Appendices

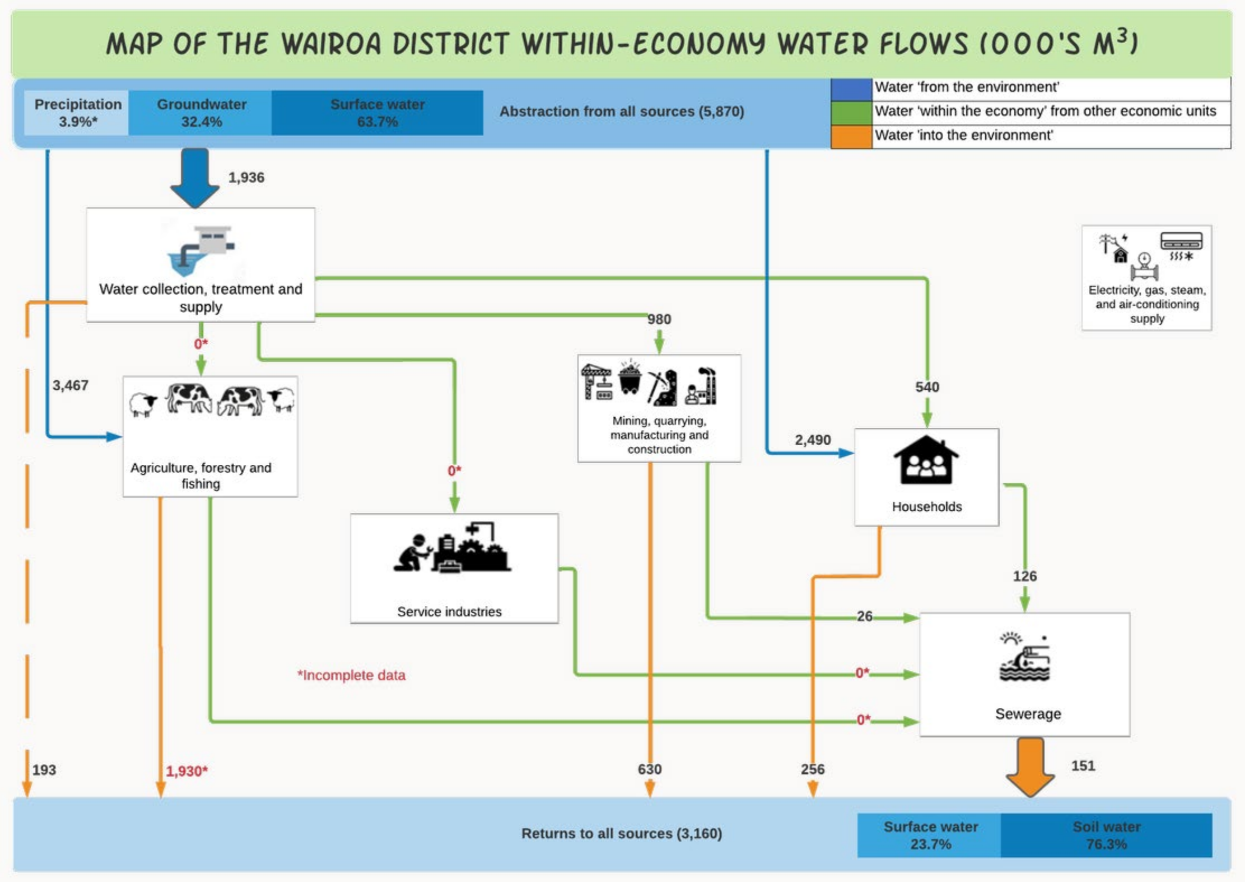
Appendix A: District Summaries

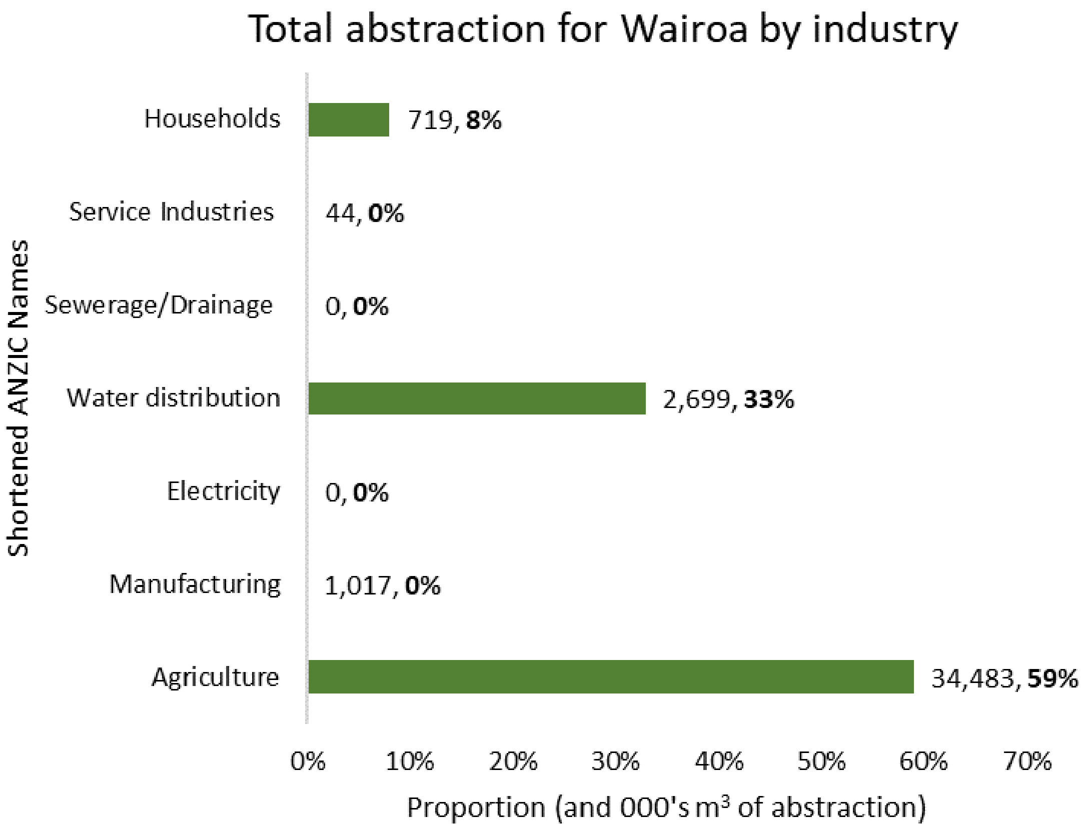
Summary by District for water Supply and Use

Wairoa District:

- In the 19/20 year the Wairoa district abstracted 5.8Mm³ of water.
- Sources of abstraction were:
  - Surface water: 64%
  - Ground water: 32%
  - Rain Collection: 4%
- Taking into account the flows of water between other industry / economic uses, total water *use* was 7.5Mm³.
- The Wairoa District received 5.7Bm³ of rain.

Here is the Wairoa District schematic overview of water supply and use.

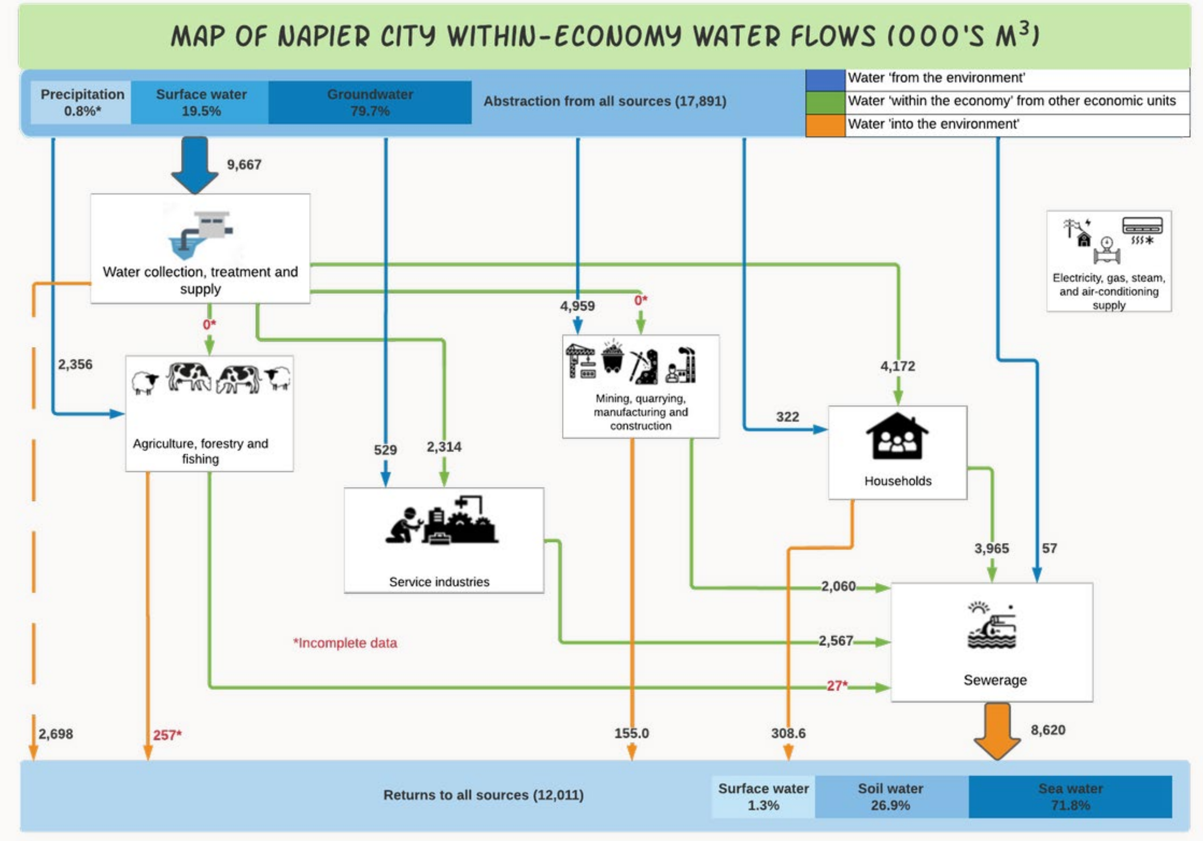


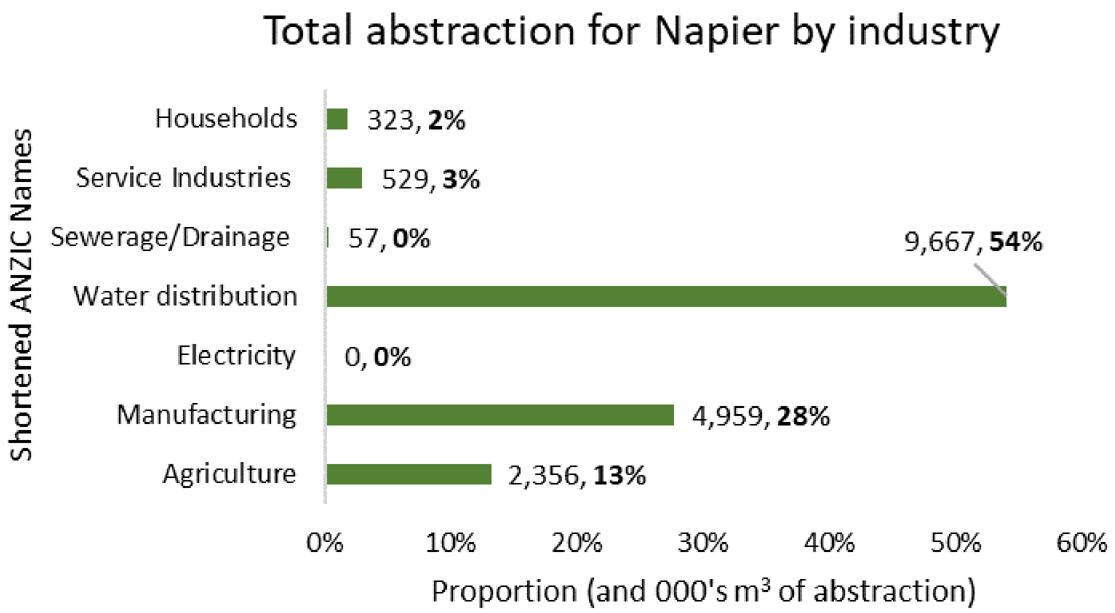

Total abstraction for Wairoa by industry
Shortened ANZIC Names
Households
719, 8%
Service Industries
44, 0%
Sewerage/Drainage
0, 0%
Water distribution
2,699, 33%
Electricity
0, 0%
Manufacturing
1,017, 0%
Agriculture
34,483, 59%
0%
10%
20%
30%
40%
50%
60%
70%
Proportion (and 000's m3 of abstraction)

Napier District:

- In the 19/20 year the Napier district abstracted 17.8Mm³ of water.
- Sources of abstraction were:
    - Surface water: 19%
    - Ground water: 80%
    - Rain Collection: 1%
- Taking into account the flows of water between other industry / economic uses, total water *use* was 32.9Mm³.
- The Napier District received 67Mm³ of rain.

Here is the Napier District schematic overview of water supply and use.

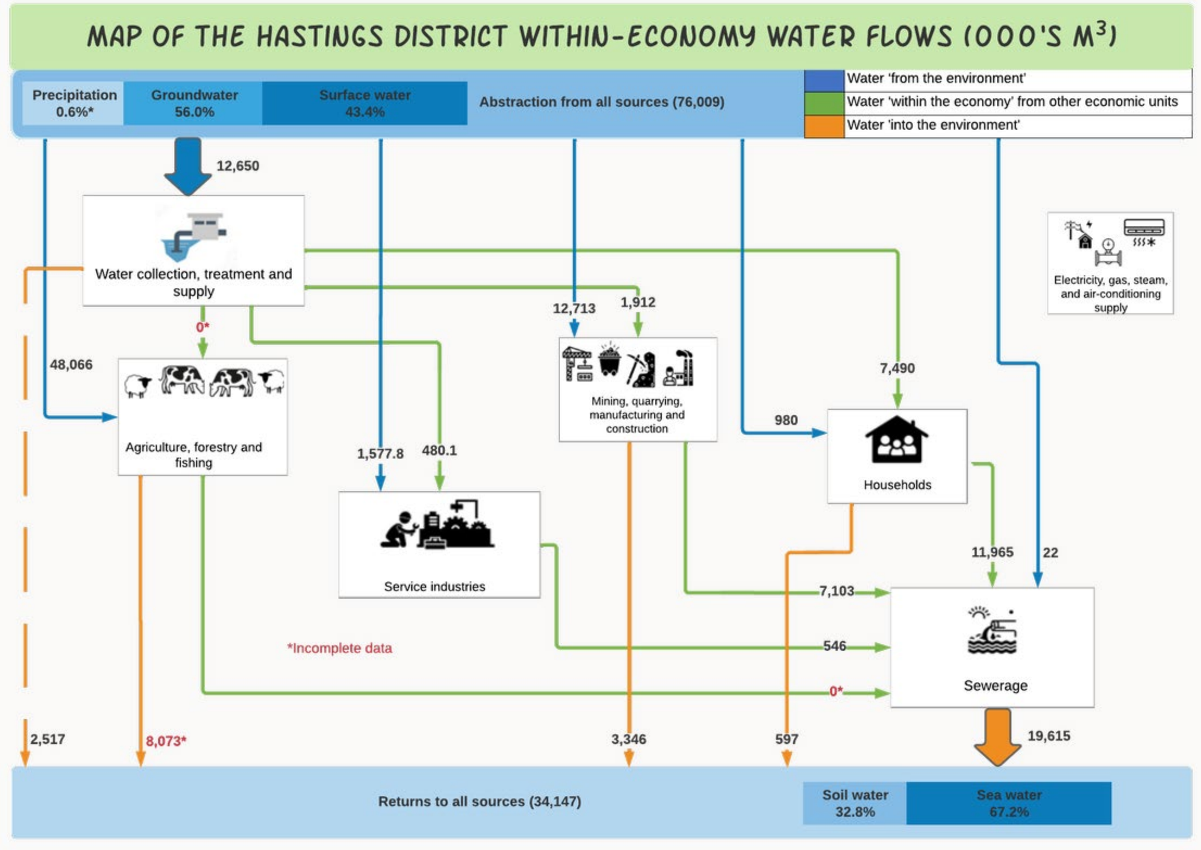


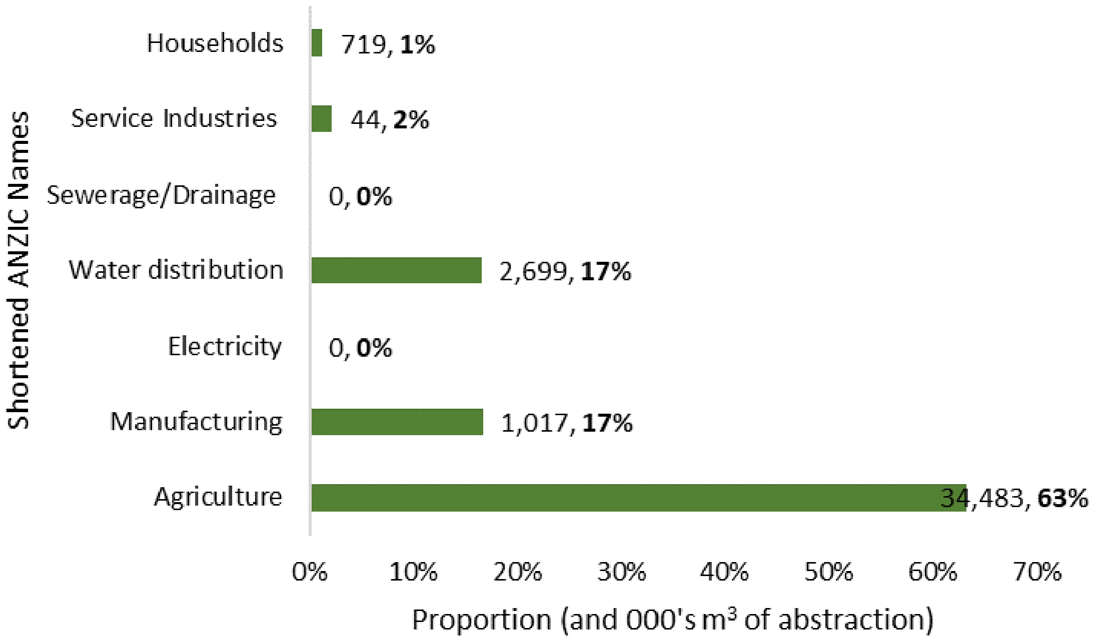

Total abstraction for Napier by industry
Shortened ANZIC Names
Households
323, **2%**
Service Industries
529, **3%**
Sewerage/Drainage
57, **0%**
Water distribution
9,667, **54%**
Electricity
0, **0%**
Manufacturing
4,959, **28%**
Agriculture
2,356, **13%**
0%
10%
20%
30%
40%
50%
60%
Proportion (and 000's m³ of abstraction)

Hastings District:

- In the 19/20 year the Hastings district abstracted 76Mm^3 of water.
- Sources of abstraction were:
    - Surface water: 43%
    - Ground water: 56%
    - Rain Collection: 1%
- Taking into account the flows of water between other industry / economic uses, total water *use* was 105Mm^3.
- The Hastings District received 5.3Bm^3 of rain.

Here is the Hastings District schematic overview of water supply and use.

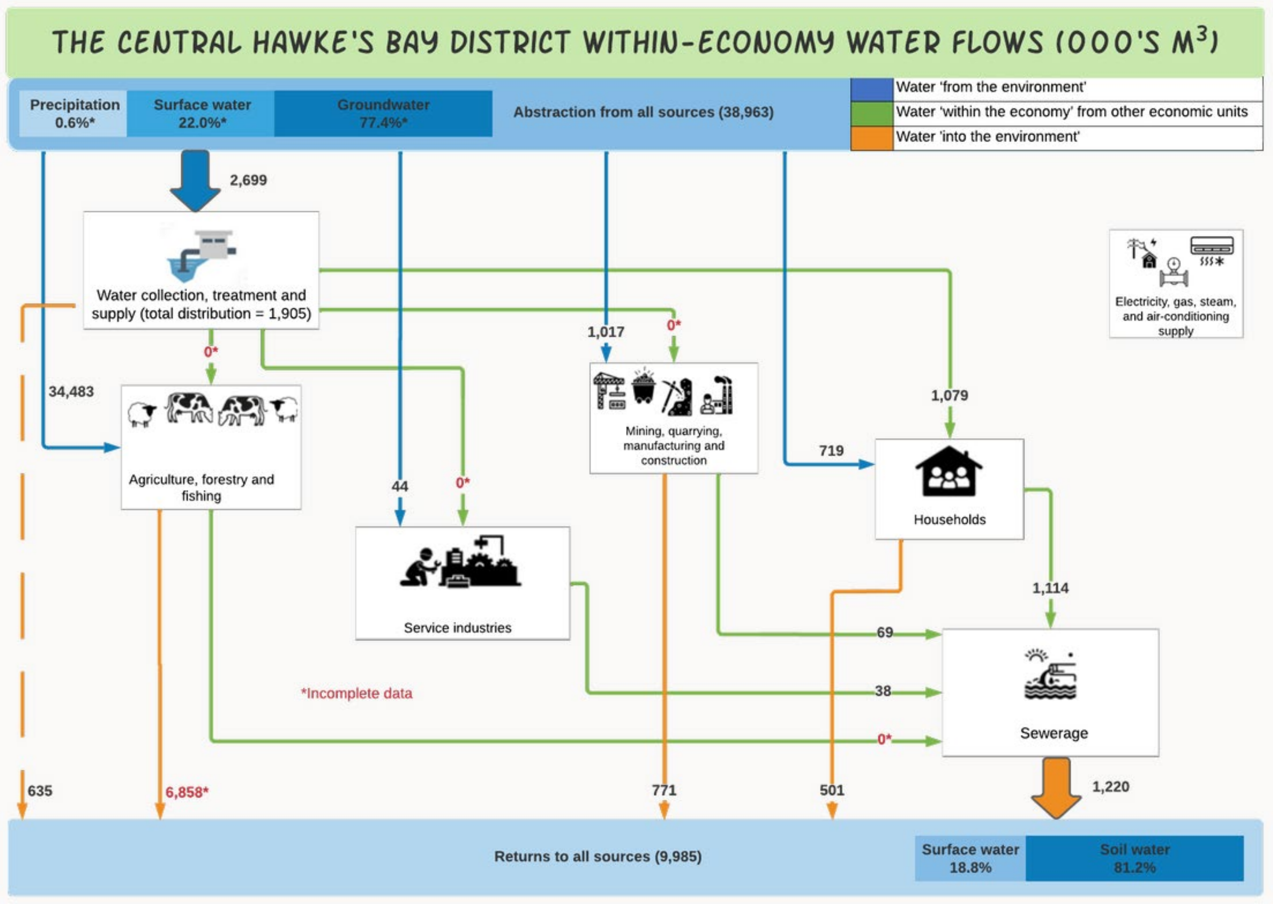


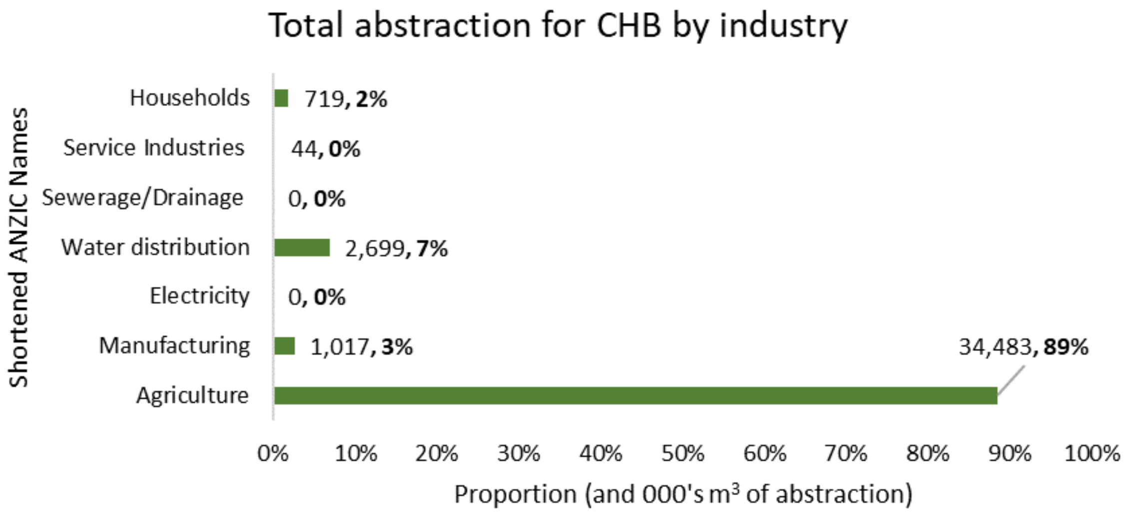

Total abstraction for Hastings by industry

Central Hawke’s Bay District:

- In the 19/20 year the Central Hawke’s Bay district abstracted 38.9Mm³ of water.
- Sources of abstraction were:
    - Surface water: 22%
    - Ground water: 77%
    - Rain Collection: 1%
- Taking into account the flows of water between other industry / economic uses, total water *use* was 41Mm³.
- The Central Hawke’s Bay District received 3Bm³ of rain.

Here is the Central Hawke's Bay District schematic overview of water supply and use.




Total abstraction for CHB by industry
Shortened ANZIC Names
Households
Service Industries
Sewerage/Drainage
Water distribution
Electricity
Manufacturing
Agriculture
719, 2%
44, 0%
0, 0%
2,699, 7%
0, 0%
1,017, 3%
34,483, 89%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Proportion (and 000's m³ of abstraction)

Appendix B: ME Research

Water Security Economic Impact Assessment
July 2020

Hawkes Bay Region Water Security Economic Impact Assessment

Final Report

17 July 2020

Hawkes Bay Region Water Security Economic Impact Assessment

Final Report

Prepared for

Hawkes Bay Regional Council

Document reference:

Date of this version: 1 July 2020

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www.me.co.nz

Executive Summary

Purpose

The objective of this study is to provide a high-level economic impact assessment of the value of water security in the TANK (Tūtaekurī, Ahuriri, Ngaruroro and Karamū) and Tukituki catchments, including the flow-on impacts to the wider Hawke's Bay region and rest of New Zealand economies, associated with climate change following a 'do-nothing' approach.

Given the initial and rapid nature of this assessment, a further objective has been to draw heavily on existing work and resources for the assessment. This includes work undertaken specifically on water supply security in the Hawke's Bay, completed studies on climate change impacts both within Hawke's Bay and further afield, as well as existing economic modelling tools and resources.

Methodology

Direct Impacts on Agricultural Systems

The first stage of the method required deriving suitable information on the likely physical impacts of climate change on water supply security, as would be relevant to agricultural activities within the Heretaunga plans and Tukituki river catchment. We recognised that both supply-side (i.e. changes in water availability for agricultural use) and demand-side (i.e. changes in demands for water by agricultural users because of climate changes leading to, say, less soil moisture on farms) needed to be considered.

Following this, water-revenue curves, and theoretical crop production functions (or response curves) for key impacted crops/farm types within the TANK and Tukituki catchments were then derived from several sources and previously developed approaches. The impacts of lesser water availability, i.e. supply-side impacts are simulated by "reading off" the revenue curve the future revenue per hectare associated with a change in water supply availability. Seen in Fig. A, a change in supply from W' to W'' reduces revenue from R' to R''.

Moving to demand changes, we concluded that an outward shift of the revenue curves developed would plausibly simulate a potentially future drier year based on the logic that, for the same level of revenues, the plant/farm/orchard will need more water given that soil moisture level will have decreased. In other words, for the same amount of water, the plant/farm/orchard will produce less and receive less revenue. In Fig. A, a drier year is simulated by shifting the blue curve out to the green curve meaning that W' becomes W''' and revenue reduces to R''').

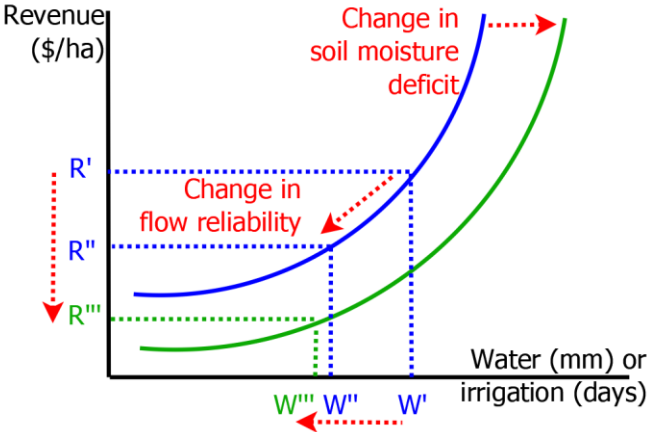


Fig. A: A Theoretical Water-Revenue Curve and its Adjustment for Changes in Supply (Flow reliability) and Demand (Soil moisture deficit) Relationships.

Flow-on Impacts to the Hawke's Bay and rest of New Zealand

We then applied a Multi-Regional Dynamic Economic Model (DEM) of the wider Hawke's Bay region and rest of New Zealand economies to estimate the flow-on socio-economic impacts of changes to water availability resulting from climate change. The DEM relies on a core set of data derived within the direct impacts analysis to model the implications of climate change under a 'do-nothing' approach. This core set of data describes for each economic industry at the level of the whole Hawke's Bay Region, and at one year intervals, the percentage of industry commodity supply that can be achieved under the new climate conditions compared to current or 'normal' climate conditions.

This model has many of the features of a fully Dynamic Computable General Equilibrium (DCGE) model i.e. pricing dynamics, substitution/transformation effects, interregional/international trade and so on. It is, however, uniquely designed for the modelling of transition pathways through time, where it is desirable to consider both the short- and medium-term.

The model considers two regions: the Hawke's Bay region and the rest of New Zealand. For each region, the model describes the behaviour of representative agents (23 industries, households, local government and central government). Each industry agent chooses the quantity and type of commodities (31 commodities) to produce, based on the prices of those commodities relative to the costs of production. Household, industries, and government agents receive income from a variety of sources (e.g. wages and salaries, business profits, dividends, taxes, and transfers from other agents), and then allocate this income towards a variety of expenditure options (e.g. purchases of goods and services, savings, taxes, and transfers to other agents).

The DEM reports value added (as measured in $\$_{2019}$m) and employment under each simulation by: (i) location – the Hawke's Bay region and Rest of New Zealand, (ii) time – annual averages at 3-day time steps, covering the period 2007 through to 2060 (with 2007-2019 used to calibrate the model), and (iii) industry – 23 aggregate economic industries comprehensively covering *all* market based economic activities. The economic impacts of climate change are presented in 'net' terms by considering the difference in each economic indicator between a simulation where no climate change is assumed, and a simulation with climate change incorporated.

Reference Futures and Scenarios Modelled

Given the uncertainty inherent in predicting the future, we have also not attempted to quantify a single 'best guess' of the climate change impacts that will result from changes in water supply-demand in the TANK and Tukituki catchments, but rather to report a range of results under differing assumptions regarding future conditions.

These assumptions are broadly defined into two key groups, Future Climate Scenarios, which draw upon the IPCC's Representative Concentration Pathways (RCPs), and secondly, world economic conditions or alternative 'Reference Futures', which represent a range of future economic conditions largely outside the control of Hawke's Bay region. In terms of RCPs, the four standard scenarios from the IPCC 5th assessment report are used in the modelling of direct impacts (i.e. RCP2.6, RCP4.5, RCP6 and RCP 8.5), but given the unlikely nature of the RCP2.6 scenario, only the last three scenarios are carried forward into the analysis of flow-on impacts. In the modelling of flow-on impacts using the DEM, five alternative reference futures are implemented providing a range of economic growth, global co-operation, technological change, and environmental focus.

Results

Direct Impacts on the Hawke's Bay region

Direct impacts on the Hawke's Bay Region's farming industries have been calculated in terms of relative and absolute changes in revenue, with respect to the 1998 historic baseline, under the four different RCP climate change scenarios. These impacts were also calculated for two time periods: mid- and late-century (corresponding to 2036-2050 and 2086-2100 respectively).

Under all four RCPs, the mid-century impacts are relatively small – all less than 2.5% compared to the 1998 baseline, with pasture experiencing the largest impacts of approximately $\$_{2019}$12 million per year.

In relative terms, crops and vegetables would be the most impacted agricultural activity in the region, particularly over the late-century scenarios, with an approximate 18% reduction in revenues under the most extreme late-century climate scenario. These would be followed by pip fruit with an approximate reduction of 11% in revenues under the same scenario. Mid- and late-century relative impacts across all climate change scenarios are shown in Fig. B.

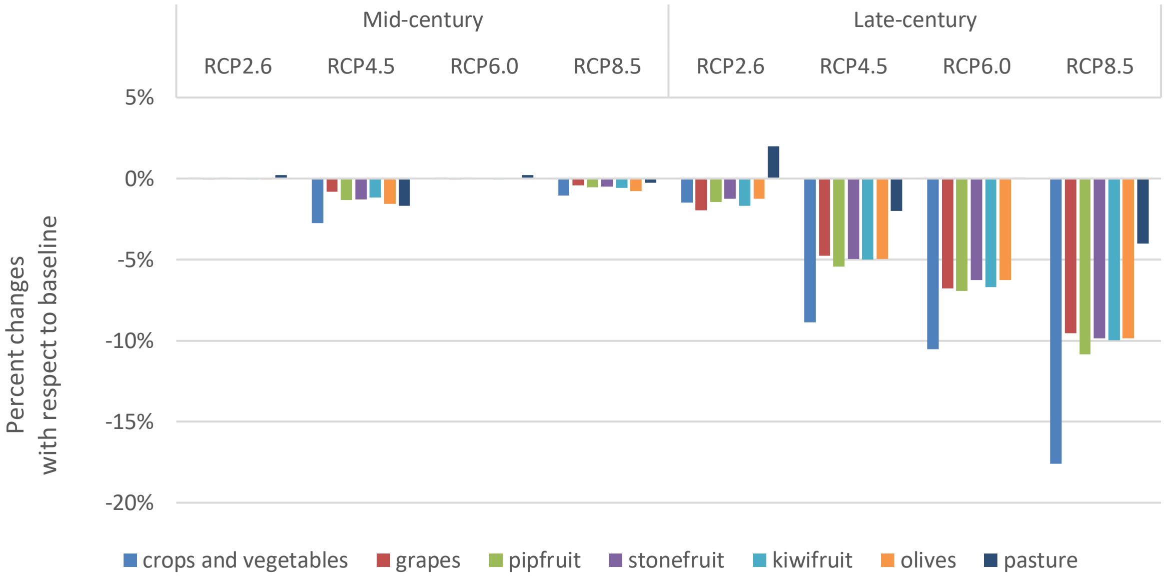


Fig. B: Net Changes in Revenues (%) for Irrigated Crops and Pasture under Different Climate Change Scenarios (RCPs) and Time Horizons for the Do-nothing Scenario

In absolute terms, again looking at the late-century impacts, pip fruit would be the most impacted agricultural crop with an approximate annual loss in revenues of $\$_{2019}$60 million within the Hawke's Bay region under the most extreme climate change scenario. Under the same climate change scenario, pasture-dependent dry-stock and crops and vegetables would be the next most impacted agricultural activities in the region with approximate annual losses of $\$_{2019}$30 and $\$_{2019}$20 million, respectively. Mid- and late-century absolute impacts across all climate change scenarios are shown in Fig. C.

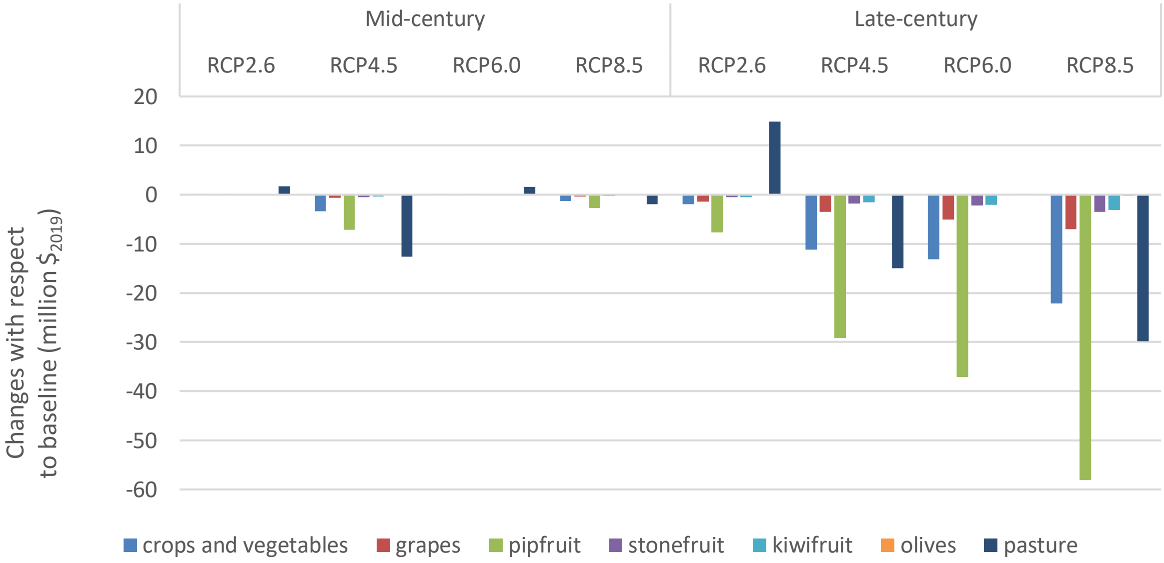


Fig. C: Net Changes in Revenues ($\$_{2019}$m) for Irrigated Crops and Pasture under the Different Climate Change Scenarios (RCPs) and Time Horizons for the Do-nothing Scenario

Our analysis indicated that Earnings Before Interest, Taxes, Depreciation, and Amortization (EBIT-DA) for several crops would drop significantly and could become negative in the latter part of the century. There are several implications associated with this including *inter alia*: (1) it is likely that horticulture and fruit growing business owners would begin to consider other potential uses of their land – including uses that may be less profitable than presently; and (2) investors may consider moving capital outside of the region to more profitable locations.

Wider Impacts on the Hawke's Bay region and rest of New Zealand

Headline results are reported in terms of annual changes in annual Gross Domestic Product (GDP) in Table A, concentrating on the RCP4.5 and RCP8.5 climate scenarios. The numbers reported in this table are the median result across the five 'Reference Futures' considered. The results for the RCP4.5 and RCP8.5 scenarios are reasonably similar, with a net change in annual GDP of $\$_{2019}$30-40million in 2030, escalating to an annual change in GDP of $\$_{2019}$470 million by 2060 for the RCP8.5 scenario and $\$_{2019}$500 million for the RCP4.5 scenario. We note that if it were possible to extend the dynamic multi-regional economic modelling out further in time, we would anticipate that the differences between the RCP4.5 and RCP8.5 scenarios would become substantial, given that the emissions under RCP8.5 will significantly outstrip emissions under RCP4.5 by the end of the century.

Table A: Net Change in Annual Gross Domestic Product under Alternative Climate Scenarios ($\$_{2019}$m) as at 2030, 2045 and 2060

	2030	2045	2060
RCP4.5			
Hawkes Bay	-30	-70	-110
Rest of NZ	-10	-90	-400
Total NZ	-40	-180	-500
RCP8.5			
Hawkes Bay	-20	-60	-120
Rest of NZ	-10	-80	-370
Total NZ	-30	-160	-470

Note: (1) Values reported are the median across five alternative Reference Economic Futures Modelled.
(2) Results are rounded to nearest $\$_{2019}$10 million.

In addition to the headline wider economic impacts on the Hawke's Bay region and the rest of New Zealand, sectoral level impacts of climate change and changes in water supply, under the RCP4.5 scenario for the Hawke's Bay region and the Rest of New Zealand are estimated. Measured in terms of value added, the largest losses within the Hawke's Bay are experienced in the agricultural sectors (e.g. $\$_{2019}$43-$\$_{2019}$87 million annually for the sheep, beef, deer, other livestock and grain farming industry) with some flow on effects to food manufacturing.

Small increases in value added are recorded in the forestry and logging and other primary industries in the Hawke's Bay region, which reflects that the model is allocating some increased land to these activities as a response to relative declines in profitability in the horticulture, drystock and dairy industries. The positive impacts reported for agriculture industries in the rest of New Zealand reflects that these industries are picking up some of the supply (both directly to consumers as well as other inter-agricultural sales) that can no longer be met via Hawke's Bay production. These industries also benefit from some appreciation in prices for the commodities they produce.

Interestingly, many of the largest impacts are associated with construction and service industries, particularly in the rest of New Zealand. This underscores the complex nature of economic systems, especially when considering relationships and feedbacks that build over a period of 30-40 years. Although losses in income may initially be generated in agriculture and closely aligned activities such food processing, they ultimately flow through the economy causing less funds available for new construction and capital investment – impacting not only on construction activities but ultimately the growth of all economic industries. These sectoral level impacts are summarised in Table B.

Table B: Net Change in Annual Industry Value Added Under the RCP4.5, at Year 2060 ($$_{2019}$m)

	Baseline Future	Techno-Global Future 101	Techno-Global Future 102	Fragmented Future	Green Growth Future
Hawkes Bay					
Horticulture and fruit growing	-6	-14	-11	-5	-10
Sheep, beef, deer, other livestock & grain farm.	-57	-87	-68	-43	-59
Dairy cattle farming	-1	-1	-1	0	0
Forestry and logging	5	8	6	4	7
Other primary	7	8	7	6	6
Food manufacturing	-17	-12	-19	-13	-10
Other manufacturing	2	5	4	1	5
Utilities, construction, transport	-12	-12	-13	-7	-13
Trade and hospitality	-3	-1	-3	-2	-3
Finance, insurance, real estate, business servs	-7	-8	-9	-5	-6
Other services	-12	-15	-14	-10	-13
Rest of New Zealand					
Horticulture and fruit growing	6	16	10	5	10
Sheep, beef, deer, other livestock & grain farm.	33	41	42	26	32
Dairy cattle farming	3	6	4	1	3
Forestry and logging	-5	-2	-5	-4	-3
Other primary	-1	-1	-1	-3	-1
Food manufacturing	-27	-3	-28	-27	-19
Other manufacturing	-27	-10	-29	-18	-19
Utilities, construction, transport	-114	-40	-105	-96	-67
Trade and hospitality	-61	-30	-39	-56	-24
Finance, insurance, real estate, business servs	-135	-58	-131	-123	-62
Other services	-85	-21	-81	-94	-52

Conclusions and Recommendations

Our analysis has focused on the period 2020-2060, but we have also made comments on the period post-2060. While our mid-century analysis does not indicate significant impact on water security from climate change, our late-century analysis shows considerable impacts. It is important to note that the socio-economic impacts of climate change are likely to be felt not only through gradual changes in climate, but also through (1) the increased frequencies of extreme events (e.g. droughts, floods), and (2) the accelerated supply and demand of water post-2060. Our study has also only focused on the water security impacts associated with climate change, there are however many other impacts (e.g. sea-level rise, coastal inundation, wildfires, etc.) which are likely to significantly impact on the Hawke's Bay region and the rest of New Zealand.

Now that the magnitude and extent of the 'do nothing' scenario on water security under climate change are, to some degree, understood it is recommended that HBRC consider the value of possible resilience building initiatives. The wellbeing of many smaller communities on the TANK and Tukituki catchments are interconnected with the fortunes of the primary sector. Our analysis shows that under climate change, with reduced water security (particularly post-2050), there is likely to be significant impacts not only on the environment and natural habitat that underpins the region's wealth, but also on the socio-economic wellbeing of the region's people. Our assessment indicates that the socio-economic implications of climate change on water security is not just a localised issue for the Hawke's Bay region, but is an issue that has impacts for all of New Zealand.

Contents

1 Objective

The objective of this study is to provide a high-level economic impact assessment of the value of water security in the TANK (Tūtaekurī, Ahuriri, Ngaruroro and Karamū) and Tukituki catchments, including the flow-on impacts to the wider Hawke's Bay region and rest of New Zealand economies, associated with climate change. At present, the Hawke's Bay Regional Council (HBRC) is most interested in understanding the economic consequences of a 'do nothing' scenario with climate change incorporated. It is expected that this rapid assessment will be coarse and preliminary, but that it would provide a foundation from which more informed and detailed investigations into water security options (e.g. storage, augmentation, aquifer recharge) may occur.

Given the initial and rapid nature of this assessment, a further objective has been to draw heavily on existing work and resources for the assessment. This includes work undertaken specifically on water supply security in the Hawke's Bay, completed studies on climate change impacts both within Hawke's Bay and further afield, as well as existing economic modelling tools resources.

2 Background

Previous economic work undertaken by AgFirst (2018), Nimmo-Bell (2018) and MEResearch (2018) on water-use restrictions for the TANK catchments, and by Butcher Partners (2013, 2016) for the proposed Ruataniwha water storage scheme (part of the Tukituki catchment), provides some insights into the economic value of water security. This work did not however explicitly consider the water-related impacts of climate change.

HBRC was recently awarded funding under the Provincial Growth Fund (PGF) for a water security programme. This programme acknowledges that, while not perfect, the current water allocation management regime is sustainable for both the TANK and Tukituki catchments. Nevertheless, recent assessments prepared for the Ministry of Primary Industries (NIWA, 2016), Ministry for the Environment (NIWA, 2018) and the Office of the Prime Minister's Chief Science Advisor (2017) have noted that the overall water supply and demand balance, under climate change, may significantly impact water security over the longer term. As a first step in understanding the implications on water security of climate change, HBRC are therefore interested in examining the economic consequences of a 'do nothing scenario' with climate change accounted for.

It is expected that this assessment will evaluate not only the direct impacts (i.e. the operation of farm systems dependent on water allocation), but also the flow-on impacts (so-called 'general equilibrium' effects) through the Hawke's Bay region and rest of New Zealand economies. This includes effects associated with changes in supply chains, changes in employee spending, associated price changes for factors of production (labour, capital) as well as for commodities, changes in investment spending, and so on. Importantly, any analysis of the implications of climate change requires that alternative transition paths for the economy be considered over time i.e. between 2020-2060 in some detail, and 2060 onwards more generally.

3 Methodology

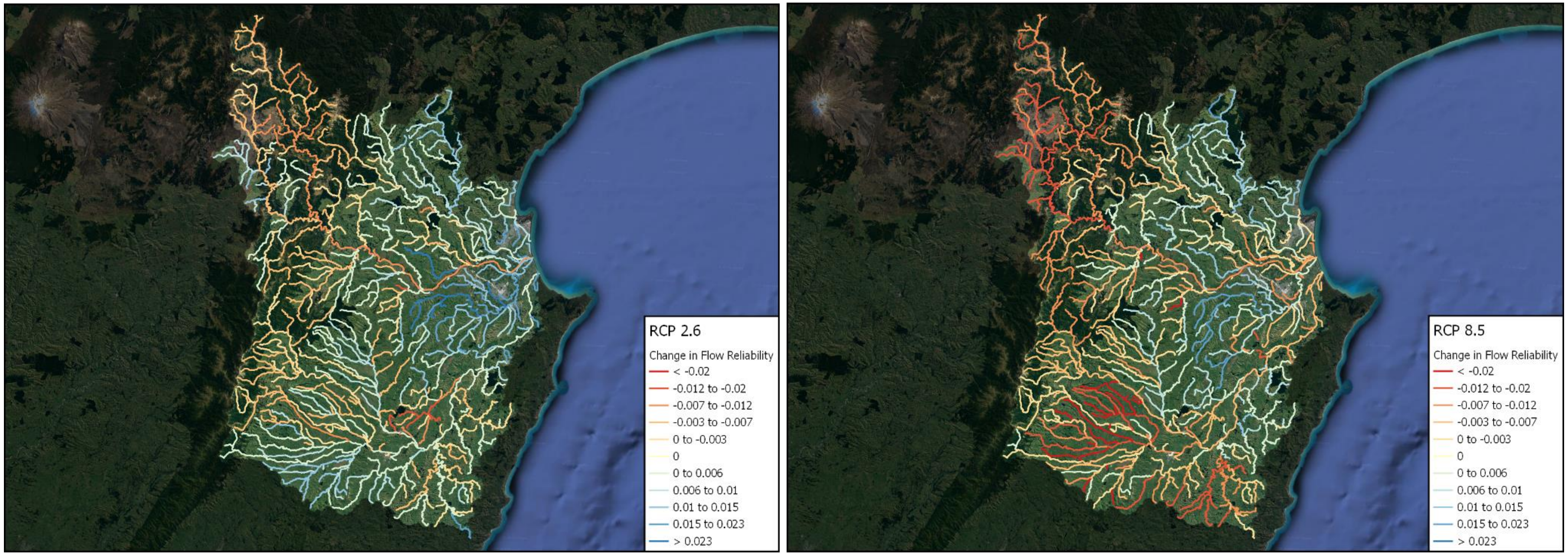
In this section we outline the stages undertaken to generate the estimated economic impacts of changes in water supply, as well as some of the key caveats relating to each stage. Also outlined in this section is the alternative assumptions about future world conditions (reference scenarios) modelled.

3.1 Key methodological stages

3.1.1 Stage 1: Water-related impacts of climate change

The first stage of the method required deriving suitable information on the likely physical impacts of climate change on water supply security, as would be relevant to agricultural activities within the Heretaunga plans (as represented by the TANK) and Tukituki river catchment. We recognised that both supply-side (i.e. changes in water availability for agricultural use) and demand-side (i.e. changes in demands for water by agricultural users because of climate changes leading to, say, less soil moisture on farms) needed to be considered.

