Waimea Plains: economics of freshwater quantity management

Santiago Bermeo, Ministry for Primary Industries
Graeme Doole, University of Waikato/Ministry for the Environment
Darran Austin, Ministry for Primary Industries
Andrew Fenemor, Landcare Research

Contributed paper prepared for presentation at the 60th AARES Annual Conference, Canberra, ACT, 2-5 February 2016

Waimea Plains: economics of freshwater quantity management

Santiago Bermeo[1]
Graeme Doole[2]
Darran Austin[1]
Andrew Fenemor[3]

[1]Ministry for Primary Industries
[2]Department of Economics, University of Waikato/Ministry for the Environment
[3]Landcare Research

Abstract

The Waimea Plains (Tasman District, New Zealand) is a major horticulture area, highly reliant on irrigation. Irrigators draw water from an integrated surface water and groundwater system. Fresh water is over-allocated by 64%. Irrigators face significant restrictions due to natural fluctuations in river flow and groundwater levels, i.e. water is unreliable.

This case study evaluates different options to address these problems. A catchment optimisation model is used to assess the benefits from enabling water permit transfers and from the proposed Waimea Community Dam ('the dam'). A spreadsheet model is used to assess the impact of different ways of cutting back water permits, should the dam not go ahead. The case study is based on farm- and orchard-level models which estimate irrigation need, profit and nitrogen leaching under different levels of water allocation, reliability and soil type for apples, viticulture, market gardening and dairy farming over a period of 40 years.

Key findings are that:

- water permit transfers would result in moderate benefits on average (8.6% increase in average profit) but significant benefits in dry years (46% increase in profit);
- the dam would result in significant benefits by enabling expansion of irrigated areas and conversion from unirrigated pasture to higher value crops, and providing a reliable water supply for existing and future irrigators (103% increase in average profit and 10% decrease in nitrogen leaching).
- Should the dam not go ahead, water permit cuts based on irrigation need would result in lower, and a more even distribution of, costs than flat-rate cuts.

Keywords

Horticulture, irrigation, freshwater management, water storage infrastructure, over-allocation, reliability, transferability.

1 Introduction

This report focuses on the assessment of a number of strategies to improve freshwater management on the Waimea Plains, in the Tasman District. This case study is part of a wider programme of catchment case studies being undertaken by the Ministry for Primary Industries, with support from the Ministry for the Environment. The aim of the case studies is to analyse the impact of different options to maximise the value of available fresh water.

The Waimea Plains is a major horticulture area. Water for irrigation, drawn from a complex integrated surface water and groundwater system, is essential for the area. Freshwater resources in the Plains are over-allocated, and water users face significant seasonal restrictions aimed at safeguarding minimum environmental flows and preventing saltwater intrusion in the aquifers. The resulting unreliability in water supply complicates agricultural management and influences investment decisions towards land uses that do not require high reliability in water supply.

The proposed Waimea Community Dam (the dam) would remove over-allocation and unreliability and would allow expansion of current irrigated areas. In contrast, if the dam does not proceed, the Tasman District Council (TDC) would have to phase out over-allocation by reducing the amount of water allocated to users, and water supply for irrigation would still be unreliable. Section 2 provides additional information about the Waimea Plains and the proposed dam.

In this context, the specific objectives of the case study are to:

a) assess what economic gains can be made from water permit transfers and the dam; and

b) compare costs, including distribution of costs, of different ways to phase out over-allocation in the event that the dam does not go ahead.

Both objectives are explored through economic modelling. Objective a) is investigated through catchment-level evaluation of freshwater management options (hereafter referred to as "catchment modelling"). This involves the application of an economic optimisation model, which is used to evaluate different scenarios for water permit transfers, construction of the dam, expansion of the irrigated area and nitrogen limits.

Objective b) involves the application of a spreadsheet model to investigate how options to reduce water allocations affect individual users within the catchment (hereafter referred to as "clawback analysis"). It looks at the impact of different approaches to phase out over-allocation on a consent-by-consent basis, should the dam not proceed.

One motivation for separating the analyses in this way is that, under a water permit transfer scenario in an economic optimisation model, water is transferred to the same highest value uses regardless of the clawback method applied and the same efficiency outcome is reached. However, different clawback methods would result in a different distribution of costs.

Consequently, catchment modelling in this case study focuses on the overall efficiency gains from water permit transfers and the dam while the clawback analysis focuses on overall costs and distribution of costs under different administrative clawback methods, in the absence of the dam. Conclusions about the impact of different approaches on overall catchment profit and the distribution of these costs are drawn. Overall, a multi-method research approach is used to evaluate the impacts of diverse policies, both at the individual and catchment scale.

An important input to the economic models applied in this study is farm systems information relating to irrigation demand, nutrient loss and production. These data come from farm modelling completed by Landcare Research, Plant and Food Research and Fruition Horticulture (Fenemor et al, 2015). Their analysis focuses on the most common productive irrigated land uses on the Waimea Plains: apples, viticulture, market gardening and dairy. This analysis is described in more detail in Section 3.

