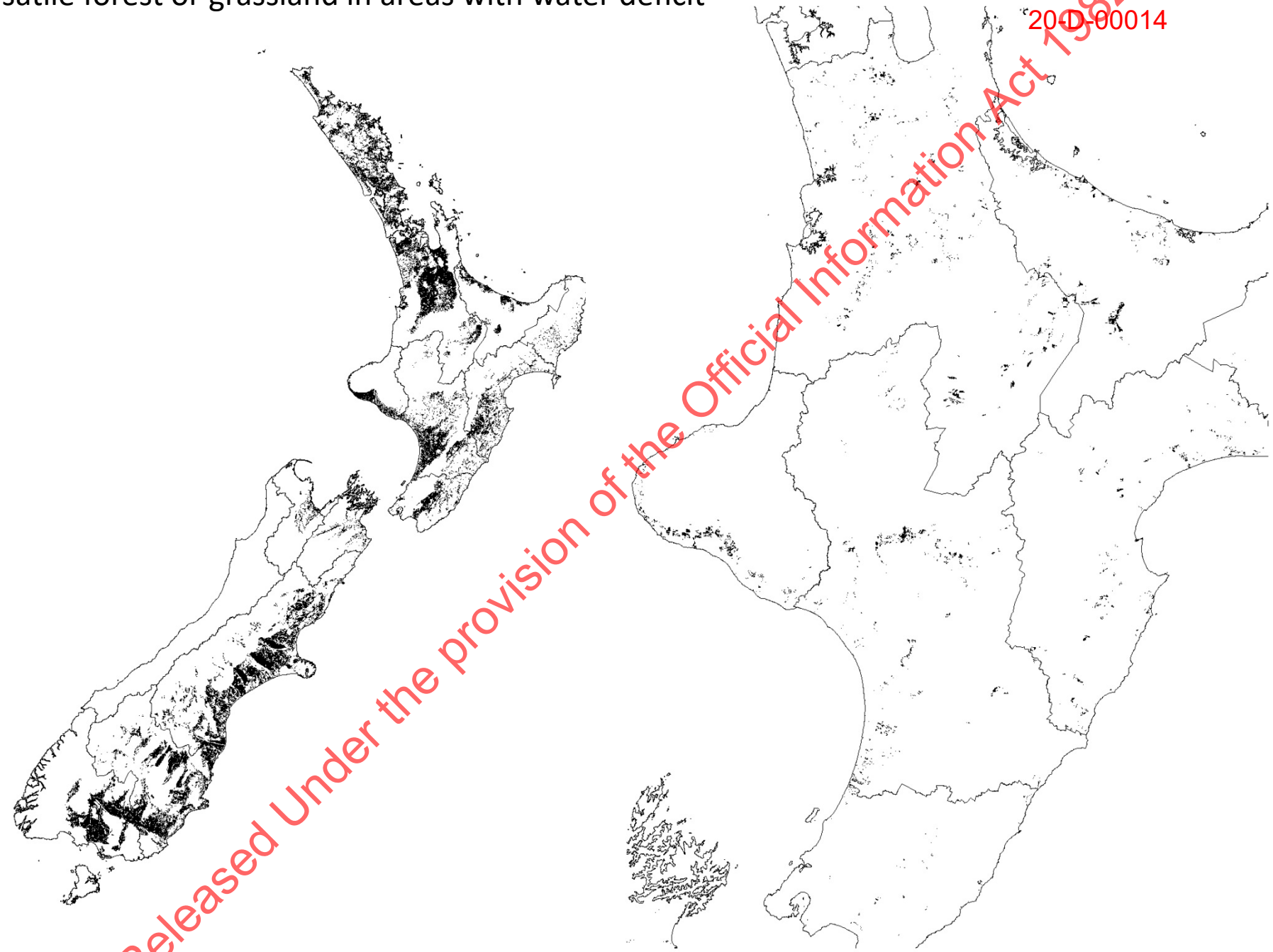


143,000 145,000 288,000

Total Maori owned forest and grass land on versatile land

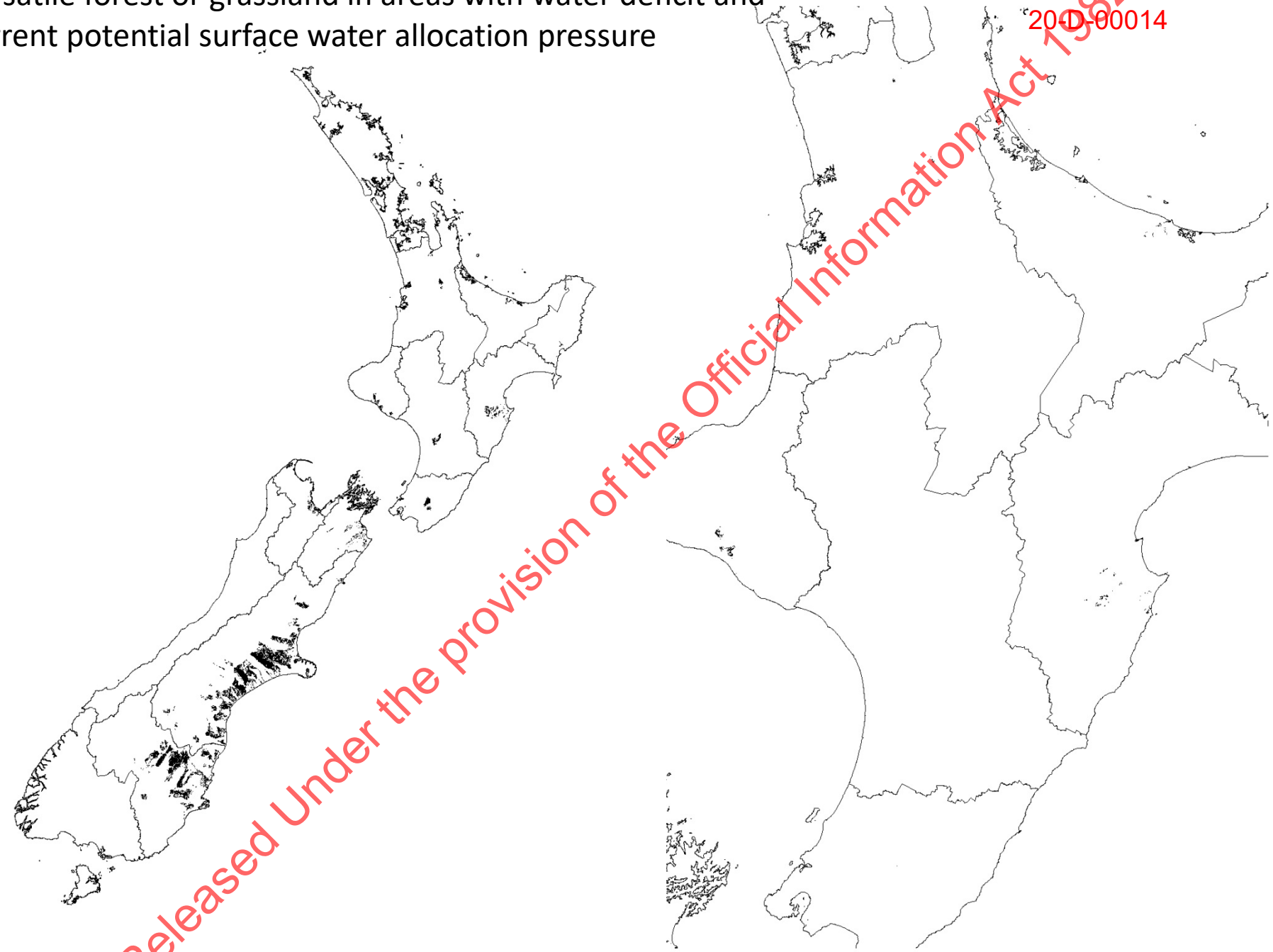
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Versatile forest or grassland in areas with water deficit



20-D-00014
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Versatile forest or grassland in areas with water deficit and current potential surface water allocation pressure