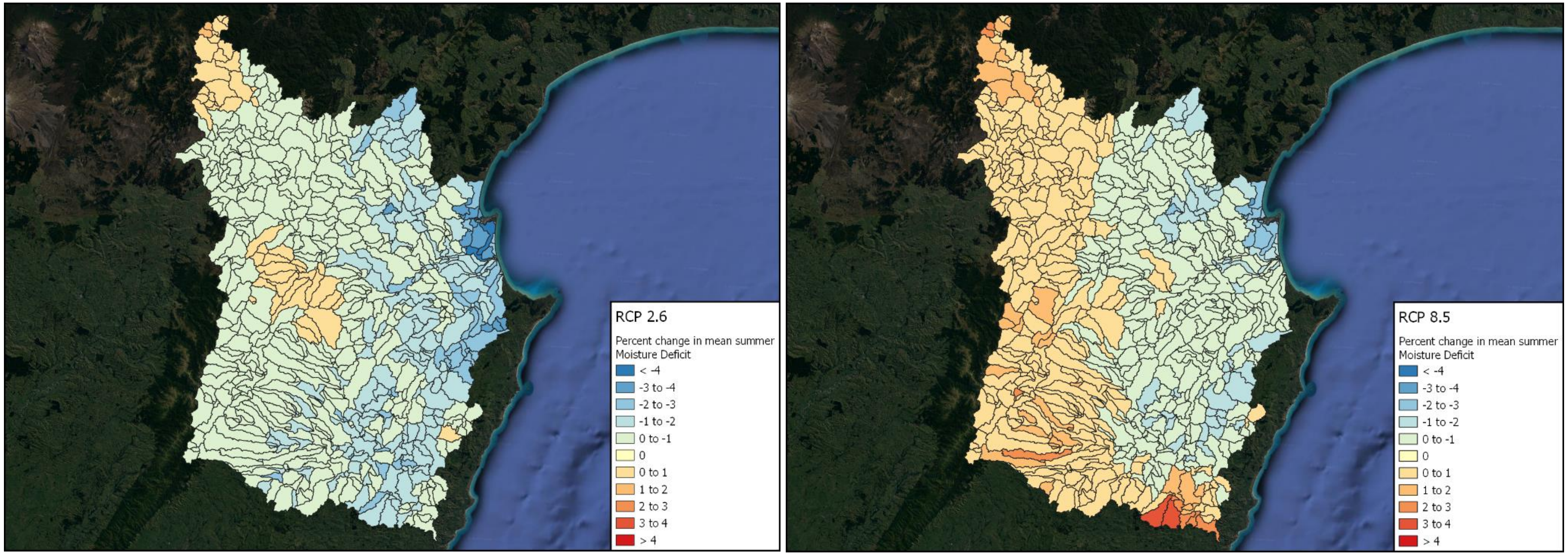
The future water related impacts of climate change for the TANK and Tukituki catchments were extracted from NIWA's (2016) mid-century maps of water-flow reliability (supply side proxy, Fig. 1) and catchment scale soil-moisture-deficit (demand side proxy, Fig. 2) forecasts under the four Representative Concentration Pathways (RCPs) climate change scenarios. Similar late-century forecasts were also obtained from NIWA (2016). Each RCP represents a greenhouse concentration trajectory adopted by the Intergovernmental Panel on Climate Change (IPCC) – refer to Table 1 for details of the RCPs considered i.e. RCP2.6, RCP4.5, RCP6.0 and RCP8.5 (and see also Burkett *et al*. 2014 for further information). Fig. 3 provides a generalised graphical representation of the RCPs expressed as CO_2-eqivalent concentrations over time.



(a) RCP 2.6

(b) RCP 8.5

Fig. 1: Average mid-century water-flow reliability forecasts (absolute changes) for the Hawke's Bay region's TANK and Tukituki catchments under (a) RCP2.6 and (b) RCP8.5 (NIWA, 2016)



(a) RCP2.6 (b) RCP8.5

Fig. 2: Average mid -century soil-moisture-deficit forecasts (percent changes) for the Hawke's Bay region's TANK and Tukituki catchments under RCP2.6 and RCP8.5 (NIWA, 2016)

Table 1: Representative Concentration Pathways (RCPs) adopted by Intergovernmental Panel on Climate Change (IPCC)

Scenario	**Radiative Forcing**	**CO_2-eq Concentration**	**Description**
	(W/m^2)	**(ppm)**	
RCP2.6	3.0	480-530	A strict reduction scenario that aims to keep global warming below 2°C above pre-industrial temperatures.
RCP4.5	4.5	580-720	A reduction scenario in which a significant GHG mitigation policy is implemented.
RCP6.0	6.0	720-1000	A normal reduction scenario in which an ordinary GHG mitigation policy is implemented.
RCP8.5	8.5	>1000	Very high GHG emissions. Scenarios without additional efforts to constrain emissions.

Note: The four RCPs use a common set of historical emissions data to initialise the integrated assessment models. The four RCPs were simulated in different Integrated Assessment Models to 2100.

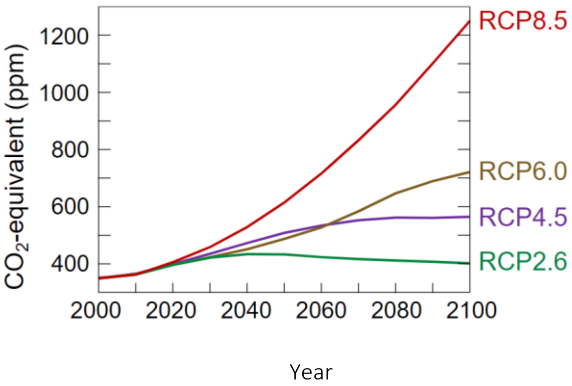


Fig. 3: Representative Concentration Pathways (RCPs) as adopted by the Intergovernmental Panel on Climate Change. Note: ppm = parts per million.

Modelling Caveats: Water-related Impacts of Climate Change

The water supply forecasts under climate change reported by NIWA (2016, 2018) was carried out under the following assumptions:

- The modelling considers surface water only. The authors of the NIWA reports state that further modelling would be needed to account for fluctuations in groundwater sources.
- Land use remains constant across the period of simulation and is set to Land Cover Database (LCDB) Version 2.
- Soil information is provided by the Fundamental Soil Layer information.
- Due to the hydrological modelling assumption, soil and land use characteristics within each computational sub-catchment are homogenised. This means that the soil characteristics and physical properties of different land uses, such as pasture and forest, will be spatially averaged, and the hydrological model outputs will approximate conditions across land uses.
- Irrigation season is defined as the period of time between 1 September and 30th April.

Irrigation restriction are provided by minimum flows based on the proposed National Environmental Standard (NES) for Environmental Flows and Water Levels.

3.1.2 Stage 2: Water-revenue curves and direct economic impacts

Water-revenue curves (Fig. 4) for key impacted industries within the TANK and Tukituki catchments were then derived from several sources: (1) the work previously undertaken by AgFirst (2018), Nimmo-Bell (2018) and MEResearch (2018) for the TANK economic assessment – covering irrigated grapes, pip fruit, summer fruit, kiwifruit and vegetables; (2) representative farm system modelling undertaken specifically for this project by AgFirst (AgFirst, 2020) – covering irrigated sheep, beef, deer, other livestock and grain farming; and (3) other studies undertaken elsewhere in New Zealand (e.g. Lieffering *et al*. (2012) and Kalaugher (2017)) – covering dairy cattle farming and non-irrigated sheep, beef, deer, other livestock and grain farming.

Horticulture and Fruit Growing

Under the TANK economic assessment AgFirst (2018) considered seven scenarios developed around irrigation restrictions and their impacts on the most relevant horticultural/fruit crops in the region, namely kiwifruit, grapes, summer fruit, pipfruit and vegetables. These seven scenarios included restrictions on surface water, groundwater and surface-connected groundwater. For these, AgFrist estimated the total number of days when irrigation would be banned due to more stringent water supply restrictions necessary to achieve various levels of freshwater habitat protection and the SPASMO model was, in turn, used to estimate the resulting loss in production for different types of crops. Nimmo-Bell (2018), in turn, used this information to produce per-hectare revenue estimates for each crop type under different water restriction scenarios (covering surface water, groundwater and surface-connected groundwater).

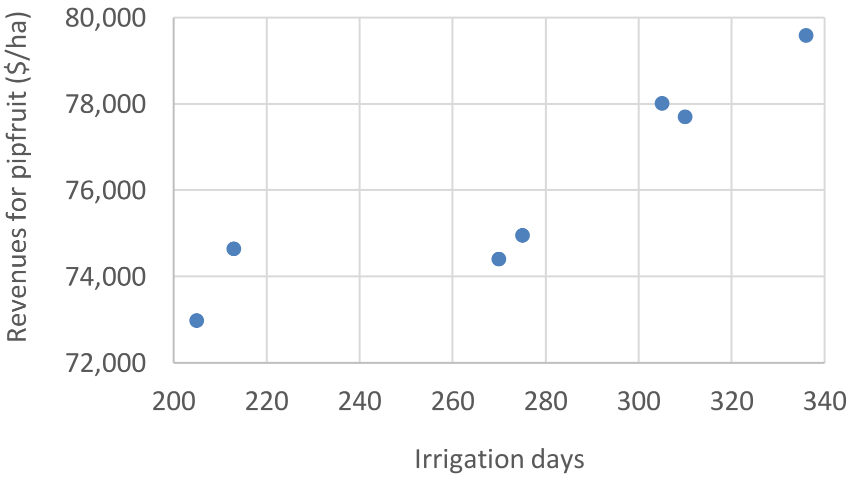


Fig 4: Example of Scatter Plot Relating Revenues to Irrigation Days

In this study, we utilise Nimmo-Bell's (2018) per-hectare revenue and ban day estimates (for a 1998 historical baseline[1]) to develop scatter plots (see pipfruit example in Fig. 4), and in turn, create water-revenue curves, that relate crop revenue to irrigation days, where irrigation days are obtained by subtracting ban days from a full water year with no restrictions (estimated by AgFirst/Nimmo-Bell (2018) to be 336 days, 12 months of 28 days each).

Following approaches that have been developed in the past for modelling productivity changes for different levels of irrigation/lengths of irrigation period, we then develop theoretical crop production functions (or response curves).[2] We identified that the best suited function would be a sigmoidal curve with an inflection point representing the point where productivity improvements start increasing at a decreasing rate due to soil saturation. The curve would also become asymptotic towards zero irrigation days provided the plant/farm/orchard would still produce something with no irrigation, i.e. using rainwater. Fig. 5 provides an example of the theoretical curve/surface response we used. For the scatter plots developed for each crop, it was determined that the best fitting curve was a 2-degree polynomial representing the section where productivity increases at an increasing rate, i.e. between the asymptote and the inflection point.

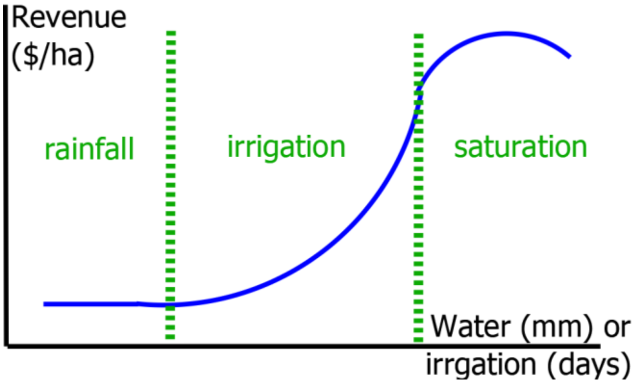


Fig 5: Example of Theoretical Crop Revenue Curve

Once appropriate revenue curves are developed for each crop, the impacts of lesser water availability are simulated by "reading off" the revenue curve the future revenue per hectare associated with a change in water supply availability (i.e. for Fig. 6, a change in supply from W' to W'' reduces revenue from R' to R''). As already explained, we relied on the mid- and late-century water-flow reliability forecasts reported by NIWA (2016) to estimate future reductions in irrigation days. To achieve this, we first assumed a baseline of 336 days, i.e. full water year or 100% reliability, and reduced the baseline reliability by the changes in water-flow reliability provided by NIWA. We used the averages for two different water zones: the Heretaunga plains and the Tukituki river catchment.

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[1] Most of the results reported by AgFirst (2018) and Nimmo-Bell (2018) were for the 1998 year as it was one of the driest years for which data was available.

[2] Since Nimo Bell (2018) assumed constant product prices, we concluded that a potential water-revenue curve would have the same shape as a water-productivity curve (or production function) with the constant prices as the main difference.

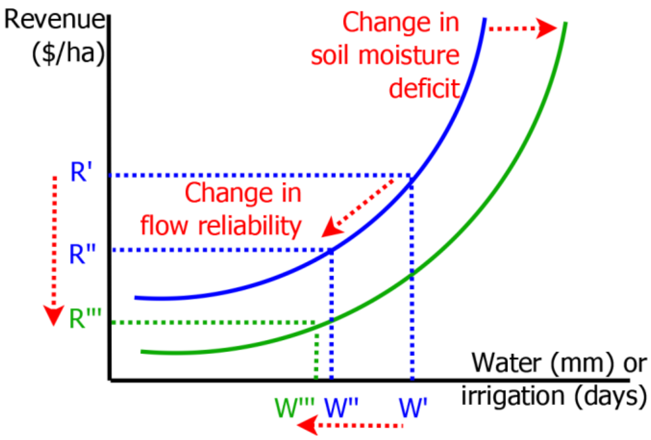

Fig. 6: A Theoretical Water-Revenue Curve and its Adjustment for Changes in Supply (Flow reliability) and Demand (Soil moisture deficit) Relationships.

Moving now to demand changes, we considered it adequate to also model water demand increments using the revenue-water functions developed. We concluded that an outward shift of the curves would plausibly simulate a potentially future drier year based on the logic that, for the same level of revenues, the plant/farm/orchard will need more water as, according to the NIWA (2016) report, the soil moisture level will decrease as the climatic change intensity increases. In other words, for the same amount of water, the plant/farm/orchard will produce less and receive less revenue, i.e. for Fig. 6, a drier year is simulated by shifting the blue curve out to the green curve meaning that W’ becomes W’’’ and revenue reduces to R’’’. We used the percent changes in soil-moisture-deficit (with respect to the 1998 baseline) derived from NIWA (2016) for the alternative RCPs, to shift the intercept of the water-revenue curves.

Drystock and Dairy

For irrigated drystock farms, we were able to apply an approach similar to that used for horticulture crops, applying a water-revenue curve to represent shifts in water supply and demand under climate change. As part of our study, AgFirst create a representative irrigated farm in the region to simulate a reduction in revenues from reductions in irrigated water. They assumed that a typical soil type in the Hawke’s Bay region requires around 400 mm of irrigation water in an average year for pastures. Considering a daily rate of 4 mm/day, the irrigation days required would be 100 days.

Importantly, as the AgFirst modelling could only be considered to apply to the irrigated block(s), it was also necessary to simulate changes for the non-irrigated components of farms, as well as farms without irrigation, to fully capture the impacts of climate change in the study areas. For these non-irrigated hectares, we relied on the literature on climate change impacts on productivity and profitability. Namely, Lieffering *et al*. (2012) produced estimates of gross margins for a modelled Hawke’s Bay sheep and beef farm for a historical (year 1990) and for a climate change scenario at 2040 (A2 SRES scenario similar to RCP8.5) in the Hawke’s Bay region.[3] The authors concluded that under this scenario, median gross margin would decrease from approximately $500/ha/yr in the baseline scenario to approximately

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[3] The modelled farm was a hill country sheep and beef farm – it would be advisable in future work to also investigate other farm types, e.g. lowland finishing farms.

$250-300/ha/yr.[4] As this report did not provide estimates post 2040, it was simply assumed that the increase in impacts between mid-century and late-century for sheep and beef farms would follow the same pattern as that estimated for irrigated pasture. Similarly, it was also assumed that the relative differences between climate change RCP scenarios would follow the same pattern as pasture.

For dairy farms within the study areas, we used the percent changes (with respect to a baseline) in milk solids developed by Kalaugher *et al*. (2017) for the A2 SRES scenario (assumed to correspond to RCP8.5), for six dairy farm sites spread over both the North and South Islands as a proxy for changes in revenue. As none of the farms modelled were located in Hawke's Bay, we applied the average percentage changes across the three farms in Northland, Bay of Plenty and Canterbury. These farms were selected on the basis that the Northland and Bay of Plenty farms were similarly described as 'drought prone', while the Canterbury farm was included to cover-off a farm with high irrigation. As with the non-irrigated drystock hectares, it was also necessary to rely on relative changes estimated for pasture to populate the late-century impacts and impacts for other climate scenarios other than RCP8.5.

Total Direct economic impacts

The core set of data required for use in the wider economic analysis (Stage 4 below) is a set of indices that describe, for each economic industry at the level of the whole Hawke's Bay Region, and at one year intervals, the percentage of industry commodity supply that can be achieved under the new climate conditions compared to current or 'normal' climate conditions. The development of this dataset involved:

- Horticulture – changes in total regional production/ revenue are estimated for the mid- and late-century under each RCP simply by applying the per hectare changes determined by the revenue curves, to the total number of hectares of each crop type within the study areas. Net changes in total revenue across all hectares were then converted to percentage changes.[5] The results for the mid-century analysis were allocated to the year 2043 (mid-point in the range specified of 2036-2050), while the results for the late-century analysis were allocated to the year 2093. To derive the necessary results for the years prior to 2036, a linear trend was applied starting from the present day (where no climate change impacts are assumed). Similarly, a linear trend was applied to extrapolate results for the years between 2036 and 2093.
- Dairy Cattle Farming – while the purpose of this study is to consider the impacts of climate change and water supply reliability only for the TANK and Tukituki catchments, a portion of dairy farming land in the Hawke's Bay Region is located outside of these catchments. The percentage changes in dairy cattle farming commodity production developed for the analysis of wider economic impacts for the mid- and late-century (assumed to be years 2043 and 2093 respectively) were thus a weighted average of impacts derived for the TANK/Tukituki catchments, and an assumed zero impact for the rest of the region. Land areas from the spatial

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[4] For simplicity it was assumed that costs of production are static and thus all changes in profit can be attributed to changes in revenue. In a more detailed study it would be preferable to investigate more fully the way in which farm systems will adapt to climate change, involving changes in both inputs (costs) and outputs (revenues).

[5] A spatial analysis of horticulture and fruit growing land areas using the 2014 Agribase and 2018 Land Cover Database (version 5) indicated that any horticulture and fruit growing areas located outside of the study catchments would be negligible from the perspective of the whole region.

data (2014 Agribase aggregates) were used to derive the relative weightings, which indicated that two-thirds (66%) of Hawke's Bay Region's dairy cattle farming is located within the study catchments. As with the horticulture industry, results for years prior to 2043 and for between 2043 and 2093 were developed simply by extrapolation of linear trends.

- Sheep, Beef, Deer, Other Livestock and Grain Farming – in a similar manner to dairy cattle farming, it was necessary to develop indices of percentage changes in commodity supply for the mid and late-century that account for the fact that only some of the industry is located within the study catchments. By inspection of the financial accounts that were created for the irrigated land and comparing these to the total industry accounts from the regional model, it is estimated that just over 10% of the total size of the industry in the region is represented by irrigated land in the study catchments. To estimate the remaining portion of the industry that is located within the study catchment (but not on irrigated land), we looked at the relative revenue per hectare of different sheep and beef farm types as estimated from the Beef + Lamb survey farms,[6] and land areas of different types derived from the Land Cover Database (LCDBv5).[7]

3.1.3 Stage 4: Wider economic impacts

We then applied a Multi-Regional Dynamic Economic Model (DEM) of the wider Hawke's Bay region and rest of New Zealand economies to estimate the flow-on socio-economic impacts of changes to water availability resulting from climate change (see Fig. 7). This model has many of the features of a fully Dynamic Computable General Equilibrium (DCGE) model i.e. pricing dynamics, substitution/transformation effects, interregional/international trade and so on. It is, however, uniquely designed for the modelling of transition pathways through time, where it is desirable to consider both short- and medium-term.

The DEM is analogous to the dynamic economic model created within the Southland Economic Project for the analysis of freshwater management policies in Southland Region, and also draws on developments in dynamic modelling produced by MBIE research funding, and through the Resilience to Nature's Challenges National Science Challenge. For a full description of the model reference can be made to the Southland Economic Model technical report (McDonald *et al*., 2019). The only substantial difference is that the Hawke's Bay DEM does not contain the specialised Primary Module – in other words, the representation of primary industries in the Hawke's Bay DEM is the same as for other types of industries, and is as explained in the Industries Module component of the report. Of course, the Hawke's Bay DEM also differs from the Southland DEM by the use of different underlying datasets (e.g. labour force projections, initial capital stocks and land uses, that represent, respectively, the different regional economies).

The basic structure of the DEM is determined by the underlying regional Social Accounting Matrix (SAM) at its core (Smith *et al*., 2015). The model considers two regions: the region of interest (Hawke's Bay in

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[6] https://beeflambnz.com/data-tools/sheep-beef-farm-survey

[7] High producing grassland on non-irrigated land within the study catchments was, for example, assumed to contain mainly Intensive Finishing Farms and thus allocated the appropriate revenue per hectare for that farm type from the Beef + Lamb survey farm, whereas low producing grassland outside the study catchments was assigned the revenue per hectare of a Class 3 farm.

this case) and the rest of New Zealand (RoNZ). For each region, the model describes the behaviour of representative agents (23 industries, households, enterprises, local government within each region, and central government). Each industry agent chooses the quantity and type of commodities (31 commodities) to produce, based on the prices of those commodities relative to the costs of production. Household, enterprise, and government agents receive income from a variety of sources (e.g. wages and salaries, business profits, dividends, taxes, and transfers from other agents), and then allocate this income towards a variety of expenditure options (e.g. purchases of goods and services, savings, taxes, and transfers to other agents).

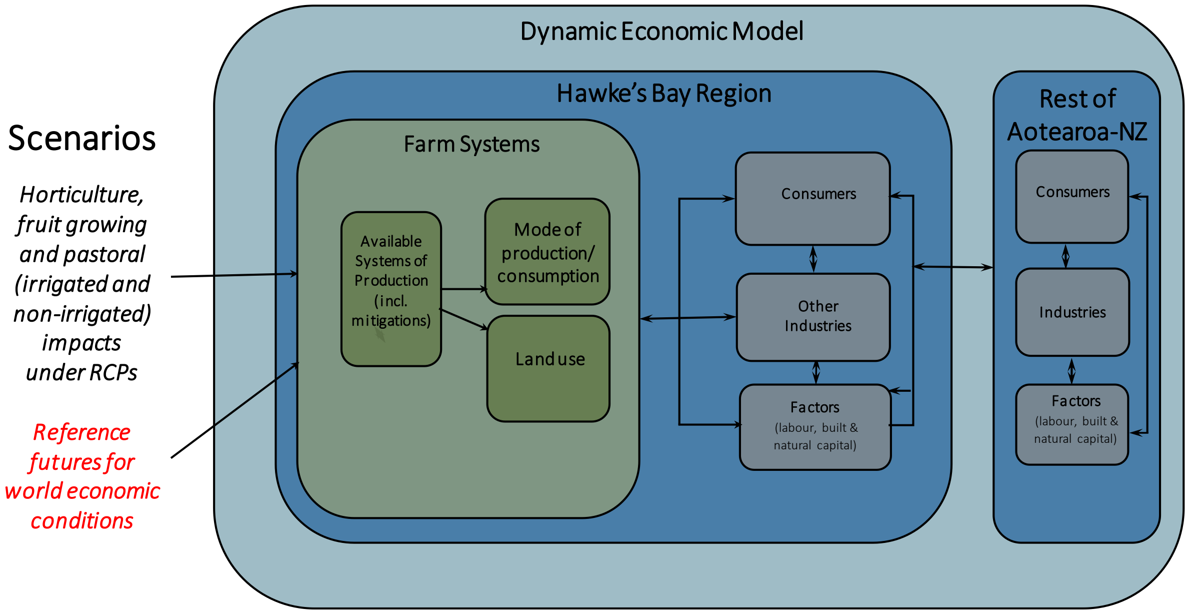

Fig.7 Components of Multi-Regional Dynamic Economic Model (DEM)

The model incorporates 'price' variables for all commodities and factors of production (i.e. types of labour and capital). These prices change in response to imbalances between supply and demand, and then 'nested' production functions allow the economy to react to these imbalances through substitution of demands and/or production between different types of commodities or factors. For example, if the demand for NZ-manufactured goods exceeds the supply, then the price of domestic goods will increase. This price increase (relative to foreign goods prices) will then lead to NZ-manufactured goods being substituted for goods produced overseas, thus reducing domestic demand and reducing prices. Similar substitution occurs in the factors and commodities used in production, and the region (within NZ) that the goods are demanded from.

On the supply side, the relative prices determine how the supply of commodities and factors are split. For example, the supply of goods manufactured in NZ is split between the NZ and export markets depending on the relative prices in each market. So, if domestic goods prices increase, more of the goods produced will be allocated to the NZ market, which will increase domestic supply, thus decreasing prices.

The model incorporates the dynamics of economic growth by keeping track of stocks of capital held by each industry. Capital stocks accumulate via investments in new capital and are diminished via the ongoing process of depreciation.

The model also includes accounts that keep track of financial flows between NZ and the rest of the world (i.e. balance of payments). When the demand for NZ currency starts to outstrip supply, this causes the exchange rate to rise. Changes in the exchange rate change the price of NZ goods relative to overseas goods, thus influencing demand and supply relationships. The model uses the NZ commodity prices along with exogenously specified world commodity prices to determine the supply and demand of exports and imports.

The DEM reports the socio-economic consequences for value added[8,9] (as measured in $\$_{2019}$m) by: (i) location – the Hawke's Bay region and Rest of New Zealand, (ii) time – annual averages calculated at 3-day time steps, covering the period 2007 through to 2060 (with 2007-2019 used to calibrate the model), and (iii) industry – 23 aggregate economic industries comprehensively covering *all* market based economic activities. The wider economic impacts are presented in net economic terms for a range of 'reference futures' (see directly below).

Modelling Caveats: Wider Economic Impacts

Due to the restricted timeframes available for our analysis we have focused solely on the impacts felt directly in the TANK and Tukituki catchments by the primary sector of the economy (i.e. horticulture and fruit growing; sheep, beef, deer and other livestock and grain farming; dairy cattle farming) along with the associated flow-on (general equilibrium) economic impacts felt in the wider Hawke's Bay and rest of New Zealand economies. Water is also taken directly by industry and municipalities – the impact of these takes on water balances with the TANK and Tukituki catchments has not been assessed. Importantly, water also underpins the provision of ecosystem services which are critical to the life support of all habitats and species – for Māori communities a healthy environment is essential for a healthy people (Oranga Taiao Oranga Tāngata).

3.2 Reference Futures

The future is inherently uncertain, both in respect to the nature and magnitude of regional climate change impacts that will be experienced as well as the way in which the regional/national/world economic systems will grow and evolve over time. Reflecting this uncertainty, we have not attempted

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[8] 'Value added' is a measure of the value added to goods and services by the contributions of capital and labour i.e. the value of output after the cost of bought-in materials and services has been deducted. It includes the National Account categories of 'gross operating surplus', 'compensation of employees', 'other taxes on productions' and 'subsidies'. Value added is equal to Gross Domestic Product (GDP) less taxes on products and import taxes net of subsidies. In New Zealand, total value added is thus approximately equal to 88% of GDP.

[9] The AgFirst (2018) report, undertaken for the TANK economic assessment, did not consider any changes in expenditure items (including labour) in response to water restrictions. For this reason, we have not been able to model potential employment impacts at this stage.

to quantify a single 'best guess' of the climate change impacts that will result from changes in water supply-demand in the TANK and Tukituki catchments, but rather to report a range of results under differing assumptions regarding future conditions. The differing assumptions are broadly defined into two key groups:

1. *Future Climate Scenarios* – As outlined in the methodology, in the modelling we looked at four of the IPCC's potential climate futures (represented by different RCPs). Given the relatively extreme nature of the RCP2.6 scenario, requiring negative world emissions to be reached, and that globally we are not tracking to stay within this scenario, only the latter three scenarios were carried forward into the multi-regional DEM.
2. *World Economic Conditions* – There are a range of future economic conditions that are largely outside of the control of Hawke's Bay region, and which are largely uncertain, for example changes in international commodity prices, speed of technology change and productivity growth or level of environmental protection. To illustrate a range of different futures that may occur in these respects, five alternative 'reference futures' are implemented in the multi-regional DEM. These futures are explained in detail in Vergara *et al.* (2019), with a short summary of the key features of each scenario provided in Table 2.

Table 2: Summary of Reference Economic Futures

Reference Economic Futures	Economic growth	Global co-operation	Technological change	Environmental focus
Baseline	Medium/ Baseline	Medium/ Baseline	Medium/ Baseline	Medium/ Baseline
Techno-global Future	High	High	High	Medium/ Baseline
Fragmented Future	Low	Low	Low	Low
Green-Oriented Future	Medium/ Baseline	Medium/ Baseline	High	High

The Techno-global Future scenario is further separated into two sub-scenarios, 101 and 102. This reflects that in a future characterised by high technological and productivity change, there can be quite divergent impacts on labour and employment, depending on whether new processes and technologies are largely job replacing (102) or job augmenting (101). To analyse the impacts of the alternative climate scenarios in the Multi-Regional DEM, each 'reference future' is individually run in the model, with and without the climate change impacts incorporated.

4 Results

4.1 Direct economic impacts on Hawke's Bay Region's farming industries

The following graphs (Fig.8 and Fig 9) for the 'do-nothing scenario' shows the relative and absolute changes in revenue, with respect to the 1998 historical baseline, for irrigated crops in the region due to climate-related reductions in water supply and increments in water demand, under the four different RCP climate change scenarios. These impacts were also calculated for two time periods: mid- and late-century.

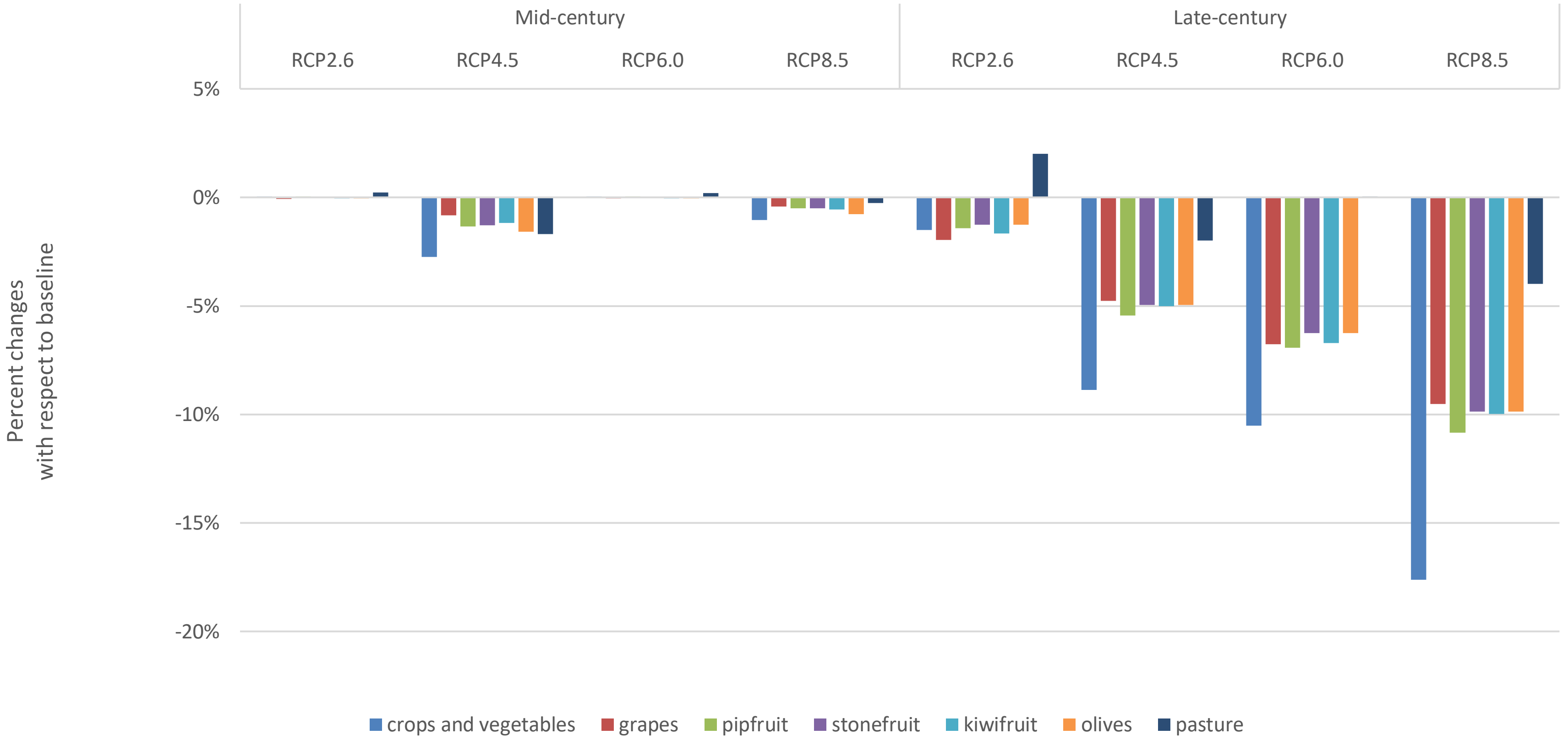

Fig. 8: Net Changes in Revenues (%) for Irrigated Crops and Pasture under Different Climate Change Scenarios (RCPs) and Time Horizons for the Do-nothing Scenario

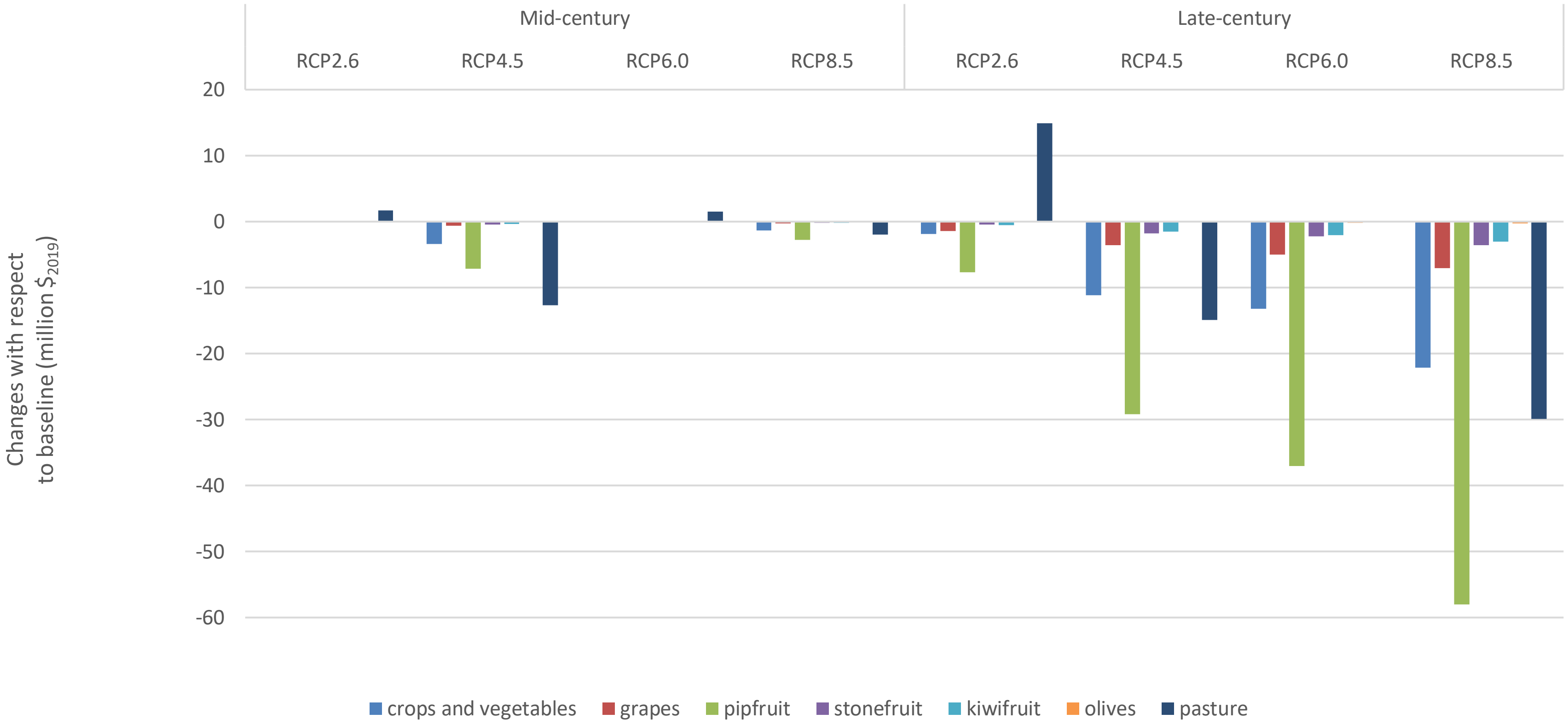

Fig. 9: Net Changes in Revenues ($_{2019}$) for Irrigated Crops and Pasture under the Different Climate Change Scenarios (RCPs) and Time Horizons for the Do-nothing Scenario

As depicted in the previous figures, the main findings are (NB: all $ are expressed in NZ$\$_{2019}$ terms):

- The late-century water-related climatic impacts on revenues are significantly more substantial than the mid-century impacts. This reflects the changes predicted by NIWA for water supply (i.e. water flow reliability) and demand (i.e. soil moisture deficit) under climate change. Under all four RCPs, the mid-century impacts are relatively small – all less than 2.5% compared to the 1998 baseline, with pasture experiencing the largest impacts of approximately $\$_{2019}$12million per year. Discussions with the authors of the NIWA (2016, 2018) reports confirmed that changes in climate, are not statistically differentiable from normal climate variability, until post-2050.
- In relative terms, crops and vegetables would be the most impacted agricultural activity in the region with an approximate reduction of 18% in revenues under the most extreme late-century climate scenario. These would be followed by pip fruit with an approximate reduction of 11% in revenues under the same scenario.
- In absolute terms, pip fruit would be the most impacted agricultural crop with an approximate annual loss in revenues of $\$_{2019}$60 million within the Hawke's Bay region. Pasture-dependent dry-stock and crops and vegetables would be the next most impacted agricultural activities in the region with approximate annual losses of $\$_{2019}$30 and $\$_{2019}$20 million, respectively.
- It is important to note that our analysis considered not only revenue, but also EBIT-DA – a measure of the surplus or profit generated each crop type or farm system. Our analysis indicated that EBITDA for several crops would drop significantly and could become negative in the latter part of the century. There are several implications associated with this including *inter alia*: (1) it is likely that horticulture and fruit growing business owners would begin to consider other potential uses of their land – including uses that may be less profitable than presently; and (2) investors may consider moving capital outside of the region to more profitable locations.

4.2 Wider Economic Impacts on the Hawke's Bay and rest of New Zealand Economies

4.2.1 Headline Results

Headline results are reported in terms of annual changes in annual Gross Domestic Product (GDP) in Table 3. The numbers reported in this table are the median result across the five 'reference futures' considered (i.e. Baseline, Techno-global Future 101, Techno-global Future 102, Fragmented Future, Green-Oriented Future). More detailed results, i.e. covering each reference future separately, as well as for the RCP6.0 scenario can be found in Table A.1 in Appendix A.

Perhaps not surprisingly, the results for the RCP4.5 and RCP8.5 scenarios are reasonably similar, with a net change in annual GDP of $\$_{2019}$30-40million in 2030, escalating to an annual change in GDP of $\$_{2019}$470 million by 2060 for the RCP8.5 scenario and $\$_{2019}$500 million for the RCP4.5 scenario. The similarities in these results reflects that the greenhouse gas concentrations and estimated climate impacts developed by NIWA are relatively consistent between these scenarios, over the period that has been modelled: the RCP4.5 scenario has emissions peaking around 2040 and then declining while the RCP8.5 scenario has emissions rising over the entire century.

Table 3: Net Change in Annual Gross Domestic Product under Alternative Climate Scenarios ($\$_{2019}$m) as at 2030, 2045 and 2060

	2030	2045	2060
RCP4.5			
Hawkes Bay	-30	-70	-110
Rest of NZ	-10	-90	-400
Total NZ	-40	-180	-500
RCP8.5			
Hawkes Bay	-20	-60	-120
Rest of NZ	-10	-80	-370
Total NZ	-30	-160	-470

Note: (1) Values reported are the median across five alternative Reference Economic Futures Modelled (2) Results are rounded to nearest $\$_{2019}$10 million.

Interestingly, the RCP6.0 scenario produces positive net changes on GDP for the period that has been modelled (see Appendix A). This reflects, however, that the climate change information used for this scenario indicated some increase in water availability for the mid-21st century. We have been advised by NIWA scientists that this outcome is not too unusual – the climate information was generated from an ensemble of models which incorporate statistical variability and it is only post mid-century that the climate manifestations become strongly different from statistical variability. It is also worth considering that this assessment does not consider some of the wider impacts of climate change on agricultural production such as increased incidence of pests.

We note that if it were possible to extend the dynamic multi-regional economic modelling out further in time, we would anticipate that the differences between the RCP4.5 and RCP8.5 scenarios would become substantial given that the emissions under RCP8.5 will significantly outstrip emissions under RCP4.5 by the end of the century. We would also anticipate that the positive gains for GDP under the modelled RCP6.0 scenario will fall away and become negative since NIWA's surface water hydrological modelling resulted in losses in water supply for the latter part of the century. To illustrate, the modelling undertaken on direct impacts on farm systems indicates that, assuming current methods of production and prices remained constant out to the latter part of the century, grape production will have per-hectare expenditures in excess of per-hectare revenues (i.e. negative EBIT-DA) under both the RCP6.0 and RCP8.5 scenarios.

In Table 4 the modelled results have been converted into 'net present value' terms via application of discounting. Under the RCP4.5 scenario, for example, a discount rate of 4% per annum produces a net present value ranging between $\$_{2019}$1.7 and $\$_{2019}$2.3 billion (for the 2020-2060 period of our analysis), while a 6% per annum discount rate reduces this range to between $\$_{2019}$1 and $\$_{2019}$1.3 billion. Obviously, this should not be interpreted as the full climate change impacts, as the modelled results only go out to 2060. It should also be noted that there is much debate around the appropriate application of discount rates when considering environmental impacts and natural resources, when many of these will not occur in the immediate future.[10] Applying a standard financial discount rate of, say, 6% per annum, a cost of $1 in 40 years' time will have a net present value of just 8 cents. Once again, more detailed results are available in Appendix A (Tables A.2 and A.3).

Table 4: Net Present Value of Impacts on Gross Domestic Product under alternative Climate Change Scenarios and Economic Futures for the Period 2020-2060 ($$_{2019}$m)

	4% Annual Discount Rate		6% Annual Discount Rate	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Baseline Future				
Hawkes Bay	-800	-700	-500	-430
Rest of New Zealand	-1,230	-1,070	-660	-570
Total New Zealand	-2,030	-1,760	-1,150	-1,000
Fragmented Future				
Hawkes Bay	-730	-630	-460	-400
Rest of New Zealand	-1,430	-1,220	-790	-670
Total New Zealand	-2,160	-1,850	-1,250	-1,070
Techno-Global Future 01				
Hawkes Bay	-950	-840	-590	-510
Rest of New Zealand	-810	-690	-470	-390
Total New Zealand	-1,760	-1,530	-1,050	-910
Techno-Global Future 02				
Hawkes Bay	-930	-820	-580	-500
Rest of New Zealand	-1,350	-1,170	-750	-640
Total New Zealand	-2,280	-1,990	-1,330	-1,150
Green Growth Future				
Hawkes Bay	-790	-690	-500	-430
Rest of New Zealand	-880	-750	-490	-410
Total New Zealand	-1,670	-1,440	-990	-840

4.2.2 Sectoral Level Results

To illustrate how impacts of climate change and changes in water supply-demand are distributed across economic industries, Table 5 provides a breakdown of the changes in annual industry value added at 2060 under the RCP4.5 scenario. Essentially, value added records the income generated by each industry in terms of payments of wages and salaries and generation of profits received by business/capital owners. Furthermore, except for a small component that is associated with taxes, the sum of industry value added will equal GDP.

Not surprisingly, the largest losses within the Hawke's Bay are experienced in the agricultural sectors (e.g. $$_{2019}$43-$$_{2019}$87 million annually for the sheep, beef, deer, other livestock and grain farming industry) with some flow-on effects to food manufacturing. Small increases in value added are recorded in the forestry and logging and other primary industries, which reflects that the model is allocating more

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[10] For some recent literature on the topic refer to Sumaila and Walters (2005) and Pearce *et al*. (2006).

land to these activities as a response to relative declines in profitability in the horticulture/drystock/dairy industries. Small increases in value added are also recorded for other manufacturing within the Hawke’s Bay. A primary reason is that with declining relative profitability in activities such as food manufacturing, it is receiving a greater proportion of future capital investment which helps to grow the production in other manufacturing industries.

The positive impacts reported for agriculture industries in the rest of New Zealand reflects that these industries are picking up some of the supply (both directly to consumers as well as other inter-agricultural sales) that can no longer be met via Hawke’s Bay production. These industries also benefit from some appreciation in prices for the commodities they produce. It should be noted that this assessment has not considered concurrent climate impacts for agricultural production in the rest of New Zealand, which would be likely to occur in reality.

Value added from food manufacturing also falls in the rest of New Zealand (by $\$_{2019}$3 to $\$_{2019}$28 million annually). This is largely because with declining production from Hawke’s Bay farms, there is and rising input costs to these industries.

Interestingly, many of the largest impacts recorded in Table 5 are associated with construction and service industries, particularly in the rest of New Zealand. This underscores the complex nature of economic systems, especially when considering relationships and feedbacks that build over a period of 30-40 years. Although losses in income may initially be generated in agriculture and closely aligned activities such as food processing, these ultimately flow through the economy reducing the funds available for new construction and capital investment – impacting not only on construction activities but ultimately the growth of all economic industries. As the economy in the rest of New Zealand is much larger than the economy in the Hawke’s Bay, it ultimately experiences the largest absolute losses in capital investment and growth.

Table 5: Net Change in Annual Industry Value Added Under the RCP4.5, at Year 2060 ($_{2019}$m)

	Baseline Future	Techno-Global Future 101	Techno-Global Future 102	Fragmented Future	Green Growth Future
Hawkes Bay					
Horticulture and fruit growing	-6	-14	-11	-5	-10
Sheep, beef, deer, other livestock & grain farm.	-57	-87	-68	-43	-59
Dairy cattle farming	-1	-1	-1	0	0
Forestry and logging	5	8	6	4	7
Other primary	7	8	7	6	6
Food manufacturing	-17	-12	-19	-13	-10
Other manufacturing	2	5	4	1	5
Utilities, construction, transport	-12	-12	-13	-7	-13
Trade and hospitality	-3	-1	-3	-2	-3
Finance, insurance, real estate, business servs	-7	-8	-9	-5	-6
Other services	-12	-15	-14	-10	-13
Rest of New Zealand					
Horticulture and fruit growing	6	16	10	5	10
Sheep, beef, deer, other livestock & grain farm.	33	41	42	26	32
Dairy cattle farming	3	6	4	1	3
Forestry and logging	-5	-2	-5	-4	-3
Other primary	-1	-1	-1	-3	-1
Food manufacturing	-27	-3	-28	-27	-19
Other manufacturing	-27	-10	-29	-18	-19
Utilities, construction, transport	-114	-40	-105	-96	-67
Trade and hospitality	-61	-30	-39	-56	-24
Finance, insurance, real estate, business servs	-135	-58	-131	-123	-62
Other services	-85	-21	-81	-94	-52

4.2.3 Employment Results

It is difficult to discern overall trends and conclusions regarding employment impacts, as the outcomes vary depending on the particular 'reference future' selected but in all cases the impacts are relatively small compared to the total size of labour markets and numbers of people employed. Table 6 provides a summary of the net changes in employment estimated for each reference scenario under the RCP4.5 and 8.5 scenarios, both for the Hawke's Bay Region and Rest of New Zealand. Some general trends under each reference future are noted below:

Baseline Future

- Some job losses are recorded in the sheep/beef/other livestock industry (e.g. around 34-37 MECs[11] in 2030 under RCP4.5 and RCP8.5, rising to around 100 MEC losses in 2060 for these RCPs). This occurs because prices of locally reduced goods rise relative to the situation with no climate impacts (to compensate for losses in farm output), but the rising prices cause losses in demands for regional goods and, ultimately, less demands for employment.

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[11] Modified Employment Counts, or MECs, are a measure of employment equivalent to Statistics New Zealand's Employment Counts measure except that the MECs also include the estimated number of working proprietors within each industry.

- Although the Horticulture and fruit growing industry also faces some losses in production in this period, the model predicts a more stable demand for these goods and that farms will adopt practices around working harder/utilising more labour to help make up the shortfall in supply leading to a very small increase in employment (e.g. around 5 additional MECs in 2030 under RCP4.5 and RCP8.5).
- The outcomes for other industries in the Hawke's Bay Region are quite mixed. Small losses are recorded in food manufacturing and utilities, construction and transport (around 40 MECs altogether in 2060 under RCP4.5 and 8.5), however there are also gains in employment recorded for other manufacturing and finance, insurance, real estate and business services and trade and hospitality. This appears to be largely because, with climate change reducing the profitability of agriculture, the model allocates a slightly higher proportion of regional investment to these industries, many of which are more labour intensive. Overall a very small, almost negligible, net increase in employment is recorded in 2060 for Hawke's Bay under the RCP4.5 scenario, while a very small net loss of employment (<10MECs) is recorded for the RCP8.5 scenario.
- For the rest of New Zealand, in the first years of the simulation the total estimated changes in employment are positive (e.g. a net gain of 50 MECs generated in 2030 for RCP4.5 compared to a 40 MECs for RCP8.5). In all cases, however, the results are very small relative to the size of total employment in the rest of New Zealand. Industries that experience a growth in employment in the rest of New Zealand are largely the agriculture industries, as these pick up some of the demands that cannot be met by Hawke's Bay. By the end of the simulation, regardless of whether it is the RCP4.5 or RCP8.5 considered, the rest of NZ experiences a net loss in employment (ranging from 100 to 130 MECs). By far the most significant job losses are in the utilities, construction and transport industry, reflecting the overall reduction in the size of the economy and the quantum of investment activity occurring.

Fragmented Future and Techno-Global Future 02

- The net employment impacts generated under these two scenarios are similar to those generated under the Baseline Future.