The case study is based on rules outlined in the Tasman Resource Management Plan (TRMP) as of May 2015. On 19 September 2015, TDC notified proposed amendments to the TRMP to provide for higher reliability of supply for irrigators that affiliate to the dam and a much lower level of reliability for irrigators that do not affiliate to the dam. The proposed amendments seek to provide consent-holders and landowners with an informed choice about whether to invest in the dam or not. The case study does not reflect any of the proposed changes.

The report is structured as follows. Section 2 provides a background to the case study, while Section 3 outlines the farm modelling performed by Landcare Research, Plant and Food Research and Fruition Horticulture. Sections 4 and 5 describe the methods, results and limitations of the catchment modelling and clawback analysis respectively. Section 6 presents conclusions.

2 Waimea Plains and Waimea Community Dam

2.1 Waimea Plains

Land in the study area (about 6,000 hectares) is devoted predominantly to horticulture, viticulture and pasture, as illustrated in Figure 1. Nearly 80% of land devoted to these land uses in the Plains is irrigated. Most of the unirrigated area devoted to agriculture is pasture. A significant portion of irrigated (non-dairy) pasture is under lifestyle properties.

Surface water and groundwater in the Plains area are connected and managed in an integrated manner through nine Water Management Zones (WMZs), illustrated in Figure 2. The TRMP establishes individual allocation limits for each WMZ.

Figure 1: Distribution of land use in the study area

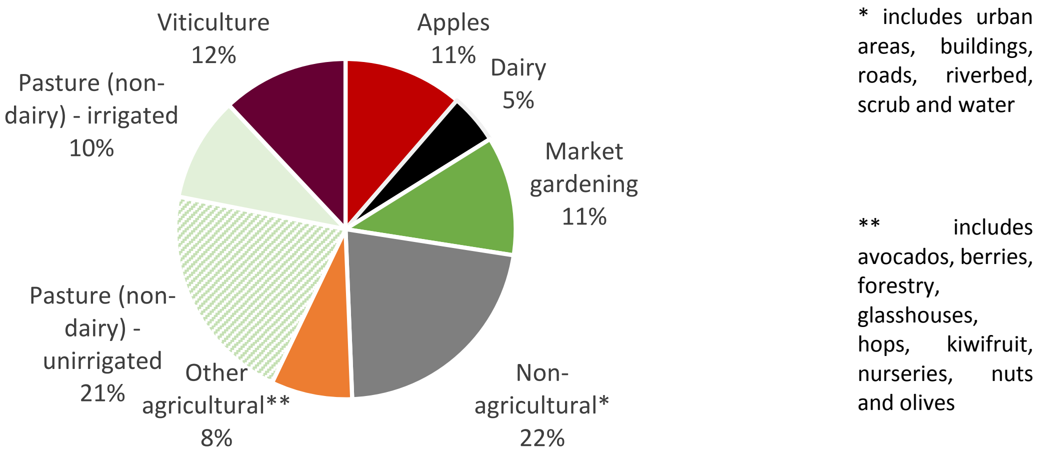


Figure 2: Waimea Water Management Zones ("no dam" scenario)

