Hawkes Bay Region Water Security Economic Impact Assessment

Final Report

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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''').

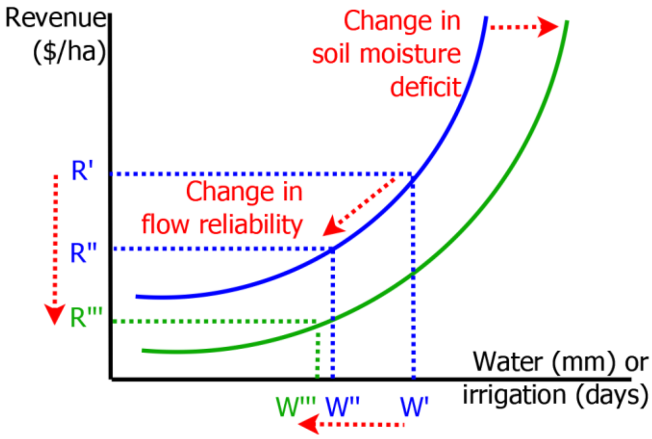


Fig. A: A Theoretical Water-Revenue Curve and its Adjustment for Changes in Supply (Flow reliability) and Demand (Soil moisture deficit) Relationships.

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.

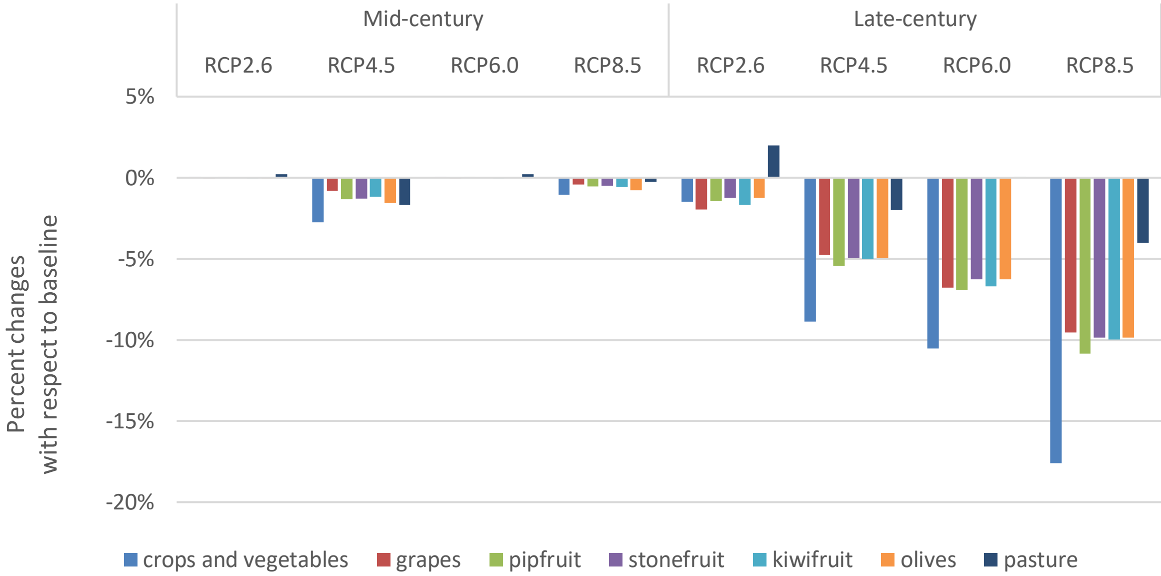


Fig. B: Net Changes in Revenues (%) for Irrigated Crops and Pasture under Different Climate Change Scenarios (RCPs) and Time Horizons for the Do-nothing Scenario

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.