Techno-global Future 01

- Compared to the results generated for the Baseline Future and the Techno-global Future 102, the Techno-global Future 101 generally records less losses in employment for the rest of New Zealand. In fact, the net change in employment for the rest for the rest of New Zealand, for both the RCP4.5 and 8.5 scenarios, is estimated to be slightly positive in 2060. One reason is that the employment rate is higher to begin with in the Techno-global Future 102 scenario compared to both the Baseline and Techno-global Future 101 scenarios. Thus, when some industry investment is moved out of agriculture into slightly more labour-intensive industries as a response to climate change, it does not benefit from a low labour costs in the Techno-global Future 102 scenario. The relatively higher costs of production for Hawke's Bay in this scenario then mean that a greater proportion of total demands is captured by producers in the rest of New Zealand.

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Green Growth Future

- Compared to the results generated under the Baseline Future, the employment impacts are generally lower under the Green Growth Future. This is largely because the Green Growth Future already contains some policy measures which already constrain growth and productivity in the agricultural sector, and so the relative shifts in productivity between the scenarios with and without climate change impacts considered are not as significant, at least for the period modelled out to 2060.

Table 6: Net Change in Employment Under RCP4.5 and RCP8.5 under alternative Reference Futures (Modified Employment Counts)

	2030		2045		2060	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Baseline Future						
Hawkes Bay	10	10	70	70	40	0
Rest of New Zealand	50	40	40	30	-130	-100
Total New Zealand	60	50	110	100	-80	-100
Fragmented Future						
Hawkes Bay	-10	-10	50	60	0	-30
Rest of New Zealand	30	30	40	30	-140	-110
Total New Zealand	20	20	80	90	-140	-140
Techno-Global Future 01						
Hawkes Bay	10	10	30	40	0	-10
Rest of New Zealand	30	20	60	50	110	120
Total New Zealand	40	30	100	100	120	120
Techno-Global Future 02						
Hawkes Bay	0	10	10	30	30	0
Rest of New Zealand	50	40	-10	-20	-170	-140
Total New Zealand	50	50	0	10	-140	-140
Green Growth Future						
Hawkes Bay	-10	-10	-20	-20	-10	10
Rest of New Zealand	40	40	40	40	-10	10
Total New Zealand	30	30	20	20	-20	10

Notes: (1) Modified Employment Counts (MECs) are a metric of employment based on Statistics New Zealand's Employment Counts but adjusted to also include estimates of the number of working proprietors in each industry. (2) All results are rounded to the nearest 10.

Some general comments on employment impacts and modelling

- The results show that employment impacts are highly sensitive to the nature and structure of the future economy, particularly the assumptions incorporated around the relative productivity of different types of factor inputs, and the relative productivity of industries in the Hawke's Bay compared to the rest of New Zealand.
- A key advantage of the DEM used in this analysis, over some other methods of regional economic analysis, is that it does not hold wage rates constant. It is therefore important to note that even when a change in the *number* of people employed is negligible (or even positive), the amount of

income earned by employees can still decline. This indeed occurs for some of the industries and scenarios modelled. It is the value-added results which tell us the changes in incomes (wages/salaries plus business profits) earned by each economic industry.

- Another key tenet of the type of economic model applied is that it assumes substitution between factors of production. That is even if productivity of factors of production go down and investment in capital goes down, it is still possible to increase production by adding more labour to production methods. In the real world, however, there may be limitations reached regarding the extent to which labour can substitute for other factors of production and allow for production to increase – this is a topic that is often identified when considering production activities that depend on natural capital and there becomes significant constraints reached on the supply and quality of that capital. Had the economic modelling been able to address these complexities fully; it may have reached slightly different results, particularly in relation to the extent of agricultural production in Hawke's Bay that can be 'recaptured' in the rest of New Zealand.

5 Concluding Comments

Our analysis has focused on the period 2020-2060, but we have also made comments on the period post-2060. While our mid-century analysis does not indicate significant impact on water security from climate change, our late-century analysis shows considerable impacts. It is important to note that the socio-economic impacts of climate change are likely to be felt not only through gradual changes in climate, but also through (1) the increased frequencies of extreme events (e.g. droughts, floods), and (2) the accelerated supply and demand of water post-2060. Our study has also only focused on the water security impacts associated with climate change, there are however many other impacts (e.g. sea-level rise, coastal inundation, wildfires, etc.) which are likely to significantly impact on the Hawke's Bay region and the rest of New Zealand.

Now that the magnitude and extent of the 'do nothing' scenario on water security under climate change are, to some degree, understood it is recommended that HBRC consider the value of possible resilience building initiatives. The wellbeing of many smaller communities on the TANK and Tukituki catchments are inextricably interconnected with the fortunes of the primary sector. Our analysis shows that under climate change, with reduced water security (particularly post-2050) there is likely to be significant impacts not only on the environment and natural habitat that underpins the region's wealth, but also on the socio-economic wellbeing of the region's people. Our rapid assessment indicates that the socio-economic implications of climate change on water security is also not just a localised issue for the Hawke's Bay region, but instead an issue for all of New Zealand.

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Appendix A: Detailed Results from Dynamic Economic Modelling

Table. A.1 Net Change in Annual Gross Domestic Product under alternative Climate Change Scenarios and Economic Futures for the Period 2030-2060 ($\$_{2019}$m)

	2030			2045			2060		
	RCP4.5	RCP6.0	RCP8.5	RCP4.5	RCP6.0	RCP8.5	RCP4.5	RCP6.0	RCP8.5
Baseline Future									
Hawkes Bay	-20	10	-20	-70	40	-60	-110	20	-120
Rest of New Zealand	-10	0	-10	-90	60	-80	-450	220	-410
Total New Zealand	-30	20	-20	-170	100	-140	-560	240	-530
Fragmented Future									
Hawkes Bay	-30	10	-20	-70	40	-60	-80	20	-90
Rest of New Zealand	-10	10	-10	-130	90	-110	-420	240	-380
Total New Zealand	-40	20	-30	-200	120	-170	-510	260	-470
Techno-Global Future 01									
Hawkes Bay	-30	20	-20	-90	50	-80	-140	20	-150
Rest of New Zealand	-10	10	-10	-90	60	-80	-110	60	-100
Total New Zealand	-40	20	-30	-180	110	-150	-250	80	-250
Techno-Global Future 02									
Hawkes Bay	-30	20	-20	-90	50	-70	-130	20	-140
Rest of New Zealand	-10	10	-10	-120	80	-100	-400	190	-370
Total New Zealand	-40	30	-30	-210	130	-180	-530	220	-510
Green Growth Future									
Hawkes Bay	-30	20	-20	-70	40	-60	-100	10	-110
Rest of New Zealand	-10	0	-10	-80	50	-70	-220	110	-200
Total New Zealand	-30	20	-30	-150	90	-130	-320	120	-310

Table. A.2 Net Present Value of Impacts on Gross Domestic Product under alternative Climate Change Scenarios and Economic Futures for the Period 2020-2060, 4% annual discount rate ($\$_{2019}$m)

	2030			2045			2060		
	RCP4.5	RCP6.0	RCP8.5	RCP4.5	RCP6.0	RCP8.5	RCP4.5	RCP6.0	RCP8.5
Baseline Future									
Hawkes Bay	-90	50	-70	-440	250	-350	-800	390	-700
Rest of New Zealand	-10	10	-10	-280	180	-230	-1,230	700	-1,070
Total New Zealand	-100	60	-80	-720	430	-590	-2,030	1,080	-1,760
Fragmented Future									
Hawkes Bay	-90	50	-80	-420	240	-340	-730	360	-630
Rest of New Zealand	-20	10	-20	-430	260	-350	-1,430	870	-1,220
Total New Zealand	-110	60	-90	-850	510	-700	-2,160	1,230	-1,850
Techno-Global Future 01									
Hawkes Bay	-100	60	-80	-500	290	-410	-950	440	-840
Rest of New Zealand	-20	10	-20	-320	190	-260	-810	460	-690
Total New Zealand	-120	70	-100	-820	490	-670	-1,760	900	-1,530
Techno-Global Future 02									
Hawkes Bay	-100	60	-80	-510	310	-410	-930	460	-820
Rest of New Zealand	-30	20	-20	-430	270	-360	-1,350	760	-1,170
Total New Zealand	-130	80	-110	-940	580	-770	-2,280	1,220	-1,990
Green Growth Future									
Hawkes Bay	-100	60	-80	-440	270	-360	-790	380	-690
Rest of New Zealand	-10	10	-10	-270	160	-220	-880	490	-750
Total New Zealand	-110	70	-90	-720	430	-590	-1,670	870	-1,440

Table. A.2 Net Present Value of Impacts on Gross Domestic Product under alternative Climate Change Scenarios and Economic Futures for the Period 2020-2060, 6% annual discount rate ($\$_{2019}$m)

	2030			2045			2060		
	RCP4.5	RCP6.0	RCP8.5	RCP4.5	RCP6.0	RCP8.5	RCP4.5	RCP6.0	RCP8.5
Baseline Future									
Hawkes Bay	-80	50	-60	-320	180	-260	-500	250	-430
Rest of New Zealand	-10	10	-10	-190	120	-160	-660	380	-570
Total New Zealand	-90	50	-70	-510	300	-410	-1,150	630	-1,000
Fragmented Future									
Hawkes Bay	-80	50	-70	-310	180	-250	-460	240	-400
Rest of New Zealand	-20	10	-10	-290	180	-240	-790	480	-670
Total New Zealand	-100	50	-80	-600	350	-490	-1,250	720	-1,070
Techno-Global Future 01									
Hawkes Bay	-90	50	-70	-360	210	-290	-590	290	-510
Rest of New Zealand	-20	10	-10	-220	130	-180	-470	270	-390
Total New Zealand	-100	60	-80	-580	340	-470	-1,050	560	-910
Techno-Global Future 02									
Hawkes Bay	-90	50	-70	-370	220	-300	-580	300	-500
Rest of New Zealand	-30	20	-20	-290	180	-240	-750	430	-640
Total New Zealand	-110	70	-90	-660	400	-540	-1,330	730	-1,150
Green Growth Future									
Hawkes Bay	-80	50	-70	-320	190	-260	-500	250	-430
Rest of New Zealand	-10	10	-10	-180	110	-150	-490	270	-410
Total New Zealand	-90	60	-80	-510	300	-410	-990	530	-840

Appendix C: ME report

ME Research – Water Demand Projections
October 2022

Hawkes Bay Region Water Demand Projections

Final Report

October 2022

Hawkes Bay Region Water Demand Projections

Final Report

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Executive Summary

Background and Scope

Hawke's Bay Regional Council has requested the development of projections of future water demands for Hawke's Bay Region based on forecasts of future population and economic growth within the region. The Council has separately commissioned the development of a set of water accounts by EnviroStrat. These accounts are for the 2019-20 water year and are developed in alignment with the United National Satellite Environmental and Economic Accounting System for Water (UN SEEA-W). The Water Use Table taken from the EnviroStrat accounts constitutes the base year data from which future changes in water demands are extrapolated in this study. The projections presented in this report are up until the year 2060 and are provided by households and economic sectors.

The primary question that we have sought to address in this study is "how can we expect the demand for water to change over time, assuming that there are no restraints on the ability to meet those demands, and hence no decisions need to be made about allocating water to only some uses?". The water demand projections thus generated are referred to as 'unconstrained' projections in the sense that no constraints are placed on industry growth through water supply limitations. By comparing the unconstrained demand projections with knowledge of water supply availability, we can appreciate the size of the 'water availability gap'.

In the real world, water is constrained and while it is likely that some restrictions will be placed on water use, there are many possibilities regarding how these might eventuate. Increasingly water constraints are evident within the region and policies to maintain river flows have significant implications, particularly for the agriculture sector through limiting irrigation potential. It is possible that constraints placed on agriculture water use will have flow on effects to the water demanded by other sectors, given that agriculture is highly connected within the regional economy. In addition to the unconstrained projections, we have therefore also developed a set of constrained projections. The additional question we have sought to answer via the constrained projections is "how can we expect the future demands for water to change over time, should agriculture be constrained to current water use"?

Scenarios Considered

When developing projections of future economic activity, and consequently future water demands, we are confronted with significant and unresolvable uncertainties, for example changes in international commodity prices, speed of technology change, future increases in water use efficiency, and future population growth. Rather than seeking to develop a best guess projection, it is more informative to produce a range of projections so that it is possible to envisage the way in which demands will alter under different conditions. For the unconstrained scenarios, 30 alternative scenarios have been considered covering three principal domains of uncertainty, i.e:

- *Global/National economic futures* – Five alternative 'Reference Economic Futures' were considered.

- *Climate change* – Two alternative Representative Concentration Pathways (RCPs) developed by the International Panel on Climate Change (IPCC) were considered, i.e. the RCP4.5 and RCP8.5.
- *Water intensity* – Three alternative scenarios of changes in water use intensity were considered. The lowest rate of change scenario (Technology Scenario 1) assumes there is zero improvement in water use intensity for industries and households over the next 40 years in terms of the quantity of water required per $ of economic goods produced (or per person in the case of households). The middle scenario (Technology Scenario 2) assumes rates of improvement in water use intensity of between 0.6 and 1.0% per annum, and the high scenario (Technology Scenario 3) assumes rates of 1.2 and 2.1% per annum. The selection of these scenarios to test within the modelling has been guided by a review of national and international literature.

For all scenarios we have applied the same population projections, that is Statistics New Zealand's sub-national population projections, medium series (2018 Base).

For the constrained projections we have focused just on modelling the RCP4.5 climate future and the Baseline economic future scenario. We do, however, provide modelled results for each of the three water intensity scenarios.

Methodology

The steps required for the development of the water use projections were:

(1) *Disaggregation of Water Use Table*
The Water Use Table provided by EnviroStrat recognised eight different industry types plus households. The first part of the analysis required disaggregating the Water Use Table to a more detailed, 106-industry level set of data. EnviroStrat provided information to disaggregate some of the most significant flows. For the remaining flows we relied on information taken from financial supply and use tables on purchases of water, and on previous examples of water accounting undertaken in New Zealand, as a guide to the relative use of water among industries.

(2) *Derive projections of future industry output*
We have utilised a Multi-Regional Dynamic Economic Model (DEM) of the Hawke's Bay region and rest of New Zealand economies to produce projections of industry output for the Hawkes Bay region. For the unconstrained projections, the model is set up to run and produce results for each of the economic reference futures. For the constrained projections, the model is also set up to incorporate constraints such that production in agriculture industries can only increase at the rate of gains in water use efficiency (less any additional water demands that accrue from climate change).
The outputs that are produced by the DEM for each scenario is a trajectory of the quantities of commodities (31 types) produced within the Hawke's Bay region from 2020-2040. These commodity projections are then converted to estimates of changes in industry output in constant dollar terms)

(3) *Calculate future water demand by industries and households*
For industries it is assumed that water demands scale linearly with changes in industry output. Similarly, household demands are assumed to scale linearly with population growth. Adjustments are, however, made to account for improvements in water use intensity. For agriculture industries,

the projections are also adjusted to account for additional water demands resulting from climate change and reduced soil moisture.

Results

Unconstrained Results

For the unconstrained projections Table E.1 reports the quantity of water demanded at three snapshots (2019-20, 2039-40, 2059-60) for the Baseline Future-RCP 4.5 scenario and for the three alternative water use intensity scenarios (i.e., Technology Scenario 1, Technology Scenario 2 and Technology Scenario 3). To illustrate the variation between the Baseline Future-RCP4.5 results and other Reference Economic Futures/ climate scenarios, Table E.1 also specifies the difference between the Baseline Future-RCP4.5 and (1) the lowest result among the other Reference Economic Future and climate scenarios, and (2) the highest Result among the other Reference Economic Future and climate scenarios.

Table E.1 Hawke's Bay Current and Future Water Projections under Alternative Scenarios (thousand cubic metres)

	Agriculture		**Water Supply**		**Other**	
	Baseline Future, RCP4.5	Range (low scen. - Baseline) (high scen. - Baseline)	Baseline Future, RCP4.5	Range (low scen. - Baseline) (high scen. - Baseline)	Baseline Future, RCP4.5	Range (low scen. - Baseline) (high scen. - Baseline)
2019-20						
All scenarios	88,470	n/a	26,950	n/a	23,030	n/a
2039-40		n/a		n/a		n/a
Technology Scenario 1	132,430	-14,510 15,210	34,260	-1,410 2,570	33,230	-3,410 4,100
Technology Scenario 2	104,520	-11,630 11,930	30,370	-1,240 2,280	29,460	-3,020 3,640
Technology Scenario 3	82,330	-9,310 9,320	26,910	-1,110 2,020	26,100	-2,670 3,220
2059-60						
Technology Scenario 1	170,140	-38,000 59,690	40,000	-5,140 11,550	43,470	-11,600 21,500
Technology Scenario 2	106,090	-23,720 36,660	31,440	-4,040 9,080	34,170	-9,120 16,900
Technology Scenario 3	65,970	-16,490 22,440	24,680	-3,170 7,130	26,820	-7,150 13,270

NB: Excludes *in-situ* hydroelectric water use.

It is evident that the rate at which improvements in water use intensity can be achieved will have a huge impact on future water demands. When no change in water use intensity is assumed (Technology Scenario 1), growth in economy wide water demands is very significant (i.e., 83% growth by 2060 under the Baseline Future and up to 149% growth under the highest economic growth scenario – excluding consideration of hydroelectric water use). There is, however, very little difference between the results for the two climate scenarios. This occurs because for the two RCP scenarios investigated, large differences between the scenarios do not manifest in the Hawkes Bay until after 2050 (i.e., mostly beyond the timeframe considered).

When technology change is low, the quantity of water demanded varies hugely depending on the future economic growth trajectory. For Technology Scenario 1 and RCP4.5, there is a range of between 44% and 148% growth in water demands projected in 2060 compared to current water demands meaning that the difference between the maximum and minimum projections is some 145 million cubic metres (excludes hydroelectric generation). However, for Technology Scenario 3 and RCP4.5, the variation in the 2060 results between the Reference Economic Futures is only about half of the variation for Technology Scenario 1 (i.e. some 69 million cubic metres).

Constrained Results

Although we might intuitively expect constraints on growth in the agriculture sector, caused by limited water supply, to lead to losses in water demand elsewhere in the economy due to the strong connection between agriculture and the rest of the economy, this does not appear to be a strong outcome of the modelling. While the constrained specification will have lower economic activity and economic growth overall compared to the unconstrained specification, there is still resources available within the economy to allocate towards economic production (i.e., labour, existing capital, and funds for investment in new capital). Given the constraints placed on agriculture, it becomes a much less desirable sector for allocation of these resources under the constrained specification compared to the unconstrained specification, and so more of these resources end up allocated to other economic activities. This causes slight increases in production and hence water demands for some industries. Thus, it is prudent to presume that any limitations placed on the agriculture sector will not alone be sufficient to curb water demands in non-agriculture industries (in the absence of strong improvements in water use intensity).

Concluding Comments

Along with future global-to-local economic conditions, future changes in water use efficiency/ water use intensity will clearly be one of the most significant determinants on future water demands. Given the limited information currently available on changes in water use intensity over time, it is imperative that we seek to better understand potential future trends in water use intensity.

Planning and managing the region's water use is clearly an example of decision making under deep uncertainty. Uncertainty also becomes more significant the longer out in time we look. Given that many uncertainties are unresolvable, the approach taken to water planning should not be optimised towards the best guess of the future, but rather robust to the alternative futures that may prevail. There is a need to constantly monitor, reflect and re-evaluate as more information becomes available. For these reasons water use accounts and projections should be produced regularly as part of an ongoing process of resource management within the region.

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Contents

1 Background

1.1 Objective

Hawkes Bay Region Council have requested the development of regional economic projections that could be used in conjunction with static (i.e., for a single, current year) regional water accounts to provide future estimates of water demand within the region. This report presents the results of this analysis, providing estimates of future water demand, by economic sector and households, out to the year 2060. Recognising that there are significant and unresolvable uncertainties associated with the development of these accounts (e.g., limitations in the data used to create the accounts, uncertainties regarding future rates of change in water use intensity/efficiency, uncertainties in future global and national economic conditions, uncertainties in future climate change) we do not attempt to provide a single best guess estimate of future water demands, but rather a range of projections based on alternative scenarios.

1.2 Static Water Accounts

The static water accounts were developed separately by EnviroStrat but constitute a core input into the projections developed within this study. These accounts constitute the base year data from which future changes in water demands are projected. The static accounts were developed by EnviroStrat are for the 2019-20 water year and were developed in alignment with the United Nations Satellite Environmental and Economic Accounting System (UN SEEA-W). The accounts cover both takes (Use Table) and discharges of water (Supply Table). Since the topic of this study is water demands, we have focused almost entirely on the water takes or water Use Table. We do however acknowledge that some activities also return water to the environment, and this needs to be considered when evaluating the implications of water uses or abstraction. The obvious example to illustrate is that some 17 million cubic metres[1] are recorded in the Use Table as an abstraction for hydroelectricity generation. However, since hydroelectricity generation is an *in situ* use, an equal volume of water is also recorded in the Supply Table as a discharge to the environment. Finally, it is worth noting that several limitations and caveats exist within regard to the water accounts developed by EnviroStrat – these are not covered in this report, readers are directed to EnviroStrat for further information.

Following the SEEA structure, the Water Use Table provides information on the reason or use behind water takes, i.e., either abstraction for own use, or abstraction for distribution. The former category is then split further into (1) hydroelectricity power generation, (2) irrigation water, (3) mine water, (4) urban run-off, (5) cooling water and (6) other. The Water Use Table also separately records for the total quantity of water abstracted from the environment, the proportion that comes from surface water and ground water and collected precipitation.

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[1] This is only a partial coverage of the hydroelectricity water takes as data was not available for all schemes (pers. Comm. Envirostrat).

The level of sectoral breakdown for the Water Use Table is relatively coarse (8 aggregated industries plus households). However, for the three largest 'abstraction for own use' data entries, we were provided with a separate information on the industries responsible according to a very detailed industry classification (i.e., 4D ANZSIC).

1.3 Unconstrained and Constrained Future Projections

The primary question that we have sought to address in this study is "how can we expect the demand for water to change over time, assuming that there are no restraints on the ability to meet those demands, and hence no decisions need to be made about allocating water to only some uses?" There is of course potential for the projections consequentially developed to never be able to be achieved, due to limits in water supply and policy decisions that will restrict the allocation to all or some human uses. Nevertheless, by comparing the unconstrained demand projections with knowledge of water supply availability, we can appreciate the size of the 'water availability gap'.

In addition to the unconstrained water demand projections, it is recognized that it may also be informative to consider scenarios of constrained water demand projections. There are many possibilities for how water might be allocated in the future, and it is not possible to consider all of these within the narrow scope of this study. Furthermore, if we were to develop scenarios that fully specified the allocation of water among users, there would not be significant added utility in creating future water use projections, as these would largely follow the given allocation. We do nevertheless recognize that water supply restraints have become increasingly evident within the Hawkes Bay Region and policies to maintain river flows have significant implications particularly for the agriculture sector, restricting the availability of water for irrigation. If water supply availability is going to act as a significant constraint to future growth in the agricultural sector, other sectors within the Hawkes Bay Region will likely also be constrained in terms of growth, given interdependencies between sectors within an economy. Constraints on agricultural growth may also constrain other sectors indirectly limiting the additional water required by those sectors too. The additional question we therefore seek to answer by the additional set of 'constrained' water demand projections is "how can we expect the future demands for water to change over time, should agriculture be constrained to current water use"?

2 Scenarios Considered

2.1 Scenarios for Unconstrained Projections

For the unconstrained scenarios we have identified three major categories of uncertainty: (1) the global and national economic conditions that help set the future economic trajectory for the Hawkes Bay Region; (2) the future climate conditions that may cause water demands to increase regardless of any growth in economic activity; and (3) the rate of change in water use efficiency or 'water intensity' over time. The details of these scenarios/futures are discussed further below. Altogether five separate economic futures/ scenarios have been considered, two alternative climate futures, and three different scenarios of changes in water use efficiency. Allowing for all the various combinations of these options means that 30 different combined scenarios have been analysed.

It is noted that another source of uncertainty that could be investigated through additional scenarios is future population growth in Hawke's Bay. For the purposes of this analysis, we have simply relied on Statistics New Zealand's medium sub-national population projections. However, alternative futures and projections could also be included as additional scenarios.

2.1.1 Reference Economic Futures

There are a range of future economic conditions that are largely outside of the control of Hawke's Bay region, and which are largely uncertain, for example changes in international commodity prices, speed of technology change and productivity growth or level of environmental protection. To illustrate a range of different futures that may occur in these respects, five alternative Reference Economic Futures are implemented in the modelling of economic futures. These futures are explained in detail in Vergara *et al.* (2019), with a short summary of the key features of each scenario provided in Table 1.

Table 1: Summary of Reference Economic Futures

Reference Economic Futures	Economic growth	Global co-operation	Technological change	Environmental focus
Baseline	Medium/ Baseline	Medium/ Baseline	Medium/ Baseline	Medium/ Baseline
Techno-global Future	High	High	High	Medium/ Baseline
Fragmented Future	Low	Low	Low	Low
Green-Oriented Future	Medium/ Baseline	Medium/ Baseline	High	High

The Techno-global Future scenario is further separated into two sub-scenarios: 101 and 102. This reflects that in a future characterised by high technological and productivity change, there can be quite divergent impacts on labour and employment, depending on whether new processes and technologies are largely job replacing (102) or job augmenting (101).

2.1.2 Climate Scenarios

The International Panel on Climate Change (IPCC) has produced a set of climate change scenarios derived around alternative assumptions of future greenhouse gas emissions and atmospheric concentrations, termed Representative Concentration Pathways (RCPs). Table 2 and Figure 1 provide some information on these alternative scenarios and reference can be made to Burkett *et al* 2014 for further information. In this study, given the need to keep the number of combined scenarios tractable, only two of the four RCP scenarios are considered – the moderate-low emission pathway given by RCP4.5, and the high emission scenario of RCP8.5. It should however be noted that all four scenarios do not track too differently during the first half of this century and that the forecasts developed in this study do not extend past 2060.

Table 2: Representative Concentration Pathways (RCPs) adopted by Intergovernmental Panel on Climate Change (IPCC)

Scenario	**Radiative Forcing**	**CO_2-eq Concentration**	**Description**
	(W/m^2)	**(ppm)**	
RCP2.6	3.0	480-530	A strict reduction scenario that aims to keep global warming below 2°C above pre-industrial temperatures.
RCP4.5	4.5	580-720	A reduction scenario in which a significant GHG mitigation policy is implemented.
RCP6.0	6.0	720-1000	A normal reduction scenario in which an ordinary GHG mitigation policy is implemented.
RCP8.5	8.5	>1000	Very high GHG emissions. Scenarios without additional efforts to constrain emissions.

Note: The four RCPs use a common set of historical emissions data to initialise the integrated assessment models. The four RCPs were simulated by the IPCC in different Integrated Assessment Models to 2100.

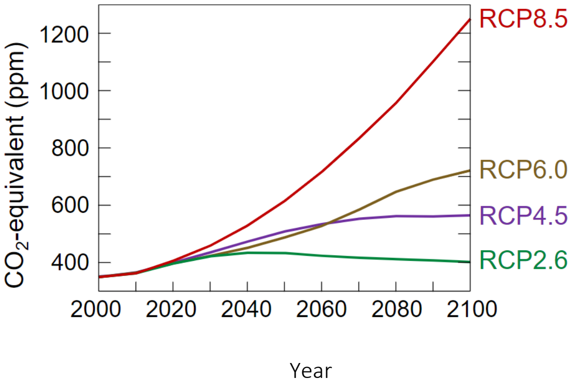

Fig. 1: Representative Concentration Pathways (RCPs) as adopted by the Intergovernmental Panel on Climate Change. Note: ppm = parts per million.

2.1.3 Water Intensity Scenarios

The concept of 'water intensity' is intended to capture the quantity of water that is required in a sector, relative to some other unit of measurement. In the household sector, for example, a common unit of measurement is the number of people, and thus water intensity is the cubic metres of water used per person. For other sectors, other types of measurement units are more typically used, such as the hectares of agricultural crops, value of industry output, or GDP.

A key question to address in developing the water use projections is to determine how water intensity may change over time. As there is huge uncertainty associated with this question, the best way to approach this problem is to incorporate some alternative assumptions or plausible scenarios around water use intensity changes. With these incorporated in the modelling, it becomes possible to see how sensitive the future water projections are to changes in water use intensity.

Although there are many studies concerned with water use intensity, either directly or implicitly, there is still a general paucity of information upon which to propose scenarios of future changes in intensity. Indeed, in the generation of water use projections, the calibration of water intensity change parameters has been identified as one of the key challenges (Wada *et al*., 2016). Few studies are related specifically to the New Zealand context, and those that are New Zealand specific tend to deal only specific economic activities (e.g., Martin *et al*., 2006). Even looking to international experience, published historical time series of water withdrawals are limited for many countries (Wada *et al*., 2016). Table 3 provides a short summary of some academic papers that provide an indication of the magnitude of changes in water use intensity. These papers are concerned both with direct analysis of changes in water use, as well as the development of global water projection models that similarly require parameters specifying future changes in water use intensity.

Of particular interest, the papers by Alcamo *et al*. (2003) and Flörke *et al*. (2013), provide an overview of the WaterGAP global model of water use and availability developed by the Centre for Environmental Systems Research of the University of Kassel (Germany) and the National Institute of Public Health and the Environment of The Netherlands (RIVM). Within the water use component of the model, three principal sectors are recognised: (1) domestic, covering households, small businesses and other municipal units, (2) industry, covering power plants and manufacturing facilities, and (3) agriculture. Water use is calculated by multiplying the driving force of water use (mainly population for domestic, electricity production for industry, and area of irrigated land and livestock numbers for agriculture) by the water use intensity (per unit use of water).

Table 3: Examples of Literature Addressing Water Use Intensities

Article Reference	Information contained in the Article on Changes in Water Use Intensity
Carr *et al*., 1990	Technological changes likely caused 2.2% per year drop in water intensity in the US manufacturing sector between 1950s and 1980s
German Federal Statistics Agency, 1996	Between 1975 and 1995 the water intensity of Germany's industry sector showed a decrease of 1.9% per year attributed mostly to technological change
Möhle, 1998	Water intensity of washing machines in German households dropped 2% per year over 15-year period
Flörke *et al*., 2013	For the domestic (municipal) component of the global WaterGAP model, the reduction in water intensity due to technological change is assumed to be 2% per year for the more developed countries, 1% per year for the less developed countries, and 0.5% per year for the least developed countries.

	For the manufacturing component of the global WaterGAP model, the reduction in water intensity due to technological change in OECD countries is set to 2.4% per year for 1960-1999 and 1% per year thereafter.
Wada *et al.*, 2016	The study uses three global water models to project future water use regionally and globally. Projections are developed for three scenarios consistent with the IPCC shared socio-economic pathways. Across these scenarios the assumed annual rate of technological change causing changes in water intensity in the Energy, Manufacturing and Domestic Sectors are assumed to range from 0.6% to 1.1% for rich communities with low exposure to hydrologic challenges, and 1.0% to 1.2% for rich communities with high exposure to hydrological complexity and challenges.

For the domestic and industry sectors, the authors describe two main concepts used for modelling the change in water intensity – structural change and technological change. The former refers to the change in water intensity that follows from a change in the structure of water use, for example more households becoming urban with indoor plumbing, or changes in the mix/type of manufacturing. The authors note that water structural intensity is generally stable in developed regions or follows a very slight downward trend. Technological change almost always leads to efficiency of water use and a decrease in water intensity. Some examples of historic water use intensity change due to technological change are also provided (see Table 3).

For agriculture systems, models used to estimate water demand generally consider the main drivers of water use to be the numbers of livestock (e.g., Wada *et al.*, 2016), the hectares of land irrigated for crop production, and the types of crops grown (as different crops have different water requirements). Changes in water intensity through technology change tend to be considered mainly in terms of irrigation technologies, and it is extremely challenging to find literature that proposes the likely rate of change in irrigation technology over time. We have however identified a very well cited paper by Hsiao *et al*. (2007) that provides a method for calculating the overall water use efficiency for irrigated grain (or fruit crops) in terms of the kg of biomass produced per m^3 of water. Mid-range efficiency values are presented for poor circumstances and practices and compared to good circumstances and practices indicating that the biomass production per m^3 of water can increase 50 times for the good situation compared to the poor situation.

In terms of New Zealand studies, the *Eco*Link study (McDonald *et al*., 1999a; McDonald *et al*., 1999b) funded by Ministry for the Environment's Sustainable Management Fund, while undertaken some years ago, is still one of the few national attempts to create industry water use accounts using the SEEA framework. McDonald *et al*. (1999b) developed accounts for water abstraction and discharge, including for pollutant loadings for the Northland, Auckland, and Waikato Regions. These accounts were, in turn, extrapolated using employment data to provide estimates for New Zealand as a whole. They also constructed economic, energy (by delivered and end-use type) with associated emissions. This information was used extensively in developing New Zealand's GHG inventory for Ministry of the Environment. It was also used to develop Eco-footprints for a range of resources (see McDonald *et al*. (2004), McDonald *et al*. (2006); and Patterson *et al*. (2011)). These eco-footprints captured not only direct resource use, but also indirect resource use through supply chains (see McDonald and Patterson (2004) and Smith and McDonald (2007). Furthermore, the *Eco*Link accounts were used to construct a

Physical Input-Output Table for the New Zealand and Auckland Region economies (McDonald and Patterson., 2006) – one of only a handful created globally. The study recorded water abstraction and use information for two alternative years (1994-95 and 1997-98) allowing for some investigation of changes in water use intensity, at least over that period. It also reconciled consent data with available compliance monitoring data providing estimates closer to actual water use than accounts based purely on consented maximums. The study indicates that water use intensities changed from 4,500m^3/$ million to 4,200m^3/$ million, suggesting an eco-efficiency of ~2.3 percent p.a. It is worth noting however that these estimates also reflect climatic conditions in those years – with less water being used in 1998 as Auckland experienced a dry summer with a resulting water shortage. More recently, water accounts based on the *Eco*Link approach were developed for Waikato Regional Council (see McDonald *et al*., 2016; Cardwell *et al*., 2018) – although these accounts are only available for a single year.

Putting all this information together, we have devised three alternative water use intensity scenarios (Table 4). Each scenario is specified according to the annual rate of decline in water use intensity for individual economic industries. Given that the principal underlying driver for declines in water intensity relate to improvements in technologies, the scenarios are termed "Technological Scenario 1", "Technology Scenario 2" and "Technology Scenario 3". The first scenario, although not very probable, has been included simply to provide a 'worst case' option for each of the demand projections and assumes no decreases in water use intensity. For Technology Scenarios 2 and 3, all industries have been allocated annual rates of changes in water use intensity informed by those used in Flörke *et al*. (2013) and Wada *et al*. (2016).

For the agricultural industries and Technology Scenario 3, the approach has been to assume that farming operations generally move towards good circumstances and practices as defined by Hsiao *et al*. (2007) over the 40-year timeframe. Recognising however that not all operations will start from the very poor situation and move to the very good situation, only two-thirds of the water use efficiency gains between those two extremes is assumed to be possible over the 40 years. Also, since the Hsaio *et al*. (2007) study relates to irrigation water use we have only applied the derived water intensity change to the current proportion of industry water use that is for irrigation. For other water takes the annual change of other sectors (i.e., 1.2% per annum) is applied. The overall 'weighted' annual percentage decreases in water use intensity for the agricultural industries are provided in Table 4.

Table 4 Assumed Changes in Water Use Intensity

Industry	Annual Decrease in Water Use, assuming Constant Production (industries)/ Consumption (households)		
	Technology Scenario 1	Technology Scenario 2	Technology Scenario 3
Horticulture and fruit growing	0.0%	1.0%	1.9%
Sheep, beef cattle and grain farming	0.0%	0.8%	1.7%
Dairy cattle farming	0.0%	1.0%	2.1%
Poultry, deer and other livestock farming	0.0%	0.8%	1.7%
Other Industries	0.0%	0.6%	1.2%
Households	0.0%	0.6%	1.2%

2.2 Scenarios for Constrained Projections

To keep this part of the modelling tractable and to narrow down the focus towards the impacts of agricultural water use constraints under different technology futures, we have focused just on the Baseline economic future scenario, and the RCP4.5 climate future. The Baseline economic future is a ‘middle scenario’ with national GDP growth lower than the two Techno-global futures, and higher than the Green Growth and Fragmented Future scenario. We do, however, provide modelled results for each of the three Technology scenarios.

3 Methodology

In this section we outline the stages undertaken to generate the future water demand projections.

3.1 Key methodological stages

3.1.1 Step 1: Disaggregate Water Use Table

As already explained, the Water Use Table provided by EnviroStrat recognised eight different industry types plus households. The first part of the process was to disaggregate the Water Use Table to a more detailed list of industries. The chosen level of disaggregation was 106 different industry types to achieve consistency with the economic modelling used in next steps of the analysis. Some of the flows recorded in the table could be easily mapped to the detailed industry classification based on the type of flow – for example, the abstraction for hydroelectric power generation was allocated to the Electricity Generation and On-selling industry. Of the remaining flows, EnviroStrat provided further information to disaggregate three of the most significant flows: (1) irrigation water by agriculture, (2) 'other' water abstraction by agriculture and 3) 'other' abstraction by the mining, quarrying, manufacturing, and construction sector.

Although municipal water takes (under 'abstraction for distribution' within the Water Use Table) are undertaken by the Water Supply industry, for the purposes of the futures analysis we have chosen to allocate this abstraction to the ultimate users, i.e., households and across industries. Also, we have allocated not only the water that is supplied to other economic units by the Water Supply Industry to industries and households, but also the quantity of water that is used by the Water Supply Industry itself, as well as the water that is lost as leakages from the system.[2][3] Once the future projections are calculated, these flows are then allocated back to the Water Supply industry for reporting. It would appear from the Water Use Table that some 64% of the water available for distribution is supplied to households, 18% to Mining, Quarrying, Manufacturing and Construction, and 18% to Service Industries. To split the latter two categories among sub-industries, we have relied on employment data per industry from the Statistics New Zealand's Business Directory, and ratios of reticulated water use per employee generated at a national level from (McDonald *et al*. 1999a, 1999b; McDonald and Patterson, 2006,2008).

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[2] The implication of this approach is that water use within the Water Supply industry as well as water leakages are assumed to grow at the same rate as municipal water use. It is, however, acknowledged that this will not necessarily occur in. Both Napier City Council and Hastings District Council have indicated commitment to improving water use efficiency in part through reducing leakages from municipal systems. Napier City Council is involved with a leaks detection survey and is implementing improved monitoring to detect leakages (Evidence of Russel Bond presented in the TANK hearings). Hastings District Council is seeking to reduce leakages to 15% over the next 25 years and is undertaking a network wide pressure reduction strategy to help achieve these reductions.

[3] The EnviroStrat Water Use Table specifies that in addition to the 26,203 thousand cubic metres of water extracted by the water supply industry for distribution, service industries also extract 114 thousand cubic metres for distribution. Given the relatively small value of the latter (0.4% of water takes for distribution), it has been ignored for the purposes of the modelling and calculations.

Table 5 provides a summary of the base water accounts for the 2019-20 year. Note that in this table we have redistributed water used for municipal supply back to the Water supply industry. When comparing this table with the Physical Water Use Table provided by EnivroStrat, it is also worth pointing out that 'Other' water use by Agriculture (16,870 thousand cubic metres) is slightly less than that reported by EnviroStrat (16,890 thousand cubic metres). This is because when further information was provided by EnviroStrat on the breakdown of this water use among sub sectors, a small share was allocated to food product manufacturing and households and thus appears in those categories in Table 5 below. The EnviroStrat table also records 'within the economy' data on water use. As these are secondary water flows, rather than the primary takes of water from the environment these have not been included in Table 5 and in the development of the water demand projections.

Table 5 Base Year Water Demand Accounts for Hawke's Bay Region (2019-20 Water Year, thousand cubic metres)

Sector Water Use	Agriculture	Other Primary	Food and Beverage Manufacturing	Other Manufacturing	Water supply	Other Utilities, Construction, Transport	Wholesale and Retail Trade and Hospitality	Finance, Insurance, Property, Scientific, Business Servs	Government, Health, Education	Personal Services	Households	Total
Abstraction for own use												
Hydroelectric power gen.	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
Irrigation water	71,600	0	0	0	460	0	330	10	80	650	30	**73,150**
Cooling water	0	720	530	220	0	0	0	0	0	0	0	**1,470**
Other	16,870	330	8,090	8,800	290	0	240	10	50	470	2,480	**37,630**
Abstraction for distribution	0	0	0	0	26,200	0	0	0	0	0	0	**26,200**
Total	**88,470**	**1,050**	**8,620**	**9,020**	**26,950**	**17,150**	**560**	**20**	**130**	**1,120**	**2,510**	**155,600**

Table 5 provides the final disaggregated water Use Table that constitutes the base water accounts used in this study. Note that to enable the data to be presented easily in this report, the industries have been aggregated back up to 10 industries plus households. However, for the purposes of the calculations described below, 106 different industry types are used.

Given limitations associated with the Water Accounts which underpin our analysis comparison were made with other datasets. Specifically, we compared the EnviroStrat-based estimates with estimates derived from *Eco*Link (for each industry, calculated as m^3/employee multiplied Hawkes Bay Region employees), this indicated:

- Mining, quarrying, manufacturing, and construction: 30.1 million m^3 *Eco*Link vs 22.3 million m^3 EnviroStrat.
- Electricity, gas, steam, and air-conditioning supply: 11.9 million m^3 *Eco*Link vs 17.1 million m^3 EnviroStrat.
- Water collection, treatment, and supply: 22.9 million m^3 *Eco*Link vs 27.7 million m^3 EnviroStrat.
- Services: 5.5 million m^3 *Eco*Link vs 5.3 million m^3 EnviroStrat
- Households: 8.1 million m^3 *Eco*Link vs 15.2 million m^3 EnviroStrat. NB: The *Eco*Link estimates are net of leakages.

While it is difficult to make comparison between the *Eco*Link accounts and the EnviroStrat accounts, given that the accounts were developed 20 years apart by different researchers with different but comparable methodologies, there does appear to be some alignment with all figures in the same order of magnitude. Due to significant differences in the types of crops (horticulture and fruit growing) grown in the Hawkes Bay vs Northland/Auckland/Waikato coupled with significant climatic differences, no comparison was made for agriculture. We also compared the EnviroStrat estimates of water use for households with estimates derived from Learnz: 83 m^3/capita/year Learnz vs 107 m^3/capita/year EnviroStrat.

3.1.2 Step 2: Derive Projections of Future Industry Output

We then applied a Multi-Regional Dynamic Economic Model (DEM) of the Hawke's Bay region and rest of New Zealand economies to produce projections of future industry output for the Hawkes Bay Region. This model has many of the features of a fully Dynamic Computable General Equilibrium (DCGE) model i.e., pricing dynamics, substitution/transformation effects, interregional/international trade and so on. It is, however, uniquely designed for the modelling of transition pathways through time, where it is desirable to consider both short- and medium-term.

The DEM is analogous to the dynamic economic model created within the Southland Economic Project for the analysis of freshwater management policies in Southland Region, drawing on developments in dynamic modelling produced by MBIE research funding, and through the Resilience to Nature's Challenges National Science Challenge. For a full description of the model reference can be made to the Southland Economic Model technical report (McDonald *et al*., 2020). The only substantial difference is that the Hawke's Bay DEM does not contain the specialised Primary Module – in other words, the representation of primary industries in the Hawke's Bay DEM is the same as for other types of industries as explained in the Industries Module component of the report. The Hawke's Bay DEM also differs from the Southland DEM using different underlying datasets (e.g., labour force projections, initial capital stocks and land uses, that represent, respectively, the different regional economies).

The basic structure of the DEM is determined by the underlying regional Social Accounting Matrix (SAM) at its core (Smith *et al*., 2015). The model considers two regions: the region of interest (Hawke's Bay in this case) and the rest of New Zealand (RoNZ). For each region, the model describes the behaviour of representative agents (23 industries, households, enterprises, local government within each region, and central government). Each industry agent chooses the quantity and type of commodities (31 commodities) to produce, based on the prices of those commodities relative to the costs of production. Household, enterprise, and government agents receive income from a variety of sources (e.g., wages and salaries, business profits, dividends, taxes, and transfers from other agents), and then allocate this income towards a variety of expenditure options (e.g., purchases of goods and services, savings, taxes, and transfers to other agents).

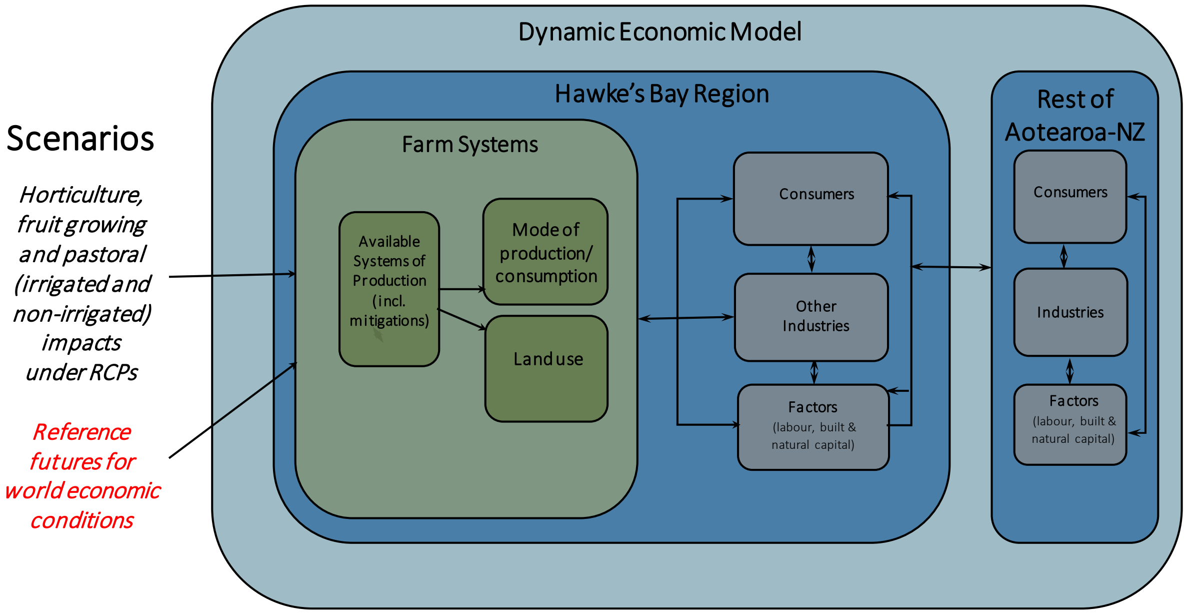


Fig.2 Components of Multi-Regional Dynamic Economic Model (DEM)

The model incorporates 'price' variables for all commodities and factors of production (i.e., types of labour and capital). These prices change in response to imbalances between supply and demand, and then 'nested' production functions allow the economy to react to these imbalances through substitution of demands and/or production between different types of commodities or factors. For example, if the demand for NZ-manufactured goods exceeds the supply, then the price of domestic goods will increase. This price increase (relative to foreign goods prices) will then lead to NZ-manufactured goods being substituted for goods produced overseas, thus reducing domestic demand and reducing prices. Similar substitution occurs in the factors and commodities used in production, and the region (within NZ) that the goods are demanded from.

On the supply side, the relative prices determine how the supply of commodities and factors are split. For example, the supply of goods manufactured in NZ is split between the NZ and export markets depending on the relative prices in each market. So, if domestic goods prices increase, more of the goods produced will be allocated to the NZ market, which will increase domestic supply, thus decreasing prices.

The model incorporates the dynamics of economic growth by keeping track of stocks of capital held by each industry. Capital stocks accumulate via investments in new capital and are diminished via the ongoing process of depreciation. Future population change also impacts on economic growth pathways due to its relationship to labour supply.

The model also includes accounts that keep track of financial flows between NZ and the rest of the world (i.e., balance of payments). When the demand for NZ currency starts to outstrip supply, this causes the exchange rate to rise. Changes in the exchange rate change the price of NZ goods relative to overseas goods, thus influencing demand and supply relationships. The model uses the NZ commodity prices along with exogenously specified world commodity prices to determine the supply and demand of exports and imports.

For this study, the model is applied as follows:

- *Unconstrained Scenarios* – For the unconstrained scenarios, the model is set up to run and produce results for each of the economic reference futures.
- *Constrained Scenarios* – For these scenarios we have incorporated a constraint within the DEM that prevents an agricultural industry from exceeding its base year water demands. For the Technology scenario (Technology Scenario 1) that assumes no reduction in water use per unit of industry output. On the face of it, this means that agricultural production must remain static in terms of production. When, however, consideration is also made of the increases in water demand induced by climate change, actual reductions in industry output are required into the future. For the two Technology Scenarios that assume reductions in water use intensity over time, agricultural output can increase according to the rate at which water intensity declines (less any gains in water use efficiency that are taken up in addressing climate change impacts).

The set of outputs that are produced by the DEM for each scenario is a trajectory of the quantities of commodities (31 different types) produced within the Hawkes Bay region from 2020-2060. These projections are then converted to estimates of the value of industry production (in constant dollar terms and for 106 different industry types) by assuming that the proportion of commodities supplied by each industry is the same as that derived from the latest economic Supply and Use tables for the Hawkes Bay region.

3.1.3 Step 3: Calculate Future Water Demand by Industries and Households

For an industry i, the quantity of water demanded for a use type u at a future time t, $wd_{i,u}(t)$ is calculated according to the formula,

$$wd_{i,u}(t) = wd_{i,u}(0) \times \frac{output_i(t)}{output_i(0)} \times (1-\tau_i)^t \times smd_{i,u}(t) \times exirr_{i,u}(t)$$

where $wd_{i,u}(0)$ is the quantity demanded by that same industry and for that same use in the base year water accounts. The ratio $\frac{output_i(t)}{output_i(0)}$ defines the relative output of the industry in the future t year compared to the base year, and the scalar defined by $(1-\tau_i)^t$ captures the reduction in water use intensity enabled through technology change of an annual rate of τ_i. The next two terms in the equation, $smd_{i,u}(t)$, and $exirr_{i,u}(t)$ are included to account for additional water demands that may be caused by climate change (discussed further in the next section). Note these scalars are only relevant for the agricultural industries, i.e., for other industries the scalars are set to 1, assuming no change in water intensity.