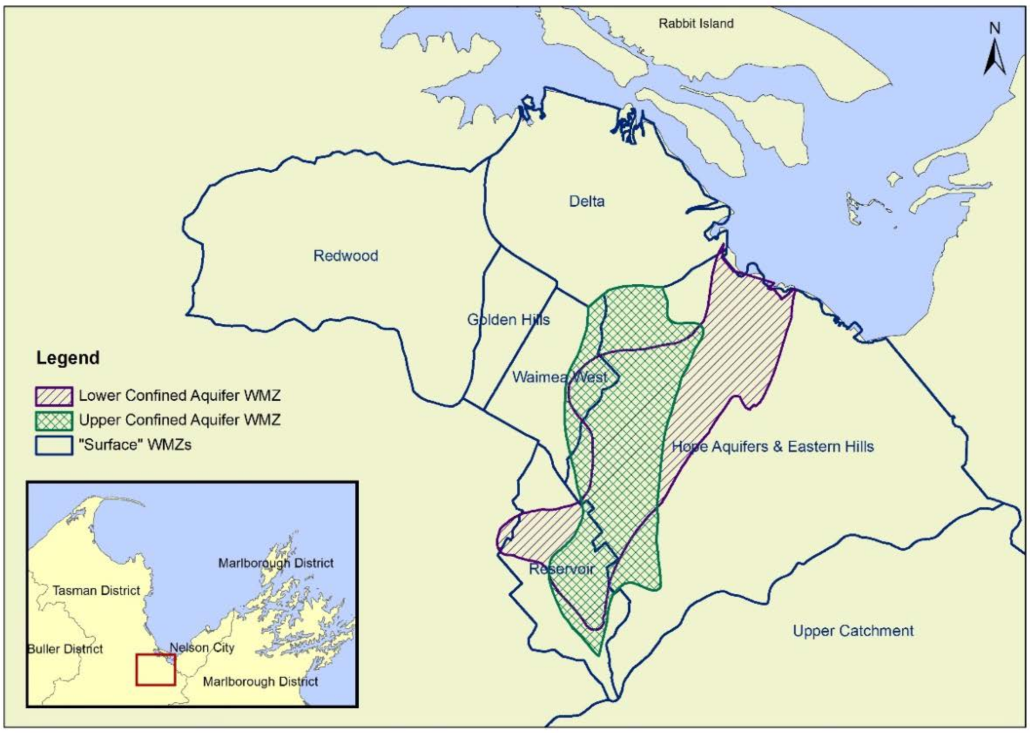
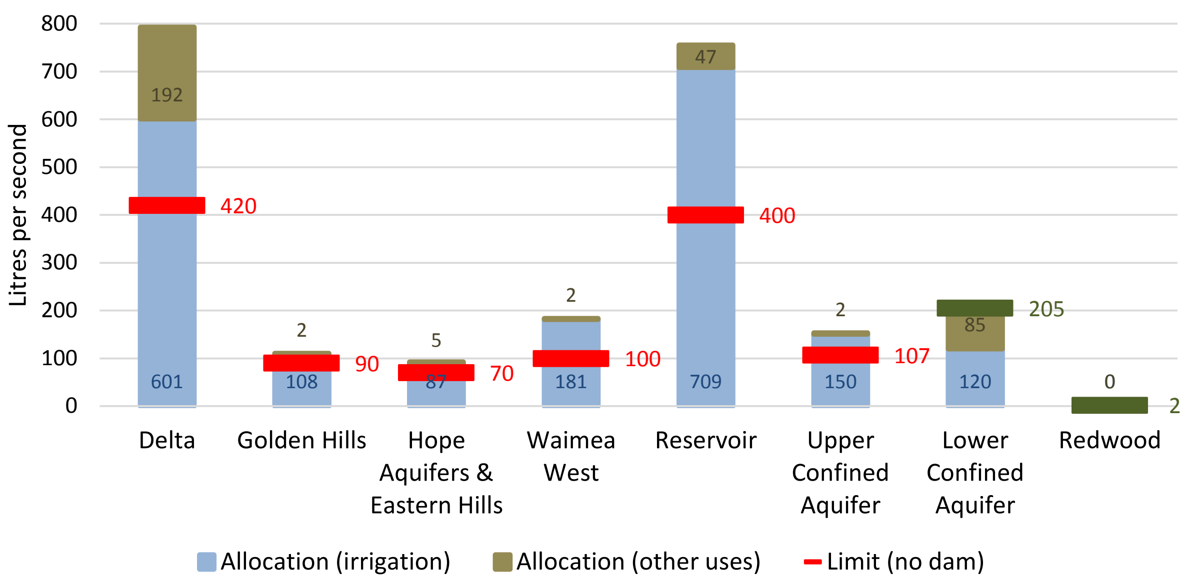


Figure 3 sets out the current allocation level for each WMZ as vertical bars (the Upper Catchment WMZ is not shown). The red horizontal bars for each WMZ denote the allocation limit that applies if the dam is not built, in WMZs in which over-allocation is currently present. In contrast, green horizontal bars are defined for those WMZs that are not presently over-allocated. Figure 3 shows that six of the WMZs are currently over-allocated, pushing allocation across the Plains area to 64% above the combined limit.

Pressure on freshwater resources in the Plains has been evident since the 1990s, particularly during a severe drought in 2000/01, which resulted in the Waimea River drying up completely. Since then, understanding of the surface water and aquifer system has improved significantly, resulting in justification for an increase in the required minimum flow for the Waimea River. Recent changes to the TRMP, giving effect to the National Policy Statement for Freshwater Management by setting revised allocation limits, have made the state of over-allocation illustrated in Figure 3 obvious. Most of the current irrigation consents were first issued before improved information on the resource, which has informed the setting of more precise management measures. The great majority of irrigation consents are due to expire in 2016 and 2017.

Water users face limited supply reliability due to natural fluctuations in climate patterns and flow. To protect the minimum flow of 800 litres per second currently set for the Waimea River and prevent saltwater intrusion in the aquifers, users are subject to flow-based restrictions, which are largely independent from abstractions.[1]

Figure 3: Baseline: allocation limits ("no dam") versus current allocation in Waimea Water Management Zones



[1] Restrictions cutting consented allocations by up to 50% are driven by flow measured at the top of the catchment at the Wairoa Gorge, before abstractions occur. Restrictions cutting consented allocations by 70% or more are driven by flow measured at the bottom of the catchment at Appleby Bridge, after most abstractions have occurred. Restrictions apply equally to surface water and groundwater irrigation consents across all WMZs. Lower restrictions apply to community water supply consents.

Some existing irrigation infrastructure is present in the area, specifically the Waimea East Irrigation Scheme (WEIS) that services about one-fifth of the study area. This irrigation scheme does not have any major storage facilities so is also subject to flow restrictions and, therefore, limited water supply reliability.