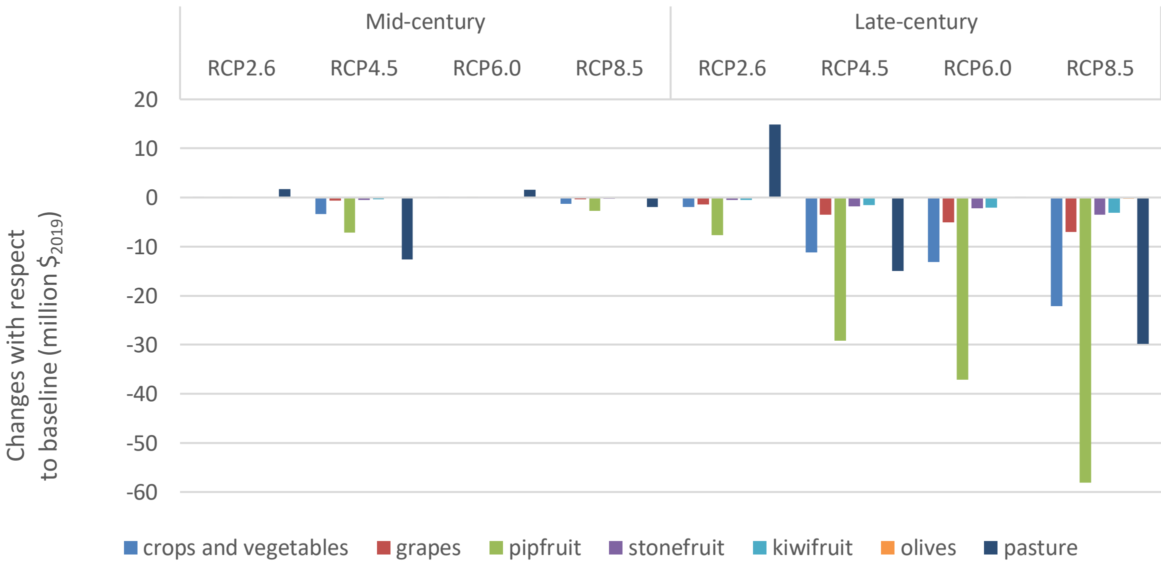


Fig. C: Net Changes in Revenues ($\$_{2019}$m) for Irrigated Crops and Pasture under the Different Climate Change Scenarios (RCPs) and Time Horizons for the Do-nothing Scenario

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

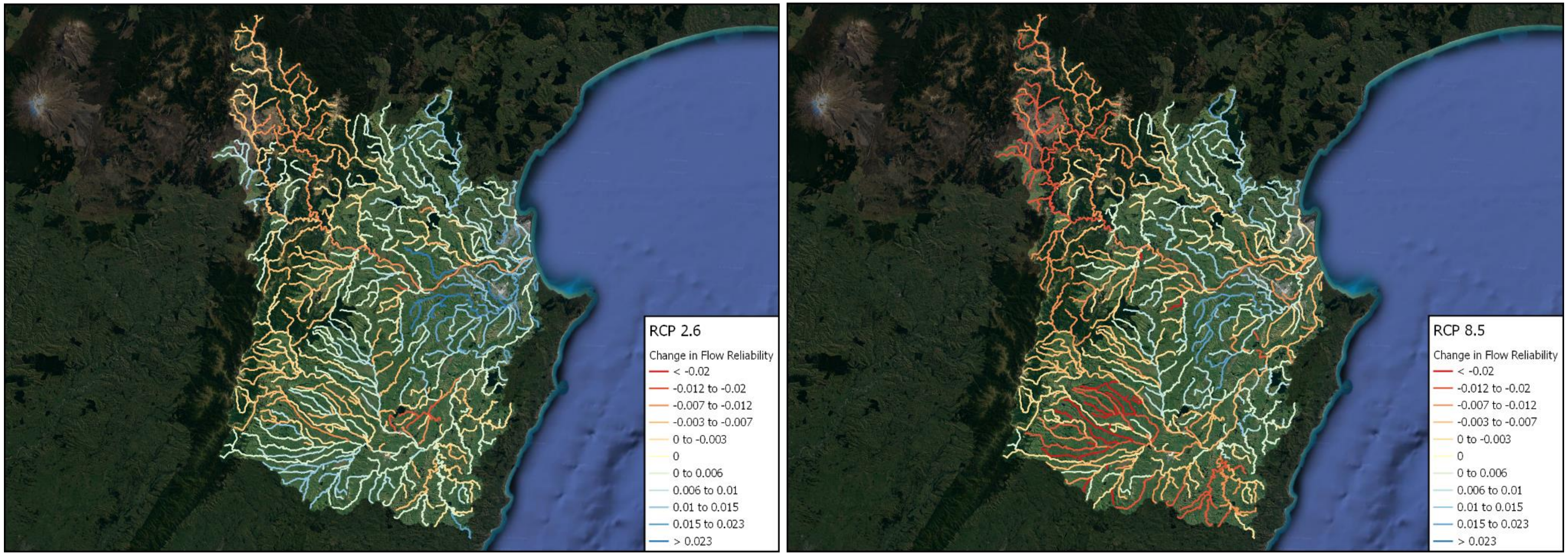
In this section we outline the stages undertaken to generate the estimated economic impacts of changes in water supply, as well as some of the key caveats relating to each stage. Also outlined in this section is the alternative assumptions about future world conditions (reference scenarios) modelled.