For households, the key drivers of future water demands are assumed simply to be population change and the rate of reduction in water use intensity. Thus, future water demands at time t and for water use type u, $wd_{h,u}(t)$, is defined as,

$$wd_{h,u}(t) = wd_{h,u}(0) \times \frac{pop(t)}{pop(0)} \times (1-\tau_h)^t .$$

The ratio in this equation defines the relative size of the total regional population in future years compared to the base year. We have relied on the most recent sub-regional population projections available from Statistics New Zealand to set the population growth pathway (2018 base, medium series). In a similar manner to the industries equation, $(1-\tau_h)^t$ captures the reduction in water use intensity per person enabled through technology change of rate τ_h.

3.2 Impacts of Climate Change on Future Water Demands

The analysis of future impacts of climate change on water demands has been confined to the agricultural industries and has been informed by the methodology that was followed in McDonald *et al.* (2020). The three categories of water use for agricultural industries within the Water Use Table are ‘irrigation’ (81% of agricultural water takes), livestock water (19% of agriculture water takes) and ‘other’ (<0.1% of agricultural water takes). We understand the ‘other’ category includes some water for private facilities and stockyards. For the purposes of this analysis, we have not attempted to quantify how the ‘livestock’ and ‘other’ uses may need to increase simply because of climate change (i.e., otherwise holding production constant). It is however recognised that there may be some climate implications for this use, for example in extensive livestock systems livestock are exposed to the elements which may include periods of higher temperatures thus increasing drinking water demands (Wada *et al*., 2014).

- **Scalar $smd_{i,u}(t)$**: This scalar is only relevant for the irrigation water use, i.e. for other uses the scalar is set to 1. For irrigation, it is surmised that even with irrigation land remaining constant, the quantity of water required would need to increase under drier conditions. For this study we have used the proportional increase in the % soil moisture deficit as a proxy for the proportional increase in water required for irrigation under climate change. As with the

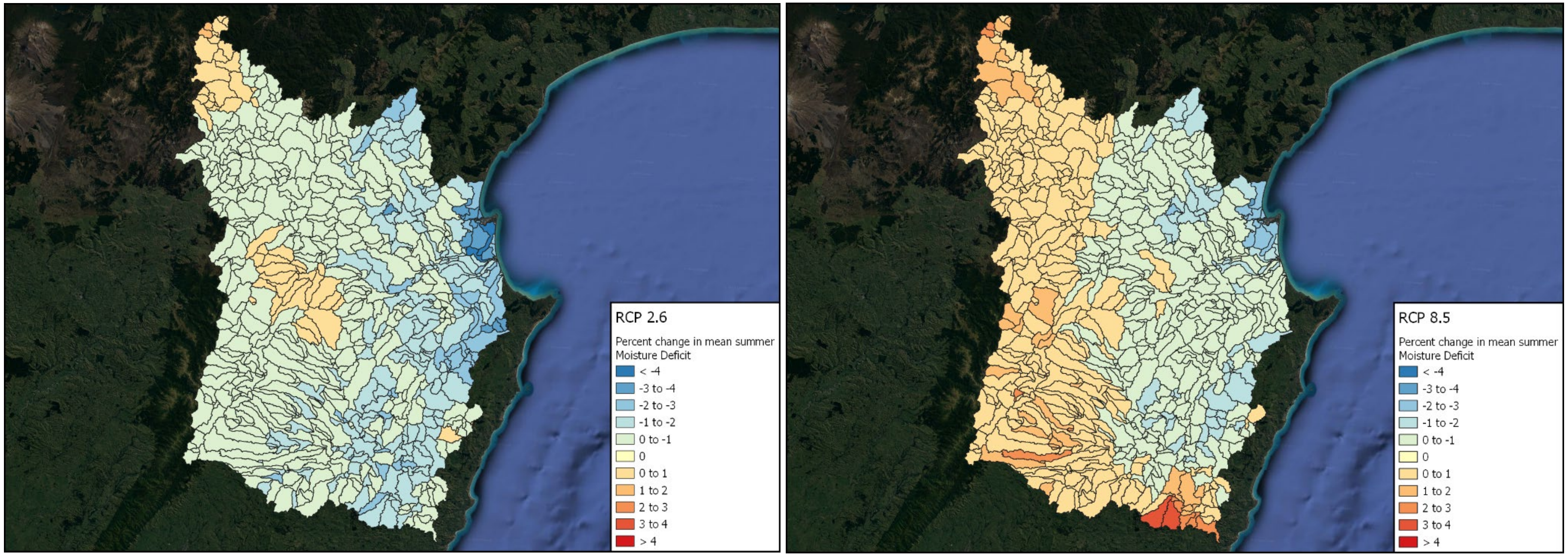
McDonald *et al*. (2020) study, we have obtained data on changes in soil moisture for alternative RCP scenarios from NIWA (2016,2018) – see Figure 3. This information has been used to create average changes in soil moisture over the entire region. Over the 40-year study timeframe, the derived $smd_{i,u}(t)$ grow from 1 in the base year, to 1.016 for the RCP4.5 scenario and 1.028 for the RCP8.5 scenario.

- Scalar **$exirr_{i,u}(t)$**: With losses in soil moisture content, we might also expect some reduction in pasture and other currently non-irrigated feed production. To maintain farm output under these conditions, one option is for farmers to increase the quantity of feed available through increasing the quantity of hectares under irrigation – this might happen directly within the farm itself, or indirectly through purchasing more feed from other farms that increase land under irrigation. The $exirr_{i,u}(t)$ scalar is intended to capture this proportional increase in irrigated water use associated with climate change. Unfortunately, there is not a significant number of previous studies and information available upon which we can quantify this effect and thus the results presented in this study should be viewed simply as broad estimates.

  As in the McDonald *et al.* 2020 study, we have been informed by Lieffering *et al*. (2020) as to the potential magnitude of changes in production of non-irrigated pasture under climate change. We have then calculated the quantity of additional irrigated hectares that might effectively replace this loss of production. Relative revenues per hectare from irrigated crops and pasture (AgFirst 2018; Nimmo-Bell, 2018), as well information on the relative stocking rates between irrigated and non-irrigated pasture (Howest *et al*., 2014) has been used to convert from hectares of non-irrigated pasture to effective replacement hectares of irrigated land. Once the number of additional hectares of irrigated land is estimated for the 40-year study period, this is converted to a scalar that defines the proportional increase in irrigated land, simply by comparing the additional hectares with current irrigated hectares.

There are several caveats to the incorporation of climate change implications within this study. First and foremost, given the paucity of previous scientific studies addressing exactly the questions that need to be answered for these projections, it should be recognised that this is only a first attempt to incorporate climate considerations into regional water use projections and much further work could be undertaken to refine the data and methods applied.

A second point to keep in mind is that adding additional land under irrigation will involve costs, particularly in terms of setting up the necessary infrastructure. Thus, even in a world where water does not act as a constraint to additional irrigation (note we are modelling 'unconstrained' scenarios), farmers may not choose this as the best option to adapt to climate change. In many cases the best financial options will involve some reductions in production. The economic model from which the economic growth projections are derived did not incorporate any additional costs for irrigation associated with climate change into the functions that determine the desired levels of production on farms. One should therefore consider the economic growth pathways produced for agriculture as somewhat optimistic.



(a) RCP2.6

(b) RCP8.5

Figure 3: Average mid -century soil-moisture-deficit forecasts (percent changes) for the Hawke's Bay region's TANK and Tukituki catchments under RCP2.6 and RCP8.5 (NIWA, 2016)

4 Results

4.1 Unconstrained Results

To begin, Figures 4-6 demonstrate the growth trajectory for water demand under the unconstrained scenarios for each of the reporting industries and households. Although it would be easier to compare among industries if the same scale were used for each plot, this was not possible given that the agriculture industry's water demands are significantly greater than any other industry, particularly once the impacts of future economic growth are included. Thus, for the agriculture industry the maximum scale is set at 250 million cubic metres, while for the other industries and households the maximum scale is 50 million cubic metres. Tables 6-11 have also been included to provide detailed information on the range in water use demanded under the various scenarios at 20-year snapshots into the future. Recorded in the table is the minimum and maximum water demand for each industry and water use category, across all 30 scenarios assessed.

Some general observations from these results are as follows:

- The rate at which improvements in water use intensity can be achieved will have a huge implication on future water demands. When no change in water use intensity is assumed (i.e., Technology Scenario 1), growth in economy wide water demands is very significant – i.e., up to 150% growth for the TechnoGlobal Future 101 scenario by 2060, around 84% growth by 2060 under the Baseline Future, and 44% growth under the Fragmented Future scenario (excludes hydroelectric uses). Recall that these are unconstrained projections and do not account for constraints that may be placed on sector's growth and water demands due to lack of water supply. For the middle scenario on technological change (i.e., Technology Scenario 2), the results are significantly less with a maximum growth of 69% for the TechnoGlobal Future 101 scenario at 2060, around 30% growth compared to current water demands for the Baseline scenario, and -2% growth for the Fragmented Future scenario (excluding hydroelectric). Under the high technology change scenario (i.e., Technology Scenario 3) there is very low-to quite significantly negative growth in water demands projected – i.e., the highest growth in 2060 compared to current water uses is 16% under the TechnoGlobal Future 101 scenario, while the Baseline future projects around 15% decline in water demands, and the Fragmented Future projects 33% decline (excludes hydroelectric).
- There is very little difference between the results for the two climate scenarios, in fact the differences are barely discernible in the plots. Recalling that climate implications on water demands only impact on the agriculture industry in the modelling, it is only towards the very end of the study's time period that we can start to make out two different lines emerging for each scenario – i.e., one straight line and one dashed line representing the two alternative RCPs. The outcome occurs because while climate change is adding to the water demanded by agriculture for all simulations, the difference between the two alternative RCP scenarios (4.5 and 8.5) is very small. This reflects the nature of the RCP scenarios, where atmospheric greenhouse gases remain relatively similar between the scenarios until the mid-century and is only beyond this that there starts to be significant variation between the scenarios.

- When technology change is low, the quantity of water demanded varies hugely depending on the future economic growth trajectory. For Technology Scenario 1 (i.e., assuming no rates of improvement in water use intensity), total water demand projections vary between around 198 (Fragmented Future reference future) and 344 (TechnoGlobal Future 101) million cubic metres by 2060 (excluding hydroelectric uses) under RCP4.5. Recall again that these are unconstrained projections that do not account for limitations that may be put on sector's water use into the future. For Technology Scenario 3, the variation in the results at 2060 is around half of the variation for Technology Scenario 1, i.e. between 91 and 159 million cubic metres (excluding hydroelectric).
- For industries other than agriculture, the largest potential growth in water demands in absolute terms appears to be in Water Supply followed by Food and Beverage Manufacturing and Other Manufacturing.
- The water supply industry generally experiences lower forecast proportional growth in water demands compared to the other industries. This reflects that the water supply industry is mainly driven by population change, as according to the base Water Use Table some 64% of municipal supply is for households, while the other industries' water demand growth is driven by economic growth in each respective sector. Generally, population growth is forecast to be lower than the growth in output of industries.

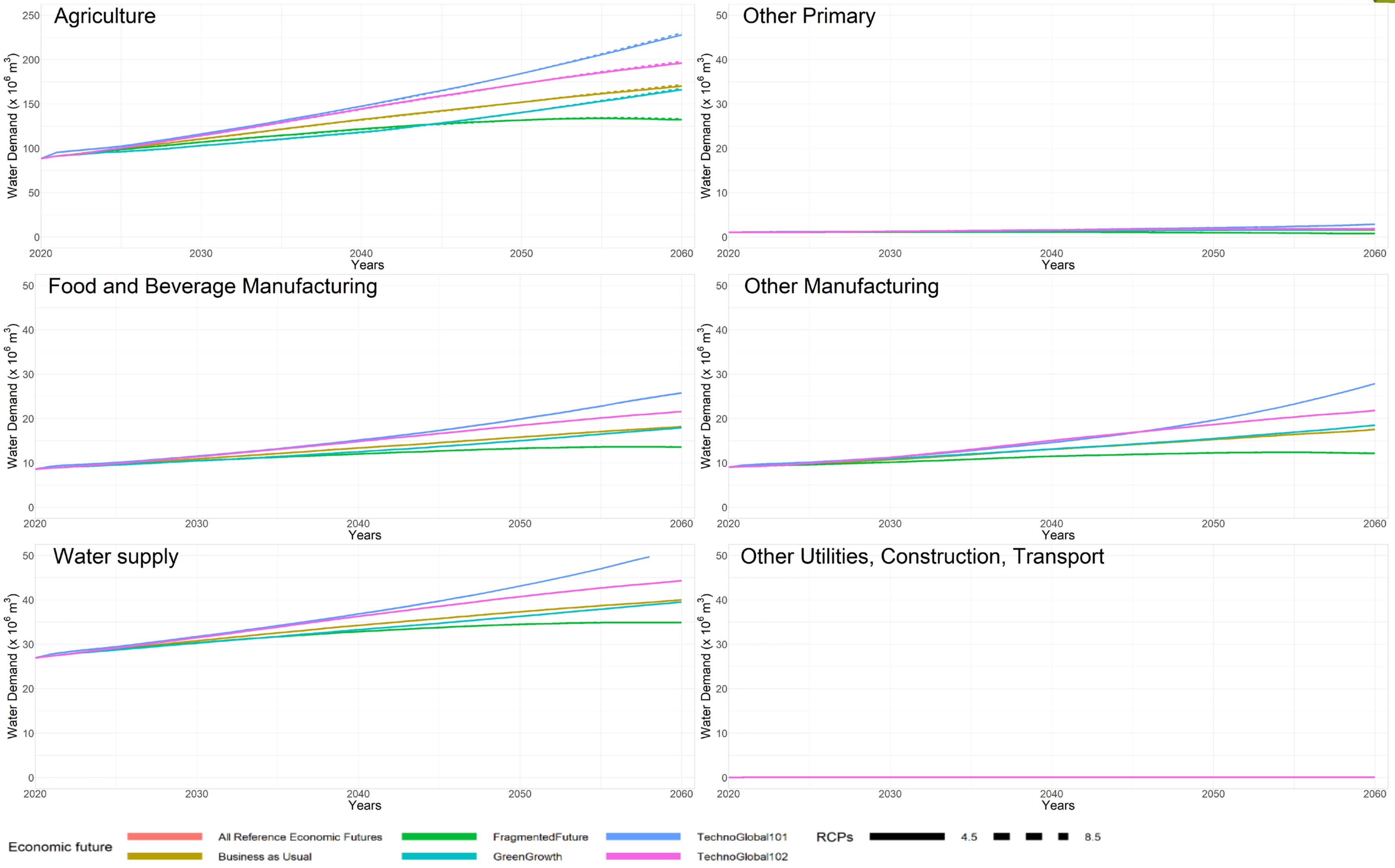


Figure 4 Unconstrained Future Water Demands for Hawke’s Bay – Technology Scenario 1 (Excl. Hydroelectric, 2020-60)

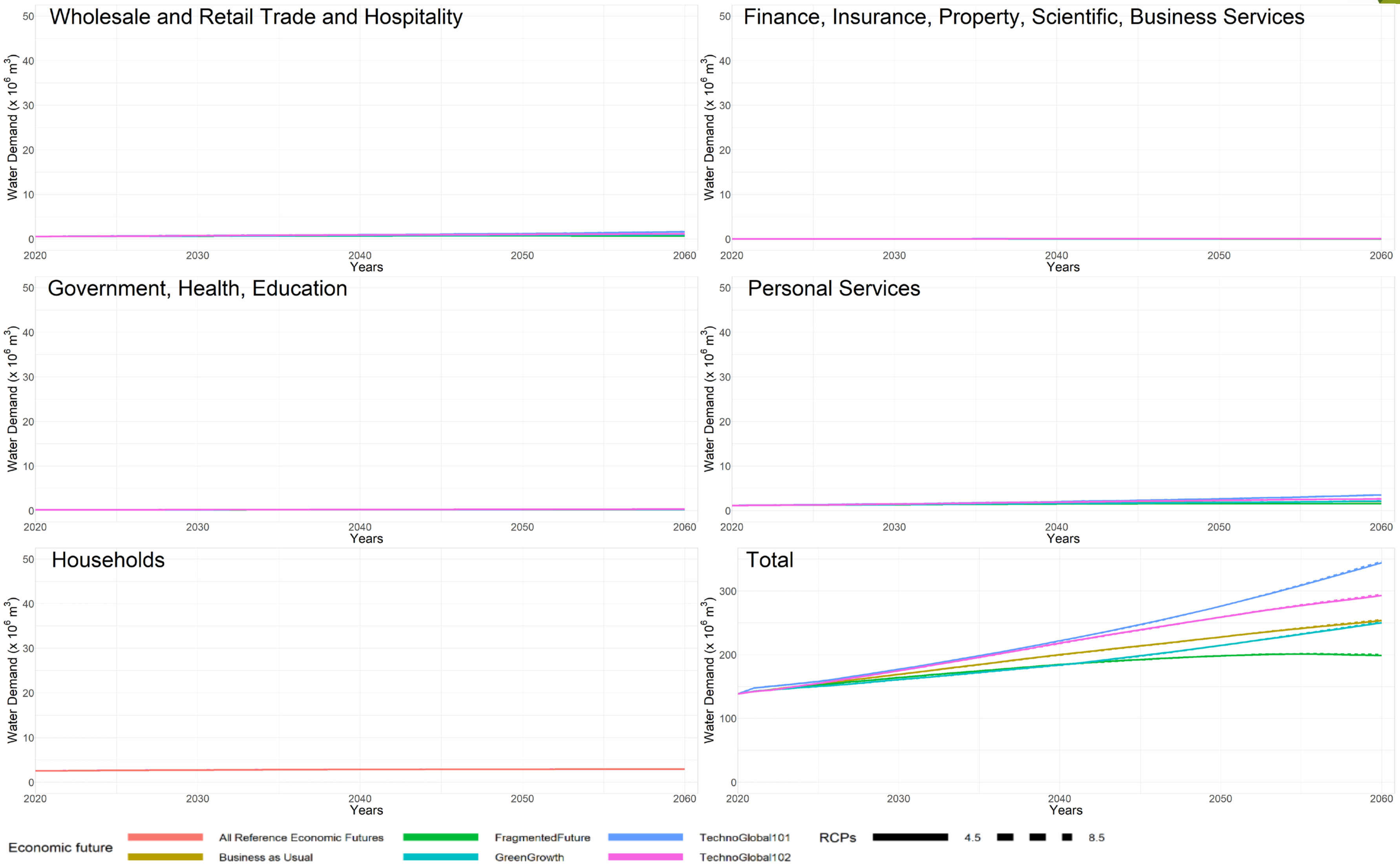


Figure 4 (continued) Unconstrained Future Water Demands for Hawke's Bay – Technology Scenario 1 (Excl Hydroelectric 2020-60)

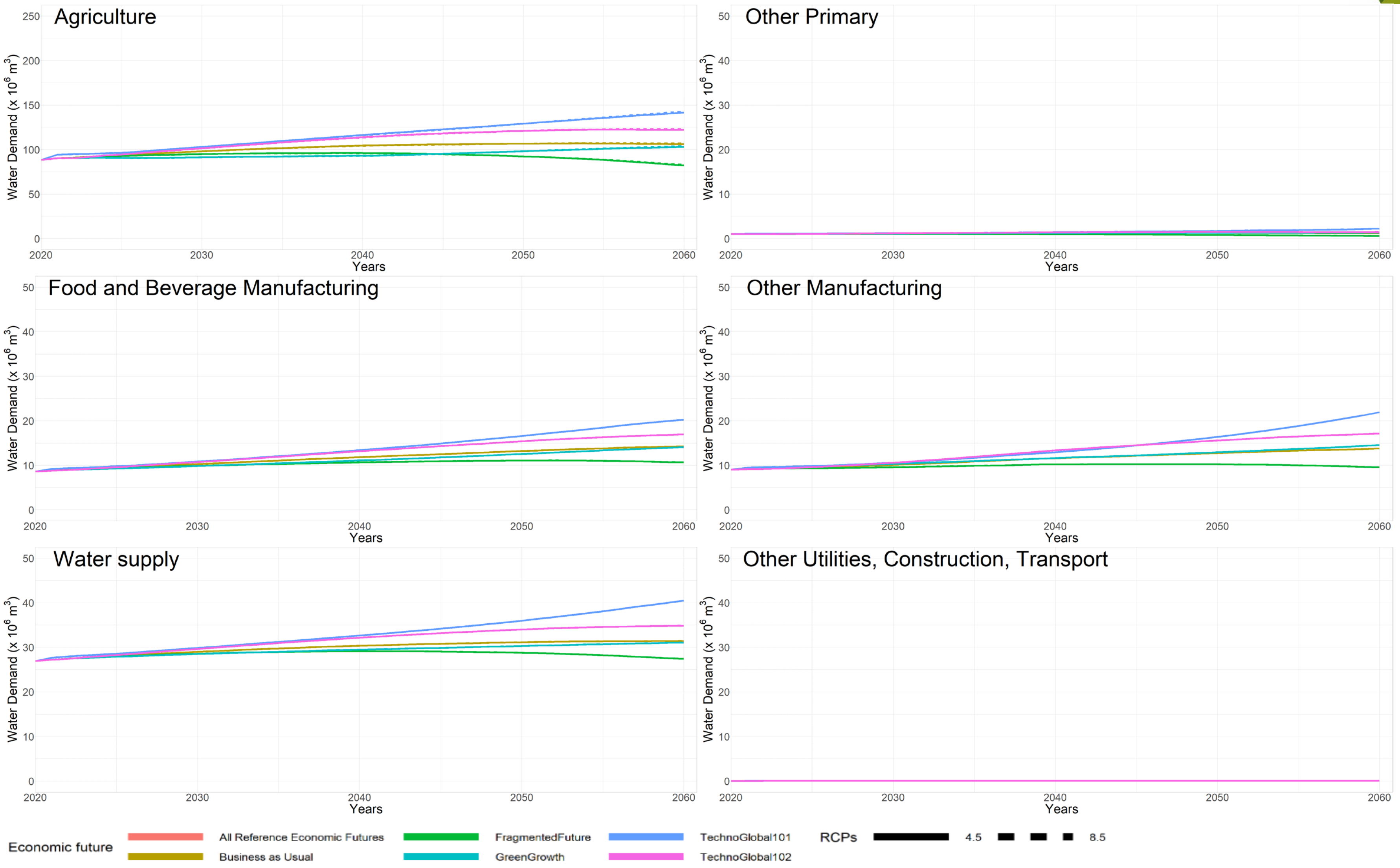


Figure 5 Unconstrained Future Water Demands for Hawke's Bay – Technology Scenario 2 (Excl. Hydroelectric 2020-60)

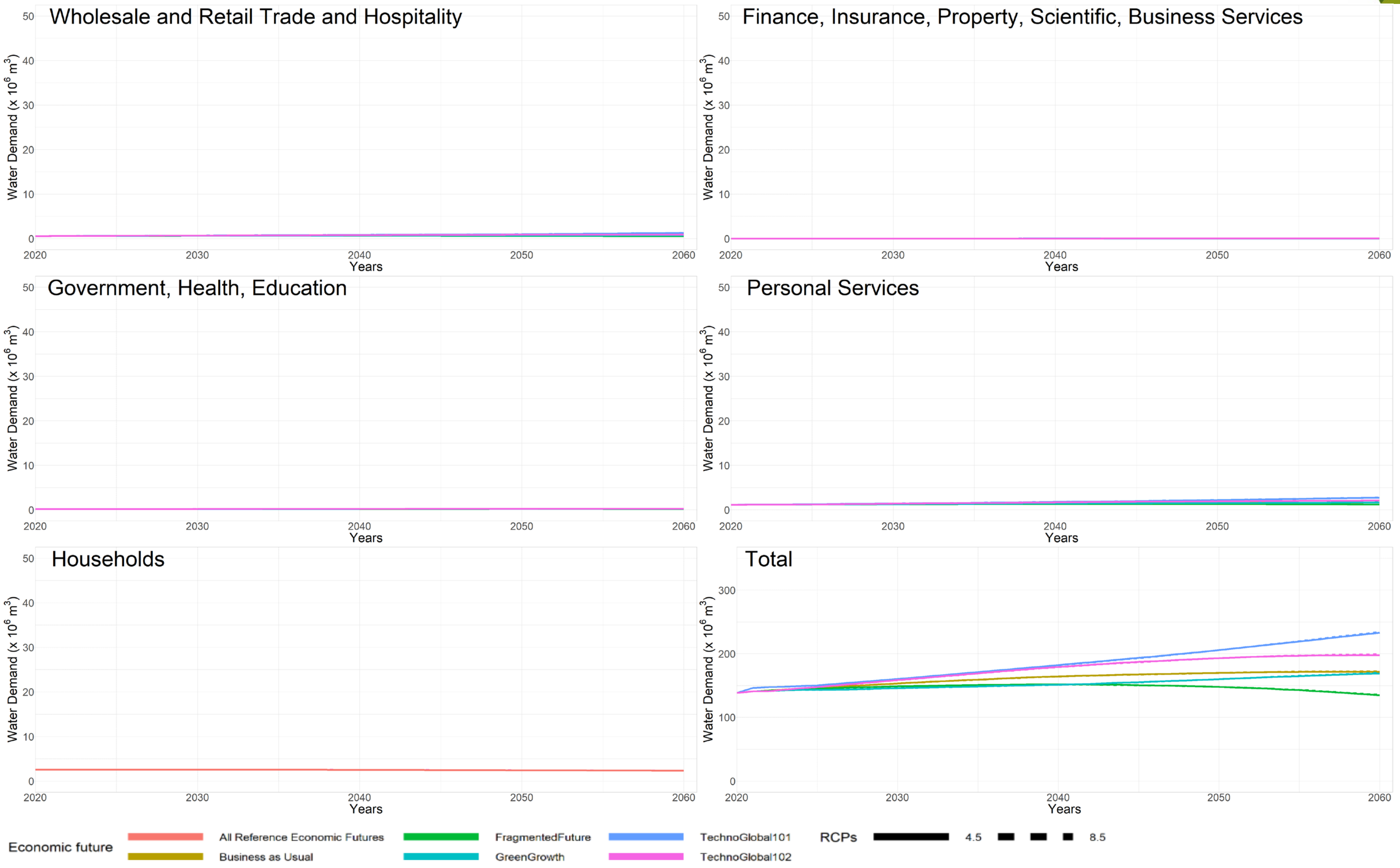


Figure 5 (continued) Unconstrained Future Water Demands for Hawke's Bay – Technology Scenario 2 (Excl. Hydroelectric 2020-60)

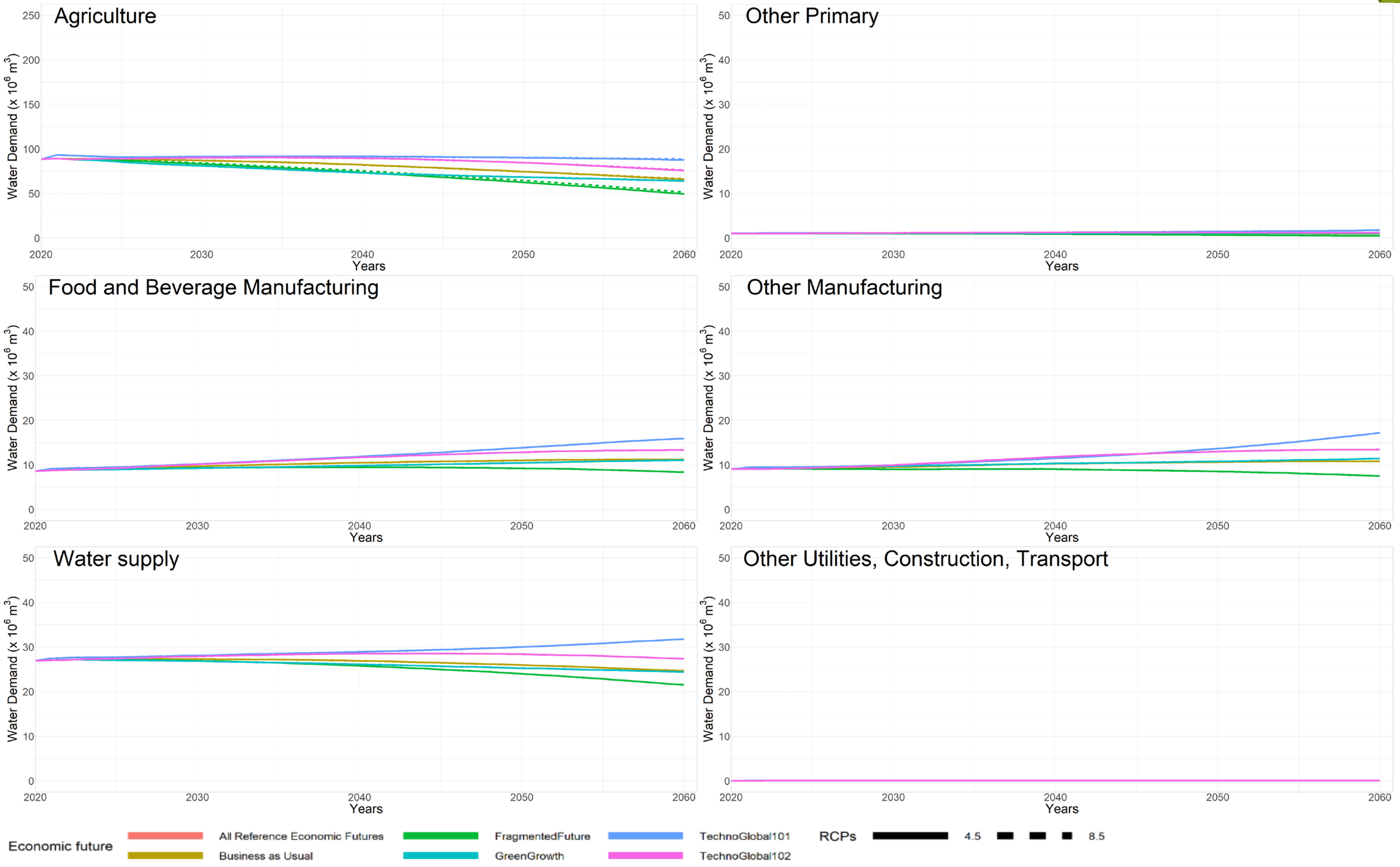


Figure 6 Unconstrained Future Water Demands for Hawke's Bay – Technology Scenario 3 (Excl. Hydroelectric 2020-60)

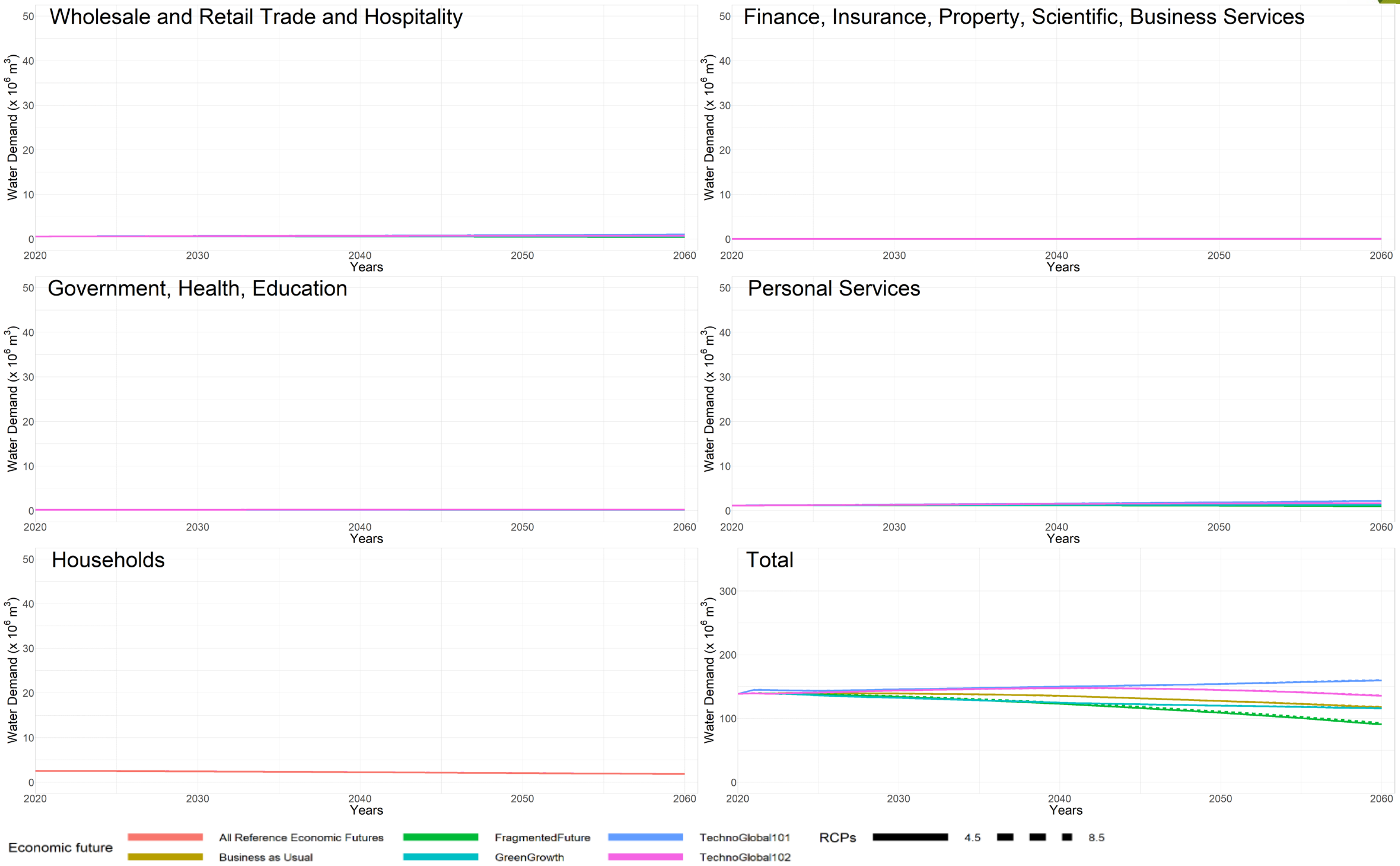


Figure 6 (continued) Unconstrained Future Water Demands for Hawke's Bay – Technology Scenario 3 (Excl. Hydroelectric 2020-60)

Table 6 Unconstrained Water Demand Projections for Hawke’s Bay Region under Technology Scenario 1 (2039-40 Water Year, thousand cubic metres)

Sector **Water Use**		**Agriculture**	**Other Primary**	**Food and Beverage Manufacturing**	**Other Manufacturing**	**Water supply**	**Other Utilities, Construction, Transport**	**Wholesale and Retail Trade and Hospitality**	**Finance, Insurance, Property, Scientific, Business Servs**	**Government, Health, Education**	**Personal Services**	**Households**	**Total**
Abstraction for own use													
Hydroelectric power gen.	Min	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
	Max	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
Irrigation water	Min	97,380	0	0	0	450	0	410	20	110	850	30	**99,380**
	Max	120,830	0	0	0	620	0	550	20	130	1,160	30	**123,340**
Cooling water	Min	0	770	660	270	0	0	0	0	0	0	0	**1,750**
	Max	0	1,110	850	360	0	0	0	0	0	0	0	**2,310**
Other	Min	20,540	350	11,300	11,220	350	0	290	10	80	610	2,780	**49,630**
	Max	26,810	510	14,270	14,690	400	0	400	20	100	830	2,780	**60,340**
Abstraction for distribution	Min	0	0	0	0	32,050	0	0	0	0	0	0	**32,050**
	Max	0	0	0	0	35,820	0	0	0	0	0	0	**35,820**
Total	Min	**117,920**	**1,120**	**12,020**	**11,490**	**32,850**	**17,160**	**700**	**30**	**180**	**1,470**	**2,810**	**197,750**
	Max	**147,640**	**1,620**	**15,120**	**15,040**	**36,830**	**17,160**	**950**	**40**	**230**	**1,990**	**2,810**	**239,430**

Table 7 Unconstrained Water Demand Projections for Hawke’s Bay Region under Technology Scenario 1 (2059-60 Water Year, thousand cubic metres)

Sector **Water Use**		**Agriculture**	**Other Primary**	**Food and Beverage Manufacturing**	**Other Manufacturing**	**Water supply**	**Other Utilities, Construction, Transport**	**Wholesale and Retail Trade and Hospitality**	**Finance, Insurance, Property, Scientific, Business Servs**	**Government, Health, Education**	**Personal Services**	**Households**	**Total**
Abstraction for own use													
Hydroelectric power gen.	Min	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
	Max	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
Irrigation water	Min	108,040	0	0	0	350	0	400	20	120	890	30	**109,850**
	Max	190,790	0	0	0	840	10	960	40	190	2,030	30	**194,890**
Cooling water	Min	0	530	810	270	0	0	0	0	0	0	0	**1,610**
	Max	0	1,970	1,340	640	0	0	0	0	0	0	0	**3,950**
Other	Min	24,100	240	12,750	11,900	380	0	290	10	90	640	2,890	**53,280**
	Max	39,040	910	24,410	27,230	560	10	690	30	140	1,460	2,890	**97,360**
Abstraction for distribution	Min	0	0	0	0	34,130	0	0	0	0	0	0	**34,130**
	Max	0	0	0	0	50,150	0	0	0	0	0	0	**50,150**
Total	Min	**132,140**	**770**	**13,550**	**12,180**	**34,860**	**17,160**	**690**	**30**	**210**	**1,520**	**2,920**	**216,030**
	Max	**229,830**	**2,880**	**25,750**	**27,870**	**51,550**	**17,170**	**1,660**	**80**	**320**	**3,490**	**2,920**	**363,520**

Table 8 Unconstrained Water Demand Projections for Hawke's Bay Region under Technology Scenario 2 (2039-40 Water Year, thousand cubic metres)

Sector Water Use		Agriculture	Other Primary	Food and Beverage Manufacturing	Other Manufacturing	Water supply	Other Utilities, Construction, Transport	Wholesale and Retail Trade and Hospitality	Finance, Insurance, Property, Scientific, Business Servs	Government, Health, Education	Personal Services	Households	Total
Abstraction for own use													
Hydroelectric power gen.	Min	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
	Max	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
Irrigation water	Min	76,270	0	0	0	400	0	360	10	90	760	30	**78,050**
	Max	94,760	0	0	0	550	0	490	20	120	1,020	30	**96,980**
Cooling water	Min	0	680	590	240	0	0	0	0	0	0	0	**1,550**
	Max	0	980	760	320	0	0	0	0	0	0	0	**2,050**
Other	Min	16,620	310	10,020	9,950	310	0	260	10	70	540	2,470	**42,250**
	Max	21,690	450	12,650	13,020	350	0	350	20	90	740	2,470	**51,420**
Abstraction for distribution	Min	0	0	0	0	28,410	0	0	0	0	0	0	**28,410**
	Max	0	0	0	0	31,760	0	0	0	0	0	0	**31,760**
Total	Min	**92,890**	**990**	**10,650**	**10,190**	**29,130**	**17,160**	**620**	**30**	**160**	**1,300**	**2,490**	**165,610**
	Max	**116,450**	**1,440**	**13,400**	**13,340**	**32,650**	**17,160**	**840**	**40**	**210**	**1,760**	**2,490**	**199,780**

Table 9 Unconstrained Water Demand Projections for Hawke's Bay Region under Technology Scenario 2 (2059-60 Water Year, thousand cubic metres)

Sector Water Use		Agriculture	Other Primary	Food and Beverage Manufacturing	Other Manufacturing	Water supply	Other Utilities, Construction, Transport	Wholesale and Retail Trade and Hospitality	Finance, Insurance, Property, Scientific, Business Servs	Government, Health, Education	Personal Services	Households	Total
Abstraction for own use													
Hydroelectric power gen.	Min	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
	Max	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
Irrigation water	Min	66,580	0	0	0	280	0	310	10	90	700	20	**68,000**
	Max	117,200	0	0	0	660	10	760	40	150	1,600	20	**120,430**
Cooling water	Min	0	410	630	220	0	0	0	0	0	0	0	**1,260**
	Max	0	1,550	1,050	500	0	0	0	0	0	0	0	**3,100**
Other	Min	15,780	190	10,020	9,360	300	0	230	10	70	500	2,270	**38,720**
	Max	25,550	710	19,190	21,410	440	0	540	30	110	1,150	2,270	**71,390**
Abstraction for distribution	Min	0	0	0	0	26,830	0	0	0	0	0	0	**26,830**
	Max	0	0	0	0	39,420	0	0	0	0	0	0	**39,420**
Total	Min	**82,370**	**610**	**10,650**	**9,570**	**27,400**	**17,160**	**540**	**20**	**160**	**1,200**	**2,300**	**151,980**
	Max	**142,750**	**2,260**	**20,240**	**21,910**	**40,520**	**17,160**	**1,300**	**60**	**250**	**2,750**	**2,300**	**251,500**

Table 10 Unconstrained Water Demand Projections for Hawke's Bay Region under Technology Scenario 3 (2039-40 Water Year, thousand cubic metres)

Sector **Water Use**		**Agriculture**	**Other Primary**	**Food and Beverage Manufacturing**	**Other Manufacturing**	**Water supply**	**Other Utilities, Construction, Transport**	**Wholesale and Retail Trade and Hospitality**	**Finance, Insurance, Property, Scientific, Business Servs**	**Government, Health, Education**	**Personal Services**	**Households**	**Total**
Abstraction for own use													
Hydroelectric power gen.	Min	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
	Max	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
Irrigation water	Min	58,900	0	0	0	350	0	320	10	80	670	20	**60,360**
	Max	74,140	0	0	0	480	0	430	20	110	910	20	**76,100**
Cooling water	Min	0	600	520	210	0	0	0	0	0	0	0	**1,370**
	Max	0	870	670	280	0	0	0	0	0	0	0	**1,810**
Other	Min	13,410	280	8,880	8,810	280	0	230	10	60	480	2,190	**36,000**
	Max	17,520	400	11,210	11,540	310	0	310	10	80	650	2,190	**43,860**
Abstraction for distribution	Min	0	0	0	0	25,170	0	0	0	0	0	0	**25,170**
	Max	0	0	0	0	28,140	0	0	0	0	0	0	**28,140**
Total	Min	**73,020**	**880**	**9,440**	**9,030**	**25,800**	**17,150**	**550**	**20**	**140**	**1,150**	**2,210**	**139,390**
	Max	**91,650**	**1,270**	**11,870**	**11,820**	**28,930**	**17,160**	**750**	**30**	**180**	**1,560**	**2,210**	**167,430**

Table 11 Unconstrained Water Demand Projections for Hawke's Bay Region under Technology Scenario 3 (2059-60 Water Year, thousand cubic metres)

Sector **Water Use**		**Agriculture**	**Other Primary**	**Food and Beverage Manufacturing**	**Other Manufacturing**	**Water supply**	**Other Utilities, Construction, Transport**	**Wholesale and Retail Trade and Hospitality**	**Finance, Insurance, Property, Scientific, Business Servs**	**Government, Health, Education**	**Personal Services**	**Households**	**Total**
Abstraction for own use													
Hydroelectric power gen.	Min	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
	Max	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
Irrigation water	Min	39,180	0	0	0	220	0	250	10	70	550	20	**40,300**
	Max	71,750	0	0	0	520	10	590	30	120	1,250	20	**74,280**
Cooling water	Min	0	330	500	170	0	0	0	0	0	0	0	**990**
	Max	0	1,210	830	390	0	0	0	0	0	0	0	**2,430**
Other	Min	10,300	150	7,870	7,340	230	0	180	10	50	390	1,780	**28,310**
	Max	16,660	560	15,060	16,800	340	0	430	20	80	900	1,780	**52,650**
Abstraction for distribution	Min	0	0	0	0	21,060	0	0	0	0	0	0	**21,060**
	Max	0	0	0	0	30,940	0	0	0	0	0	0	**30,940**
Total	Min	**49,480**	**480**	**8,360**	**7,510**	**21,510**	**17,150**	**420**	**20**	**130**	**940**	**1,800**	**107,800**
	Max	**88,410**	**1,780**	**15,890**	**17,200**	**31,810**	**17,160**	**1,020**	**50**	**200**	**2,150**	**1,800**	**177,470**

4.2 Constrained Results

For this second sets of results, we are concerned with examining how restricting future water demands by the agricultural sector so that demands must be equal to (or less than) current water use will impact on water demands across the whole of the Hawkes Bay economy. To illustrate these outcomes, Tables 12-17 specify how, for the RCP4.5 and Baseline reference future, future water demands vary between the unconstrained and constrained specifications. Results are also shown separately for two snapshots, i.e., 2039-40 and 2059-60, and for each of the three alternative Technology scenarios.

- At high rates of technology change there is very little difference between the constrained and unconstrained specifications. This is because the agriculture sector is already near to or at the level of water use efficiency increase necessary to not exceed current water demands.
- Intuitively we might expect constraints on growth in the agriculture sector, caused by limited water supply, to lead to losses in water demand elsewhere in the economy, due to the close connection between economic industries. This does not however appear to be a strong outcome of the modelling and the results presented below. We see that while there is indeed some lower water demands for Food and Beverage under the constrained results compared to the unconstrained, some other sectors experience minor *increases* in water demands for the constrained scenario compared to the unconstrained. For example, in 2040, under the Baseline scenario, RCP4.5 and Technology Scenario 1, the Other Manufacturing industry demands 13.3 million cubic metres under the constrained specification compared to 13.1 million cubic metres under the unconstrained specification. The primary reason for these outcomes is that for the constrained specification economic activity is effectively being displaced from agriculture to non-agricultural activities. Although the constrained specification will certainly have *lower economic activity and economic growth overall* compared to the unconstrained specification due to limited water supply for agriculture, there is still a need to allocate resources within the economy to towards economic production (i.e., labour, existing capital, and funds for investment in new capital). Given the constraints placed on agriculture, it becomes a much less desirable sector for allocation of these resources under the constrained specification compared to the unconstrained specification, and so more of these resources end up allocated to other economic activities. This can cause slight increases in production and hence water demands for some industries.
- Given the observations and system relationships described in the preceding paragraph, it would seem prudent to presume that any limitations placed on the agriculture sector will not alone be sufficient to curb water demands in non-agriculture industries (in the absence of strong improvements in water use intensity), even despite the Hawke's Bay economy currently being strongly interconnected with agriculture.