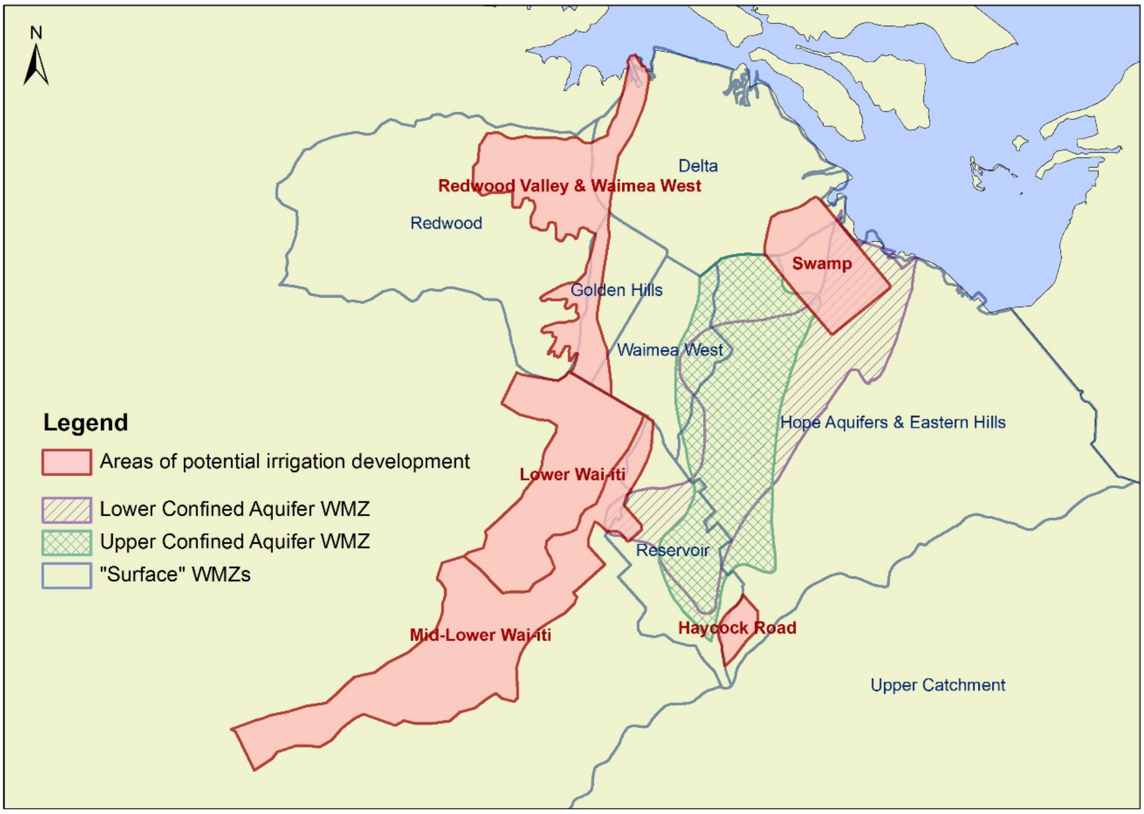
A Fresh Water and Land Advisory Group established by the TDC is currently working to set freshwater quality objectives and limits for the Waimea area. Water quality has been an issue in parts of the Plains, including high nitrate concentrations being observed in some aquifers and in some coastal springs.

2.2 Waimea Community Dam

The proposed dam would provide a secure water supply for existing and expected future users. It has been estimated it would provide enough water to meet expected demand in a 1-in-50 year drought, including meeting the water needs of an additional 1200 hectares of new irrigated areas outside of the main study area and future urban water supply needs. The dam would enable this by maintaining minimum flows in the Waimea River during the drier summer months and allowing recharging of the Plains area aquifers.

Figure 4 shows areas inside and outside of the main study area that have been identified for potential irrigation development associated with the dam, either by supplying currently unirrigated areas or providing a reliable supply to existing irrigated areas (Fenemor and Bealing, 2009). It is important to note that significant parts of some of these areas, particularly the Swamp and Lower Wai-iti areas, already have some irrigation but supply is unreliable due to flow restrictions.

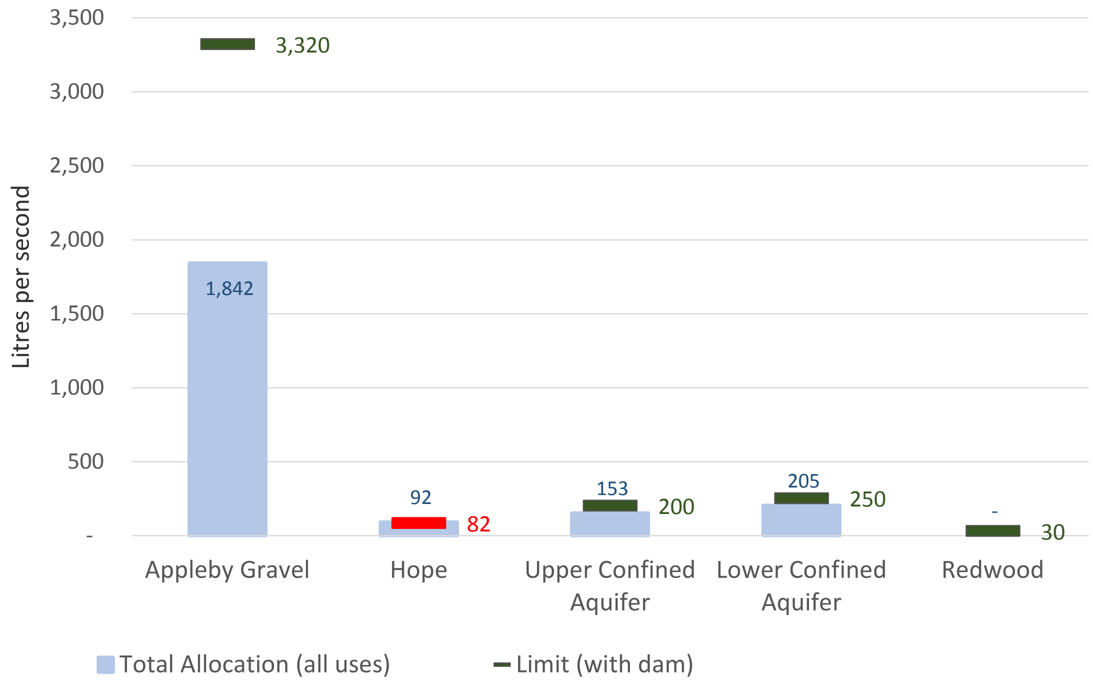
Figure 4: Areas of potential irrigation development associated with the Waimea Community Dam