20-D-00014

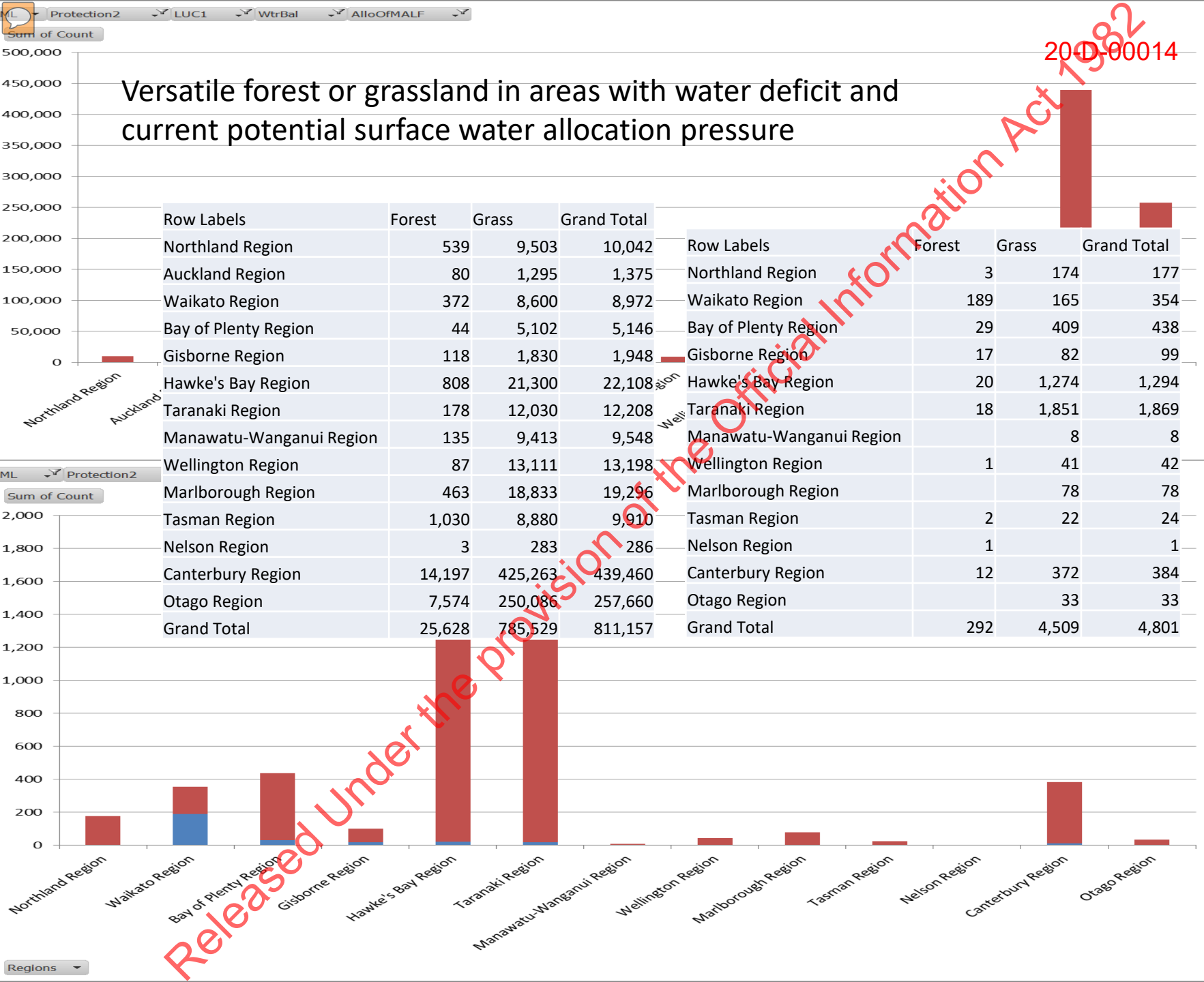
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Versatile forest or grassland in areas with water deficit and current potential surface water allocation pressure

Row Labels	Forest	Grass	Grand Total
Northland Region	539	9,503	10,042
Auckland Region	80	1,295	1,375
Waikato Region	372	8,600	8,972
Bay of Plenty Region	44	5,102	5,146
Gisborne Region	118	1,830	1,948
Hawke's Bay Region	808	21,300	22,108
Taranaki Region	178	12,030	12,208
Manawatu-Wanganui Region	135	9,413	9,548
Wellington Region	87	13,111	13,198
Marlborough Region	463	18,833	19,296
Tasman Region	1,030	8,880	9,910
Nelson Region	3	283	286
Canterbury Region	14,197	425,263	439,460
Otago Region	7,574	250,086	257,660
Grand Total	25,628	785,529	811,157

Row Labels	Forest	Grass	Grand Total
Northland Region	3	174	177
Waikato Region	189	165	354
Bay of Plenty Region	29	409	438
Gisborne Region	17	82	99
Hawke's Bay Region	20	1,274	1,294
Taranaki Region	18	1,851	1,869
Manawatu-Wanganui Region		8	8
Wellington Region	1	41	42
Marlborough Region		78	78
Tasman Region	2	22	24
Nelson Region	1		1
Canterbury Region	12	372	384
Otago Region		33	33
Grand Total	292	4,509	4,801



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