Table 12 Hawkes Bay Water Demand Projections - Baseline Reference Future, RCP 4.5, Technology Scenario 1(2039-40 Water Year, thousand cubic metres)

Sector **Water Use**		**Agriculture**	**Other Primary**	**Food and Beverage Manufacturing**	**Other Manufacturing**	**Water supply**	**Other Utilities, Construction, Transport**	**Wholesale and Retail Trade and Hospitality**	**Finance, Insurance, Property, Scientific, Business Servs**	**Government, Health, Education**	**Personal Services**	**Households**	**Total**
Abstraction for own use													
Hydroelectric power gen.	Unconstrained	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
	Constrained	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
Irrigation water	Unconstrained	107,780	0	0	0	490	0	450	20	110	940	30	**109,820**
	Constrained	71,600	0	0	0	490	0	450	20	110	940	30	**73,660**
Cooling water	Unconstrained	0	960	790	310	0	0	0	0	0	0	0	**2,060**
	Constrained	0	970	730	310	0	0	0	0	0	0	0	**2,010**
Other	Unconstrained	24,640	440	12,550	12,760	370	0	320	10	80	670	2,780	**54,640**
	Constrained	16,870	450	12,220	12,930	370	0	330	10	80	680	2,780	**46,710**
Abstraction for distribution	Unconstrained	0	0	0	0	33,390	0	0	0	0	0	0	**33,390**
	Constrained	0	0	0	0	33,050	0	0	0	0	0	0	**33,050**
Total	Unconstrained	**132,430**	**1,410**	**13,340**	**13,070**	**34,260**	**17,160**	**770**	**30**	**190**	**1,610**	**2,810**	**217,080**
	Constrained	**88,470**	**1,430**	**12,940**	**13,250**	**33,910**	**17,160**	**780**	**30**	**190**	**1,620**	**2,810**	**172,590**

Table 13 Hawkes Bay Water Demand Projections - Baseline Reference Future, RCP 4.5, Technology Scenario 1(2059-60 Water Year, thousand cubic metres)

Sector **Water Use**		**Agriculture**	**Other Primary**	**Food and Beverage Manufacturing**	**Other Manufacturing**	**Water supply**	**Other Utilities, Construction, Transport**	**Wholesale and Retail Trade and Hospitality**	**Finance, Insurance, Property, Scientific, Business Servs**	**Government, Health, Education**	**Personal Services**	**Households**	**Total**
Abstraction for own use													
Hydroelectric power gen.	Unconstrained	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
	Constrained	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
Irrigation water	Unconstrained	138,950	0	0	0	490	10	530	20	140	1,200	30	**141,370**
	Constrained	71,600	0	0	0	490	10	540	20	140	1,220	30	**74,070**
Cooling water	Unconstrained	0	1,090	1,060	400	0	0	0	0	0	0	0	**2,540**
	Constrained	0	1,110	930	410	0	0	0	0	0	0	0	**2,450**
Other	Unconstrained	31,190	500	17,120	17,120	430	0	380	20	100	860	2,890	**70,620**
	Constrained	16,870	510	16,550	17,480	430	0	390	20	100	880	2,890	**56,120**
Abstraction for distribution	Unconstrained	0	0	0	0	39,080	0	0	0	0	0	0	**39,080**
	Constrained	0	0	0	0	38,480	0	0	0	0	0	0	**38,480**
Total	Unconstrained	**170,140**	**1,590**	**18,180**	**17,520**	**40,000**	**17,160**	**920**	**40**	**240**	**2,060**	**2,920**	**270,770**
	Constrained	**88,470**	**1,620**	**17,490**	**17,880**	**39,400**	**17,160**	**930**	**40**	**250**	**2,100**	**2,920**	**188,260**

Table 14 Hawkes Bay Water Demand Projections - Baseline Reference Future, RCP 4.5, Technology Scenario 2 (2039-40 Water Year, thousand cubic metres)

Sector **Water Use**		**Agriculture**	**Other Primary**	**Food and Beverage Manufacturing**	**Other Manufacturing**	**Water supply**	**Other Utilities, Construction, Transport**	**Wholesale and Retail Trade and Hospitality**	**Finance, Insurance, Property, Scientific, Business Servs**	**Government, Health, Education**	**Personal Services**	**Households**	**Total**
Abstraction for own use													
Hydroelectric power gen.	Unconstrained	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
	Constrained	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
Irrigation water	Unconstrained	84,580	0	0	0	440	0	400	20	100	830	30	**86,390**
	Constrained	71,600	0	0	0	440	0	400	20	100	840	30	**73,420**
Cooling water	Unconstrained	0	850	700	270	0	0	0	0	0	0	0	**1,830**
	Constrained	0	860	660	280	0	0	0	0	0	0	0	**1,800**
Other	Unconstrained	19,940	390	11,120	11,320	330	0	280	10	70	600	2,470	**46,540**
	Constrained	16,870	400	10,950	11,420	330	0	290	10	70	600	2,470	**43,410**
Abstraction for distribution	Unconstrained	0	0	0	0	29,610	0	0	0	0	0	0	**29,610**
	Constrained	0	0	0	0	29,430	0	0	0	0	0	0	**29,430**
Total	Unconstrained	**104,520**	**1,250**	**11,820**	**11,590**	**30,370**	**17,160**	**680**	**30**	**160**	**1,430**	**2,490**	**181,500**
	Constrained	**88,470**	**1,260**	**11,620**	**11,700**	**30,190**	**17,160**	**690**	**30**	**170**	**1,440**	**2,490**	**165,220**

Table 15 Hawkes Bay Water Demand Projections - Baseline Reference Future, RCP 4.5, Technology Scenario 2 (2059-60 Water Year, thousand cubic metres)

Sector **Water Use**		**Agriculture**	**Other Primary**	**Food and Beverage Manufacturing**	**Other Manufacturing**	**Water supply**	**Other Utilities, Construction, Transport**	**Wholesale and Retail Trade and Hospitality**	**Finance, Insurance, Property, Scientific, Business Servs**	**Government, Health, Education**	**Personal Services**	**Households**	**Total**
Abstraction for own use													
Hydroelectric power gen.	Unconstrained	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
	Constrained	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
Irrigation water	Unconstrained	85,660	0	0	0	380	0	420	20	110	940	20	**87,560**
	Constrained	71,600	0	0	0	390	0	430	20	110	950	20	**73,520**
Cooling water	Unconstrained	0	850	830	310	0	0	0	0	0	0	0	**2,000**
	Constrained	0	870	770	320	0	0	0	0	0	0	0	**1,960**
Other	Unconstrained	20,430	390	13,460	13,460	340	0	300	10	80	680	2,270	**51,420**
	Constrained	16,870	400	13,210	13,640	340	0	310	10	80	690	2,270	**47,820**
Abstraction for distribution	Unconstrained	0	0	0	0	30,720	0	0	0	0	0	0	**30,720**
	Constrained	0	0	0	0	30,460	0	0	0	0	0	0	**30,460**
Total	Unconstrained	**106,090**	**1,250**	**14,290**	**13,770**	**31,440**	**17,160**	**720**	**30**	**190**	**1,620**	**2,300**	**188,860**
	Constrained	**88,470**	**1,270**	**13,990**	**13,960**	**31,180**	**17,160**	**730**	**30**	**190**	**1,640**	**2,300**	**170,920**

Table 16 Hawkes Bay Water Demand Projections - Baseline Reference Future, RCP 4.5, Technology Scenario 3 (2039-40 Water Year, thousand cubic metres)

Sector Water Use		Agriculture	Other Primary	Food and Beverage Manufacturing	Other Manufacturing	Water supply	Other Utilities, Construction, Transport	Wholesale and Retail Trade and Hospitality	Finance, Insurance, Property, Scientific, Business Servs	Government, Health, Education	Personal Services	Households	Total
Abstraction for own use													
Hydroelectric power gen.	Unconstrained	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
	Constrained	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
Irrigation water	Unconstrained	66,220	0	0	0	390	0	350	10	80	740	20	**67,820**
	Constrained	66,220	0	0	0	390	0	350	10	80	740	20	**67,830**
Cooling water	Unconstrained	0	750	620	240	0	0	0	0	0	0	0	**1,620**
	Constrained	0	750	620	240	0	0	0	0	0	0	0	**1,620**
Other	Unconstrained	16,110	350	9,860	10,030	290	0	250	10	60	530	2,190	**39,670**
	Constrained	16,110	350	9,860	10,030	290	0	250	10	60	530	2,190	**39,640**
Abstraction for distribution	Unconstrained	0	0	0	0	26,230	0	0	0	0	0	0	**26,230**
	Constrained	0	0	0	0	26,230	0	0	0	0	0	0	**26,230**
Total	Unconstrained	**82,330**	**1,100**	**10,480**	**10,270**	**26,910**	**17,160**	**600**	**30**	**150**	**1,270**	**2,210**	**152,510**
	Constrained	**82,330**	**1,100**	**10,480**	**10,270**	**26,910**	**17,160**	**600**	**30**	**150**	**1,270**	**2,210**	**152,510**

Table 17 Hawkes Bay Water Demand Projections - Baseline Reference Future, RCP 4.5, Technology Scenario 3 (2059-60 Water Year, thousand cubic metres)

Sector Water Use		Agriculture	Other Primary	Food and Beverage Manufacturing	Other Manufacturing	Water supply	Other Utilities, Construction, Transport	Wholesale and Retail Trade and Hospitality	Finance, Insurance, Property, Scientific, Business Servs	Government, Health, Education	Personal Services	Households	Total
Abstraction for own use													
Hydroelectric power gen.	Unconstrained	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
	Constrained	0	0	0	0	0	17,150	0	0	0	0	0	**17,150**
Irrigation water	Unconstrained	52,640	0	0	0	300	0	330	10	90	740	20	**54,130**
	Constrained	52,640	0	0	0	300	0	330	10	90	740	20	**54,140**
Cooling water	Unconstrained	0	670	650	240	0	0	0	0	0	0	0	**1,570**
	Constrained	0	670	650	240	0	0	0	0	0	0	0	**1,560**
Other	Unconstrained	13,330	310	10,560	10,560	270	0	240	10	60	530	1,780	**37,660**
	Constrained	13,330	310	10,560	10,560	270	0	240	10	60	530	1,780	**37,640**
Abstraction for distribution	Unconstrained	0	0	0	0	24,110	0	0	0	0	0	0	**24,110**
	Constrained	0	0	0	0	24,110	0	0	0	0	0	0	**24,110**
Total	Unconstrained	**65,970**	**980**	**11,220**	**10,810**	**24,680**	**17,160**	**570**	**20**	**150**	**1,270**	**1,800**	**134,630**
	Constrained	**65,970**	**980**	**11,220**	**10,810**	**24,680**	**17,160**	**570**	**20**	**150**	**1,270**	**1,800**	**134,630**

5 Concluding Comments

Water Use Intensity

Future changes in water use efficiency/ water use intensity will clearly be one of the most significant determinants on future water demands. Unfortunately, we have found it difficult to find context appropriate information, particularly at the industry scale and comprehensively for all industries, upon which to establish a set of plausible assumptions regarding likely future changes in water use intensity. In this study we have had to look at international literature and apply assumptions used in other international water projection models as a guide to the appropriate ranges of reduction in water use intensity to consider within the scenarios. In the case of agriculture, the scenarios selected have been partly informed by a well-cited paper on the great variation that can occur in water use intensity for irrigated systems which implies that there may be room for reasonably high improvement in terms of biomass production per m^3 of water, however we acknowledge that the timeframe over which such improvements could be made is very uncertain and that the international context may vary substantially from that of Hawke's Bay.

This study has also applied constant annual rates of change in water use intensity when projecting forward future water demands. Although this is a reasonably typical approach to the inclusion of technological change within future forecasts, one should note that when the timeframe is reasonably long, such as the 40 years of this study, small differences in the annual rate chosen will accumulate to very large changes in water use overall. As there are likely to be diminishing returns to actions that reduce water use intensity, it may not be realistic to assume that the same rate of decline can be achieved over the longer timeframes, i.e., a diminishing rate of change may be more appropriate.

Overall, to improve our understanding of future water demands, there is a clear need to obtain better information on likely future changes in water use intensity, not only for agricultural systems but also for other economic industries and households.

Decision Making Under Uncertainty

Planning and managing the region's water uses is clearly an example of decision making under significant and unresolvable uncertainty. The range of scenarios considered in this application illustrate that future water demands will vary significantly depending on the economic context and economic growth pathway followed by the regional/national/international economic system, the ability to implement improvements in water use technologies, and the way water is allocated among uses. Generally, the level of uncertainty also grows the further out in time we attempt to look. Given that such uncertainties are unresolvable, the approach taken to water planning should not be optimised towards the best guess of the future, but rather robust to the alternative futures that may prevail.

There is also a need to constantly monitor, reflect and re-evaluate as more information becomes available. For these reasons water use accounts and projections should be produced regularly as part of the ongoing process of resource management within the region.

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Appendix D: Envirostrat

Hawke's Bay Physical Supply, Use and Asset Accounts
Phase Two Report, September 2022

EnviroStrat
Impact Investment Project Development

Hawke's Bay Regional Council

Hawke's Bay Region Physical Supply, Use and Assets Water Accounts

Final Report for Phase 2

Prepared by Cerasela Stancu, Sandra Cortés-Acosta and Robbie Maris

September 2022

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Acronyms

ANZSIC	Australia New Zealand Standard Industrial Classification of All Economic Activities
FMU	Freshwater Management Unit
IRIS	Integrated Regional Information System
RWA	Regional water assessment

Glossary of terms

Abstraction	Water extracted from the environment
Indicators	Quantitative or qualitative factors or variables that provide direct and reliable means to measure progress (or changes) related to an activity/outputs/outcomes, and to measure achievement.

Natural Capital	Natural capital are natural assets in their role of providing natural resource inputs and environmental services for economic production.
Physical water supply and use account	Flow accounts, covering the amount of water abstracted from the environment by agriculture, industry, services and households (domestic), how it flows through the economy, and the volumes that are returned to the environment.
Water Accounting	Water accounting is a systematic process of identifying, recognising, quantifying, and reporting information about water and how it has been used.
Water assets (stocks)	Water resources such as lakes, rivers, soil water, artificial reservoirs, ice and snow.
Water supplied	Flows of water within the economy (water uses for intermediate consumption, final consumption and export) plus water returned to the environment
Water use	A gross concept referring to a flow between two industries or units.
Water consumption	A net concept referring to water that has been re-supplied to another industry like the Sewerage industry, returned to the environment or incorporated into products.
Trade waste	Wastewater discharged into the wastewater network from trade (or commercial) premises.
Non-household	Any water user or “discharger” that is not a household. Includes small businesses, services, manufacturers, farmers, etc.

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Summary

This project, initiated by the Hawke's Bay Regional Council with significant involvement from district councils, represents the first systematic effort to produce water accounts at a regional and district level in New Zealand (NZ) following the UN System of Environmental-Economic Accounting (SEEA) – Water – (known as SEEA-Water). The SEEA-Water framework is recognised as the gold standard for water accounting globally. Water accounting provides a framework for systematically integrating multiple sources of water data to provide an overview of the state of water assets, water supply and water use.

This report describes the preliminary results for the physical supply and use, and water assets accounting for the Hawke's Bay region and the district/city council territories (Napier City, Hastings District, Central Hawke's Bay District and Wairoa District). The reporting period is from 1 July 2019 to 30 June 2020.

The supply and use tables report the abstraction, use and discharge of water from various economic agents (delineated by ANZSIC codes – for example agriculture, manufacturing and sewerage). These tables show where water is used in the regional or district economy and tracks where that water came from and where it ends up. The water assets tables provide preliminary estimates for the total stocks of water assets i.e. storage/reservoirs, lakes, rivers, snow, groundwater and soil water, and documents the flows in and out of these assets within the reporting period. Data uncertainties notwithstanding, the asset tables are intended to provide insights into water availability and provides a more in-depth description of where water is flowing from and to for Hawke's Bay.

Results

Overall, 138.65 million m^3 of water was abstracted from the Hawke's Bay Region over the reporting period. 49.4 million m^3 of that abstraction is recirculated within the economy (for water consumption, sewerage treatment and water distribution). Agriculture is the largest user of water, using 88.49 million m^3. Each district has a unique profile of water consumption based on their industrial composition. Furthermore, industries have considerably different water productivity (value add per m^3 of water use).

The regional water asset results are indicative at this point as a wide range of assumptions and uncertainties are in play. The complexities of the hydrological cycle and the lack of models/previous practice in New Zealand make it difficult to generate robust assets accounts following SEEA methodology. More data, modelling and analysis is required to better estimate the flow of water between assets (which impacts the availability of water for abstraction) and to calculate actual evapotranspiration (in relation to assets). Specific areas for improvement of water accounts include key data sources and assumptions (relating to water distribution, effluent, livestock water consumption and the water assets tables, to name a few), ANZSIC codes alignment of abstraction and discharge water consents, and consistency regarding units used for volume. This will enable future accounting to be more accurate and efficient.

The scope of water accounts can be expanded in the future to include monetary accounts (to improve understanding of the value of water and benchmark performance of water users based on their water productivity) and water condition account (linked to broader water quality policy objectives and targets for Hawkes Bay or specific catchment health objectives).

The insights from water accounting can also be used to produce other ecosystems / natural capital accounts of relevance to long term regional policies and strategies in Hawkes Bay i.e. biodiversity or climate adaptation.

1. Introduction

Hawke's Bay Regional Council is conducting a Regional Water Assessment (RWA) as part of a broader effort to develop a long-term strategic plan to manage water. The project aims to comprehensively assess the state of Hawke's Bay's freshwater resources to enable better planning and water management into the future. The project is co-funded by the central government via a Provincial Growth Fund grant and comes amid the major Three Waters Reforms and the latest revisions to freshwater policy to the National Policy Statement for Freshwater Management 2020. In addition, there are significant developments in the climate agenda that are relevant for water management, however, not immediately relevant for this first-generation water accounts.

This report builds on the Report for Phase One and describes the processes and results for water accounting in the Hawke's Bay Region. Specifically, this report provides for the data component of the Hawke's Bay Region's approach to long term water management and supply (Figure 1). Understanding the state of play for water demand and supply is critical for developing well-informed and effective strategies for water management, which contributes significantly to food security, economic activity and the wellbeing of residents.

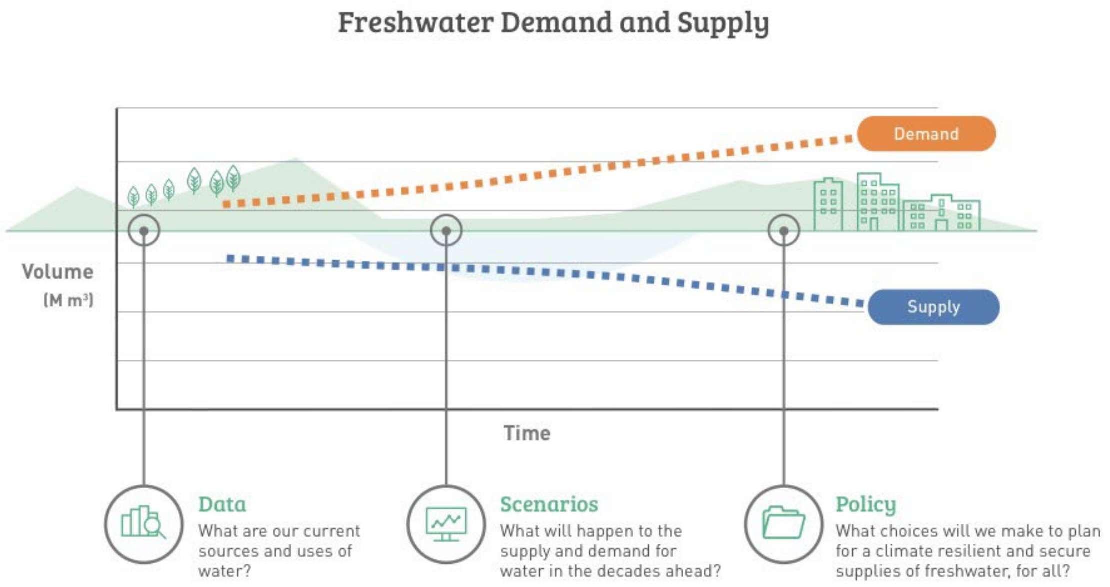

Figure 1. Approach to long term management of water supply and demand in Hawke's Bay (retrieved from HBRC, 2020)[1]

At its core, water accounting is built on a thorough understanding of the regional water cycle (hydrological cycle). A conceptual model of the Hawke's Bay water cycle is presented in Figure 2. This figure is based on the United Nations water accounting framework discussed in section 2.1. The natural input of water (to the surface and sub-surface of the land) from the atmosphere is precipitation. A proportion of this will evaporate (through evapotranspiration) back into the atmosphere and the remaining precipitation will either drain into water assets (rivers, lakes, artificial reservoirs, for example) or infiltrate and recharge groundwater resources (i.e. aquifers).[2] Economic (and community) agents abstract water from assets, use the water within the economy and then discharge water back into the environment. The abstraction, use and return of water by economic agents are represented in physical water supply and use tables (see

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[1] Hawke's Bay Regional Council (HBRC), "Introducing the Regional Water Assessment."
[2] United Nations, *System of Environmental-Economic Accounting for Water*.

section 2.5. for more detail). Descriptions of the stocks of water assets (and flows to and from these assets) are reported in water assets tables (see section 2.6. for more detail).

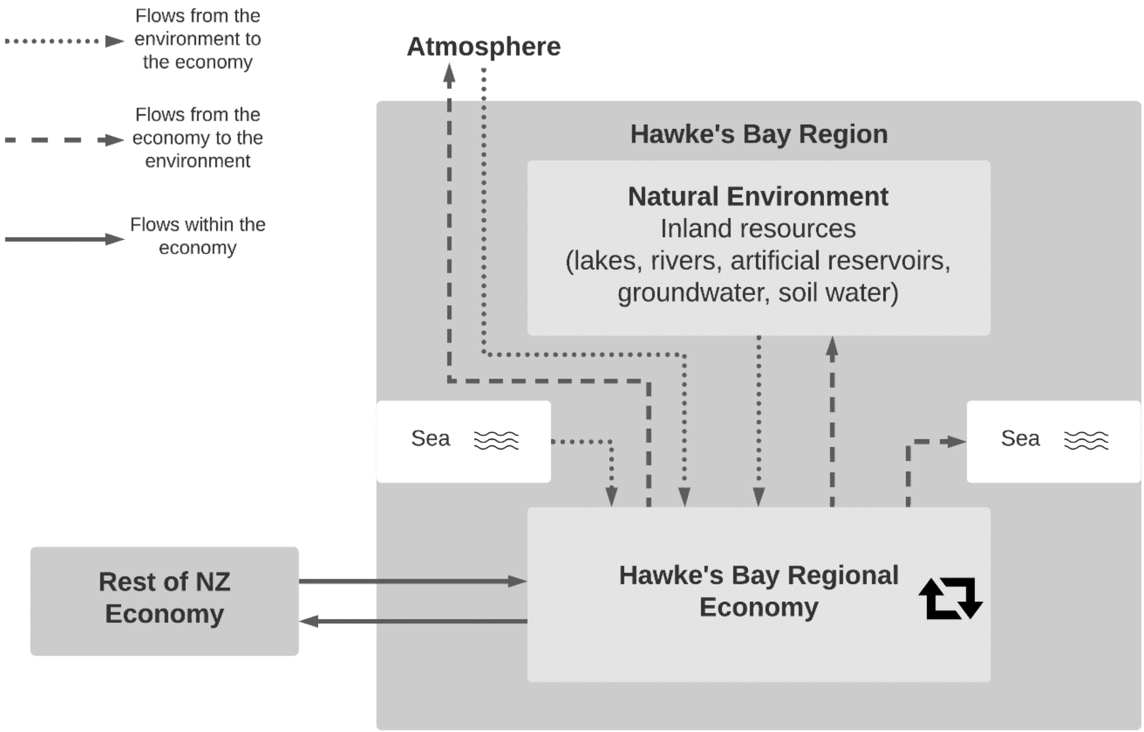
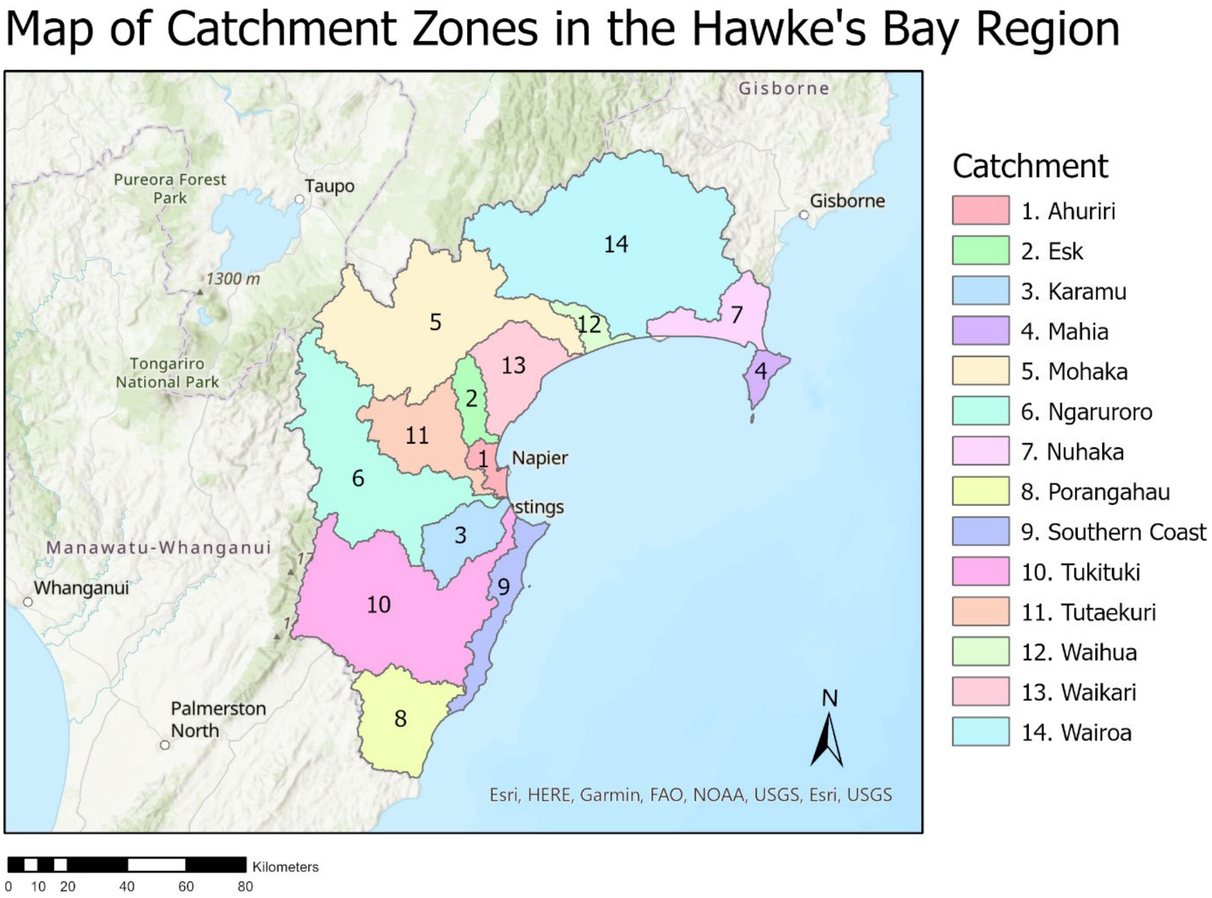


Figure 2. Conceptual model of the Hawke's Bay water (adapted from SEAA-Water Framework)

This report studies and produces water accounts and insights for the Hawke's Bay Region. The Hawke's Bay Regional management area is 1.53 million hectares and has a diverse set of topographies and catchment areas. There are 14 sub-catchment zones in the Hawke's Bay. These zones are summarised in Table 1. Wairoa is the largest sub-catchment (366,073 ha), followed by Tukituki (250,815 ha) and Mohaka (243,598 ha). Māhia, Ahuriri and Waihua are the smallest catchments (14,504, 15,123 and 18,323 ha, respectively). Figure 3 shows how these catchments are spatially distributed across the Hawke's Bay Region.

Table 1. Catchment Zones and Areas in the Hawke's Bay Region

Catchment Zone	Area (ha)	Catchment Zone	Area (ha)
Ahuriri	15,122.5	Pōrangahau	87,852.2
Esk	26,740.9	Southern Coast	49,182.0
Karamu	51,399.8	Tukituki	250,814.8
Māhia	14,503.6	Tūtaekurī	82,976.4
Mohaka	243,597.6	Waihua	18,322.6
Ngaruroro	201,029.9	Waikari	71,192.6
Nūhaka	49,865.2	Wairoa	366,072.5
Total (ha)	**1,528,672.6**		



Esri, HERE, Garmin, FAO, NOAA, USGS, Esri, USGS

Figure 3. Map of the Catchment Zones in the Hawke's Bay Region.

The following sections describe the methodologies and approaches taken to produce the physical water supply and use tables and the water assets tables for Hawke's Bay.

2. General Methods

2.1. Core Methodology: SEAA-Water

The UN System of Environmental-Economic Accounting (SEAA) – Water – (known as SEEA-Water) is the core reference methodology for developing the Hawke's Bay Water Accounts Framework. SEEA-Water is a module within the UN System of Environmental Economic Accounting's Central Framework (SEEA-CF), which was adopted by the United Nations Statistical Commission in 2012 as the international statistical standard for environmental-economic accounts.[3]

The SEEA framework follows a similar accounting structure as the System of National Accounts (SNA) that New Zealand and all other countries use for macro-economic statistics. It generates a wide range of statistics, accounts and indicators with many different potential analytical applications such as policy analysis, resource management and budget allocation or investment.

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[3] United Nations (UN), "System of Environmental Economic Accounting."

The SEEA framework (including SEEA-Water) uses concepts, definitions and classifications consistent with the SNA – such as gross domestic product - in order to facilitate the integration of environmental and economic statistics. As a statistical accounting framework, it includes stocks, flows and transactions.

In addition to SEEA-Water, the accounting framework covers seven other thematic areas:

- Agriculture, forestry and fisheries
- Air emissions accounts
- Energy
- Environmental activity accounts
- Ecosystem accounts (adopted by UN in 2021)[4]
- Land accounts
- Material flow accounts

The outputs consist of a comprehensive set of tables and accounts on the environment and its relationship with the economy. Many countries produce environmental-economic accounts based on SEEA central framework. Australia, Canada and the Netherlands are some of the countries with most experience with SEEA-Water. U.S. has recently announced efforts to develop a standardized U.S. Government Natural Accounting Framework which is seen critical for business and economic growth.[5]

In New Zealand, Stats NZ has been producing national environmental-economic accounts since 2001.[6] The frequency of the reports and the scope they cover is increasing. Currently Stats NZ applies SEEA (at national level) to develop three broad types of account: stocks, flows, and transactions (e.g. environmental expenditures). For water, Stats NZ only produces physical stock accounts (asset accounts) following the SEEA-Water methodology and based on TopNet water model calculations provided by NIWA and GNS. The NZ national water account covers inflows, outflows, and changes in storage levels. The most recent water physical stock account was published in May 2021 and covers the years ended June, from 1995 to 2020.[7] Total opening and closing stocks are not quantified and no water supply and use accounts have been produced to date at a national level.

2.2. Data and ANZSIC codes

Region-specific methods and methodology were developed during the Phase 1 of the project in 2020. This included establishing a list of sources, references and personnel within the regional and district councils. We reported this information against the SEEA-Water methodology using 'data cards'. This process was fluid and data cards were updated as the tables were populated and connections and access to data was unfolding.

The key data sources for the supply and use tables were the HBRC Integrated Regional Information System (IRIS) resource consents database (hereafter, Resource Consents dataset), Department of Internal Affairs (DIA) Three Waters data requests and other data sources direct from district councils (like internal water balance and loss reports, and trade waste volumes) and industry. These sources were complemented by research from relevant academic and grey literature.

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[4] The System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA) is a spatially-based, integrated statistical framework for organizing biophysical information about ecosystems, measuring ecosystem services, tracking changes in ecosystem extent and condition, valuing ecosystem services and assets and linking this information to measures of economic and human activity. SEEA EA was adopted by UN as a statistical framework in 2021.

[5] See more information here Readout: OSTP Initial Engagement on Developing Natural Capital Accounts - The White House

[6] Stats NZ, "Environmental-Economic Accounts: Sources and Methods (Third Edition)."

[7] Stats NZ, "Environmental-Economic Accounts: Water Physical Stocks, Year Ended June 1995–2020."

The list of active consents between 2019 and 2020 was sourced from the Resource Consents dataset. This dataset was directly provided by Hawkes Bay Regional Council, updated for the purpose of this project in November 2021. A description of the contents of the database can be found in Appendix 1. Notably, several resource consents had industrial classifications using the Australia and New Zealand Standard Industrial Classification (ANZSIC) 2006 V1.0.0.[8] Using ANZSIC industry codes ensures the water accounts can be integrated with financial accounts and be used in conjunction with socio-economic data. For more on the alignment with ANZSIC codes, see Box 1.

Following the preliminary classification provided by Hawkes Bay Regional Council, we identified the resource consents without ANZSIC and repeated a similar exercise identifying key words as described previously. This is a time-consuming process as it requires a manual analysis of the details of the resource consents. Finally, we discussed the resource consents that were not easily classified with Stats NZ, who guided use through the final classification process, at a minimum ANZSIC level division.

Stata/SE 17.0 was used for processing the Resource Consents dataset, classifying the resource consents without ANZSIC codes and calculating the volumes of water for the supply and use tables.[9] Note that this information is desegregated for each district and region. See Box 1 for information on how resource consents without ANZSIC codes were brought into alignment with the ANZSIC classification system.

Box 1: Alignment to ANZSIC through a focus on industry categories instead of users

The development and usefulness of the water accounts (now and in the future) is dependent on the ability to combine the water accounts with socio-economic data and growth models, including in relation to assessing value add and high value water use and efficiency. This requires a statistical underpinning of the data through alignment to ANZSIC. Preliminary consultations with Statistics NZ suggest that a potential ANZSIC classification as falling into a Primary, Goods producing and Service industries, where primary industries are ANZSIC classes A and B, Goods producing are C through to E and Service industries are F to T. This is also a classification used commonly within economic statistics to summarise the economy and can help allocating / disaggregating an activity or resource use to the service industries.[1]

Discussions and review of resource consent-related information shows that in line with IRIS system, consent data is coded to use (e.g. irrigation) rather than to economic activity as per ANZSIC system. It was possible to extract data to generate statistical alignment to ISIC / ANZSIC through further coding of primary consent data to be able to generate the data as required for water accounts purposes (see Appendix for the description). However, because there can be multiple uses from a single resource consent, some allocations under ANZSIC are not fully accurate. Further guidance and practice support is required for applying the ANZSIC classifications for organisations with resource consents to increase water accounts accuracy but also enhance usefulness in terms of economic analysis. This is currently considered as part of the development of the next generation consent database, with potential implications for information requirements in consent applications and wider IRIS database scope. There are also data storage implications that will have to be considered as a result.

Data was also sourced through engagement and input from water managers, and consents and compliance teams from the regional council and districts (this was how DIA request data were procured). Direct contact with industry (e.g. hydropower) also contributed to data collection.

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[8] Trewin and Pink, *Australian and New Zealand Standard Industrial Classification (ANZSIC) 2006*.
[9] Do files (Stata coding files) are available upon request.

In compiling the physical supply and use accounts, an ‘increasing scope’ approach was taken by focusing on major water suppliers and users and then expanding based on increased understanding. This helps in identifying and prioritising the most important data sources and determining their level of availability, reliability and ideal level of disaggregation to maximise value.

Detailed information is provided in the following section on how we collected and processed the data to populate the physical use and supply tables.

2.3. Accounting period

The period covered by the accounting is July 2019 to June 2020 (12-month accounting period). This accounting period overlaps with the financial accounting period of many businesses (which is relevant for decision making processes, and when and if monetary accounts will be developed). Having the accounting period end in June also makes sense from a water balance perspective (the water assets are often replenished in winter time). In addition to this, Stats NZ also uses the same accounting period for their water stock balance report. The accounting unit is one thousand cubic meters (one million litres). Some of the data, for example precipitation or metered water abstraction by district councils, are available at high resolution (monthly, daily etc). These nuances and details are captured in the background excel spreadsheets that complement this report. However, monthly data and the capability to distinguish between seasons is not yet feasible for all data points and annual units are used in this report.

Some data retrieved from major consent holders reporting their discharge was not aligned to this accounting period. That is, their reporting requirements meant that information was not available for the full year.[10]

2.4. Spatial resolution

The supply and use water accounts and water assets accounts were developed for the region as well as the four districts, represented by the following district councils:

- Hastings District Council (HDC)
- Napier City Council (NCC)
- Central Hawkes Bay District Council (CHBDC)
- Wairoa District Council (WDC)

There is a difference between administrative boundaries, catchment boundaries and water assets extent and decisions were made to enable the systematic accounting across the different spatial resolutions. These decisions are explained in methods and calculations.

2.5. Data rating

The following data rating (using shadings) was applied to depict the reliability of datasets and values that sit behind the water accounting tables.

These ratings are high level and indicative only. The rating use is intended as guidance and an acknowledgement that demands on the use of data are increasing in terms of scope and complexity and the sources of water related are continuously developing to address such needs. Consequently, there is a spectrum of reliability for water accounting data sources.

The shadings used include:

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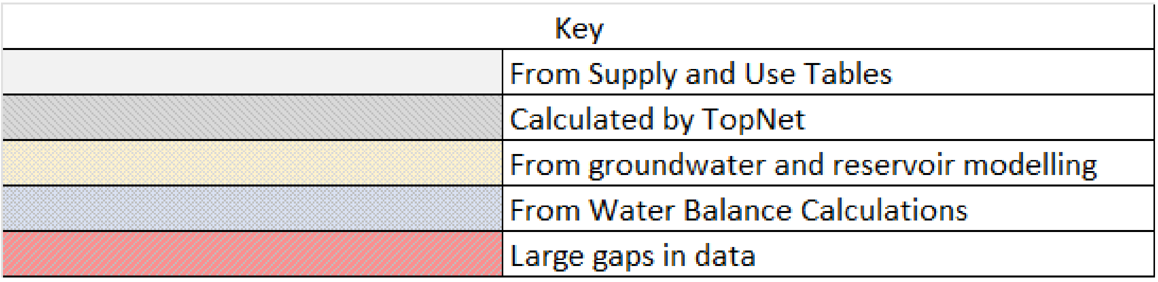
[10] Data has not been extrapolated to estimate for a full year because discharge is dependent on economic activity and is influenced by more than simply the season (e.g. COVID-19 would have impacted heavily on economic activity for some or all of these major consent holders).

A (green):	value/data used is based on actual measurements and/or records of high frequency and site resolution (as part of compliance procedures, enviro monitoring) (e.g drinking water abstraction)
B (blue):	value/data is based on resource consent parameters (not measured) or may involve some limited actual measurements/records but rely on modelling and extrapolation (e.g. precipitation) but some gaps exist (e.g. permitted activities not yet monitored/metered)
C (orange):	largely determined as result of top-down modelling or extrapolation/estimation from a limited data set (e.g. discharges) with some gaps in data sets.
D (red):	estimates using data not specific to the region (e.g stormwater) or using data sets not highly reliable with major gaps.

For the water assets tables, there are additional data categories to reflect information coming from various sources (Figure 4).



Key	
⬜	From Supply and Use Tables
▨	Calculated by TopNet
🟨	From groundwater and reservoir modelling
🟦	From Water Balance Calculations
🟥	Large gaps in data

Figure 4. Key for interpreting water assets data sources

3. Water Supply and Use Accounting

3.1. Physical supply and use tables for water

The physical supply and use tables described by SEAA-Water aim to track and quantify the abstraction, use and returns of water within a system or territory.

SEEA-Water provides a specific organising template (table) for water supply and use, informed by the concept of flows and interactions between the environment and the economy, namely:

- flows from the environment to the economy;
- flows within the economy; and
- flows from the economy to the environment.[11]

The standard economic activities included in the SEAA-Water physical supply and use tables include:

- agriculture, forestry and fishing,
- mining and quarrying, manufacturing, and construction,
- electricity, gas, steam and air-conditioning supply,
- water collection, treatment and supply,
- sewerage,

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[11] Flows within the environment (between water sources) are reported in the water assets tables.

- service industries, and
- households.

Water abstraction and use for the supply and use tables are computed using the IRIS resource consents database, data from specific industries.

Building on the experience of using ANZSIC, we reorganised the industry groups. Agriculture, forestry and fishing includes resources consents under the ANZSIC division A and subdivision 01, 02-04. mining and quarrying, manufacturing, and construction includes resource consents under the ANZSIC divisions B, C and E. Electricity, gas, steam and air-conditioning supply includes resource consents under the ANZSIC division D and subdivisions 26 and 27. Water collection, treatment and supply includes resource consents under the ANZSIC division D, subdivision 29 and class 281100. Sewerage includes resource consents under the ANZSIC division D and class 291200. Service industries includes resource consents under the ANZSIC divisions F-S.[12]

The SEEA template was further adapted for Hawkes Bay to include water use categories such as drinking water for livestock. We also exclude volume estimates for water supplied and used for electricity production, which we discuss below.

Exclusion of electricity generation

In Hawke's Bay, there is considerable hydroelectric power generation, particularly from the Waikaremoana Power Scheme operated by Genesis Energy. The Waikaremoana Power Scheme has an outsized impact on water abstraction, as the scheme generates hydroelectric power for many parts of New Zealand. To put it in context, if we include abstraction from the Waikaremoana Power Scheme, total abstractions from the environment for the Hawke's Bay Region would more than triple in size. This level of water abstraction and discharge (because all abstracted water is discharged back into the river) would distort the overall water accounts and the breakdown of water use by districts. Furthermore, water abstraction and use for hydroelectric power generation is non-consumptive (because the same volume of water is discharged). This is fundamentally different to water use within the broader economy for things like human consumption, manufacturing and agriculture. Due to these fundamental differences and the likelihood of account distortion, we agreed with HBRC to exclude water for electricity from the water supply and use tables, water assets tables and our further analyses.

Of course, qualitatively, hydroelectric water abstraction and discharge is of importance for ecosystem health and recreational riverine activities. While we acknowledge these issues, in this report, we do not discuss these impacts in depth. Theoretically, hydroelectric power schemes (like the Waikaremoana) will offset or mitigate any adverse environmental impacts as a condition of consent. Moreover, adverse environmental impacts may be greater during the initial construction and establishment of the hydroelectric schemes and fall to a stable equilibrium over time. We leave the complexity around the environmental impacts of these hydroelectric power schemes to the respective hydrology, environmental science, compliance and resource management teams at HBRC.

3.2. Results for regional supply and use tables

Table 1 shows the regional water use accounts and Table 2 shows the regional water supply accounts. Figure 3 depicts the supply and use tables visually. Overall, 155.79 million m^3 of water was abstracted from the Hawke's Bay Region over the reporting period. 49.4 million m^3 of that abstraction is recirculated within the economy (for water consumption, sewerage treatment and water distribution). Agriculture is the largest user of water, using 88.49 million m^3.

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[12] Trewin and Pink, *Australian and New Zealand Standard Industrial Classification (ANZSIC) 2006*.

Table 2. Regional water use table

		Industries (by ANZSIC category)							Households	Rest of the world	Total
		A	B, C, E	D(26&27)	D(29&D281100)	D281200	F-S	Total			
Physical use table (thousands cubic metres)		Agriculture, Forestry and Fishing (01, 02-04)	Mining, quarrying, manufacturing and construction	Electricity, gas, steam and air-conditioning supply	Water collection, treatment and supply	Sewerage	Service Industries				
From the environment	**Total Abstraction E.1**	88,487	18,689		26,952	79	1,951	136,158	2,490		138,647
	Abstraction for own use	88,487	18,689		749	79	1,837	109,840	2,490		112,330
	Hydroelectric power generation							0			0
	Irrigation water	71,597	1		459	0	1,069	73,125	26		73,151
	Mine water							0			0
	Urban run-off							0			0
	Cooling water	0	1,466		0	0	0	1,466	0		1,466
	Livestock (permitted activities)	16,865						16,865			16,865
	Households							0	2,463		2,463
	Manufacturing		15,200					15,200			15,200
	Other	25	2,023		290	79	768	3,185	0		3,185
	Abstraction for distribution	0	0		26,203	0	114	26,317	0		26,317
	From inland water resources:	88,487	18,689		26,952	79	1,951	136,158	1,432		137,589
	Surface water	29,837	3,598		15,213	0	0	48,648	260		48,908
	Ground water	58,650	15,092		11,738	79	1,951	87,510	1,171		88,681
	Soil water							0			0
	Collection of precipitation E.2							0	1,058		1,058
	Abstraction from the sea							0			0
Within the economy	**Use of water received from other economic units**	0	2,892		0	29,606	2,794	36,118	13,282		49,400
	of which:										
	Reused water	0	0		0	0	0	0	0		0
	Wastewater to sewage	0	0		0	29,606	0	29,606	0		29,606
	Distributed water	0	2,892		0	0	2,794	6,512	13,282		19,794
Total use of water		88,487	21,581		26,952	29,685	4,745	172,276	15,772		188,048

Table 3. Regional water supply table

Physical supply table (thousands cubic metres)		Agriculture, Forestry and Fishing (01, 02-04)	Mining, quarrying, manufacturing and construction	Electricity, gas, steam and air-conditioning supply	Water collection, treatment and supply	Sewerage	Service Industries	Total	Households	Rest of the world	Total
Within the economy	**Supply of water to other economic units**	27	9,258		19,794	0	3,151	32,231	17,169		49,400
	of which:							0			
	Reused water	0	0		0	0	0	0	0		0
	Wastewater to sewage	27	9,258		0	0	3,151	12,437	17,169		29,606
	Distributed water	0	0		19,794	0	0	19,794	0		19,794
Into the environment	**Total returns**	17,118	4,902		6,043	29,606	0	57,669	1,662		59,331
	Hydroelectric power generation	0	0		0	0	0	0	0		0
	Irrigation water	7,148	0		0	0	0	7,148	0		7,148
	Mine water	0	0		0	0	0	0	0		0
	Urban run-off	0	0		0	0	0	0	0		0
	Cooling water	0	0		0	0	0	0	0		0
	Livestock (permitted activities)	9,970	0		0	0	0	9,970	0		9,970
	Households	0	0		0	0	0	0	1,662		1,662
	Losses in distribution because of leakages	0	0		6,043	0	0	6,043	0		6,043
	Treated wastewater	0	4,117		0	29,606	0	33,723			33,723
	Other	0	785		0	0	0	785	0		785
	To inland water resources	17,118	1,566		6,043	1,372	0	26,099	1,662		27,760
	Surface water	0	785		0	1,225	0	2,011	0		2,011
	Groundwater	0	0		0	0	0	0	0		0
	Soil water	17,118	781		6,043	146	0	24,088	1,662		25,750
	To other sources (e.g. sea water)	0	3,336		0	28,234	0	31,571	0		31,571
Total supply of water		17,145	14,161		25,837	29,606	3,151	89,900	18,831	0	108,731
	Consumption	71,226	7,420		1,115	79	1,794	81,635	-3,059	0	78,576
	of which:	0	0		0	0	0	0	0	0	0
	Losses in distribution not because of leakages	0	0		956	0	0	956	0	0	956

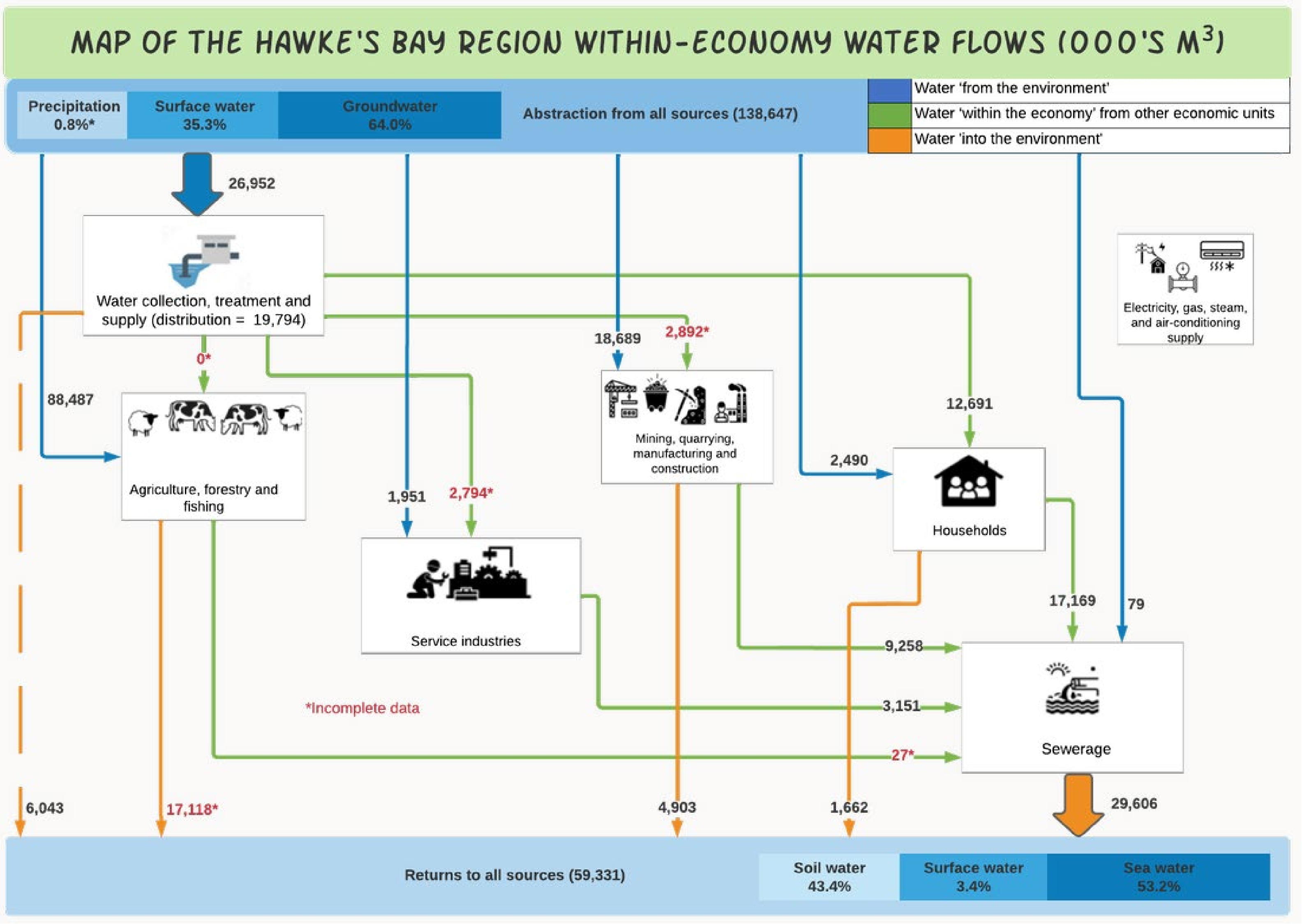

Figure 5. Regional schematic overview of water supply and use

3.3. Results for districts' supply and use tables

Please see Appendix 2 for the full supply and use tables (as seen for the region) for each district or city council.