Based on rules in the TRMP, as of May 2015, the dam would resolve the current state of over-allocation, so no clawback would be necessary to phase out over-allocation. This is illustrated in Figure 5, which shows that current allocation in all WMZs, except Hope, would be below allocation limits, as depicted by the green horizontal bars. There are fewer WMZs outlined in Figure 5 relative to Figure 3 because under the "with dam" rules in the TRMP, the Delta, Golden Hills, Waimea West and Reservoir WMZs would be merged into the Appleby Gravel WMZ.

The minor remaining over-allocation in the Hope WMZ could be addressed by shifting some of those consents to either the Upper or Lower Confined Aquifer WMZs or by extending the command area of the WEIS.

Figure 5: Current allocation versus "with dam" allocation limits in Waimea Water Management Zones



By increasing flows in the river and recharging aquifers, the dam would also increase the assimilative capacity of the river and aquifers, potentially addressing water quality concerns in those systems. Increased flows in the river would also have other positive environmental effects, by helping to maintain minimum flows, and recreational benefits, particularly during the drier summer months.

Resource consents for construction and operation of the dam were granted in February 2015. The next hurdle is obtaining enough funds to construct the dam, which is currently estimated to cost around $70 million. The current funding model is for TDC to fund $25 million from general rates and water rates and charges, motivated by benefits for environmental flow and urban supply. The remaining $45 million would come from irrigators (existing and potential). The Community Irrigation Fund (predecessor to the Irrigation Acceleration Fund) provided $980,000 in funding for the pre-construction phase of the dam.

On 19 September 2015, TDC notified proposed changes to the TRMP to provide for higher reliability of supply for irrigators that affiliate to the dam and a much lower level of reliability for irrigators that do not affiliate to the dam. The aim of the proposal is to avoid “free-riding” from the benefits of the dam and to provide clarity to irrigators about the consequences of their choice to contribute, or not, to the construction of the dam. This is particularly relevant as virtually all irrigation consents are due to come up for renewal over the next two years. This case study is based on TRMP rules as of May 2015; it does not consider any of these proposed changes in accessibility to individual irrigators based on affiliation status.