3.1 Key methodological stages

3.1.1 Stage 1: Water-related impacts of climate change

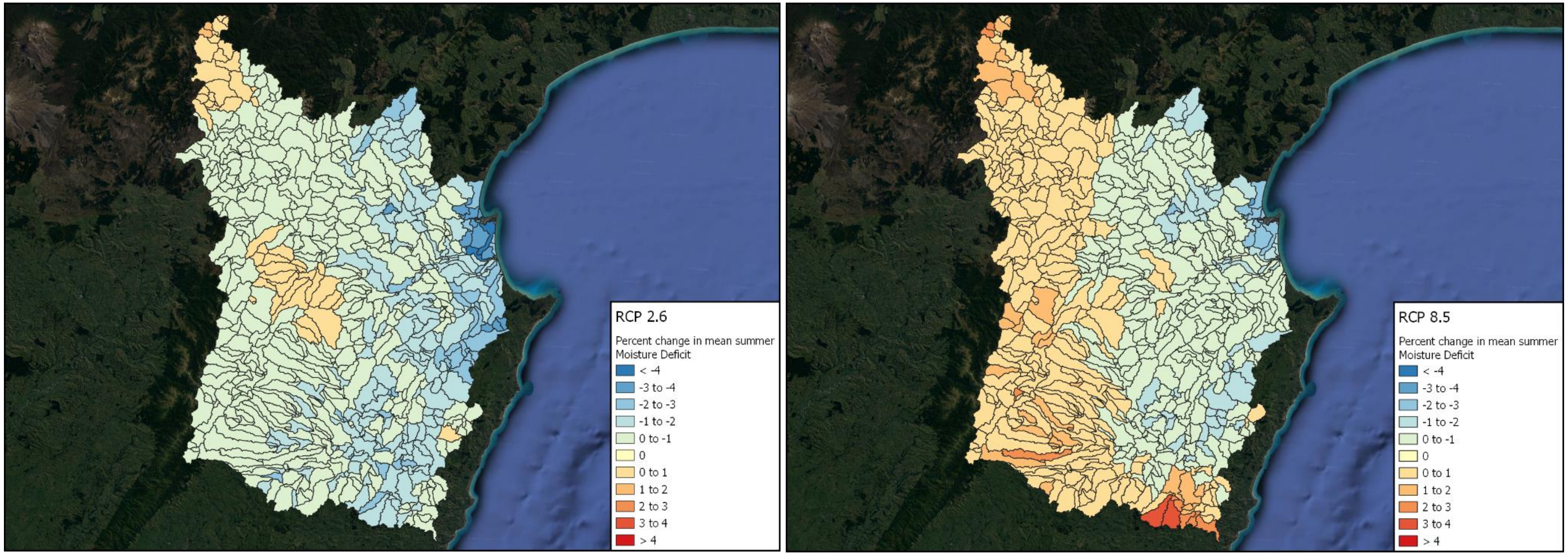
The first stage of the method required deriving suitable information on the likely physical impacts of climate change on water supply security, as would be relevant to agricultural activities within the Heretaunga plans (as represented by the TANK) and Tukituki river catchment. We recognised that both 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.

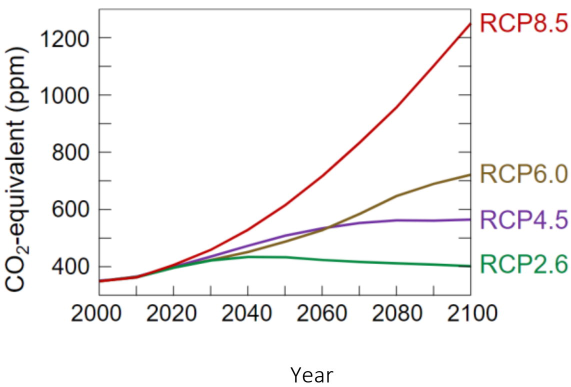


Fig. 3: Representative Concentration Pathways (RCPs) as adopted by the Intergovernmental Panel on Climate Change. Note: ppm = parts per million.

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).