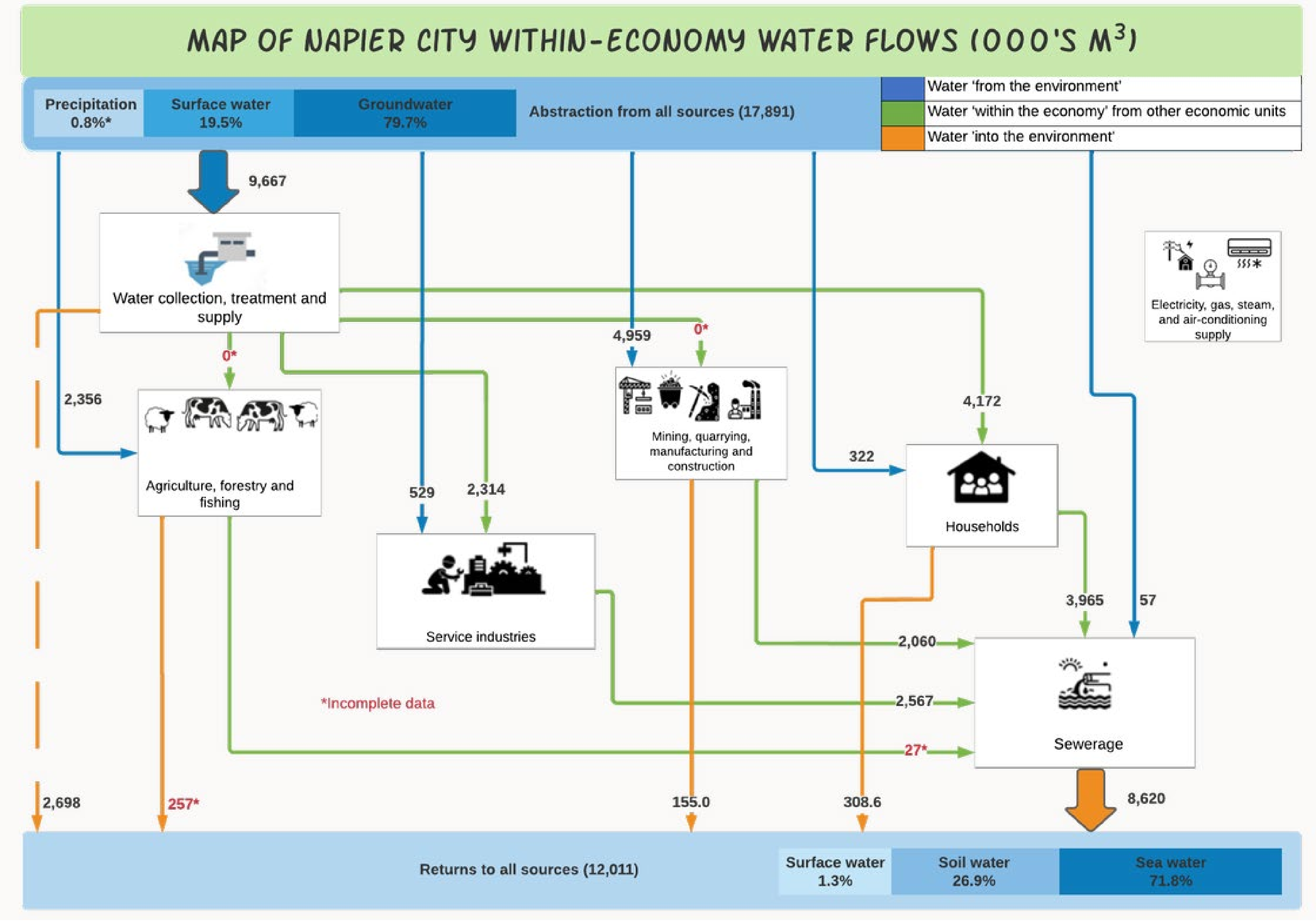

Figure 6. Napier City schematic overview of water supply and use

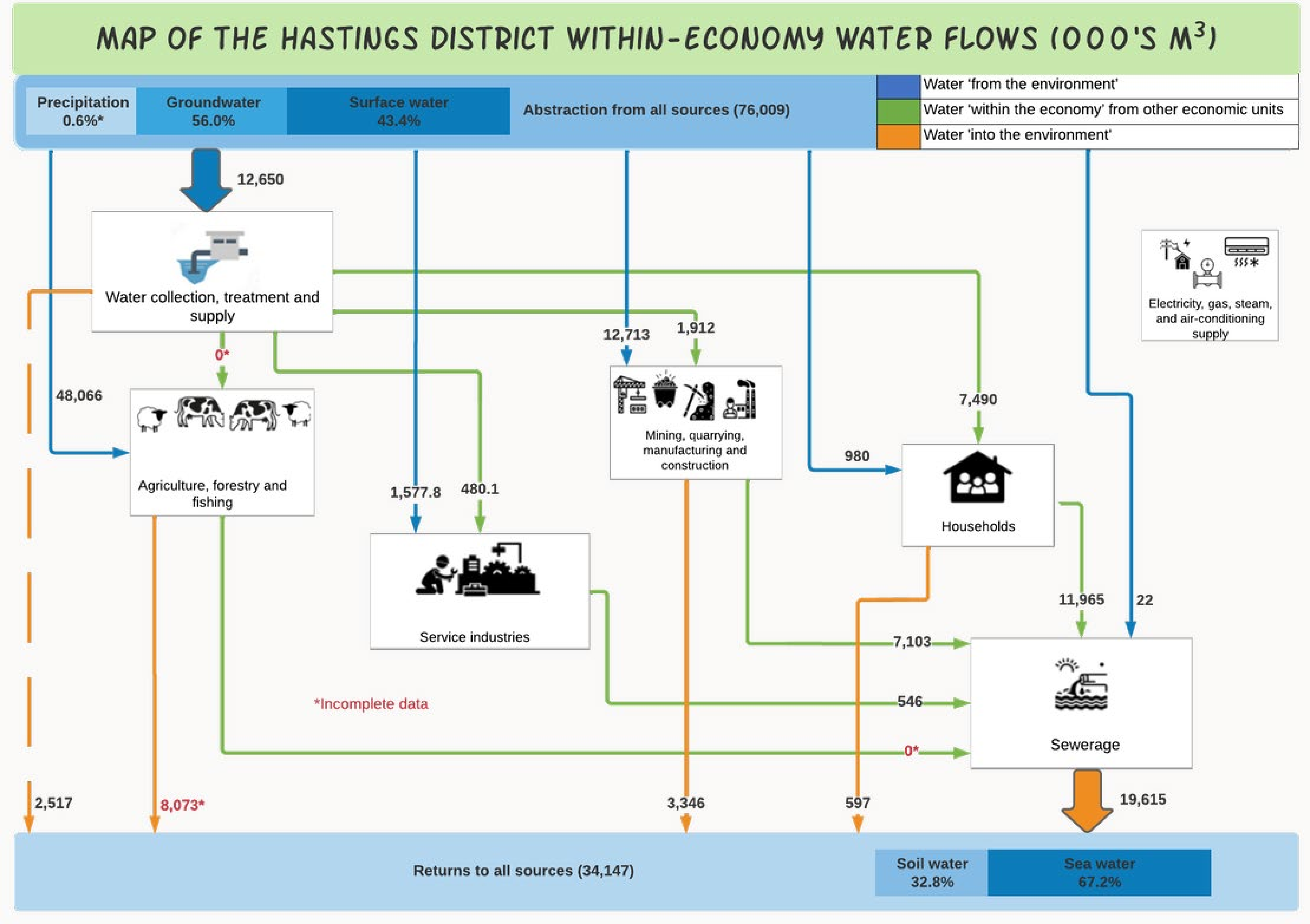

Figure 7. Hastings District schematic overview of water supply and use

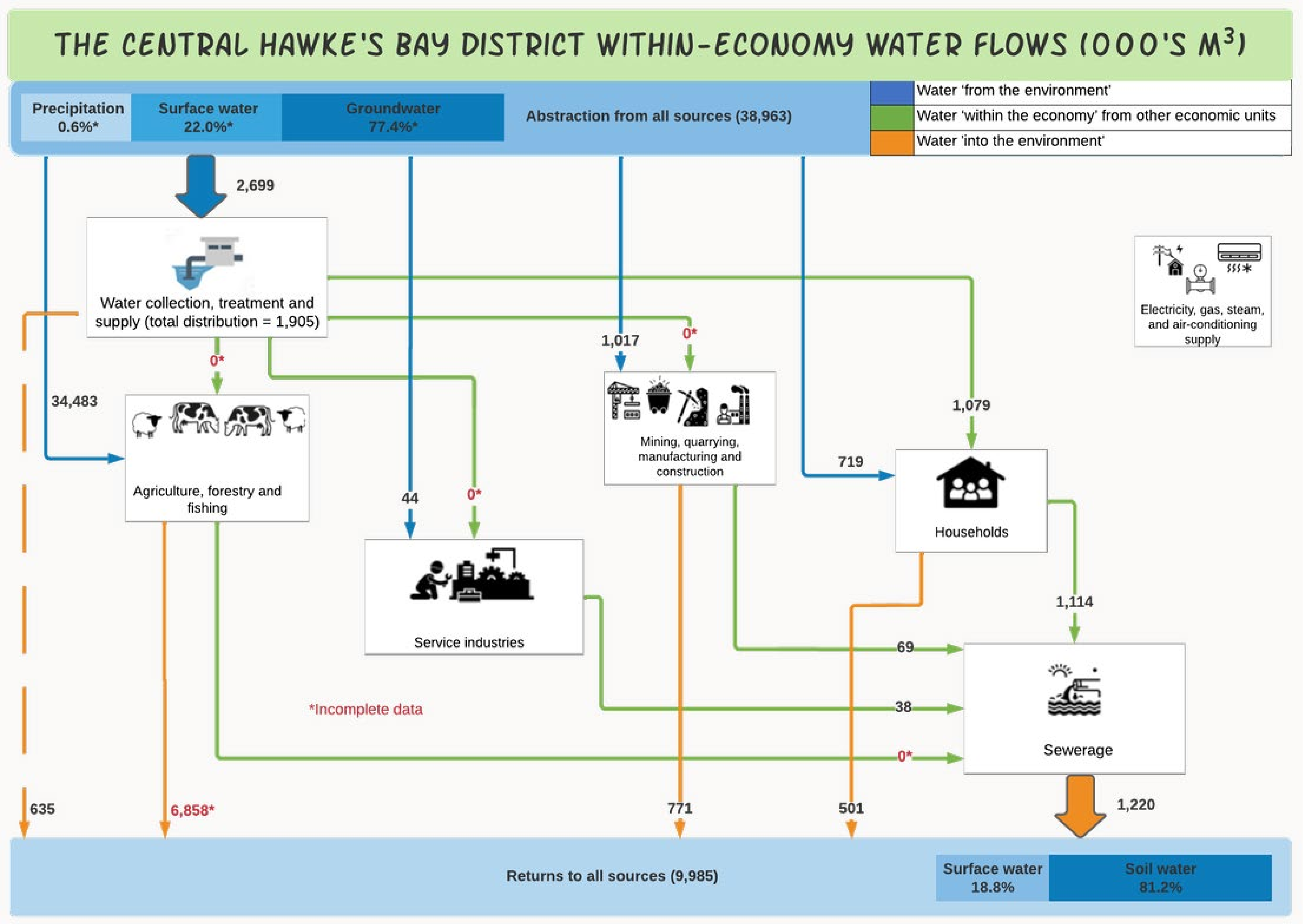

Figure 8. Central Hawke's Bay District schematic overview of water supply and use

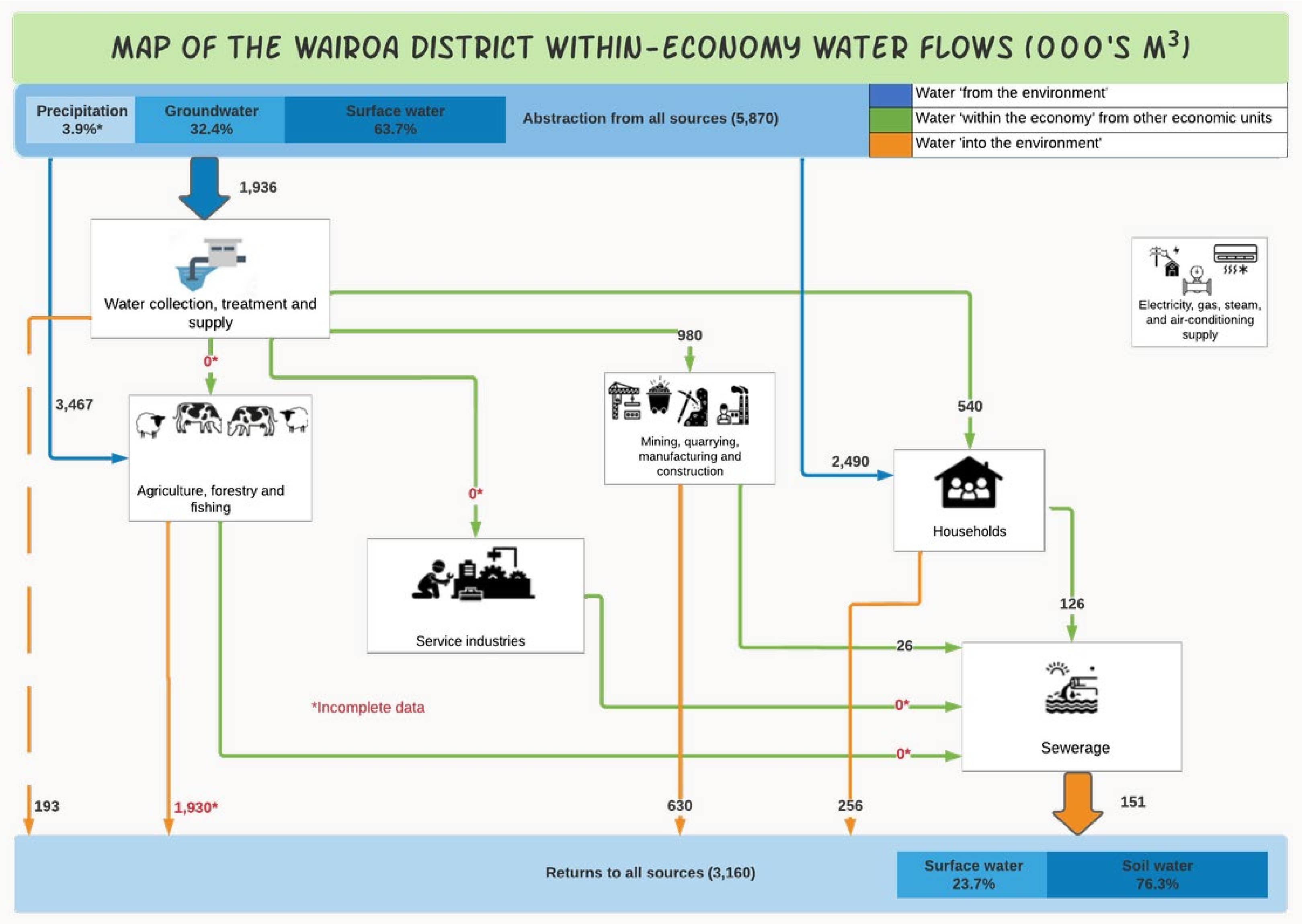

Figure 9. Wairoa District schematic overview of water supply and use

4. Water assets accounting

Water assets tables are produced in line with the SEAA-Water methodology for water assets accounting. As mentioned earlier, Stats NZ produce high-level overviews of physical water assets for each region. They follow the SEEA-Water methodology, but do not account for human interaction with water and do not provide data on the opening and closing stocks of water assets. In that sense, Stats NZ reporting on physical water stocks is based on a purely hydrological model of water movement (which excludes anthropogenic involvement in the water cycle).

SEEA-Water methods divide water assets into:

- Surface waters: Artificial reservoirs / storage; Lakes; Rivers and streams; and Glaciers, snow and ice;
- Groundwater
- Soil water.

The supply and use tables report abstraction and returns to surface water (not individual assets). Thus, when developing the assets accounts, the surface water results from the supply and use tables are separated into the appropriate asset classes. For more on this process, see section 3.2. The next two sub-sections describe the methods for producing the modelled data for the water assets tables (section 4.1.) and the underlying principles of the water assets tables (section 4.2.).

4.1. Water assets components methodology

To facilitate the calculations of water assets, a tiered-spatial approach was agreed made up of 15 catchment zones (list below) and 262 sub-catchments.

1. Ahuriri
2. Esk
3. Karamu
4. Mahia
5. Mohaka
6. Ngaruroro
7. Nuhaka
8. Porangahau
9. Southern Coast
10. Tukituki
11. Tutaekuri
12. Waihua
13. Waikari
14. Wairoa
15. Catchments not named / outside boundaries

Lakes, rivers and soil water

NIWA’s TopNet rainfall-runoff model (a semi-distributed hydrological model) is used to calculate the opening stocks of lakes, rivers and soil water assets. TopNet also estimates the distribution of precipitation (based upon asset land coverage), evapotranspiration and river flows. Below are basic descriptions of the methods used:[13]

- The TopNet model used for this project is uncalibrated. Parametrisation of the model is based on national scale datasets (see Griffiths et al 2021 for further information). As a result, the hydrological model has not been tuned to match historical surface flow observations in the Hawkes Bay region.
- Due to the relative simplicity of the groundwater model used in this version of the TopNet model, all rivers located within Hawkes Bay region are classed as gaining rivers.
- Soil water content is the volume of water stored in the soil rooting zone (usually the top one metre of soil). Soil water is simulated by TopNet and depends on soil type, land use, rainfall and evapotranspiration (which also depends on soil water – this is one interdependency within the model).
- River stocks are taken as the volume of water in the active riverbed (in line with SEAA-Water methodology) at the start and end of the reporting period. River flows are simulated by TopNet.
- River flows to other regions are estimated using TopNet under the assumption that no abstraction occurs. Those exchanges occur when surface water catchment and associated river reaches cross any of the reporting boundaries. This is corrected using supply and use data when the water assets accounts are compiled.
- Lake/large surface water body stocks are taken as the measured volumes of lakes at the start and end of the recording period; Lakes volume are calculated for 35 (natural) lakes linked to the aggregated river network (i.e. the lake/surface water body is physically connected to the aggregated river network).
- Overall precipitation is based on actual measurements and is applied to soil/vegetation and large surface water bodies. Precipitation on non-modelled surface water assets by TopNet is distributed between assets based on relative area coverage and is not removed from the overall water balance approach.
- Evapotranspiration is simulated by TopNet as actual soil evapotranspiration based on measurements of wind speed, temperature, solar radiation, data on vegetation and estimates of soil water content. Evapotranspiration from non-modelled surface water assets by TopNet is distributed between assets based on relative area coverage and is not removed from the overall water balance approach.

Groundwater and artificial reservoirs

These assets were calculated based on an extensive review of relevant information pertaining to developing an estimate of groundwater and water storage for the Hawke's Bay Region. It appears that many of the approaches and reports are vastly under counting the amount of storage held in groundwater across the HB region. Therefore, to develop a scientifically credible estimates for Hawkes Bay, a combination between data outputs from the Topnet Model, GIS Spatial Analysis and expert judgements of storage estimates for the eight aquifer types across is applied.

Groundwater

The following items were calculated for each of the modelled sub-catchment areas (262 sub-catchments) through TopNet model run, at a minimum we would require:

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[13] For more information, see: NIWA, "New Zealand Water Accounts Update 2020."

- Total Groundwater Recharge – Topnet is cumulative infiltration from the root zone to the saturated zone (d).
- Total Groundwater Discharge – Topnet reports as cumulative baseflow discharge (qb).
- Total GW Storage – Topnet reports as total storage in the aquifer at the start and end of the year (Sa).
- Basic water budget parameters by 15 Catchments Zones

It should be noted that TopNet only simulates and reports groundwater recharges and discharges for sub-catchments that are associated with receiving streams, rivers or lakes. It does not simulate groundwater discharges to the ocean. Consequently, TopNet does not provide recharge and discharge values for small coastal catchments that lack a receiving stream or river and where all groundwater is considered to discharge offshore. These coastal sub-catchments represent a small fraction of the overall area of the Hawke's Bay and are generally in areas where there is little utilisation of groundwater resources. Consequently, these catchments have been excluded from the current stocktake as a change in storage through the reporting period cannot be provided from the TopNet model outputs.

Methodology beyond TopNet: The outputs from TopNet were augmented with the GNS hydrogeological map and the HBRC wells GIS shapefile database to generate estimates of groundwater storage and usage across all of HB. Further information on methodology can be found in Appendix 3.

Artificial reservoirs / storage ponds

- There are several thousand ponds across the region, of different size.
- Several sources of data are used to determine volume, including a 2014 master these on water storage on farms in Hawkes Bay
- Allocation of precipitation and evapotranspiration to reservoirs is carried out through postprocessing of TopNet simulations. This is based on the area covered by reservoirs (run off is not included at this point), is not removed from the soil water balance and assumes that the reservoir is empty at the start of the simulation (i.e. no reservoir overflow is simulated).
- Allocation of runoff and other inflows are produced through water balance calculations (using reservoir volumes, evapotranspiration and precipitation).
- Total cumulative precipitation (P) and total cumulative evaporative losses (er + ec) for the region are generated by the TopNet model.
- It is assumed that artificial reservoirs are full at the start of the period and full at the end of the period (total inflows – precipitation, returns to reservoirs, runoff – equal total outflows – abstractions for irrigation and stockwater and evapotranspiration.

4.2. Considerations and methodology for assets tables

The assets accounts align with the basic hydrological model described in section 1. The following list documents some important considerations for interpreting water assets accounts (informed by the SEAA-Water framework).

- Closing stocks represents opening stocks, plus increases in stocks, minus decreases in stocks.

- The water assets tables do not include water flows *within* the economy. The assets tables track water movement relating to water assets and therefore do not account for water movement between economic agents.
- The stock of a river is measured as the volume of the active riverbed at the point of reference (time of the opening and closing stock measurements). However, rivers are in constant motion and the flows in and out of rivers tend to be substantially greater than the snapshot stock of the river (over an accounting period). For example, based on the results in this report, annual flows could be anywhere between 20 to 100 times greater than the opening or closing stocks. This will vary significantly by geography, river volumes, river flow speed and other factors.
- Actual evapotranspiration is a simulated quantity (by NIWA in this instance) that represents all evaporation and plant transpiration that returns water vapour to the atmosphere. Water taken up by plants (pasture, crops, horticulture, trees) will be returned through this process. Similarly, evaporation from surface water is recorded here.
- Water assets accounts can describe flows between water assets. The first generation assets accounts in this report have limited information of these flows because there is insufficient data. However, we expect exchanges between assets to be significant in some cases. For example, Figure 10 provides a visual description of the New Zealand Water Model and you can see that snow melts and moves into river systems, surface precipitation runs off into rivers and soil water drains into groundwater assets. These exchanges are known to be hydrologically significant.

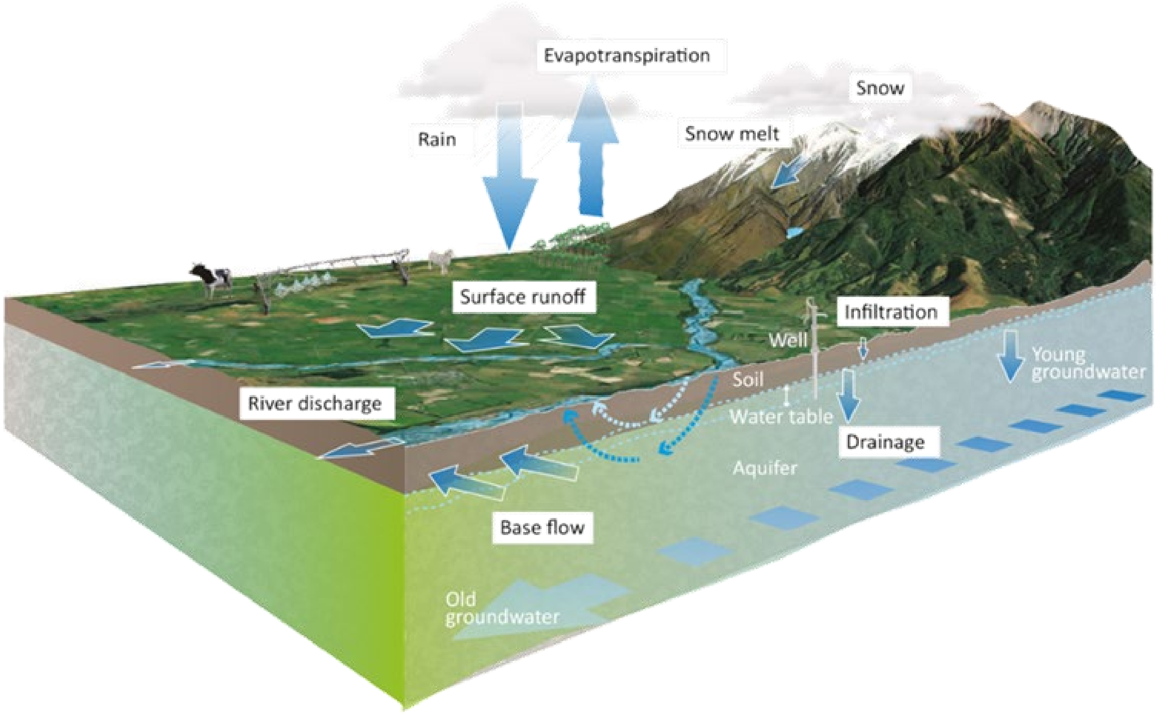

Figure 10. Diagram of the New Zealand Water Model (illustrating flows between assets).[14]

- Inflows from, and outflows to, other resources within the region represent water moving between assets over the accounting period. In the assets tables (see Table 3 as template), these flows do not affect overall stocks as total inflows are balanced by total outflows.
- The assets tables include flows to seawater. For example, outflows from rivers to oceans/seas and precipitation into other resources (a significant portion of precipitation originates from seawater).

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[14] NIWA, "The New Zealand Water Model (NZWaM) – a New Water Modelling Approach."

- Because of the above point, total returns to the environment from the supply and use accounting tables do not equal total returns in the assets tables. Returns to the sea from economic agents (predominantly through treated wastewater discharge) are not included in the assets tables.
- Likewise, total abstraction in the assets tables differs from total abstraction in the supply and use tables. The supply and use tables include the collection of precipitation as an abstraction. Precipitation is not an asset – rather, it is a process in the hydrological cycle that is linked with several water assets. Thus, the assets tables do not contain "abstraction" from precipitation.
- Abstraction for "other uses" includes household abstraction, abstraction for cooling water (and other minor abstractions.
- Lag time between the different sources of water (mainly surface water/groundwater/river water) within the region is assumed to be less than one year. This assumes that any rainfall falling anywhere within Hawkes Bay region will discharge at sea within the accounting year. This is an important assumption impacting the water accounting.

4.3. Regional assets accounting results

The assets accounts for the region are in Table 4. The complexities of the hydrological cycle and the lack of models/previous practice in New Zealand make it difficult to generate assets accounts. As more work is done, these difficulties will be reduced in magnitude and a more comprehensive overview of water assets will be possible. We performed water balance calculations to estimate the distribution of precipitation and flows of water between assets. As a reminder, the key for the water assets tables is reported in Section 2.5.

We also show a Table of flows between water assets in Table 5. These flows are far from comprehensive (as broadly, there is little modelling of these inter-asset flows) but it is important to recognise the interdependencies that exist between water assets. In the water assets tables, inter-asset flows are described under the flows from and to other resources in the region. Table 5 is a way of breaking these flows down to understand how and where water is moving between assets.

Table 4. Regional water assets table.

Regional: Period: 1 July 2019 – 30 June 2020, Volume, thousands cubic metres							
	Artificial reservoirs	**Lakes**	**Rivers**	**Snow**	**Groundwater**	**Soil water**	**Total**
Opening stocks	**34,729**	**5,061,873**	**137,924**	**5**	**4,774,664**	**272,948**	**10,282,143**
Increase in stocks (A+B+C)	**36,895**	***1,109,870***	***14,073,639***	***41,916***	**10,881,581**	***16,082,476***	**42,226,377**
A. Precipitation	13,080	100,852	148,050	41,916	0	16,056,726	**16,360,624**
B. Inflows	23,797	1,009,018	13,906,450	0	10,881,581	0	**25,820,846**
B.i. From other regions	0	0	2,491,761	0	0	0	**2,491,761**
B.ii. From other resources within region	23,797	1,009,018	11,414,689	0	10,881,581	0	**23,329,085**
C. Returns (Ci+Cii+Ciii)	**19**	**0**	**19,138**	**0**	**0**	**25,750**	**44,907**
C.i. Irrigation leakage	0	0	0	0	0	7,148	**7,148**
C.ii. Effluent discharge (Livestock)	0	0	0	0	0	9,970	**9,970**
C.iii. Treated wastewater	0	0	2,011	0	0	927	**2,938**
C.iv. Distribution leakages	0	0	0	0	0	6,043	**6,043**
C.v. Hydroelectric discharge	19	0	17,127	0	0	0	**17,146**
C.vi. Other discharges	0	0	0	0	0	1,662	**1,662**
Decreases in stocks (D+E+F)	**36,876**	***1,105,304***	***13,840,181***	***41,906***	**10,470,206**	***15,873,999***	**41,368,473**
D. Evaporation/actual evapotranspiration	13,553	56,739		41,906	0	5,275,811	**5,388,009**
E. Outflows	0	1,048,528	13,806,201	0	10,389,958	10,598,188	**35,842,875**
E.i. To downstream territories	0	0	5,299,801	0	0	0	**5,299,801**
E.ii. To the sea	0	0	7,213,989	0	0	0	**7,213,989**
E.iii. To other resources within region	0	1,048,528	1,292,411	0	10,389,958	10,598,188	**23,329,085**
F. Abstraction	**23,323**	**37**	**33,980**	**0**	**80,248**	**0**	**137,589**
F.i. Irrigation	6,458	3	15,072	0	51,618	0	**73,151**
F.ii. Livestock	16,865	0	0	0	0	0	**16,865**
F.iii. Manufacturing	0	0	3,452	0	11,748	0	**15,200**
F.iv. Distribution	0	34	15,045	0	11,238	0	**26,317**
F.v. Hydroelectric power generation	0	0	0	0	0	0	**0**
F.vi. Other uses	0	0	412	0	5,645	0	**6,056**
Other changes in volume*							**0**
Closing stocks (Opening + Increases - Decreases)	**34,748**	**5,066,439**	**371,382**	**15**	**5,186,038**	**481,425**	**11,140,047**

* most likely zero

Water balance calculations

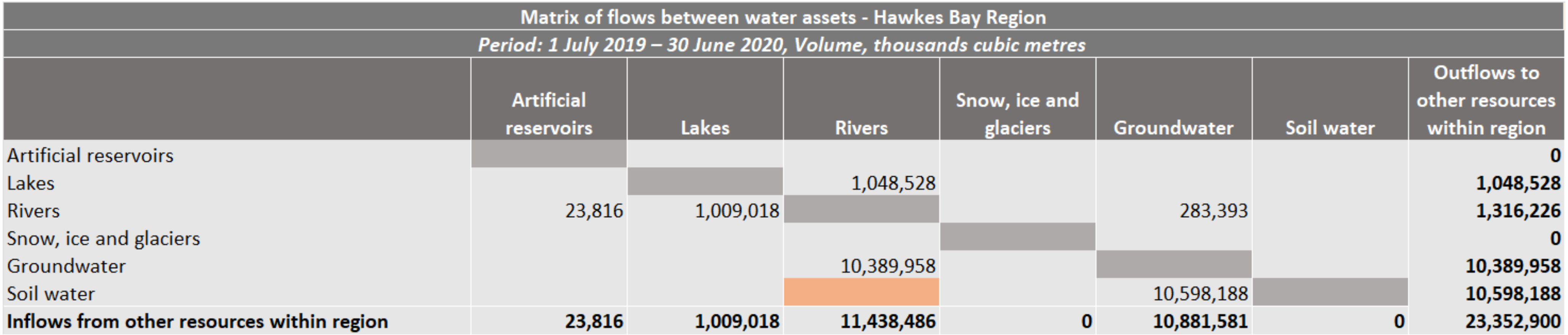
In some instances, modelled inflows and outflows of water did not align to the opening and closing asset stocks reported by TopNet. This is in large part because TopNet has limited capability in modelling the full range of water exchanges between assets (like runoff to rivers, or water flowing from groundwater to rivers). We perform water balance calculations to compute the required inflows and outflows (excluding anthropogenic contributions initially) to reconcile the closing and opening stocks estimates. These water balance calculations include:

- Estimating outflows to other water assets from soil water (as precipitation far exceeds evapotranspiration and the modelled closing stocks).
    - These outflows are very similar to the modelled inflows to groundwater, so we assume that all excess soil water moves to groundwater.
- Inflows to artificial reservoirs were estimated by considering the difference between opening and closing stocks, evapotranspiration and precipitation.
- Flows to rivers (from other water resources) were calculated as the outflows from groundwater (which itself was modelled using the methodology in Appendix 3) plus the outflows from lakes to other resources (modelled by TopNet) less the inflows to artificial reservoirs (see point above).
- Flows from rivers (to other water resources) were calculated as the inflows to lakes from other water resources (TopNet) plus the inflows to groundwater which were left outstanding after accounting for flows of soil water.

It is important to note that these water balance estimates and flows are not necessarily the actual flows that occurred in the given accounting period. A full hydrological assessment of the exchanges between water assets was outside the scope of this work and would be challenging given the current state of data and modelling in New Zealand. Rather, these exchange calculations serve to ensure that we can appropriately incorporate multiple data sources and produce meaningful water asset accounts. Not doing so would leave closing stocks as unreasonably high (or negative) based on the opening stocks, plus inflows, minus outflows. Or, we could include the TopNet modelled closing stocks, but they wouldn't align with the rest of the table. Either way, without these water balance estimates, the assets accounts would not make sense. Hence, while some assumptions may be unsettling or relatively strong, they are necessary to compute the water assets tables. In saying that, these assumptions can be changed if required (but some strong assumptions will always be required, given current data and modelling limitations).

We also show a Table of flows between water assets in Table 5. These flows are far from comprehensive (as broadly, there is little modelling of these inter-asset flows) but it is important to recognise the interdependencies that exist between water assets. In the water assets tables, inter-asset flows are described under the flows from and to other resources in the region. Table 5 is a way of breaking these flows down to understand how and where water is moving between assets.

Table 5. Matrix of flows between water assets at the regional level.



Matrix of flows between water assets - Hawkes Bay Region

Period: 1 July 2019 – 30 June 2020, Volume, thousands cubic metres

	Artificial reservoirs	Lakes	Rivers	Snow, ice and glaciers	Groundwater	Soil water	Outflows to other resources within region
Artificial reservoirs							**0**
Lakes			1,048,528				**1,048,528**
Rivers	23,816	1,009,018			283,393		**1,316,226**
Snow, ice and glaciers							**0**
Groundwater			10,389,958				**10,389,958**
Soil water					10,598,188		**10,598,188**
Inflows from other resources within region	**23,816**	**1,009,018**	**11,438,486**	**0**	**10,881,581**	**0**	**23,352,900**

4.4. Districts assets accounting results

The districts water assets tables are presented over the following four pages.

Table 6. Napier City water assets table.

Napier: Period: 1 July 2019 – 30 June 2020, Volume, thousands cubic metres							
	Artificial reservoirs	Lakes	Rivers	Snow	Groundwater	Soil water	Total
Opening stocks	**443**	**0**	**414**	**0**	**30,495**	**1,212**	**32,565**
Increase in stocks (A+B+C)	**227**	***0***	***1,606,498***	***0***	**26,454**	***70,436***	**1,703,615**
A. Precipitation	123	0	0	0	0	67,173	**67,296**
B. Inflows	104	0	1,606,343	0	26,454	0	**1,632,901**
B.i. From other regions	0	0	1,580,324	0	0	0	**1,580,324**
B.ii. From other resources within region	104	0	26,019	0	26,454	0	**52,577**
C. Returns (Ci+Cii+Ciii)	**0**	**0**	**155**	**0**	**0**	**3,263**	**3,418**
C.i. Irrigation leakage	0	0	0	0	0	230	**230**
C.ii. Effluent discharge (Livestock)	0	0	0	0	0	27	**27**
C.iii. Treated wastewater	0	0	155	0	0	0	**155**
C.iv. Distribution leakages	0	0	0	0	0	2,698	**2,698**
C.v. Hydroelectric discharge	0	0	0	0	0	0	**0**
C.vi. Other discharges	0	0	0	0	0	309	**309**
Decreases in stocks (D+E+F)	**227**	***0***	***1,612,728***	***0***	**38,933**	***65,961***	**1,717,850**
D. Evaporation/actual evapotranspiration	183	0		0	0	38,084	**38,267**
E. Outflows	0	0	1,609,265	0	24,699	27,877	**1,661,842**
E.i. To downstream territories	0	0	1,418,972	0	0	0	**1,418,972**
E.ii. To the sea	0	0	190,293	0	0	0	**190,293**
E.iii. To other resources within region	0	0	0	0	24,699	27,877	**52,577**
F. Abstraction	**44**	**0**	**3,463**	**0**	**14,234**	**0**	**17,741**
F.i. Irrigation	0	0	46	0	3,006	0	**3,052**
F.ii. Livestock	44	0	0	0	0	0	**44**
F.iii. Manufacturing	0	0	3,417	0	1,504	0	**4,921**
F.iv. Distribution	0	0	0	0	9,463	0	**9,463**
F.v. Hydroelectric power generation	0	0	0	0	0	0	**0**
F.vi. Other uses	0	0	0	0	261	0	**261**
Other changes in volume*							**0**
Closing stocks (Opening + Increases - Decreases)	**443**	**0**	**-5,816**	**0**	**18,017**	**5,687**	**18,330**

* most likely zero

Table 7. Hastings District water assets table.

Hastings: Period: 1 July 2019 – 30 June 2020, Volume, thousands cubic metres

	Artificial reservoirs	Lakes	Rivers	Snow	Groundwater	Soil water	Total
Opening stocks	**11,033**	**39,161**	**52,451**	**3**	**1,711,312**	**97,280**	**1,911,240**
Increase in stocks (A+B+C)	**16,553**	***28,781***	***32,241,772***	***22,948***	**3,375,221**	***5,306,918***	**40,992,193**
A. Precipitation	3,662	3,341	0	22,948	0	5,295,722	**5,325,673**
B. Inflows	12,891	25,440	32,224,645	0	3,375,221	0	**35,638,197**
B.i. From other regions	0	0	29,055,091	0	0	0	**29,055,091**
B.ii. From other resources within region	12,891	25,440	3,169,554	0	3,375,221	0	**6,583,106**
C. Returns (Ci+Cii+Ciii)	**0**	**0**	**17,127**	**0**	**0**	**11,197**	**28,324**
C.i. Irrigation leakage	0	0	0	0	0	4,134	**4,134**
C.ii. Effluent discharge (Livestock)	0	0	0	0	0	3,940	**3,940**
C.iii. Treated wastewater	0	0	0	0	0	10	**10**
C.iv. Distribution leakages	0	0	0	0	0	2,517	**2,517**
C.v. Hydroelectric discharge	0	0	17,127	0	0	0	**17,127**
C.vi. Other discharges	0	0	0	0	0	597	**597**
Decreases in stocks (D+E+F)	**16,553**	***28,725***	***32,218,603***	***22,943***	**3,178,646**	***5,214,392***	**40,679,862**
D. Evaporation/actual evapotranspiration	4,334	4,415		22,943	0	1,820,487	**1,852,179**
E. Outflows	0	24,307	32,194,453	0	3,139,454	3,393,905	**38,752,119**
E.i. To downstream territories	0	0	28,476,895	0	0	0	**28,476,895**
E.ii. To the sea	0	0	3,692,118	0	0	0	**3,692,118**
E.iii. To other resources within region	0	24,307	25,440	0	3,139,454	3,393,905	**6,583,106**
F. Abstraction	**12,219**	**3**	**24,150**	**0**	**39,192**	**0**	**75,564**
F.i. Irrigation	5,500	3	11,633	0	25,165	0	**42,301**
F.ii. Livestock	6,719	0	0	0	0	0	**6,719**
F.iii. Manufacturing	0	0	7	0	9,282	0	**9,289**
F.iv. Distribution	0	0	12,383	0	1	0	**12,384**
F.v. Hydroelectric power generation	0	0	0	0	0	0	**0**
F.vi. Other uses	0	0	128	0	4,744	0	**4,872**
Other changes in volume*							**0**
Closing stocks (Opening + Increases - Decreases)	**11,033**	**39,217**	**75,620**	**8**	**1,907,888**	**189,806**	**2,223,571**

* most likely zero

Table 8. Central Hawke's Bay District water assets table.

Central Hawke's Bay: Period: 1 July 2019 – 30 June 2020, Volume, thousands cubic metres							
	Artificial reservoirs	**Lakes**	**Rivers**	**Snow**	**Groundwater**	**Soil water**	**Total**
Opening stocks	**16,384**	**6,476**	**17,444**	**2**	**1,150,683**	**85,861**	**1,276,849**
Increase in stocks (A+B+C)	**14,102**	***35,793***	***9,217,913***	***11,353***	**1,834,785**	***3,075,811***	**14,189,756**
A. Precipitation	5,561	1,115	0	11,353	0	3,066,932	**3,084,961**
B. Inflows	8,541	34,678	9,216,807	0	1,834,785	0	**11,094,810**
B.i. From other regions	0	0	7,399,411	0	0	0	**7,399,411**
B.ii. From other resources within region	8,541	34,678	1,817,396	0	1,834,785	0	**3,695,399**
C. Returns (Ci+Cii+Ciii)	**0**	**0**	**1,106**	**0**	**0**	**8,879**	**9,985**
C.i. Irrigation leakage	0	0	0	0	0	2,767	**2,767**
C.ii. Effluent discharge (Livestock)	0	0	0	0	0	4,091	**4,091**
C.iii. Treated wastewater	0	0	1,106	0	0	885	**1,991**
C.iv. Distribution leakages	0	0	0	0	0	635	**635**
C.v. Hydroelectric discharge	0	0	0	0	0	0	**0**
C.vi. Other discharges	0	0	0	0	0	501	**501**
Decreases in stocks (D+E+F)	**14,102**	***35,778***	***9,217,321***	***11,348***	**1,791,147**	***3,030,487***	**14,100,184**
D. Evaporation/actual evapotranspiration	6,330	1,669		11,348	0	1,168,279	**1,187,626**
E. Outflows	0	34,106	9,213,115	0	1,764,407	1,862,208	**12,873,836**
E.i. To downstream territories	0	0	8,721,768	0	0	0	**8,721,768**
E.ii. To the sea	0	0	456,669	0	0	0	**456,669**
E.iii. To other resources within region	0	34,106	34,678	0	1,764,407	1,862,208	**3,695,399**
F. Abstraction	**7,772**	**3**	**4,206**	**0**	**26,740**	**0**	**38,721**
F.i. Irrigation	958	0	3,145	0	23,602	0	**27,705**
F.ii. Livestock	6,814	0	0	0	0	0	**6,814**
F.iii. Manufacturing	0	0	28	0	962	0	**990**
F.iv. Distribution	0	3	763	0	1,774	0	**2,540**
F.v. Hydroelectric power generation	0	0	0	0	0	0	**0**
F.vi. Other uses	0	0	271	0	402	0	**673**
Other changes in volume*							**0**
Closing stocks (Opening + Increases - Decreases)	**16,384**	**6,491**	**18,036**	**7**	**1,194,320**	**131,184**	**1,366,422**
* most likely zero							

Table 9. Wairoa District water assets table.

Wairoa: Period: 1 July 2019 – 30 June 2020, Volume, thousands cubic metres

	Artificial reservoirs	Lakes	Rivers	Snow	Groundwater	Soil water	Total
Opening stocks	**6,255**	**5,016,237**	**60,617**	**0**	**1,676,105**	**62,171**	**6,821,385**
Increase in stocks (A+B+C)	**5,783**	***958,536***	***12,482,329***	***462***	**4,116,911**	***5,732,213***	**23,296,233**
A. Precipitation	3,411	9,636	0	462	0	5,729,802	**5,743,311**
B. Inflows	2,352	948,900	12,481,579	0	4,116,911	0	**17,549,742**
B.i. From other regions	0	0	7,509,647	0	0	0	**7,509,647**
B.ii. From other resources within region	2,352	948,900	4,971,932	0	4,116,911	0	**10,040,095**
C. Returns (Ci+Cii+Ciii)	**19**	**0**	**749**	**0**	**0**	**2,411**	**3,179**
C.i. Irrigation leakage	0	0	0	0	0	18	**18**
C.ii. Effluent discharge (Livestock)	0	0	0	0	0	1,912	**1,912**
C.iii. Treated wastewater	0	0	749	0	0	32	**782**
C.iv. Distribution leakages	0	0	0	0	0	193	**193**
C.v. Hydroelectric discharge	19	0	0	0	0	0	**19**
C.vi. Other discharges	0	0	0	0	0	256	**256**
Decreases in stocks (D+E+F)	**5,764**	***1,040,800***	***12,267,935***	***462***	**3,984,427**	***5,653,773***	**22,953,161**
D. Evaporation/actual evapotranspiration	2,475	50,655		462	0	1,671,168	**1,724,760**
E. Outflows	0	990,114	12,265,871	0	3,984,171	3,982,605	**21,222,761**
E.i. To downstream territories	0	0	8,272,887	0	0	0	**8,272,887**
E.ii. To the sea	0	0	2,909,779	0	0	0	**2,909,779**
E.iii. To other resources within region	0	990,114	1,083,205	0	3,984,171	3,982,605	**10,040,095**
F. Abstraction	**3,289**	**31**	**2,064**	**0**	**257**	**0**	**5,640**
F.i. Irrigation	0	0	159	0	19	0	**178**
F.ii. Livestock	3,289	0	0	0	0	0	**3,289**
F.iii. Manufacturing	0	0	0	0	0	0	**0**
F.iv. Distribution	0	31	1,899	0	0	0	**1,930**
F.v. Hydroelectric power generation	0	0	0	0	0	0	**0**
F.vi. Other uses	0	0	5	0	238	0	**243**
Other changes in volume*							**0**
Closing stocks (Opening + Increases - Decreases)	**6,274**	**4,933,973**	**275,011**	**0**	**1,808,589**	**140,610**	**7,164,456**

* most likely zero

5. Further analysis of the water accounts

In the following section, key results from the supply and use tables and the assets tables are extracted, condensed, and presented. This allows for easy comparisons across industries, districts, abstraction sources and asset types.

5.1. Regional water abstraction and use by industry

Figure 11 shows water abstraction by industry for the entire Hawke's Bay region. **Error! Reference source not found.**[2] exhibits water use by industry for the entire Hawke's Bay region. The difference between the two figures represents water flowing within the economy (water that is not abstracted *per. se,* but recirculated within the economy). Agriculture makes up the majority of water abstraction (64%) and is the largest water user (43% of total water use) across the Hawke's Bay. Water distribution and manufacturing make up 19% and 13% of water abstraction, respectively. Services, households and sewerage are minor contributors to water abstraction in the Hawke's Bay. The story is more nuanced for water use because some industries/groups are more likely to use water that is supplied within the economy. As a result, services, sewerage and households become more important in relative terms (they make up 3%, 16% and 8% of water use, respectively). Water distribution and manufacturing are still significant in relative terms, but their relative water use contributions are lower than water abstraction contributions (because these industries tend to supply themselves with water through direct abstraction). Again, we note that water abstraction and use for electricity have not been included in these analyses. Graphs for abstraction by industry for each district are presented in Appendix 4.

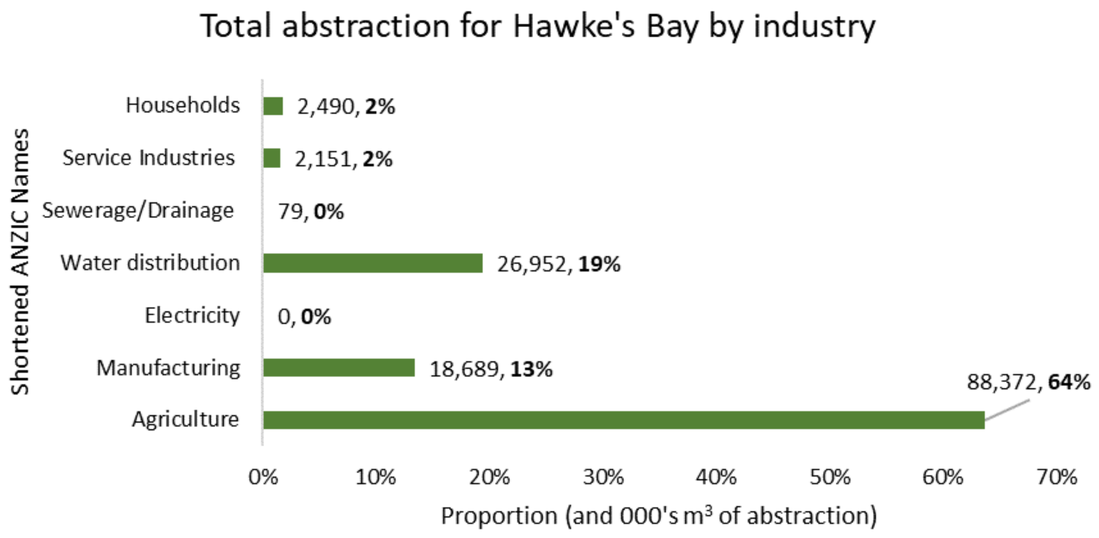


Figure 11. Water abstraction by industry for the entire Hawke's Bay region.

5.2. Water use and use per capita across the districts

Figure 12 reports overall water use by district. From Figure 11, Hastings has the highest water use of 105.5 million m^3 (making up 56% of total water use across Hawke's Bay). Hastings is followed by the Central Hawke's Bay district (22% of Hawke's Bay water use), Napier city (18%) and Wairoa district (4%).

In Figure 12, we show water use per capita across the districts. Central Hawke's Bay is the most water intensive and Napier City is the least water intensive. This report does not delve into which districts are more efficient with their water use (for a given industry). Most of the headline differences observed here are due to differences in industry composition. See Appendix 4 for graphs that decompose districts' water abstraction by industry.

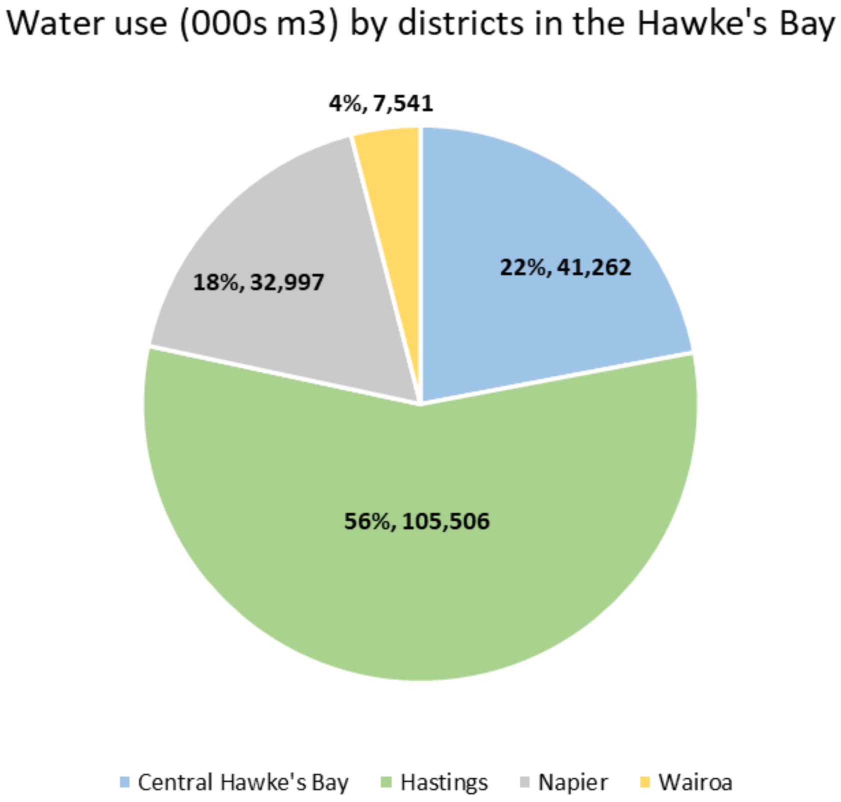


Figure 12. Water use by Hawke's Bay districts (absolute and relative contributions).