3 Farm and orchard modelling

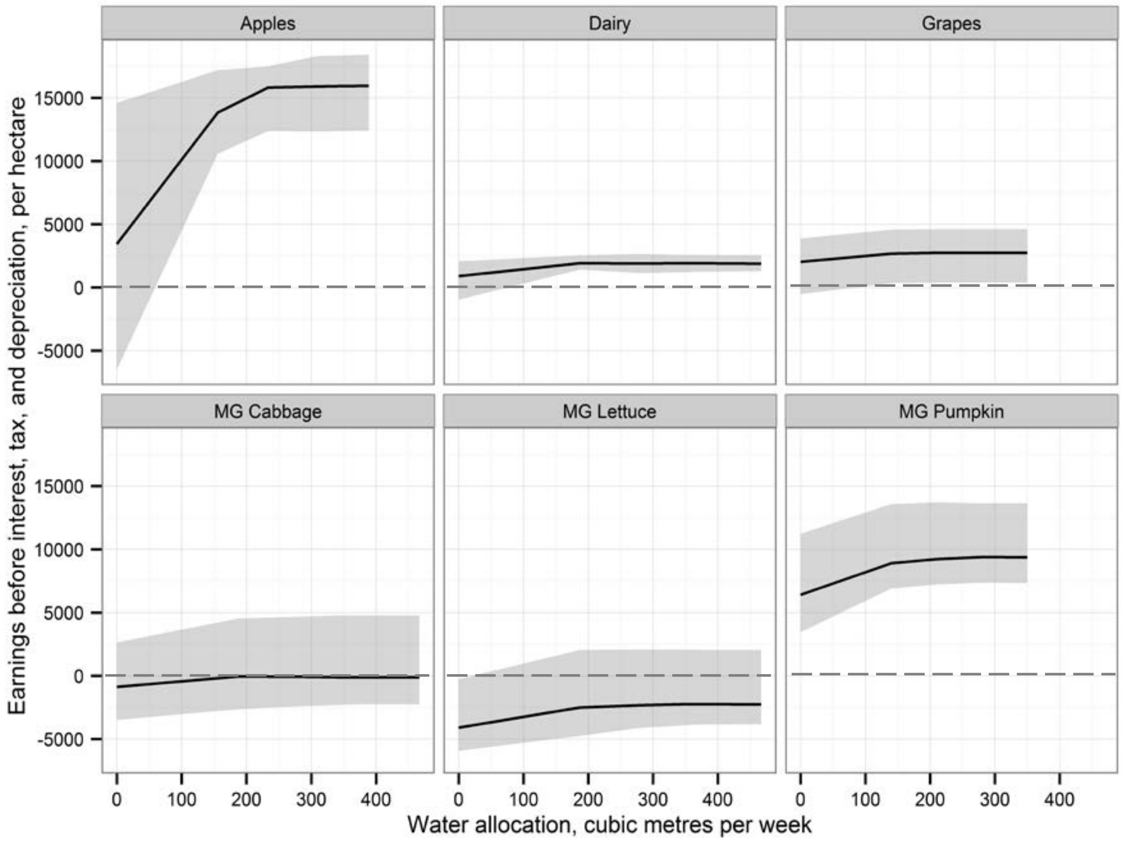
3.1 Overview

The farm and orchard modelling, which underpins both the catchment economic modelling and the consent-by-consent clawback analysis, was prepared by Landcare Research, Plant and Food Research and Fruition Horticulture. This modelling relates different irrigation allocations and supply reliabilities to crop production, profit and nutrient leaching for apples, viticulture, dairy and market gardening in the Waimea Plains.

The modelling estimates monthly irrigation demand for these land uses on different soil types over a period of 40 years. Most irrigation demand occurs during the drier months. Two water supply reliability scenarios were modelled: one with full reliability (that is, “with dam”) and one with flow-based supply restrictions (that is, “without dam”). Plant and Food Research’s Soil Plant Atmosphere System Model (SPASMO) was used to estimate crop production and nitrate leaching. Estimates of earnings before interest, tax and depreciation (EBITD) were produced from the production estimates using an economic model developed by Fruition Horticulture. Please refer to the farm modelling technical report (Fenemor et al, 2015), for more information.

A summarised example of the farm model output is illustrated in Figure 6 below.

Figure 6: Waimea Plains farm model output example



— Median over 40 years | Range experienced in 90% of years over 40 years | MG = market gardening rotation

A few significant results from this farm-scale analysis are evident. First, starting from the 350 cubic metres per hectare per week currently allocated to irrigation consents, profitability remains fairly constant across most land uses until about 200 cubic metres per hectare and then declines with further reductions in allocation. Indeed, while water is an important input to agricultural and horticultural production, it is apparent that its relationship with profit across diverse land uses is quite flat. This has been validated through literature reviews and consultation with experienced irrigation modellers throughout New Zealand.

Second, apples are far more profitable than other land uses but their profitability drops significantly, and becomes more variable, with larger reductions in water allocation.

Third, the profit function for viticulture defined with respect to water supply is much flatter than the others, denoting the relatively lower water needs of this land use.

Market gardening was modelled as the combination of three seasonal rotations of winter lettuce and either summer pumpkin, summer cabbage or summer lettuce. Crop rotations are necessary to maintain soil health, meet market requirements and manage price risk as, at any time, profitability of different crops may vary. Market gardening profits in the modelling are the combination of the profits of the three rotations. The relatively poor financial performance of the lettuce and cabbage rotations illustrated in Figure 6 is therefore countered by the stronger financial performance of the pumpkin rotation.

Average product prices from 2010–14 were used for apples and wine grapes, more recent prices were used for market gardening, and $6 per kilogram of milk solids was assumed for dairy.

Variability, illustrated by the shaded area in Figure 6, is explained by changing climatic conditions (that is, more production and profit in wet years, less production and profit in dry years).

Farm model outputs were adjusted for typical irrigation application efficiencies: 90% for apples and viticulture and 75% for dairy and market gardening.

3.2 Land use and soil type maps

To aggregate the farm- and orchard-level results up to the catchment scale, a 2013 land use map was developed by Landcare Research and TDC from various sources: a 2010 map developed for the Waimea Water Augmentation Committee, AgriBase, Land Cover Database 4, WEIS data, Google Earth, visual ground-truthing and validation by Landcare Research and TDC.

A soil type map developed from the National Soils Database was adjusted, based on information from TDC and advice from a local farm consultant.

Please refer to the farm modelling technical report (Fenemor et al, 2015) for more information. Land use and soil type maps are shown in Figures 7a and 7b respectively.