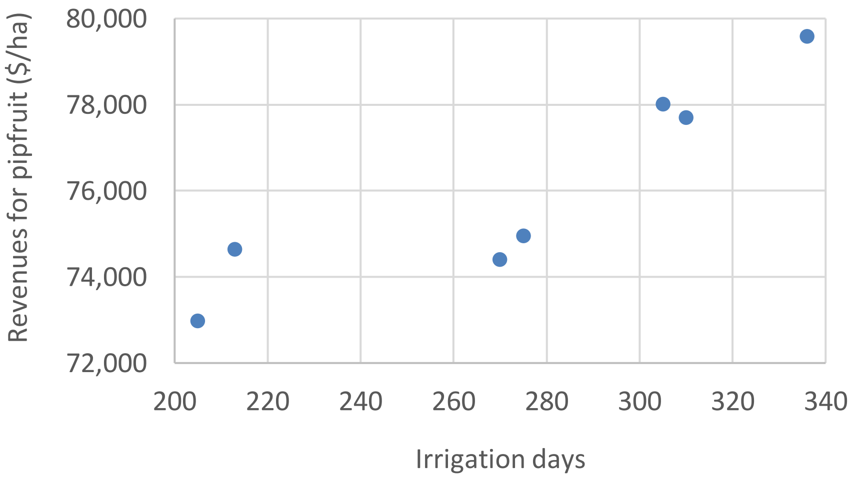


Fig 4: Example of Scatter Plot Relating Revenues to Irrigation Days

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.

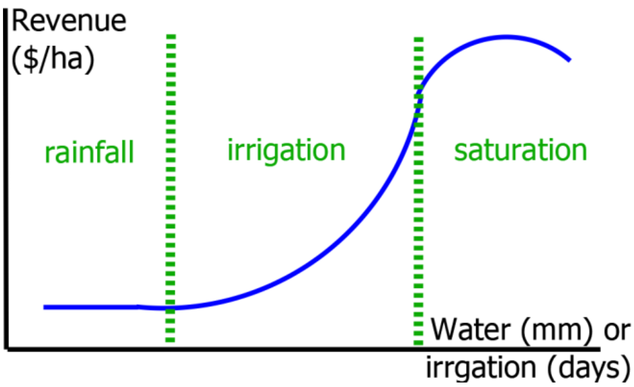


Fig 5: Example of Theoretical Crop Revenue Curve

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.

[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.

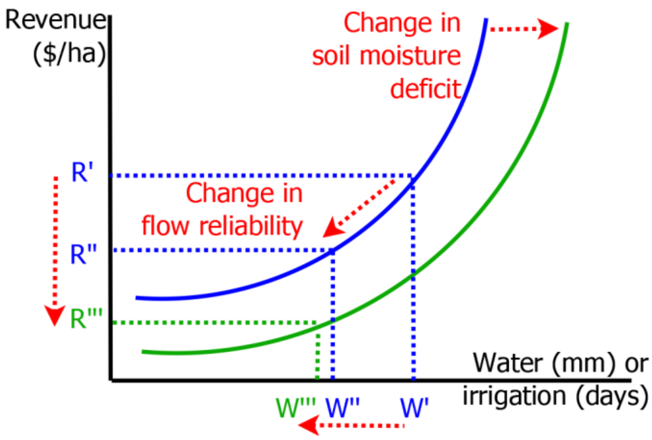


Fig. 6: A Theoretical Water-Revenue Curve and its Adjustment for Changes in Supply (Flow reliability) and Demand (Soil moisture deficit) Relationships.

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

[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

[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

[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).