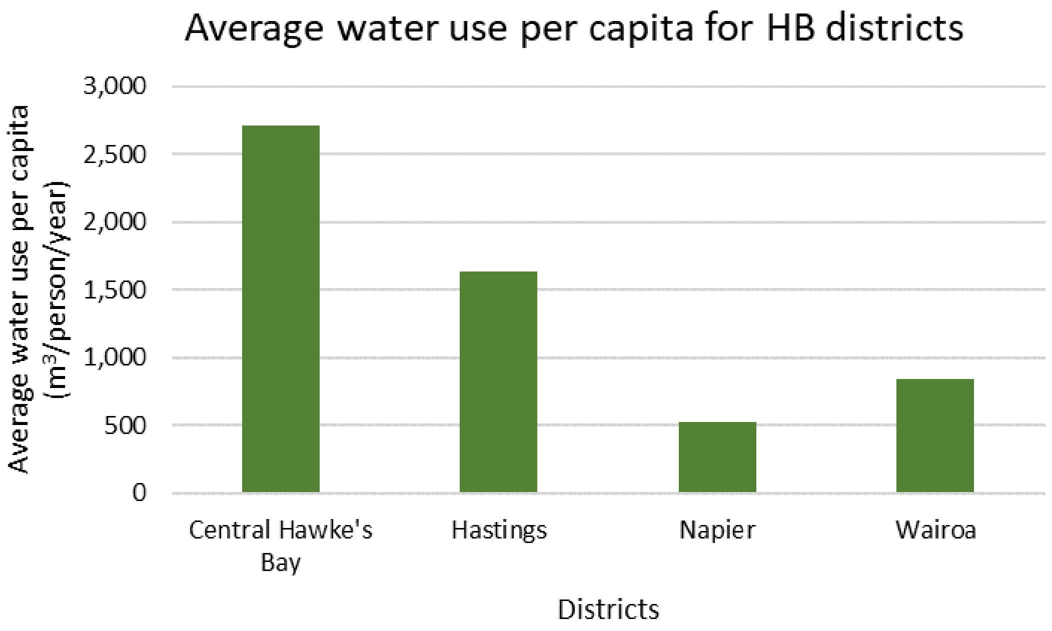


Figure 12. Water use per capita for Hawke's Bay districts.

5.3. Regional abstractions and discharges by asset type

Another relevant area to explore is the source of water abstraction and the destination for water discharges. This provides a sense for which assets may be at risk of depletion as there are higher ratios of abstraction to returns. In Figure 13, abstraction and discharges are recorded for each of the main water assets (artificial reservoirs, rivers, groundwater, soil water). As per our previous analyses, water abstraction and discharges for hydroelectric power generation are not included (which abstract mainly from rivers).

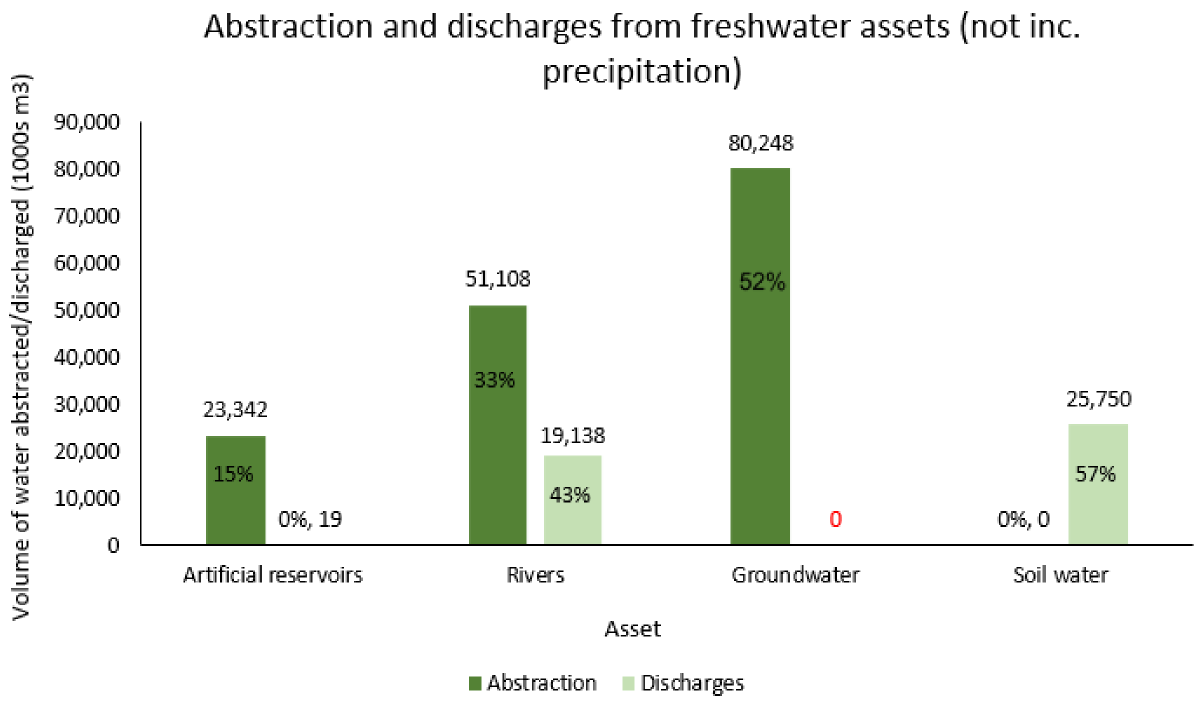


Figure 13. Abstraction and discharges by freshwater asset for the Hawke's Bay region.

5.4. Regional returns by industry

Returns to the environment volumes and relative contributions by each industry for the entire Hawke's Bay region are presented in Figure 14. These discharges do not include evapotranspiration, which is likely to be the most significant contribution to "returns" from agriculture as irrigation water is used in pasture life cycle processes. Aside from this caveat, the households are the largest discharger (32% of total and a volume of 18.8 million m^3). While most households do not directly discharge their sewerage, we include sewerage from households under the household category to better represent where discharges originate. They are followed by agriculture (29% of discharges), non-household sewerage (21%), water distribution (through leakages at 10%) and manufacturing (8%). Services do not discharge directly themselves (their small volume of discharges all go to sewerage first).

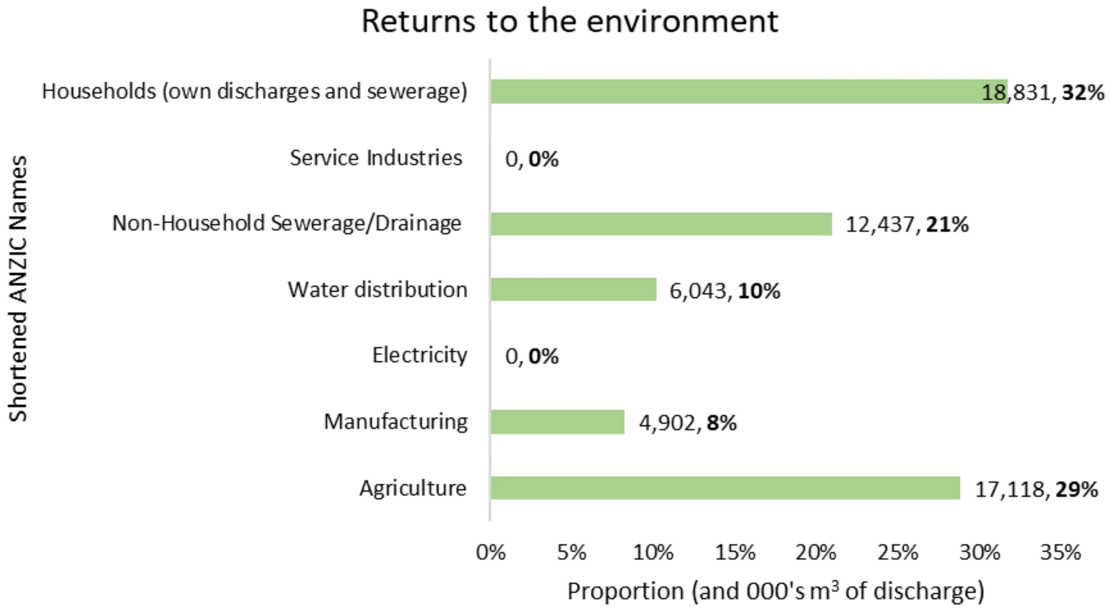


Figure 14. Total discharges to the environment by industry.

5. Insights and Discussion

5.1. Water availability and accessibility

A critical distinction needs to be made between water stocks and water accessibility. Just because there are large stocks of water assets (relative to abstraction and use) doesn't mean these are accessible for the region's and districts' needs. As described by Dinka in the 2018 book *Water Challenges of an Urbanizing World*, physical and economic scarcity are not the same thing.[15] This is a familiar concept in economics – abundant freshwater may be contained within water assets, but it may be too expensive to extract and use, and it can involve trade-offs with ecological health. Therefore, care must be taken when interpreting the values for asset stocks in the water assets tables.

Taking significantly more water from an asset than is supplied to it (through hydrological cycles and economic discharges) can have adverse impacts on the ecosystems that rely on these assets. Ecosystems and biodiversity provide a range of ecosystem services that improve water quality and availability (through filtration, flood protection, water storage and several other services). The capability of ecosystems to provide these services diminishes with poor water management decisions.16 Therefore, water management decisions should consider the implications for local biodiversity, as any harmful effects will likely flow on to water assets within the region. Under the *National Policy Statement on Freshwater Management 2020* and the requirement to "give effect to Te Mana o Te Wai", water management decisions must consider the implications for local biodiversity. Water accounts could be combined with biodiversity and ecosystem health indicators to track how different volumes and types of water use and discharge impact biodiversity values. The water

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[15] Dinka, *Safe Drinking Water: Concepts, Benefits, Principles and Standards*.

[16] Secretariat of the Convention on Biological Diversity, "Water and Biodiversity: Summary of the Findings of the Fourth Edition of the Global Biodiversity Outlook as They Relate to Water."

accounts should also serve as a guide for producing further natural capital accounts (for biodiversity, water quality, marine ecosystems, etc.). If ANZSIC codes are used throughout these accounts, it becomes much easier to connect natural capital accounts with traditional financial accounts.

Moreover, the water accounts, do not differentiate between individual assets within a class. In many instances, water will be extracted from one lake (for example) and discharged into another. This process could deplete the first lake while maintaining "overall lake stocks". Clearly, this stresses the importance of effective, transparent and efficient water management decisions. As Rogers et al. (2005) asserts, water scarcity is a *"governance crisis, not a [water] resource crisis"*.[17]

Finally, precipitation is the main input into the hydrological cycle but it is falling over time and highly variable in the Hawke's Bay Region. This doesn't account for the sizable heterogeneity that exists across the Hawke's Bay Region, meaning some areas may experience greater volumes of annual precipitation and some may experience declines. This is likely to have a lag effect on the annual/seasonal groundwater accounting (Mean residence Time – see NZRiverMaps tool)

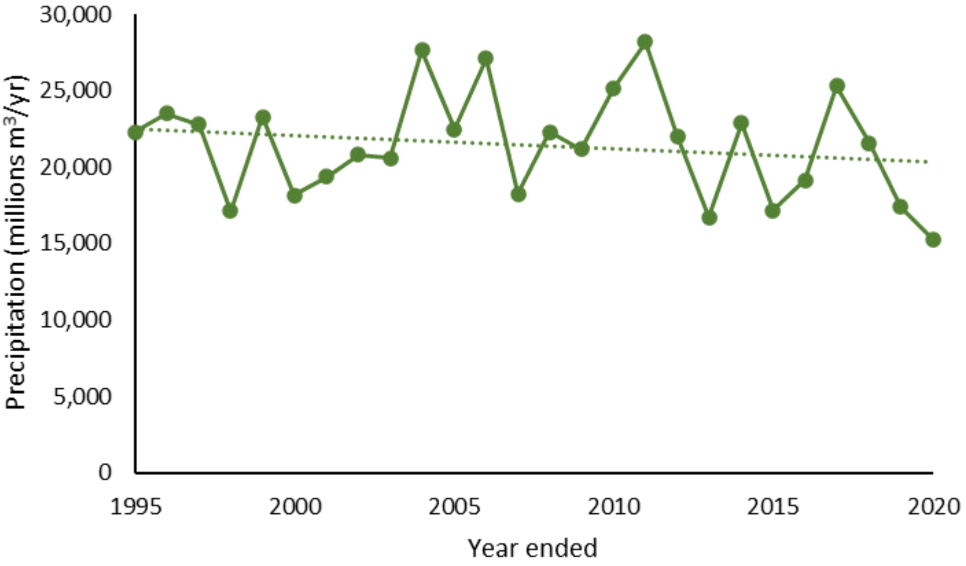

Figure 15. Annual precipitation in the Hawke's Bay Region from year ending 1995 to 2020

5.2. Water productivity and benchmarking

Productivity is a ratio of output to input (how much of a resource do we need to produce a given level of output). Water productivity is the ratio of an output to the input of water.[18] For this report, water productivity ($/m³) is calculated as value added (in nominal GDP terms) divided by water use.[19] Using regional GDP data from Stats NZ, water productivity by ANZIC industries are reported in Figure .[20] Water productivity varies enormously by industry. On average, agriculture generates a value add of $13.93 and manufacturing creates $89.14 of value add per m³ of water use. Services are not included in the chart because they generate over 25 times as much value than manufacturing (because they produce higher value products and services, and their industry tends to use less

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[17] Rogers, Llamas, and Cortina, *Water Crisis*.

[18] For more on water productivity, see; Food and Agricultural Organisation (FAO) of the United Nations, "Why Agricultural Water Productivity Is Important for the Global Water Challenge."

[19] We also present some water intensity results in Appendix 4 for each district (which is the ratio of water use to GDP).

[20] Stats NZ, "Regional Gross Domestic Product: Year Ended March 2020."

water). Moreover, basic calculations suggest that the electricity industry produces very little value add per m^3 of water use. However, this water is not “used” in the same sense as water is used for manufacturing, agriculture and services.

Comparing water productivity between industries within a region (Hawke’s Bay here) has limited usefulness. It is often more pertinent to compare across regions than within. That way, policymakers, councils and stakeholders can assess where industries are more productive with their water use and may prompt improvements and/or specialisation across the regions. This would also enable councils to learn from one another and improve the state of water management in New Zealand. To achieve this benchmarking exercise, more work would need to be done in merging water accounts with monetary and financial accounts (rather than taking a simple ratio of GDP to water use).

Water accounting will be at its most valuable when it is integrated with other accounting methods. Policymakers are recognising that integrating natural capital accounting (water accounting is one component of this) and financial accounting is fundamental for improving decision making and the management of natural resources. Neither accounting method fully captures the costs and benefits of economic activity (“one accounting approach does not fit all”). Combining these accounts has sizable benefits, including;

- The ability to benchmarking water productivity and use across and within regions, industries and other relevant aggregations;
- Benchmarking may encourage specialisation in areas of strong performance and will promote discussion on optimal water management strategies;
- Water decisions, use and supply become more transparent and decision-making improves;
- Creating the foundations for improved valuation and pricing of water (based on the embodied value that water contributes to economic activity);

We discuss indicators (which reconcile water and financial accounts and provide for improved decision making and monitoring) in Section 6.4.

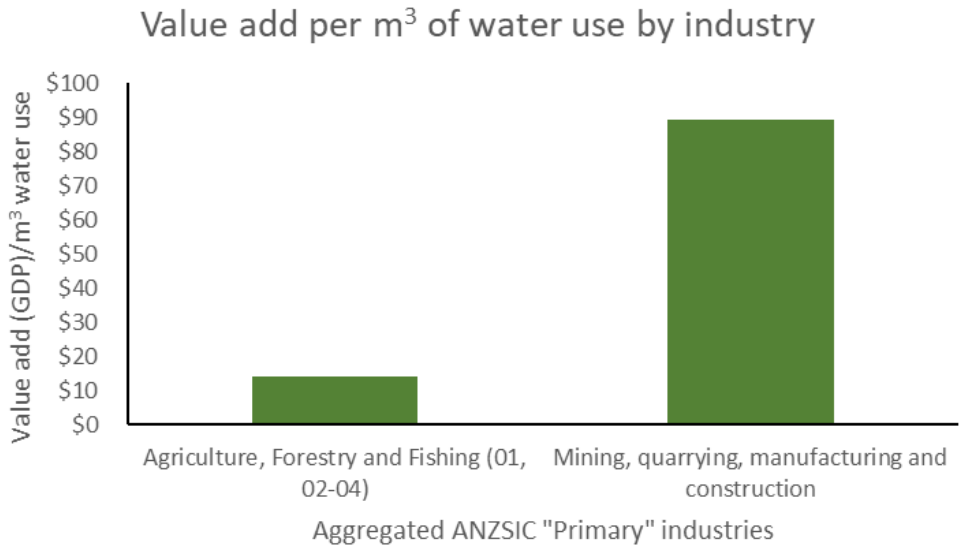

Figure 16. Water productivity (value add per m3 water use) across Hawke’s Bay industries.

5.3. Three Waters Reforms

Water accounting aligns with the guiding principles and target outcomes of the Three Waters Reform. One of the key target outcomes of the reform is:

"Efficient, sustainable, resilient and accountable multi-regional water and sewage services".[21]

Water accounting builds on the initial data requests from the DIA to inform the Three Waters Reform. Water accounting provides a methodology for consistent and transparent evaluation of water management across New Zealand. Combined with financial accounting and benchmarking processes, water accounting enables targeted investment in water infrastructure. The water accounts will demonstrate which areas, regions and industries use more water, where the most leakage is occurring and thus enable informed investment decisions. A comprehensive understanding of water supply, abstraction, flows and stocks is critical for creating efficient, sustainable, resilient and accountable water services.

5.4. Indicators

To reap the full benefits of water accounting exercises, it's fundamental to establish a set of indicators to inform future assessments, water management and policy. The transparent, consistent, and transferrable nature of UN SEAA natural capital accounting means accounts are easily studied over time. However, to do so, indicators must be identified and defined so that they may be tracked and compared over time. Such exercises will allow decision makers to study the impacts of water management projects and understand important trends over time.

Water accounts are highly detailed so there are a range of potential indicators. SEAA-Water describes four broad categories of indicators that can be derived from water accounts. They are indicators for:

1) *Water resource availability;*

2) *Water use for human activities, pressure on water resources and opportunities to increase water efficiency;*

3) *Opportunities to increase effective water supply through the management of return flows, reuse and system losses;*

4) *Water cost and pricing policy: the user-pays and polluter-pays principle.*

In this report, we focus on documenting relevant indicators from the first three categories as the fourth category requires an in-depth reconciliation of water accounts with financial accounts i.e. water monetary accounts which has not yet been undertaken.

Water accounts can be used to great effect in input output (IO), computable general equilibrium (CGE) and optimisation models. These modelling approaches can project future water demands and requirements, disaggregated by industry. They can also predict changes in water use and pressures that may arise from potential policy or management interventions. Moreover, CGE models could simulate water demands, distributions and pressures across New Zealand while considering the interactions between each region. However, for these models to be developed, all regions would need consistent water accounts – a further reason why SEEA-Water is a valuable and recommended method.

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[21] DIA, "About the Three Waters Reform Programme."

Spotlight on Water Productivity and Intensity Indicators

Water productivity and water intensity indicators are the most widely used indicators from water accounting exercises. They provide high-level indications of the socio-economic benefits of allocating water to a specific industry and the potential gains from water reallocation. Moreover, these indicators can track how policies, innovation and other interventions impact the productivity of water use within a region. These indicators can be conducted at a regional, district or sub-catchment level.

Productivity and intensity indicators decouple GDP and water use to better understand how water use is changing over time. To illustrate the value in this approach, we could envisage a scenario where a region is experiencing a 5% annual rate of real economic growth (measured by real GDP per capita). Likewise, average water use per capita may be increasing at a rate of 3%. If we look at the orange line in Figure 19, we may conclude that the region isn't performing well over time because water use per person is increasing. However, that misses an important story. Water use per unit of GDP is declining over time. Hence, the region is becoming more efficient with its water use (as it produces greater economic value with a unit of water). Indeed, the overall increase in water use is still an important consideration (for water scarcity management). However, it doesn't tell the entire story and demonstrates the importance of studying multiple indicators/metrics.

We also recommend computing and tracking water productivity (water use/GDP) indicators for each sector within a region. Comparing water productivity between sectors (like Agriculture and Services) provides limited information because the industries differ significantly in other attributes. There is greater value in examining water productivity changes over time for a given sector to understand whether sectors are becoming more or less efficient. Moreover, it may be useful to compare growth rates in water productivity between sectors to see where the greatest improvements and declines are occurring. Although, attention needs to be paid to each industry's starting point. A highly productive sector may have less room for improvement and therefore not score as favourably in changes in water productivity metrics.

Overall, a region could increase water productivity by reallocating activity and resources from highly water-intensive industries to less water-intensive industries. Alternatively, water productivity will improve if new water technologies and innovation or better water management practices are implemented within an industry.

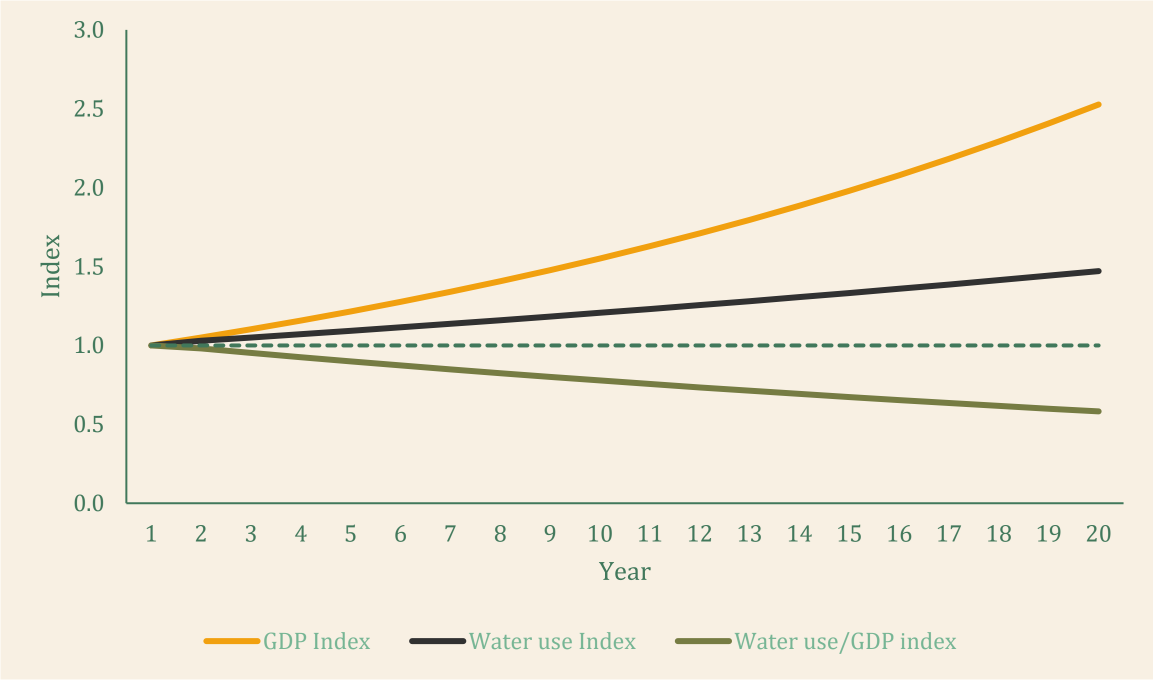

Figure 19. Hypothetical trends in GDP, water use and water intensity. All values are indexed to allow for direct comparison.

Table of Indicators Derived from Water Accounts

Table 10. List of potential indicators from water accounts.

Indicator	Definition	Value/Purpose
Total Water Abstraction (m^3)	The total volume of water that is being extracted from water resources.	Shows trends in total water abstraction from natural resources.
Total Water Use (m^3)	The total volume of water that is used in a defined area (includes reused water).	Shows trends in total water use for a defined area/unit.
Water Productivity ($/$m^3$)	The value-add (or GDP) generated per unit of water use.	Demonstrates trends in the productivity and efficiency of water use. Can evaluate interventions and policy.
Water Intensity (m^3/$)	The inverse of water productivity: the units of water required to generate a unit of value-add (i.e. $1 NZD).	Identifies which areas of the economy are most water-intensive and how water intensity is changing.
Reuse Ratio	Water use divided by water abstracted. Can exclude water use by the distributed water industry.	Shows the extent to which water is reused and recycled within the region.
Water Availability (m^3)	The total stock of water assets that are accessible.	Shows the volume of water available for use.
Sustainability Ratio	Water abstraction divided by water availability.	Compares water availability with water abstraction to illustrate the sustainability of current activity.
Groundwater Recharge Ratio	Ratio of groundwater recharge to groundwater abstraction.	Demonstrates the pressures on groundwater resources and stocks.
Dependency Ratio	Ratio of externally sourced water resources (from upstream territories) to total water resources.	Illustrates the reliance on other regions (upstream territories) for water supply.
Internal Renewable Resources (m^3/yr)	Average flow of rivers and recharge of groundwater from endogenous (within the system) precipitation.	Shows how much water is being made available each year from precipitation within the region.
Distribution Loss Ratio	Ratio of distribution losses (leakages) to total water use for distribution.	Demonstrates the efficiency of the water distribution network and infrastructure.
Water Consumption (m^3)	Water use less water supplied back to the environment.	Shows how much water is consumed over a period.
Inland Water Consumption (m^3)	Water use less water supplied back to freshwater resources.	Shows how much water is lost (to consumption or the sea) and not immediately available.
Household Water Consumption (m^3)	Average per capita household water consumption.	Shows the intensity of household water consumption. Can use this to examine the effect of behaviour change policies.

Note: Most indicators apply at a regional, sub-catchment and industry level, depending on the information required. Also, the FAO suggest that **water availability indicators** need to consider the dependability of water flows, the extractability of groundwater and the minimum level of flow required for environmental, social and non-consumptive uses.

6. Summary and next steps

This water accounting project was a first attempt at compiling comprehensive water accounts for the Hawke's Bay region in line with UN SEEA-Water methodology. There are several areas where data could be improved which would enable greater confidence in the accounting numbers and provide an enhanced level of detail and understanding around certain areas of water supply and use. The assumptions and limitations for the supply and use tables and the assets tables have been documented in Appendix 5. In that section, assumptions and limitations are broken down by water use type and district (reflecting that districts have different levels of data currently and are unique in their industry composition and breakdown of water use). Here, we provide a condensed version of the limitations and improvements for the collection and availability of water data. The extensive set of improvements and limitations are unsurprising given that the relative abundance of water in the past meant there was not a strong need to focus on the systems and methods for capturing water-related data. However, this is changing with the realisation that water is a scarce resource, and there are increasing efforts to enhance water data (for example, metering efforts in residential, irrigation etc).

Data improvements:

1. There is a need for better data on livestock water consumption and volumes of effluent. The quality of effluent is frequently discussed in research but the volume of effluent has received much less attention. As we have discussed, the quality and quantity of water used and discharged are important considerations for effective water management.

2. At the districts level, more data is needed on which industries are using distributed (network) water. In many instances, there is insufficient data to determine which industries are using water. Alignment with ANZSIC codes would be beneficial and strongly recommended.

3. There are often large discrepancies between household water use (from the water distribution network) and household wastewater discharged (through the wastewater network). Wastewater often exceeds water use, which indicates there may be issues with the data or large amounts of infiltration and inflow (I&I) into the wastewater network (estimated at about 30% based on available numbers). This requires further investigation to improve the understanding of current data and generate purpose-build data that aligns with the understanding and current research on household water use.

4. The discharge consents database poses challenging in its use for water accounting purposes. One of the fundamental issues is that consents and data describe the maximum allowable discharge (often daily). This makes it difficult to assess the actual volumes of discharge over an accounting year without supplementary reporting data from the consents holders. Reporting requirements augmentation would be a valuable addition to discharge consents and allow for a more comprehensive and robust assessment of discharges from the economy.

5. An assessment of how much irrigation water is taken up and transpired and how much is run-off to rivers, lakes or artificial reservoirs is also needed. The scope for the New Zealand Water Model (NZWaM) does not include human activities and there isn't sufficient data on how irrigation impacts overall actual evapotranspiration. If irrigation is highly targeted (increasingly occurring with the advancement of irrigation and monitoring technology), there

may be limited run-off because water is applied to soils with deficient moisture content for the purpose at hand.[22]

6. Improve the understanding of evaporation from artificial reservoirs and moving bodies of water in New Zealand (rivers and streams). The current methods (see Stats NZ for more) likely generate large overestimates for these values.

There are other key recommendations for progressing and maximising value from water accounting within the Hawke's Bay region and the wider country. These are summarised below (in accordance with the discussion in the previous section).

Key overall recommendations:

1. Improve key data sources and assumptions (relating to water distribution, effluent, livestock water consumption and the water assets tables, to name a few). See previous data improvements list.
2. Enhance the scope and accuracy of information provided in resource consents, with a focus on ANZSIC codes alignment in abstraction and discharge water consents, and consistency regarding units used for volume. Consider options to expand monitoring and reporting requirements into abstraction and discharge consents and ensure that consents describe the volume of water being taken or discharged. This will enable future accounting to be more accurate and efficient.
3. Expand the scope of water accounts to include:
    a. monetary accounts to improve our understanding of the value of water and benchmark performance on water productivity across districts, regions, industries and water users.
    b. water condition account (linked to broader water quality policy objectives and targets for Hawkes Bay or specific catchment health objectives).
4. Develop water indicators and metrics based on the reconciliation of water accounts, financial accounts and biodiversity indicators. These water indicators can be used as a simple tool to guide more effective and sustainable water management decision making.
5. Use the learnings from water accounting to develop other ecosystems / natural capital accounts of relevance to long term regional policies and strategies in Hawkes Bay i.e. biodiversity or climate adaptation. This will enable decision makers to understand all economic costs and benefits (environmental, social, economic) associated with a particular activity.

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[22] DairyNZ, "Guide to Good Irrigation Part 1: Good Irrigation Practices on-Farm."

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8. Appendices

Appendix 1. Summary list of the elements in the IRIS consents database

- Resource consent identification (current and historical);
- Name of the resource consent holder;
- Description of the resource consent;
- Primary use (i.e. combined/mixed, drinking, frost protection, industrial, irrigation, other, stock);
- Use type classification (i.e. for distribution, own use – cooling water, irrigation, manufacturing, household, other);
- Primary source (i.e. groundwater, storage, stream depleting, surface water);
- Primary purpose (i.e. augmentation/recharge, recreational facilities, shingle washing, water supply – agriculture, cooling water, damfill, frost protection, industry, irrigation, multiple uses, non-potable, potable, potable-bottling, recreation, stockyard, vehicle wash); and
- Primary industry (e.g. agriculture – cropping, dairy, pastoral farming, animal processing, timber processing, winery, wool processing)
- Industrial classification conducted by Hawkes Bay Regional Council, using the Australia and New Zealand Standard Industrial Classification (ANZSIC) 2006 V1.0.0.[23] The minimum level of classification for each resource consent is division. This classification was performed using the information reported on Ariā[24] and identifying key words from each resource consent based on their primary industry, primary purpose and description.

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[23] Trewin and Pink, *Australian and New Zealand Standard Industrial Classification (ANZSIC) 2006*.

[24] Stats NZ, "Ariā - Classifications." - Ariā is a classiffication managament system from StatsNZ, for further information see: http://aria.stats.govt.nz/aria/?_ga=2.121946827.1366430316.1616117478-604228869.1616117478#ClassificationView:uri=http://stats.govt.nz/cms/ClassificationVersion/CARS5587

Appendix 2. Supply and use tables for districts

Supply and Use Tables for Napier City (2019-20 water year)

		Industries (by ANZIC category)							Households	Rest of the world	Total
		A	B, C, E	D(26&27)	D(29&D281100)	D281200	F-S	Total			
Physical use table (thousands cubic metres)		Agriculture, Forestry and Fishing (01, 02-04)	Mining, quarrying, manufacturing and construction	Electricity, gas, steam and air-conditioning supply	Water collection, treatment and supply	Sewerage	Service Industries				
From the environment	**Total Abstraction E.1**	**2,356**	**4,959**		**9,667**	**57**	**529**	**17,568**	**323**		**17,891**
	Abstraction for own use	***2,356***	***4,959***		***318***	***57***	***415***	***8,105***	***323***		***8,428***
	Hydroelectric power generation							***0***			***0***
	Irrigation water	*2,297*	*0*		*318*	*0*	*415*	***3,029***	*23*		***3,052***
	Mine water							***0***			***0***
	Urban run-off							***0***			***0***
	Cooling water	*0*	*31*		*0*	*0*	*0*	***31***	*0*		***31***
	Livestock (permitted activities)	*44*						***44***			***44***
	Households							***0***	*300*		***300***
	Manufacturing	*0*	*4,921*		*0*	*0*	*0*		*0*		
	Other	*15*	*7*		*1*	*57*	*0*	***80***	*0*		***80***
	Abstraction for distribution	***0***	***0***		***9,349***	***0***	***114***	***9,463***	***0***		***9,463***
	From inland water resources:	***2,356***	***4,959***		***9,667***	***57***	***529***	***17,568***	***173***		***17,741***
	Surface water	*68*	*3,417*		*0*			***3,485***			***3,485***
	Ground water	*2,288*	*1,542*		*9,667*	*57*	*529*	***14,083***	*173*		***14,255***
	Soil water							***0***			***0***
	Collection of precipitation E.2							***0***	***150***		***150***
	Abstraction from the sea							***0***			***0***
Within the economy	**Use of water received from other economic units**				**0**	**8,620**	**2,314**	**10,934**	**4,172**		**15,106**
	of which:										
	Reused water							**0**			**0**
	Wastewater to sewage					8,620		**8,620**			**8,620**
	Distributed water						2,314	**2,314**	4,172		**6,486**
Total use of water		**2,356**	**4,959**		**9,667**	**8,677**	**2,843**	**28,502**	**4,495**		**32,997**

Physical supply table (thousands cubic metres)		Agriculture, Forestry and Fishing (01, 02-04)	Mining, quarrying, manufacturing and construction	Electricity, gas, steam and air-conditioning supply	Water collection, treatment and supply	Sewerage	Service Industries	**Total**	Households	Rest of the world	**Total**
Within the economy	**Supply of water to other economic units**	**27**	**2,060**		**6,486**		**2,567**	**11,141**	**3,965**		**15,106**
	of which:							**0**			**0**
	Reused water							**0**			**0**
	Wastewater to sewage	27	2,060				2,567	**4,655**	3,965		**8,620**
	Distributed water				6,486			**6,486**			**6,486**
Into the environment	**Total returns**	257	155		2,698	8,620	0	**11,729**	309		**12,038**
	Hydroelectric power generation							***0***			**0**
	Irrigation water	230						***230***			**230**
	Mine water							***0***			**0**
	Urban run-off							***0***			**0**
	Cooling water							***0***			**0**
	Livestock (permitted activities)	27						***27***			**27**
	Households							***0***	309		**309**
	Losses in distribution because of leakages				2,698			***2,698***			**2,698**
	Treated wastewater					8,620		***8,620***			**8,620**
	Other		155					***155***			**155**
	To inland water resources	**257**	**155**		**2,698**	**0**	**0**	**3,110**	**309**		**3,418**
	Surface water		*155*					***155***			***155***
	Groundwater							***0***			***0***
	Soil water	*257*			*2,698*			***2,955***	*309*		***3,263***
	To other sources (e.g. sea water)					8,620		**8,620**			**8,620**
Total supply of water		**284**	**2,215**		**9,184**	**8,620**	**2,567**	**22,871**	**4,273**		**27,144**
	Consumption	**2,072**	**2,744**		**483**	**57**	**275**	**5,631**	**222**		**5,853**
	of which:							**0**			**0**
	Losses in distribution not because of leakages				483			**483**			**483**

Supply and Use Tables for Hastings District (2019-20 water year)

		Industries (by ANZIC category)							Households	Rest of the world	Total
		A	B, C, E	D(26&27)	D(29&D281100)	D281200	F-S	Total			
Physical use table (thousands cubic metres)		Agriculture, Forestry and Fishing (01, 02-04)	Mining, quarrying, manufacturing and construction	Electricity, gas, steam and air-conditioning supply	Water collection, treatment and supply	Sewerage/Drainage	Service Industries				
From the environment	**Total Abstraction E.1**	48,066	12,713		12,649	22	1,578	75,028	981		76,009
	Abstraction for own use	48,066	12,713		266	22	1,578	62,645	981		63,625
	Hydroelectric power generation							0			0
	Irrigation water	41,338	1		141	0	818	42,298	3		42,301
	Mine water							0			0
	Urban run-off							0			0
	Cooling water	0	1,407		0	0	0	1,407	0		1,407
	Livestock (permitted activities)	6,719						6,719			6,719
	Households							0	977		977
	Manufacturing	0	9,289		0	0	0	9,289	0		9,289
	Other	10	2,015		125	22	760	2,932	0		2,932
	Abstraction for distribution	0	0		12,383	0	0	12,384	0		12,384
	From inland water resources:	48,066	12,713		12,649	22	1,578	75,028	537		75,565
	Surface water	20,366	125		12,512			33,003	11		33,013
	Ground water	27,700	12,588		138	22	1,578	42,025	526		42,552
	Soil water							0			0
	Collection of precipitation E.2							0	444		444
	Abstraction from the sea							0			0
Within the economy	**Use of water received from other economic units**		1,912		0	19,615	480	22,007	7,491		29,498
	of which:							0			0
	Reused water							0			0
	Wastewater to sewage					19,615		19,615			19,615
	Distributed water		1,912				480	2,392	7,491		9,883
Total use of water		48,066	14,625		12,649	19,637	2,058	97,035	8,471		105,506

Physical supply table (thousands cubic metres)		Agriculture, Forestry and Fishing (01, 02-04)	Mining, quarrying, manufacturing and construction	Electricity, gas, steam and air-conditioning supply	Water collection, treatment and supply	Sewerage	Service Industries	**Total**	Households	Rest of the world	**Total**
Within the economy	**Supply of water to other economic units**	0	7,103		9,883		546	17,532	11,965		29,498
	of which:							0			0
	Reused water							0			0
	Wastewater to sewage		7,103				546	7,649	11,965		19,615
	Distributed water				9,883			9,883			9,883
Into the environment	**Total returns**	8,073	3,346		2,517	19,615	0	33,551	597		34,147
	Hydroelectric power generation							0			0
	Irrigation water	4,134						4,134			4,134
	Mine water							0			0
	Urban run-off							0			0
	Cooling water							0			0
	Livestock (permitted activities)	3,940						3,940			3,940
	Households							0	597		597
	Losses in distribution because of leakages				2,517			2,517			2,517
	Treated wastewater		3,346			19,615		22,961			22,961
	Other							0			0
	To inland water resources	8,073	10		2,517		0	10,600	597		11,197
	Surface water							0			0
	Groundwater							0	0		0
	Soil water	8,073	10		2,517			10,600	597		11,197
	To other sources (e.g. sea water)		3,336			19,615		22,951			22,951
Total supply of water		8,073	10,449		12,400	19,615	546	51,083	12,562		63,645
	Consumption	39,993	4,176		250	22	1,512	45,952	-4,091		41,861
	of which:										
	Losses in distribution not because of leakages				250			250			250

Supply and Use Tables for Central Hawkes Bay District (2019-20 water year)

		Industries (by ANZIC category)									
		A	B, C, E	D(26&27)	D(29&D281100)	D281200	F-S	Total	Households	Rest of the world	Total
Physical use table (thousands cubic metres)		Agriculture, Forestry and Fishing (01, 02-04)	Mining, quarrying, manufacturing and construction	Electricity, gas, steam and air-conditioning supply	Water collection, treatment and supply	Sewerage	Service Industries				
From the environment	**Total Abstraction E.1**	**34,483**	**1,017**		**2,699**	**0**	**44**	**38,244**	**719**		**38,963**
	Abstraction for own use	***34,483***	***1,017***		***159***	***0***	***44***	***35,704***	***719***		***36,423***
	Hydroelectric power generation							***0***			***0***
	Irrigation water	*27,670*	*0*		*0*	*0*	*36*	***27,705***	*0*		***27,705***
	Mine water							***0***			***0***
	Urban run-off							***0***			***0***
	Cooling water	*0*	*28*		*0*	*0*	*0*	***28***	*0*		***28***
	Livestock (permitted activities)	*6,814*						***6,814***			***6,814***
	Households	*0*	*0*		*0*	*0*	*0*	***0***	*719*		***719***
	Manufacturing	*0*	*990*		*0*	*0*	*0*	***990***	*0*		***990***
	Other	*0*	*0*		*159*	*0*	*8*	***168***	*0*		***168***
	Abstraction for distribution	***0***	*0*		***2,540***	***0***	***0***	***2,540***	***0***		***2,540***
	From inland water resources:	***34,483***	***1,017***		***2,699***	***0***	***44***	***38,244***	***484***		***38,728***
	Surface water	*7,510*	*56*		*766*		*0*	***8,331***	*250*		***8,581***
	Ground water	*26,974*	*962*		*1,933*		*44*	***29,913***	*234*		***30,147***
	Soil water							***0***			***0***
	Collection of precipitation E.2							***0***	***234***		***234***
	Abstraction from the sea							***0***			***0***
Within the economy	**Use of water received from other economic units**				**0**	**1,220**	**0**	**1,220**	**1,079**		**3,126**
	of which:										
	Reused water							**0**			**0**
	Wastewater to sewage					1,220		**1,220**			**1,220**
	Distributed water							**826**	1,079		**1,905**
Total use of water		**34,483**	**1,017**		**2,699**	**1,220**	**44**	**39,464**	**1,798**		**41,262**

Physical supply table (thousands cubic metres)		Agriculture, Forestry and Fishing (01, 02-04)	Mining, quarrying, manufacturing and construction	Electricity, gas, steam and air-conditioning supply	Water collection, treatment and supply	Sewerage	Service Industries	**Total**	Households	Rest of the world	**Total**
Within the economy	**Supply of water to other economic units**	**0**	**69**		**1,905**		**38**	**2,012**	**1,113**		**3,126**
	of which:							**0**			**0**
	Reused water							**0**			**0**
	Wastewater to sewage		69				38	**107**	1,113		**1,220**
	Distributed water				1,905			**1,905**			**1,905**
Into the environment	**Total returns**	6,858	771		635	1,220	0	**9,484**	501		**9,985**
	Hydroelectric power generation							***0***			**0**
	Irrigation water	2,767						***2,767***			**2,767**
	Mine water							***0***			**0**
	Urban run-off							***0***			**0**
	Cooling water							***0***			**0**
	Livestock (permitted activities)	4,091						***4,091***			**4,091**
	Households							***0***	**501**		**501**
	Losses in distribution because of leakages				635			***635***			**635**
	Treated wastewater		771			1,220		***1,991***			**1,991**
	Other							***0***			**0**
	To inland water resources	**6,858**	**771**		**635**	**1,220**	**0**	**9,484**	**501**		**9,985**
	Surface water					*1,106*		***1,106***			***1,106***
	Groundwater							***0***			***0***
	Soil water	*6,858*	*771*		*635*	*114*		***8,378***	*501*		***8,879***
	To other sources (e.g. sea water)							**0**			**0**
Total supply of water		**6,858**	**840**		**2,540**	**1,220**	**38**	**11,497**	**1,614**		**13,111**
	Consumption	**27,625**	**177**		**159**	**0**	**6**	**27,968**	**184**		**28,152**
	of which:							**0**			**0**
	Losses in distribution not because of leakages							**0**			**0**

Supply and Use Tables for Wairoa District (2019-20 water year)

		Industries (by ANZIC category)							Households	Rest of the world	Total
		A	B, C, E	D(26&27)	D(29&D281100)	D281200	F-S	Total			
Physical use table (thousands cubic metres)		Agriculture, Forestry and Fishing (01, 02-04)	Mining, quarrying, manufacturing and construction	Electricity, gas, steam and air-conditioning supply	Water collection, treatment and supply	Sewerage	Service Industries		Households		
From the environment	**Total Abstraction E.1**	**3,467**	**0**		**1,936**	**0**	**0**	**5,403**	**468**		**5,870**
	Abstraction for own use	***3,467***	***0***		***5***	***0***	***0***	***3,472***	***468***		***3,940***
	Hydroelectric power generation							***0***			***0***
	Irrigation water	*178*	*0*		*0*	*0*	*0*	***178***	*0*		***178***
	Mine water							***0***			***0***
	Urban run-off							***0***			***0***
	Cooling water	*0*	*0*		*0*	*0*	*0*	***0***	*0*		***0***
	Livestock (permitted activities)	*3,289*						***3,289***			***3,289***
	Households	*0*	*0*		*0*	*0*	*0*	***0***	*468*		***468***
	Manufacturing	*0*	*0*		*0*	*0*	*0*	***0***	*0*		***0***
	Other	*0*	*0*		*5*	*0*	*0*	***5***	*0*		***5***
	Abstraction for distribution	***0***	***0***		***1,930***	***0***	***0***	***1,930***	***0***		***1,930***
	From inland water resources:	***3,467***	***0***		***1,936***	***0***	***0***	***5,403***	***238***		***5,640***
	Surface water	*1,803*			*1,936*	*0*	*0*	***3,739***			***3,739***
	Ground water	*1,663*			*0*	*0*	*0*	***1,663***	*238*		***1,901***
	Soil water							***0***			***0***
	Collection of precipitation E.2							***0***	***230***		***230***
	Abstraction from the sea							***0***			***0***
Within the economy	**Use of water received from other economic units**		**980**		**0**	**151**		**1,131**	**540**		**1,671**
	of which:							**0**			**0**
	Reused water							**0**			**0**
	Wastewater to sewage					151		**151**			**151**
	Distributed water		980					**980**	540		**1,519**
Total use of water		**3,467**	**980**		**1,936**	**151**	**0**	**6,534**	**1,008**		**7,541**

Physical supply table (cubic metres)		Agriculture, Forestry and Fishing (01, 02-04)	Mining, quarrying, manufacturing and construction	Electricity, gas, steam and air-conditioning supply	Water collection, treatment and supply	Sewerage	Service Industries	**Total**	Households	Rest of the world	**Total**
Within the economy	**Supply of water to other economic units**	**0**	**26**		**1,519**			**1,545**	**126**		**1,671**
	of which:							**0**			**0**
	Reused water							**0**			**0**
	Wastewater to sewage		26					**26**	126		**151**
	Distributed water				1,519			**1,519**			**1,519**
Into the environment	**Total returns**	1,930	630		193	151	0	**2,905**	256		**3,160**
	Hydroelectric power generation							***0***			**0**
	Irrigation water	18						***18***			**18**
	Mine water							***0***			**0**
	Urban run-off							***0***			**0**
	Cooling water							***0***			**0**
	Livestock (permitted activities)	1,912						***1,912***			**1,912**
	Households							***0***	256		**256**
	Losses in distribution because of leakages				193			***193***			**193**
	Treated wastewater					151		***151***			**151**
	Other		630					***630***			**630**
	To inland water resources	**1,930**	**630**		**193**	**151**	**0**	**2,905**	**256**		**3,160**
	Surface water		*630*			*119*		***749***			***749***
	Groundwater							***0***			***0***
	Soil water	*1,930*			*193*	*32*		***2,155***	*256*		***2,411***
	To other sources (e.g. sea water)							**0**			**0**
Total supply of water		**1,930**	**656**		**1,712**	**151**	**0**	**4,450**	**382**		**4,831**
	Consumption	**1,537**	**324**		**223**	**0**	**0**	**2,084**	**626**		**2,710**
	of which:							**0**			**0**
	Losses in distribution not because of leakages				223			**223**			**223**

Appendix 3. Groundwater water assets supplementary methodological detail

Groundwater stocks were calculated for the Hawke's Bay region using a staged methodology summarised in the following steps.

1. An estimate of the amount of stored groundwater at the start of the reporting period was based upon the spatial coverage of hydrogeologic units from the GNS GIS database and a series of data processing steps to convert geological footprints into water storage estimates. As no 3D geological model of the Hawke's Bay is currently available, assumptions needed to be incorporated into the interpretation of sub-catchment geology, as follows: a) The GNS hydrogeologic units (based on rock mass age) were combined into five generalised geological units
        i. Basement (greywacke) (Unit 1)
        ii. Tertiary sedimentary rocks (Unit 2)
        iii. Volcanics (Unit 3)
        iv. Quaternary sedimentary deposits - aquitards (Unit 4)
        v. Quaternary sedimentary deposits - aquifers (Unit 5)
    b. A pragmatic assumption was applied that groundwater stocks below a depth of 500 m are not relevant to the calculation of regional water stocks. Few water supply bores in New Zealand exceed 400 m in depth and the addition of 100m to this depth allows for the potential installation of deeper bores and the potential upward flow of groundwater to existing deep bores during abstraction.
    c. A set of 12 hydrogeological sequences were derived based on the overlapping polygons of the hydrogeological units described above.
    d. The hydrogeological sequences were then simplified into three hydrogeological layers for the purposes of calculating groundwater stocks on a sub-catchment basis.
        i. Layer 1 represents the groundwater stocks in the uppermost unconfined hydrogeological unit. An unconfined groundwater surface is defined within this uppermost layer for the purposes of calculating starting groundwater volumes for this stocktake.
        ii. Layers 2 and 3 represent deeper unconfined or confined hydrogeological units. The piezometric head within these units is free to fluctuate in response to the seasonal water balance. However, there is no allowance for the unconfined groundwater table to drop down into these layers. In effect, these layers remain fully saturated for the purposes of calculating starting groundwater volumes for this stocktake.
        iii. For each of the hydrogeological sequences, total and saturated thicknesses for each layer were then calculated based on general assumptions on the geology and topography of the region. This is generic calculation and does not take into account localised variations in geology due to the lack of a 3D geological model. Also, localised variations in topography are not taken into account. Expectations on general topographic characteristics of areas with different hydrogeological units have been incorporated into the definition of the depth to the unconfined groundwater table for Layer 1.
        iv. Groundwater stocks within the unsaturated zone of Layer 1 have been excluded from this stocktake. Stocks in the unsaturated zone are effectively unavailable for abstraction.
    e. Generic water storage characteristics for each of the above geological units were applied on a m3 /m3 water to rock volume basis.
    f. Groundwater storage volumes for starting stocks were calculated for each of the geological sequences for:
        i. Total storage (all groundwater not chemically bonded or otherwise bound to the rock/sediment solids) based on the rock mass total storage values presented in Table A1.
        ii. Drainable storage (All water theoretically available through physically draining the rock mass to a depth of 500 m) based on the rock mass specific yield values for Layer 1 and rock mass specific storage values for Layers 2 and 3.
        iii. Accessible storage (groundwater that could potentially be abstracted through pumping). An assumed generic maximum drawdown criterion has been applied in calculating the accessible storage, limiting potential drawdown to 10% of the saturated unit thickness or to 20 m, whichever is the smaller. These have been calculated using rock mass specific yield values for Layer 1 and rock mass specific storage values for Layers 2 and 3.