Figure 7a: Waimea Plains: land use

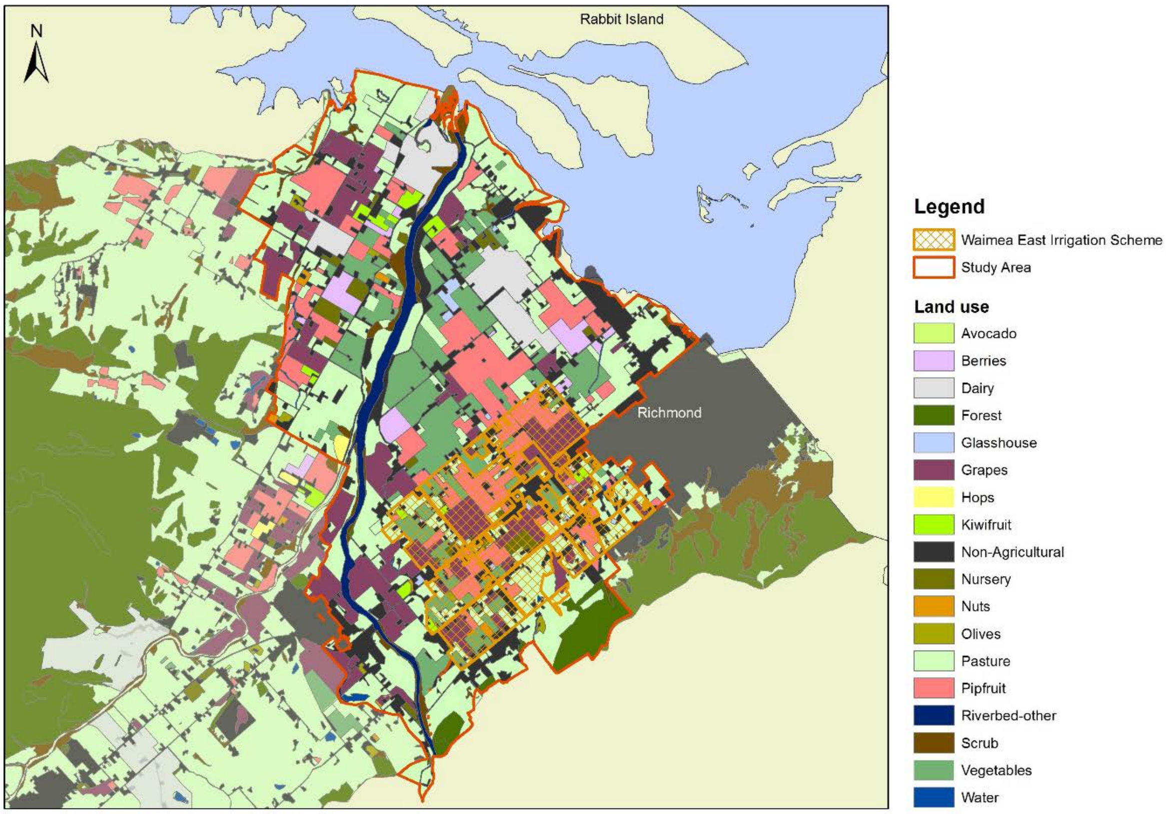
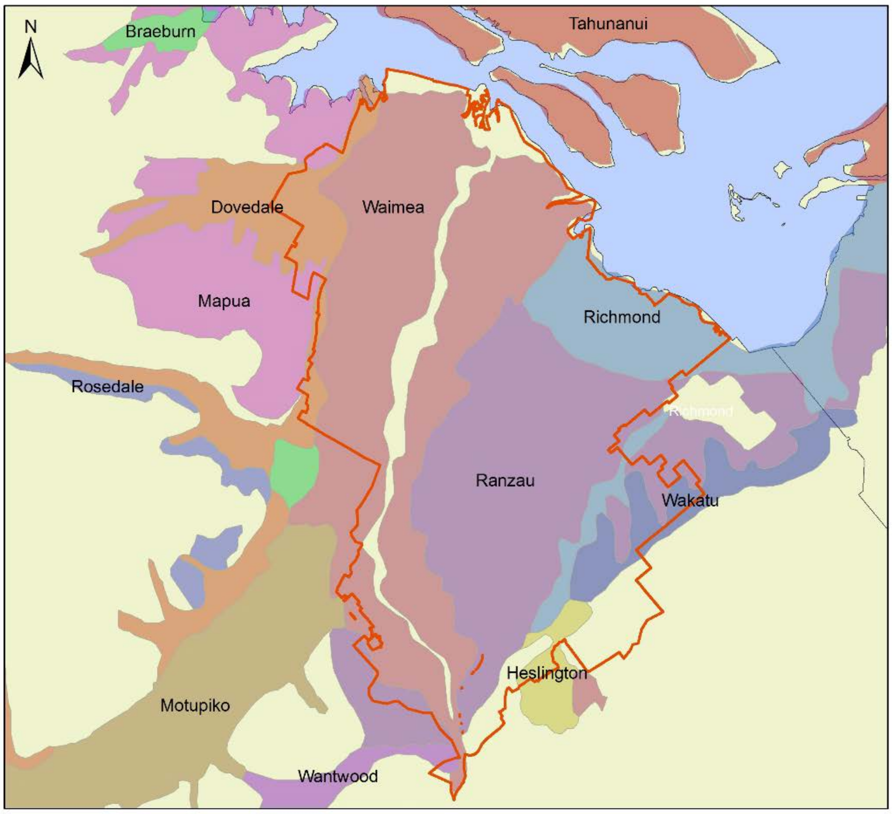


Figure 7b: Waimea Plains: soil types



3.3 Flow data and estimated restrictions

As an input into the farm- and orchard-modelling data, Landcare Research applied the current "no dam" flow-based restrictions (as outlined in Table 31.1C of the TRMP) to 44 years of flow data from the Wairoa Gorge, upstream from the Waimea Plains. Under the TRMP, the most restrictive stage 4 restrictions are controlled by flows at Appleby Bridge at the bottom of the catchment, where the minimum flow for the Waimea River is measured. Consequently, Landcare Research estimated stage 4 restrictions based on flow at the Wairoa Gorge. The result was estimates of flow-based restrictions, if any, that would have applied each day between January 1970 and December 2014, should the current "no dam" restrictions have applied over that time.