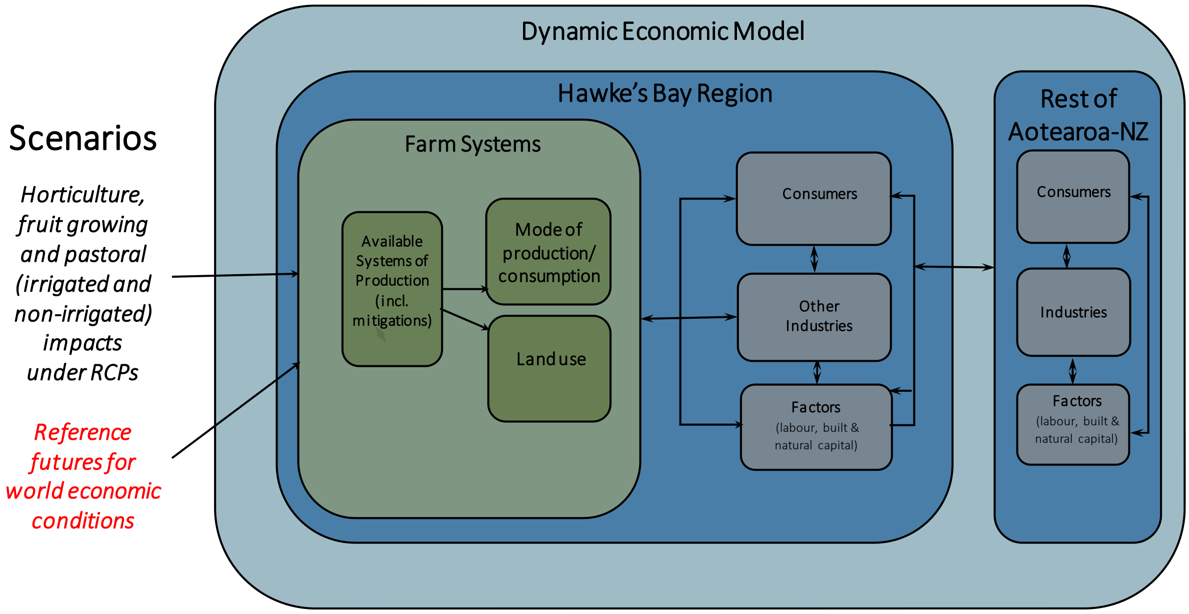


Fig.7 Components of Multi-Regional Dynamic Economic Model (DEM)

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

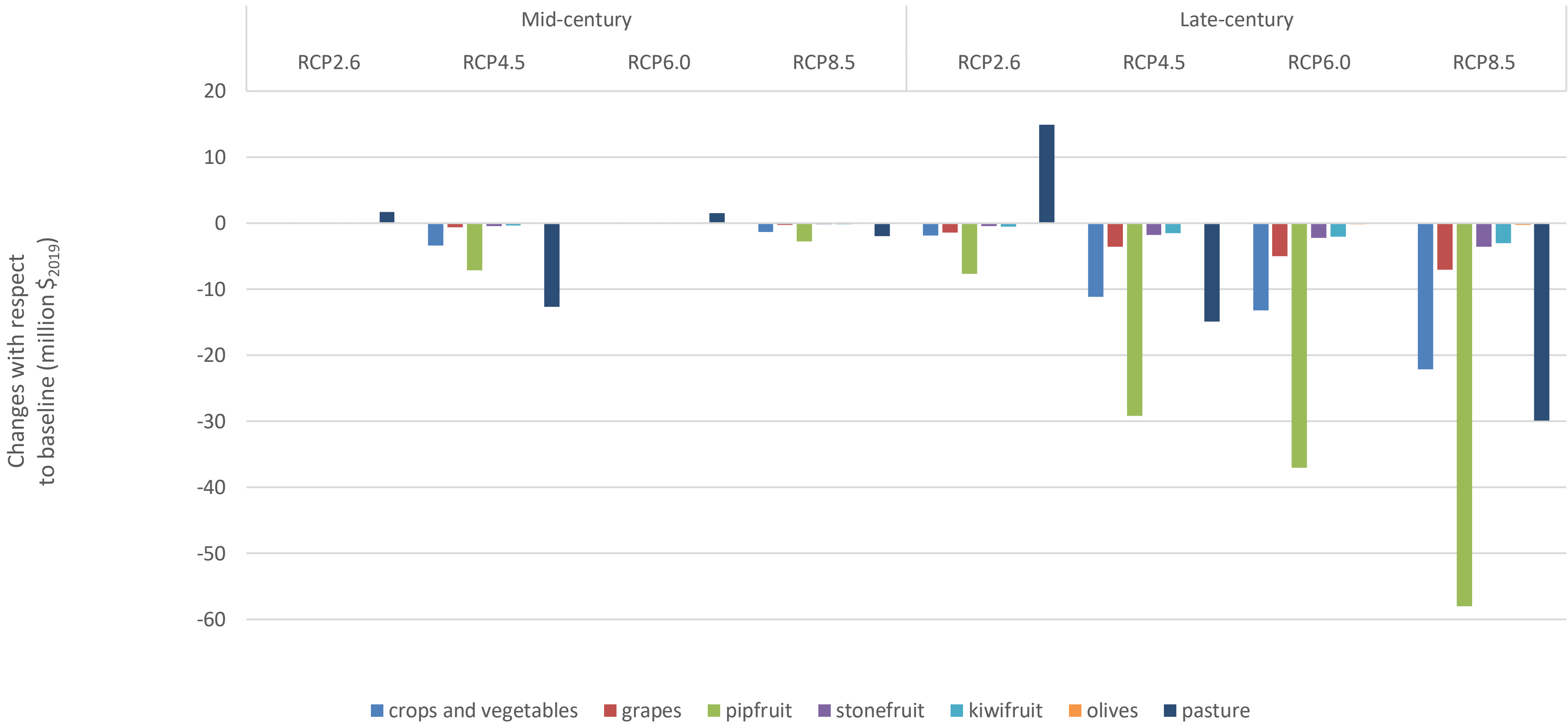

Fig. 9: Net Changes in Revenues ($_{2019}$) for Irrigated Crops and Pasture under the Different Climate Change Scenarios (RCPs) and Time Horizons for the Do-nothing Scenario

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

[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.

[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.

•

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