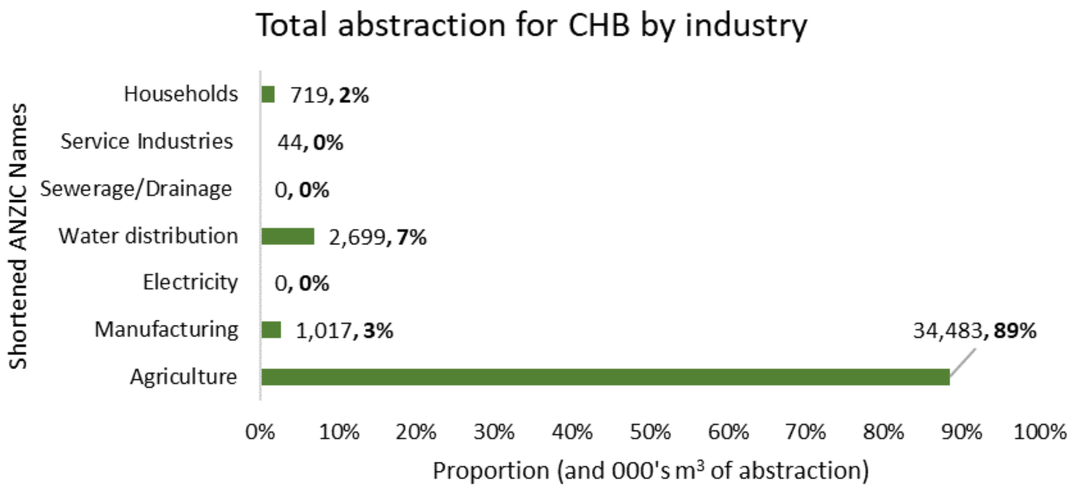
The volumetric results of the total, drainable and accessible starting groundwater stocks have been generated on a per hectare basis for the hydrogeological units represented in Layer 1, Layer 2 and Layer 3.

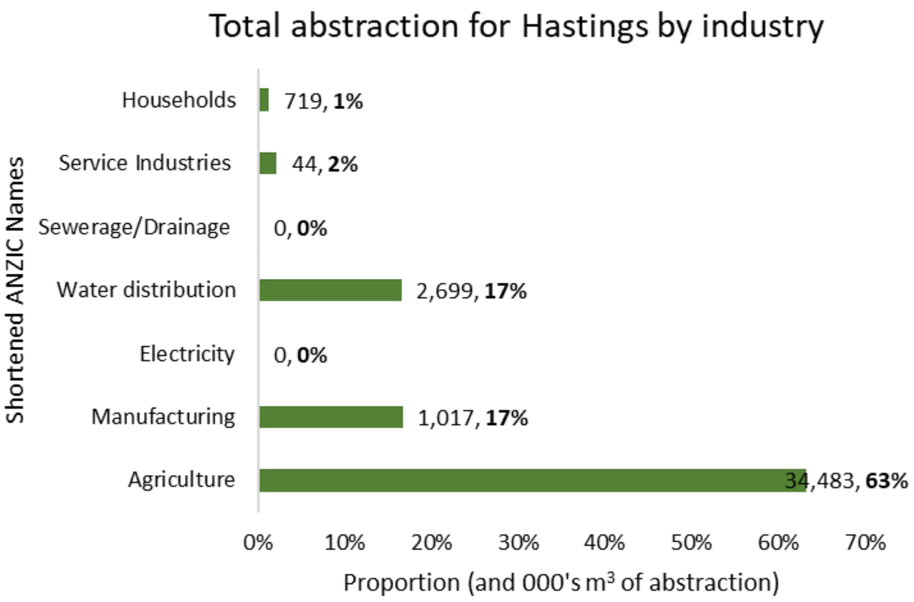
g. The starting groundwater stocks from all three layers were then totalled for each individual hydrogeological sequence present in the region, on a m3 /ha basis.
h. Cumulative starting groundwater stocks were then compiled using GIS for all river and stream sub-catchments across the Hawke's Bay region based on the area of each hydrogeological sequence represented in each catchment.

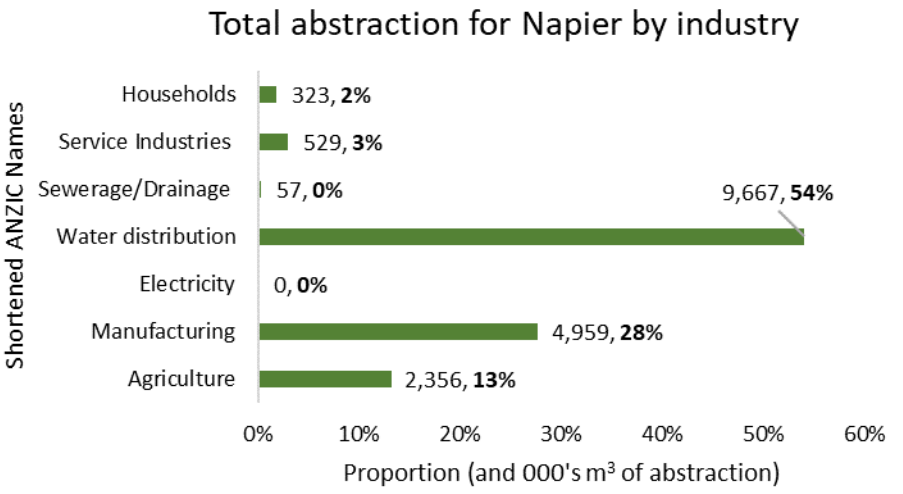
2. The cumulative starting groundwater stocks from the river and stream sub-catchments were then compiled for the districts with the Hawke's Bay region and for the region as a whole. Where a sub-catchment is split between two or more districts, the starting groundwater stock is distributed between the districts proportionally in accordance with the percentage of the sub-catchment falling within each district. Sections of sub-catchments falling outside the region have been excluded from the stocktake.
    a. The change in groundwater stocks were calculated on a sub-catchment basis from TopNet model outputs provided by NIWA. The change in stock was calculated as net recharge minus discharges to surface water bodies, as follows:
        i. Net recharge from Topnet is the calculated spatially distributed recharge to the saturated groundwater zone less any groundwater flows that return to the overlying soil horizons.
        ii. Groundwater discharges in Topnet are calculated as stream and river baseflow contributions arising from each sub-catchment.

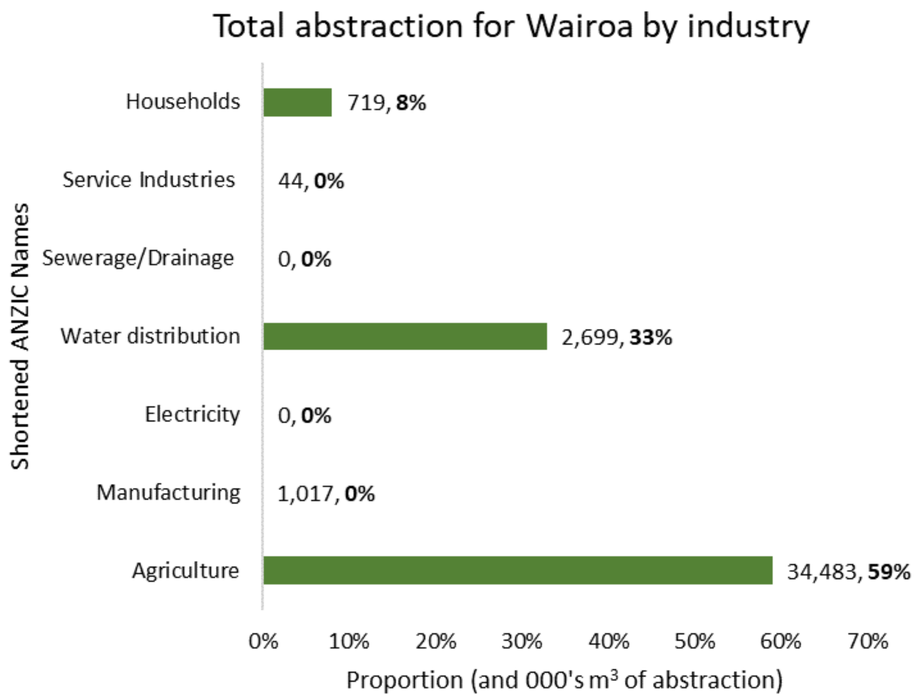
    It should be noted that TopNet only simulates and reports groundwater recharges and discharges for sub-catchments associated with receiving streams, rivers or lakes. TopNet does not provide recharge and discharge values for coastal catchments where all groundwater is considered to discharge offshore as TopNet does not incorporate a coastal receiving boundary. These coastal sub-catchments represent a small fraction of the overall area of the Hawke's Bay and are generally in areas where there is little existing utilisation of groundwater resources. These small catchments have been excluded from the current stocktake as a change in storage through the reporting period cannot be calculated from the TopNet model outputs.
3. The closing stocks were calculated for each sub-catchment, based on the starting stocks and the change in stocks through the reporting period.
4. Finally, the change in stock and the closing groundwater stocks were compiled for each district and for the entire Hawkes Bay region.

Appendix 4. Total abstraction disaggregated by industry for each of the four districts.




Total abstraction for Hastings by industry
Shortened ANZIC Names
Households
719, 1%
Service Industries
44, 2%
Sewerage/Drainage
0, 0%
Water distribution
2,699, 17%
Electricity
0, 0%
Manufacturing
1,017, 17%
Agriculture
34,483, 63%
0%
10%
20%
30%
40%
50%
60%
70%
Proportion (and 000's m³ of abstraction)

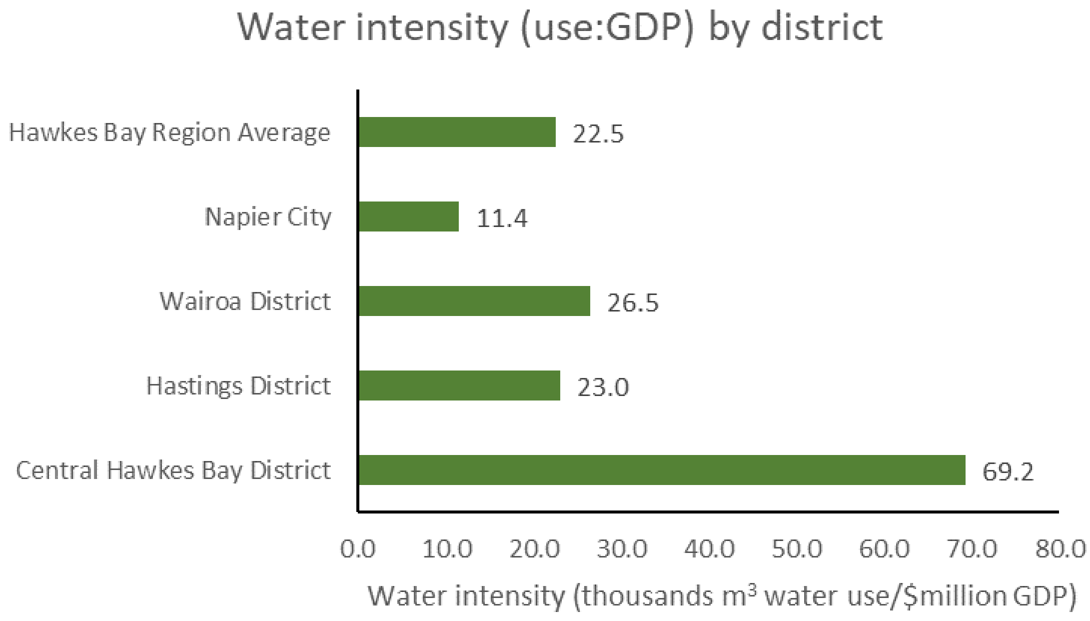

Total abstraction for Napier by industry
Shortened ANZIC Names
Households
323, 2%
Service Industries
529, 3%
Sewerage/Drainage
57, 0%
Water distribution
9,667, 54%
Electricity
0, 0%
Manufacturing
4,959, 28%
Agriculture
2,356, 13%
0%
10%
20%
30%
40%
50%
60%
Proportion (and 000's m³ of abstraction)



Water intensity results

Below, we also present water intensity results for the Hawke's Bay Region and each district. Water intensity measures the ratio of water use (in this case, measured in thousands of m^3 of use) to GDP (measured in millions). We note that for consistency, water use statistics for electricity generation (hydropower) are not included in the following results.

	Total water use (Thousands cubic metres)	GDP ($m)	Water intensity (thousands m^3 /$million)
Central Hawkes Bay District	41,262	596	69.2
Hastings District	105,506	4,579	23.0
Wairoa District	7,541	285	26.5
Napier City	32,997	2,883	11.4
Hawkes Bay Region Average	188,048	8,342	22.5


Water intensity (use:GDP) by district
Hawkes Bay Region Average
22.5
Napier City
11.4
Wairoa District
26.5
Hastings District
23.0
Central Hawkes Bay District
69.2
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
Water intensity (thousands m3 water use/$million GDP)

Appendix 5. Assumptions for the supply and use tables and the assets tables.

The following section provides an in-depth coverage of the assumptions made, and the key data limitations observed, during the development of the supply and use tables and the water assets tables. The aim of this section is to ensure that the Hawke's Bay water accounting framework is reproducible and transparent. This section also highlights key areas for data-related investment and improvement for the Hawke's Bay region. Assumptions for the supply and use tables are detailed first. as they also underpin aspects of the water assets tables.

Assumptions for the supply and use tables

Assumptions and data issues arising in the development of the supply and use tables are divided into;

a) assumptions pertaining to specific water uses or discharges (i.e. irrigation water, effluent, household water consumption); and

b) assumptions that are specific to a particular district or city council.

Assumptions that are consistent across districts are reported first followed by district-specific assumptions.

Irrigation water

- Evapotranspiration is not included in the supply and use tables. Estimates for actual evapotranspiration are recorded in the water assets tables. Evapotranspiration returns most irrigation water to the environment (as pasture and crops take up water, undergo transpiration and release water vapour to the atmosphere).
- Through discussion with industry experts, it is assumed that 10% of irrigation water is not taken up by plants and is returned to soil water (this is represented as a return to the environment from irrigation). This is likely a lower bound estimate and this parameter should be updated when data are available.

Livestock water

- Livestock numbers are taken from Stats NZ reporting.[25] We do not have enough data on water consumption (and excretion) for deer, fawns, pigs and horses. The estimates for livestock water consumption are conservative and include consumption by sheep, beef and dairy stock.
- Livestock numbers are multiplied by water consumption per head for each animal (using data for Hawke's Bay) to obtain total livestock water consumption.[26] The upper end of the confidence ranges for water consumption per head were used and industry suggests these numbers are still conservative.
- Dairy shed water use is added to the water use per cow to reflect consumption of water in dairy-specific operational infrastructure (milking sheds).[27]
- Literature and research on effluent volumes (rather than quality) is sparse. Results from a series of studies are extrapolated to the Hawke's Bay context.
    - An experiment-based study of urine volumes from Welsh mountain ewes provides a lower bound estimate for effluent per sheep.[28] This is a lower bound because the climate in New Zealand is warmer and sheep will drink and urinate in greater volumes.
    - A New Zealand study of beef cattle provides a large range of potential urine volumes per day.[29] We assume the true value is around the midpoint of this range (30.25 litres/steer/day).
    - Dairy effluent is calculated using monitoring data from a New Zealand effluent study.[30] The study includes data for the Waikato, Northland and Southland regions. Hawke's Bay effluent is assumed to be similar to Southland values because these regions are most similar in dairy stocking rates, milk platform and herd size.[31] Again, this will be a conservative value because the Hawke's Bay climate is warmer than the Southland climate.

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[25] Stats NZ, "Livestock Numbers by Regional Council."

[26] Buchanan, "Estimating Permitted Water Use in Hawke's Bay."

[27] In line with: Rutter, "Assessing Unconsented or Permitted Water Use in the Bay of Plenty Region."

[28] Marsden et al., "Sheep Urination Frequency, Volume, N Excretion and Chemical Composition."

[29] Betteridge et al., "Why We Need to Know What and Where Cows Are Urinating - a Urine Sensor to Improve Nitrogen Models."

[30] Heubeck, Nagels, and Craggs, "Variability of Effluent Quality and Quantity on Dairy Farms in New Zealand."

[31] DairyNZ, "New Zealand Dairy Statistics 2018/19."

Households

- The number of people per household is assumed to be equivalent between non-reticulated and reticulated households (on average).
- It is assumed that 50% of non-reticulated water use and abstraction comes from precipitation and 50% is abstracted from groundwater (wells or bores).
- To estimate non-reticulated household consumption, estimates for the number of non-reticulated properties were multiplied by estimates of water use per property. Non-reticulated property numbers are taken as the difference between the number of occupied households (StatsNZ or district maps)[32] [33] and the number of connected households (data supplied by each district). Consumption per household for non-reticulated households is assumed to be the same as reticulated household consumption.
- Non-reticulated wastewater is assumed to be 200 litres per person per day.[34] That value is multiplied by the number of people per household (unique for each district, taken from Stats NZ) and the number households that are not connected to the sewerage system.

Distributed water

- The distributed water accounting is limited by the low granularity and absence of data on the make-up of non-household water use (for all councils except Wairoa). We either make strong assumptions about which industries the non-household water goes to or we don't assign the water to an industry (but include the water in the totals).
- Water use for unbilled users was allocated to the services sector (as these users are likely to be parks, hospitals, schools, etc.).

Wastewater

- In the discharges consents database, volumes are quoted as the maximum allowable discharge. There is no reconciliation of maximum allowable discharge and actual discharge. If there are no penalties for applying for consent for the upper end of a discharge volume range, it is highly likely that most discharge consents overestimate the volume of water discharged to the environment. Indeed, the maximum permitted discharges for the sewerage industry far exceeds the volumes of measured sewerage treated and discharged from various wastewater facilities around the Hawke's Bay region. Where we have DIA request data and discharge permit data available, we prioritise the DIA request data. Where we have no DIA data but discharge permit data, we carefully assess the values in relation to the wider water ecosystem in the Hawke's Bay region. We then generate educated estimates for the parameters and values of interest.
- These deficiencies re-emphasise the importance of measuring outcomes and including data reporting responsibilities on discharge consents. Current consents primarily focus on the quality of wastewater discharged (which is a fundamental environmental consideration). However, quantity is also a crucial consideration (as is the specific location of discharge). It is recommended that volume monitoring and reporting is a condition for future discharge consents.
- Discharges to land are considered discharges to soil water as recharging groundwater wells and aquifers is unlikely to be the primary outcome for such wastewater. Usually, specific interventions and techniques are required to recharge groundwater assets.[35] Although a minority of discharge may percolate through to groundwater assets, for simplicity, we assume all land-based discharge goes to soil water (initially, then to other assets like rivers through runoff mechanisms).

Napier City Council (NCC)

- Measured and unmeasured (not metered) distributed water that is unbilled is treated as water for parks and public services (reported as water use for the services industry).
- There are 1.709 million m^3 of billed non-household distributed water which is assigned to the services industry (includes small businesses). This is a strong assumption and should be a priority for review and validation. It is likely that some of the commercial water use belongs to the manufacturing or agricultural sectors.

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[32] Stats NZ, "2018 Census Place Summaries; Napier City." – Analogous sources are used for CHB and Hastings districts.

[33] Wairoa District Council (WDC), "Maps Portal: LINZ Property Information."

[34] Land, Air, Water Aotearoa (LAWA), "Tips on Conserving Water."

[35] Asano and Cotruvo, "Groundwater Recharge with Reclaimed Municipal Wastewater."

- Napier City Council provide estimates of the volume of wastewater receiving that comes from household sources. In the NCC DIA information request, the comments indicate that wastewater is estimated as 95% of household water use. The corresponding value (5.16 million m^3) is significantly greater than 95% of connected household water use, by our calculations (3.96 million m^3). We adopt the latter value, which is consistent with the methodology that NCC report in their DIA request. This discrepancy requires further investigation and consideration.

Hastings District Council (HDC)

- Water use for unmetered non-household network users was assumed to be equal to the median consumption for metered, non-residential users (440 m^3/day).[36]
- The wastewater volumes assigned to households (in the HDC DIA request) are in considerable excess of the volume of distributed water used by households. This is likely due to inflow and infiltration (I&I) into the HDC wastewater network.[37] Determining the actual cause of this difference is an area for future investigation.

Central Hawkes Bay District Council (CHBDC)

- We do not have DIA request data for CHBDC and therefore do not have detailed three waters information (on distributed drinking water, stormwater and wastewater). Consequently, we deploy several strong assumptions and cannot disaggregate a range of water flows by ANZSIC industry codes.
- Water consumption per property per year is assumed to be 274 m^3, which is in line with high-level averages on the CHBDC website.[38] There is no distinction made between reticulated and non-reticulated properties.
- Publicly available Three Waters Reforms data were used to establish the number of connected households (distributed water) in the CHB district.[39] This source also provides data on the number of people connected to the wastewater system.
- There were detailed accounts for trade waste volumes in the CHB district but not for other types of waste. Household wastewater was assumed to be the remaining wastewater after accounting for trade waste.

Wairoa District Council (WDC)

- Leakages in the water distribution system for Wairoa DC are only attributable to household water distribution. Most non-household (commercial) water distribution was arranged through bespoke agreements between WDC and commercial users. This set-up means WDC do not track leakages for these users (as WDC only monitor the volumes leaving council treatment facilities).

Assumptions and limitations for water assets tables

Assumptions and data limitations for the water assets tables are reported below. Results from the water supply and use accounting feed into the water assets tables (in the abstraction and returns sections). For more information on the assumptions underlying the supply and use tables, see section 2.5.1.

The primary sources for HBRC water abstraction consents are surface water, groundwater, storage or stream depleting. Groundwater and stream depleting data are straightforward to incorporate into the water assets accounting tables (broken down by what the water is used for). However, surface water and storage water may belong to any of the three surface water assets (rivers, lakes and artificial reservoirs). Surface and storage water consents are extracted and recategorized based on the consent descriptions as abstractions from lakes, rivers or artificial reservoirs. During recategorization, we make the following assumptions:

    - Spring water: we assign half of the total volume to lakes and half of the total volume to rivers. Springs can be connected to river networks or lakes and are included under these headings in spatial planning methods which assess the stocks of water assets.
    - There are consents for water that is abstracted from a river network, stored in an artificial reservoir and subsequently used for irrigation purposes. Given the significant annual flow of rivers and the impermanence of individual molecules of water, we classify these consents as abstraction from

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[36] In line with: Hastings District Council (HDC), "Hastings District Council - Water Loss Assessment 2019/20."

[37] While we could not precisely determine I&I for Hastings, consultation with water industry experts reveal expected I&I is 30% across New Zealand (which is similar to the discrepancy observed for Hastings).

[38] Central Hawke's Bay Regional Council (CHBDC), "Water Connections and Meters."

[39] Department of Internal Affairs (DIA), "Three Waters Reform: Individual Council Models and Slidepacks."

    artificial reservoirs. For completeness, we also report these consents as inflows from rivers to artificial reservoirs (in the assets tables) – see B.ii. and E.iii. in **the tables.**
  - We equate abstraction from dams as abstraction from artificial reservoirs.
  - Some consents were coded as surface water but involved taking water from an open well. We recoded this consent as water abstracted from groundwater.
- We estimate livestock water abstraction for the supply and use tables using literature for livestock water consumption (see section 3.1.). We assume all this water is taken from artificial reservoirs.
- TopNet models the opening and closing stocks of soil water, the inflows from precipitation and the outflows from evapotranspiration. However, there is not enough outflow to account for the closing stocks level (under simple water accounting methods) because runoff is not included in the model results. We assume that all runoff goes to rivers and represent this as a flow between assets (leaving soil water and going into rivers).
- Original estimates for evaporation from artificial reservoirs and rivers are inaccurate and likely overstated by up to 98%.[40] As a result, zeroes are recorded in these sections of the water assets tables.

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[40] This was determined through personal communication with hydrology experts at NIWA. The overestimation stems from the assumptions that water is not taken from artificial reservoirs and that rivers are stagnant bodies of water. Both assumptions are highly unrealistic.

Appendix E: HB Future Farming Trust

Soil carbon, soil structure and water holding capacity of agricultural soils, 2021

HAWKE'S BAY FUTURE FARMING
TE MATAU A MĀUI AHU WHENUA-HĪKINA TAIAO

Soil Carbon, Soil structure and water holding capacity of agricultural soils.

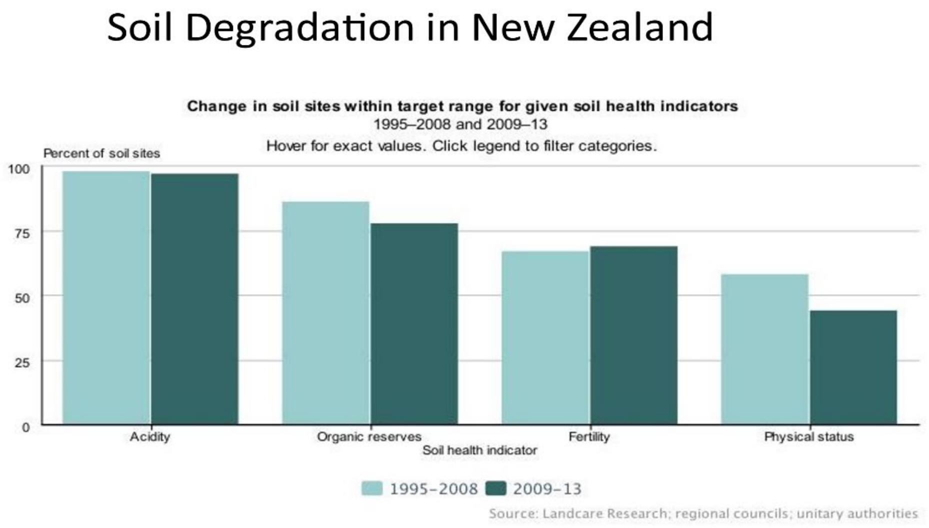
Hawkes Bay Future Farming Trust P. E. Schofield

review for Tom Skerman HBRC.

Soil Carbon levels in NZ. Can we improve soil function and sequester soil C?

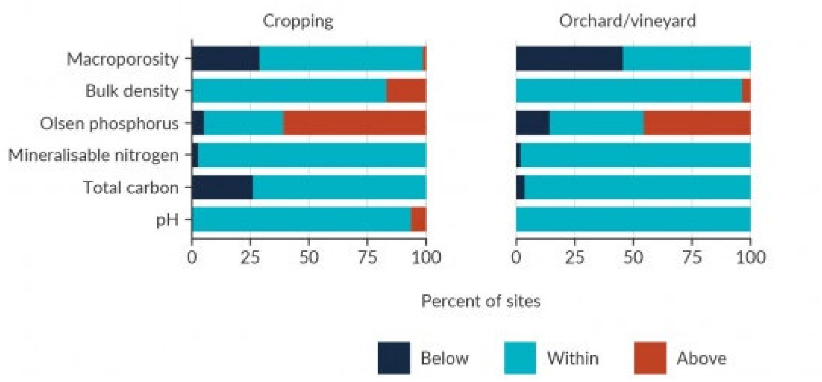
New Zealand is a geologically young land and our soils are rather ‘young’ in geological terms having formed since the end of the last Ice Age, approximately 14,000 years ago.

European Settlers arriving in New Zealand in the 1800s cleared indigenous vegetation developing land for pastoral farming and cropping from this time. Agricultural intensification has continued to now. Although NZ soils do have relatively high soil C levels compared to more degraded areas of the planet agricultural practices such as increasing stocking rates, cultivation and increasing fertiliser use have contributed to significant and increasing amounts of soil degradation. The table below shows the trend for reduction in soil organic reserves and soil physical structure in the last 20 to 30 years of measurements. (Stats NZ)



Source: Landcare Research; regional councils; unitary authorities

Sites within target range of soil quality indicators by land use, 2014–18. (Stats NZ “our land 2021”)



The soil quality indicators reported in the chart above show concerning trends for Macroporosity and Total Carbon which is below target range on 25 % percent of cropping sites but there is no upper target is set. These two declining measures of soil quality impact on water infiltration rates and soil water holding capacity.

There is debate in the NZ science fraternity about the ability to sequester C in NZ soils but little or no research and measuring has been done to prove or disprove the concept with all studies to date being reviews of old data and resampling of historic sites. There is a trend for decreasing soil C levels over the last 20 years at sites where farming practices have intensified. (Bruce-Iri 2018; Schipper et al 2008; Whitehead et al 2018) No studies of sites monitored during attempts to rebuild soil function and thus soil C levels exist in NZ yet.

Early indications from measurement of neighbouring dairy farms in HB that have had different pasture management systems indicate there is potential to rapidly increase soil C levels by following soil regenerative practices. In our latest study a farm with 10 years of soil regeneration history has 60 Tonne per Ha (to 600 mm depth) more soil carbon than a nearby farm that had been intensively farmed for the past 10 years. (Schofield, Smith and Kamp soil C pilot study 2021) Both farms have relatively high soil C levels at 7.5% total C and 5.8% total C respectively in the top 300 mm of the profile.

Relationship between Soil Carbon and Water Holding Capacity.

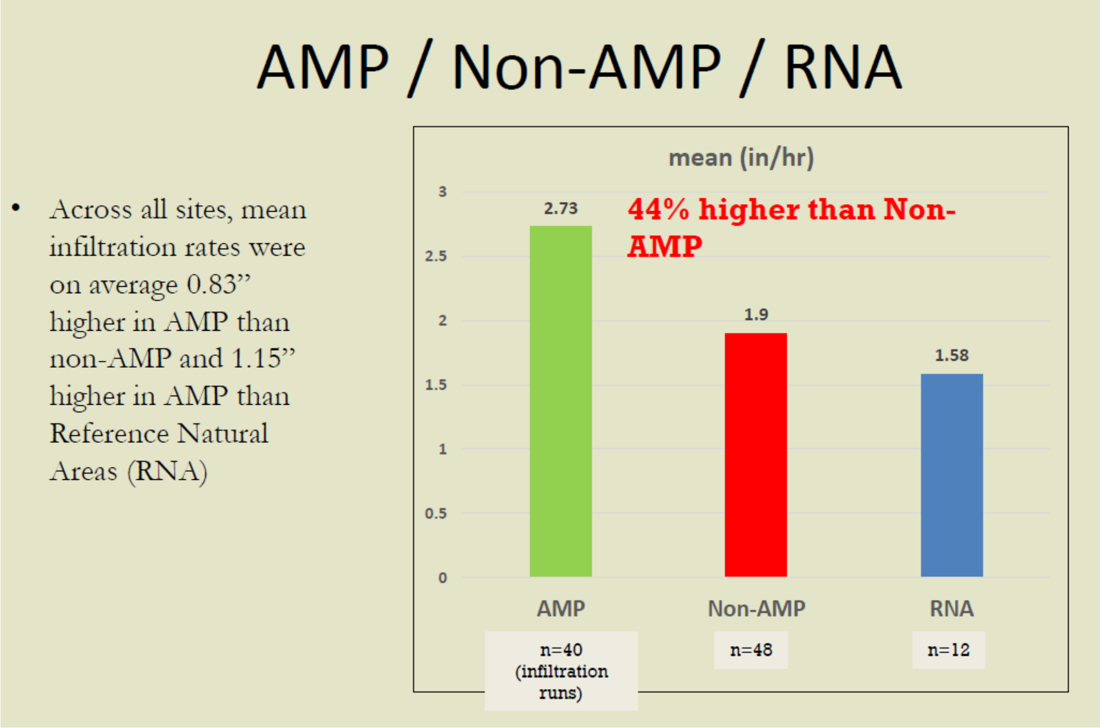
There is no data available on the effect of soil carbon levels on the water holding capacity of a soil in NZ. In recent MfE and Landcare Research reports (Our Land 2021, The State of NZ Soils) the loss of soil health and soil carbon stock is reported and the advantages of reversing the trends are discussed but not quantified.

US scientists exploring improved soil health and the effect of increased soil C levels on infiltration rate and water holding capacity in the Red River basin have found some strong relationships between improvements in soil organic matter and the water infiltration rate and water holding capacity. These researchers found use of Adaptive Multi Paddock Grazing (AMP) compared to Continuous Grazing (CG) resulted in increases in soil C stocks an average of 13% or 9 tonne per Ha (1m depth). (Mosier et al 2021)

Studies of the loamy soils in the Mississippi basin show that the increased soil C levels achieved by AMP farming practice also result in greater infiltration rates and increased soil water holding capacity. The alluvial loam soils in the Mississippi basin are somewhat older soils but have similar texture to our plainland soils in NZ with CEC of about 20 so similar silt, sand and clay proportions.

The chart below summarises the difference in water infiltration rates found between regenerative grazing management and conventional grazing. Interestingly the AMP grazing approach and conventional grazed pastureland both had better infiltration rates than the natural grassland reference sites. (Apfelbaum 2021)

AMP sites had 20mm per hr greater infiltration rates than conventional grazed pasture.



AMP / Non-AMP / RNA

- Across all sites, mean infiltration rates were on average 0.83” higher in AMP than non-AMP and 1.15” higher in AMP than Reference Natural Areas (RNA)

Saxton (2005) found that Soil Water Holding Capacity was found to increase by 2.5% if soil organic matter content increased by 1% in the Red River basin. The study looked at the top 150 mm of the soil profile only but found the following relationship between increased soil C and increased in water storage in top 150mm of soil profile.

Table 11.1 – Soil C and Water Storage – p 203 “Soil Carbon Management” CRC Press, edited by J M Kimble, C W Rice, D Reed, S Mooney, R F Follet, R Lal.

Additional soil organic matter	Additional soil Carbon	Additional Water storage (cubic m per Ha)
1%	0.57%	37.5
2%	1.14%	75
3%	1.71%	112.5

These are only small increases in additional water storage volume but are based on only a small proportion of the available soil profile (150 mm compared to others who measured up to 1m soil depth). The research by Mosier and Apfelbaum in the same area of the US found an average of 13% increase in soil C or 9 tonne per Ha (measured to 1m depth) by grazing practices aimed at increasing soil C. Their AMP trial sites also had greater biodiversity than the conventionally managed sites.

Our research on NZ pasture indicates that even soils that are already high in soil C by world standards can potentially increase by C levels 30% or store 60 Tonne more carbon per Ha to 600 mm depth. Given the degraded/compacted state of the cropping, orchard and vineyard soils in HB it may be possible to increase soil carbon levels by 10 s of tonnes per Ha rapidly by adopting soil regenerative practices.

Such practices would lead to increased water storage of several hundred cubic meters of water per Ha. and will also mitigate flood damage, soil loss and increase water percolation to shallow and deep groundwater.

The increased infiltration rate and therefore the potential for huge volumes more water to percolate to the shallow groundwater and deeper into the aquifers is probably more significant but also very poorly researched.

From the various groups who have done some measuring of infiltration rates in conjunction with changed land management (e.g Regen Ag) it is reasonable to assume that infiltration rates could increase by 20mm/hour by adopting management practices that improve soil health.

20mm infiltration increase means that we can expect 200 cubic meters more water per ha/hour to be soaked up by soils in a rainfall event where significant rain occurs. The NIWA climate models can tell us how often to expect that but even if we do that twice in a year we would have 400 cubes of water per ha per annum either in the soil supporting plant growth or adding to the shallow groundwater and recharging aquifers

Steven Apfelbaum of Applied Ecological Services (pers comm) summarises their findings in the Red River basin below:

“An increase in infiltration of just 1” (1/12th of an acre foot) is a big deal over a landscape. This equates to 27,333 gallons per acre of additional infiltration, or over a landscape of a million acres you can do the math…………very highly significant increase in water.

As for water holding capacity in the soil--- a 1% increase in SOC equates to 12,000 to 60,000 gallons per acre (depending on the soil type) of additional holding capacity in the soil organic carbon"

In metric terms this is equivalent to 100 to 500 cubic meters of extra water storage per ha achieved if by an increase in soil carbon from 3% to 4% which from our experience working with HB growers and farmers looks achievable.

Some numbers:

Heretaunga Plains 30,000 ha

Ruataniwha Plains 26,000 ha

If we can improve soil function on half the area (28,000 ha) to 600 mm depth or greater and increase soil C by 1% we could store between 2.8 million and 14 million cubic meters more water in the soils than we currently do. The co benefits probably have more value to the farmers, farm communities and farm ecosystems than the water storage alone.

References.

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2021 Jun 15;288:112409. Adaptive multi-paddock grazing enhances soil carbon and nitrogen stocks and stabilization through mineral association in southeastern U.S. grazing lands
Samantha Mosier[1], Steven Apfelbaum[2], Peter Byck[3], Francisco Calderon[4], Richard Teague[5], Ry Thompson[2], M Francesca Cotrufo[6]

S I Apfelbaum Applied Ecological Services PPT summary presentation of SE USA study on AMP grazing (2021)

Bruce-Iri , P. NorthTech; Soil Carbon Sequestration, A Contested Space in Science. Researchgate.net Nov 2018.

Agriculture, Ecosystems & Environment
Volume 265, 1 October 2018, Pages 432-443 Management practices to reduce losses or increase soil carbon stocks in temperate grazed grasslands: New Zealand as a case study DavidWhitehead[a] Louis A.Schipper[b] JackPronger[c]Gabriel Y.K.Moinet[a] Paul L.Mudge[c] RobertoCalvelo Pereira[d]Miko U.F.Kirschbaum[e] Sam R.McNally [f]Mike H.Beare[f] MartaCamps-Arbestain[d]Schipper, L., Parfitt, R., Arnold, G., Claydon, J., Baisden, W. T., & Ross, C. (2008).

Contribution of carbon loss from pasture soils to New Zealand's soil carbon budget. In *Carbon: Global Cycle to Regional Budget*. Conference held at Wellington, New Zealand.

A review of soil carbon change in New Zealand’s grazed grasslands June 2017 New Zealand Journal of Agricultural Research 60(2):93-118 Schipper,L., Mudge, P L., Kirschbaum, M U F., Hedley, C B.

Appendix F: Cost References

Appendix F: Industry and Media Reports

(Reports are listed in Date order)

Date	Industry/Area	Quoted Costs	Reference	Comments
20 February 2023	Cost to NZ (not just HB)	$13.5 billion	The Drinks Business 20 February 2023 https://www.thedrinksbusiness.com/2023/02/cyclone-gabrielle-could-cost-new-zealand-13-5-billion/	Quoting Grant Robertson, Finance Minister
20 February 2023	Horticulture pipfruit		Stuff Business 20 February 2023 Horticulture apocalypse: trees covered in 2m of silt and dead animals float through apple orchards	Quotes Paul Paynter, Yummy Fruit. Apple industry already had a bad year with markets collapsing in Europe. Some growers have lost 30 years' of work on fruit orchards
20 February 2023	General		One News 20 February 2023 Cyclone clean up likely to exacerbate inflation - economist	Economist Christina Leung: Inflation will rise. Wealth cost – damage to properties. Supply chain disruptions. Those regions impacted will see price increases most concentrated.
22 February 2023	Horticulture Kiwifruit		Stuff Business 22 February 2023 What does cyclone damage mean for our foof supplies	40% of the kiwifruit in HB affected (Zespri)
25 February 2023	$13b repair HB Infrastructure – roads, bridges, treatment plants, comms before housing	$35.9M repair for CHB roads – Need $100M	NZ Herald 25 February 2023 Cyclone Gabrielle possible 13b repair – Hawkes Bay infrastructure before housing Cyclone Gabrielle 35m boost from Waka Kotahi for Central Hawke's Bay	

28 February 2023	Horticulture Vegetables	$40M	Newshub 28 February 2023 Cyclone Gabrielle: Full economic impact on produce in Hawke's Bay, Tairāwhiti regions only just being understood	Affects sweetcorn, beans, butternut pumpkins, tomatoes
28 February 2023	Horticulture Replanting costs	Est $180k- $250k per hectare	The Conversation 28 February 2023 Cyclone Gabrielle hit NZS main fruit growing region hard – now Orchardists face critical climate choices	
3 March 2023	Hastings District	HDC been spending $600k a day since the cyclone => approx. $10.2M $1.3M spent to support the response excluding roading and three waters infrastructure costs	The Hawke's Bay App 3 March 2023 Big Financial impact - Hastings District Council spends 600,000 a day in response to cyclone Gabrielle	Spending on essential roading repairs and access restoration to roads throughout the district
6 March 2023	Apples and Pears		RNZ 6 March 2023 About 4000 hectares of apple orchards in Hawke's Bay affected by Cyclone Gabrielle	NZAP – 47% of the crop has been affected – 3 categories: completely destroyed, completely submerged with deep silt; Workable with reduced yield
9 March 2023	Horticulture		RNZ 9 March 2023 Cyclone Gabrielle's impact on New Zealand's fruit bowl	Quoted Brydon Nisbet – HB Fruitgrower's Assn president: "There's not only the cost of getting rid of the block, but the whole establishment of a new orchard and then the delay of getting an income from that orchard. So, it's a huge cost and a lot of the growers are facing that, they can't plant again."
9 March 2023	Agriculture/Farming	$1 billion	Farmers Weekly 9 March 2023 Cyclone Gabrielle after the flood – Cyclone Gabrielle a billion-dollar blow to farmers	Estimated by Federated Farmers policy team. This figure doesn't include costs to public infrastructure, food shortages, inflation.

14 March 2023	Central Hawke's Bay District	$50M	CHBDC Website https://www.chbdc.govt.nz/our-district/projects/roading-recovery/the-solution/	Costs of repairing the current infrastructure (roading) damage approx. $50M
16 March 2023	Horticulture	$650M requested. Doesn't cover income losses this year or costs of replanting to maturity (5-7 years for apples). Asking for cost of loss, cost of replanting and cost of infrastructure where needed	Hawke's Bay Horticulture Recovery Package – Letter to Grant Robertson from Nigel Bickle on behalf of the "HB Horticulture Grower Taskforce" - representatives of horticulture growers, iwi/Mana Whenua and local government.	Proposed Recovery Package: Want to avoid the intergenerational social dislocation and trauma as occurred in the 1980s with the freezing works closures. Short-term clean up, reinstatement of crops, reinvestment in orchards and vineyards when necessary. Based on three inter-connected buckets of financial support: 1) Critical response; 2) Reinstatement (12 months); 3) Re-establishment (3 years). Package also seeks to address the range of different ownership and leasing structures in HB – much Māori land affected.
23 March 2023	Insurance Claims	Half a billion- $500,000,000	NZ Herald – 23 March 2023 Cyclone Gabrielle half a billion dollars in insurance claims in Hawke's Bay	Almost half a billion claims had been made by this date according to data from the Insurance Council of NZ /Te Kāhui Inihua o Aotearoa. 13,221 claims in the region total $481,227,673: 3780 claims for home; 3939 for contents, 2426 for commercial; 28936 for motor vehicle 52 for marine and 131 for other types of insurance.
25 March 2023	Horticulture, Viticulture, Forestry, Farming	**$12.5M** to repair and replace damaged vineyards MPI set aside $25M initially, then added another $26M for urgent	Stuff Business 25 March 2023 Wine, Pipfuit, Forestry – the toll of Gabrielle is widespread	Apples and Pears – 33% of crop damaged Wine – 25% of the crop destroyed. 40 out of 200 wineries affected

		repair, clearing silt to save trees and vines		Forestry – access main concern due to roading. 10% of the plantation area cannot be accessed. Contractors could not get to their equipment. One in four people in the region rely on forestry for their income. 45 farms suffered significant damage (Dairy NZ)
29 March 2023	Cancelled Events/cost to tourism	**$30M** in insurance claims for cancelled events	Stuff Business 29 March 2023 Cyclone Gabrielle turned a bumper summer into one from hell for North Island tourist operators still reeling from border closures	HB Tourism says more than half the region's visitors come from State Highways 5 and 2 to the north.
29 March 2023	Hawke's Bay 28,000 properties identified as impacted: 102 red stickered, 1048 yellow-stickered. 150 bridges damaged across the region and more than 20 destroyed. 31 communities still isolated.	Insurance claims **$481M** $25M est.cancelled events Wairoa District Council's infrastructure costs estimated repairs of $130M- includes $50M for spillway resilience review and $25M for riverbank erosion protection.	NZ Herald 29 March 2023 Cyclone Gabrielle costs: Tourists 'key' to rebooting Hawke's Bay economy, council's multimillion-dollar weekly roading spend Briefing paper from HBCDEMG	Tens of millions wiped off the economy due to cyclone-enforced cancellation of several events – Art Deco Festival, Mission Concert, HOY, other concerts. Impact on NZ's food production and supply will slow down GDP. Will have inter-generational impacts across society. Mental scars suffered – psychological problems, frustration, stress, exhaustion and depression. Negative impacts on child wellbeing and development – children experiencing isolation, disruption to their education. Increase in crime, domestic violence and anti-social behaviours. Environmental impact on HB's flora and fauna still to be discovered – cyclone's impact on rare and endangered species including kākā, kiwi, kōkako, long-tailed bat, tree wētā and kākā beak.

				Also inter-tidal zones, dune areas where there are fish nurseries and tidal rock reefs – algae, shellfish, crayfish and fish species are expected to be significantly impacted. Cultural loss – destruction of marae and urupa. Displacement and loss.
March 2023	Economy A Market Intelligence Report This is for all areas affected by the cyclone	Economic losses expected to exceed the \$2bn-\$4bn of losses of the 2016 Kaikōura earthquake but will still be dwarfed by the \$40bn of losses from the Canterbury earthquakes. On farm revenue loss estimated between \$500M and \$1bn (excludes forestry). Fonterra estimates losses of almost \$130M for dairy farmers. On farm capital losses estimated up to \$1bn.	Cyclone Gabielle's impact on the NZ economy and exports – March 2023 Economic Division of Ministry of Foreign Affairs and Trade in consultation with NZTE Enterprise and MPI Cyclone Gabrielle's impact on the New Zealand economy and exports- March 2023	The costliest non-earthquake natural disaster in NZ. The recovery and rebuild work is expected to add to growth in the coming quarters – adding 1% to NZ's GDP over coming years. Cyclone Gabrielle likely to contribute to the rising cost of living.
2 April 2023		Residential Repair bill expected to be less than **\$2b** Roads, rail, electrical lines and substations expected to be **\$2b**	Stuff Business 2 April – Chief forecaster Infometrics Putting Cyclone Gabrielle in perspective beside last decades quakes	
Payments made from relief funds				
30 March 2023		**\$500k** HB Disaster Relief Fund	HBRC Website 30 March 2023 Hawke's Bay Disaster Relief Fund confirms first round of payments today	
21 March 2023		**\$346k** HB Foundation **\$100,000** committed to psychological support primarily through Rural Support Trust	HB Foundation has distributed four rounds of funds- 21 March Voxy http://www.voxy.co.nz/national/5/414456	

17 March 2023	Wairoa Mayoral Relief Fund Govt contrib **$1M** to Mayoral relief funds in HB	WDC Website 17 March 2023 Wairoa Mayoral relief fund open for applications
17 March 2023	CHB Mayoral Relief Fund- **$150,000**	CHBDC Website 3 April Nearly 150,000 distributed by Central Hawkes Bay Mayoral Relief Fund
27 March 2023	Red Cross **$1.1M** to Wairoa residents	Red Cross website 27 March 2023 New Zealand Red Cross announces major contribution to Wairoa Recovery effort
21 April 2023	Red Cross further allocation **$1.9M**	One News 21 April 2023 https://www.1news.co.nz/2023/04/21/why-has-red-cross-spent-just-3m-of-21m-cyclone-gabrielle-cash/
	TOTAL paid out in local relief funds $4,650,846	
Government Packages for flood relief (This is not just HB)		
	$1M to HB Mayoral Relief Funds	Beehive media release 21 February Further boost to Mayoral Relief funds for communities impacted by Cyclone Gabrielle
	$11.5M community support package from govt for non-government orgs and community groups ($4M specifically for Auckland) = > Estimate **$5M to HB**	1News 13 February 2023 Immediate relief – Govt pledges 115m in flood cyclone support
	$4M from govt for immediate recovery needs of rural communities.	Beehive Media Release 6 March 2023

	Total **$26 M** for primary sector recovery	Government approve 26 million grant extension for farmers and growers
	$25M in business support grants	NZ Herald 15 March 2023 Cyclone Gabrielle: Grant Robertson announces another $25m for affected businesses as Government support tops $100m
	$15M for Māori communities	1News 28 February 2023 Cyclone Gabrielle 15m package to support Māori communities
		1News 21 February 2023 Tens of millions paid out in initial support to cyclone victims
	Civil Defence payments: **$59.21M** paid to 105,258 people as at 11/3	Civil Defence website 20 March 2023 Cyclone Gabrielle solid Waste Management Fund
	$15M Solid Waste Management Fund to clear waste from residential properties administered by NEMA	
	WK allocated **$250M** to emergency works following the cyclone	1News 3 April 2023 Logging tracks using closed bypass road in Tokomaru Bay- See last parag
	Pre-budget announcement: Waka Kotahi roads **$275M** Rail $200M (across the North Island affected areas) Estimate **$50M** HB	15 May 2023 https://cdn.hbapp.co.nz/news/news/video-govt-announces-pre-budget-package-to-fix-cyclone-damaged-roads-to-take-pressure-off-ratepayers

		29 May 2023 Weekly Update from Cyclone Recovery Unit https://www.civildefence.govt.nz/resources/news-and-events/news-and-events/weekly-update-from-the-cyclone-recovery-unit-29-may-2023/	Lists the Government support to date for cyclone recovery
	TOTAL govt: $722.21M		

Local Government Locality Plans

Napier City Council (infrastructure)	$57,920,000	Ahuriri-Napier-Locality-Plan-v1.3.1.pdf	
Hastings District Council (infrastructure)	**$1,154,240,000**	Heretaunga-Locality-Plan.pdf (hastingsdc.govt.nz)	
Wairoa District Council (infrastructure)	$130,000,000	https://www.wairoadc.govt.nz/assets/Uploads/Te-Wairoa-Ka-Ora-Locality-Plan-28-April-2023.pdf	
Central HB District Council (infrastructure)	$50,000,000	Cyclone-Gabrielle-Recovery-and-Resilience-Plan-05042023.pdf (chbdc.govt.nz)	
HB Regional Council (infrastructure)	$93,000,000	HBRC Regional Resilience Plan- Edition 1 (28 April 2023)	
	TOTAL Local govt infrastructure costs $1,485,156,000		