Figure 8a shows, as an example, the daily flow at Wairoa Gorge and estimated restriction data for 2000/01, one of the driest years in the analysis period, with a return period of 25 years based on Wairoa Gorge river flows. Figure 8b shows the monthly allocation, average monthly restrictions and estimated monthly water demand over the same period for a hectare of the land uses modelled. The large difference between irrigation need and available allocations between February and May would have had a significant impact on irrigators.

Figure 8a: Wairoa Gorge flow and estimated restrictions for the Waimea Plains 2000/01

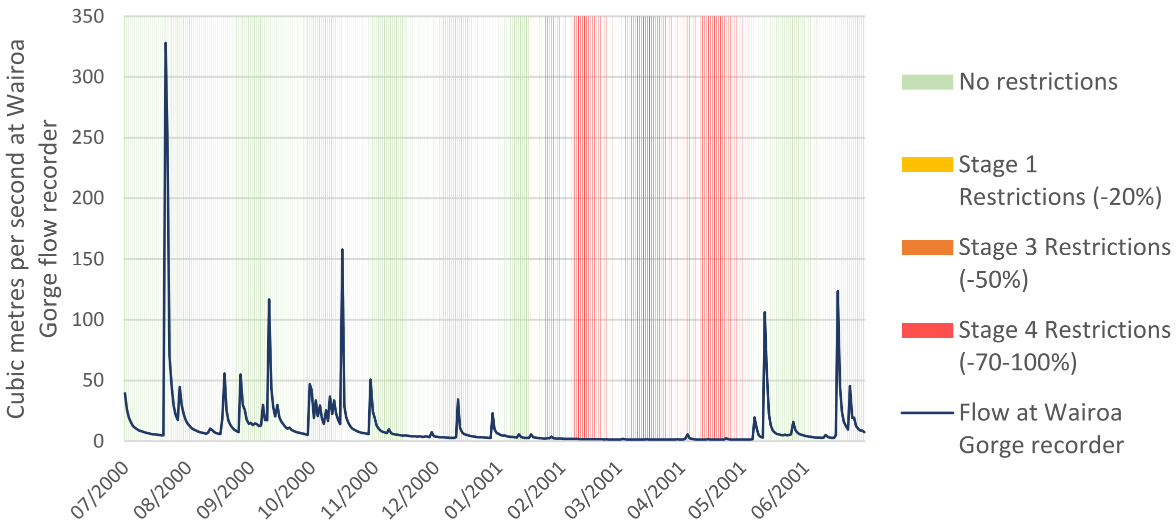
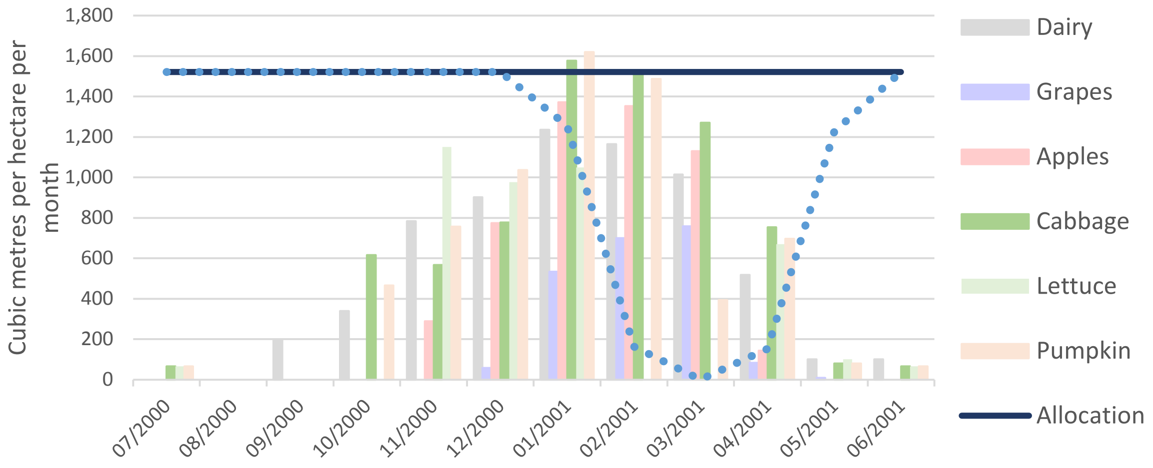


Figure 8b: Average monthly allocation, flow-based restrictions and estimated irrigation need for land uses modelled in the Waimea Plains 2000/01



3.4 Limitations

Representative orchards and farms are used to generate expected returns, water demand for irrigation and leaching losses. These provide a coarse characterisation of the decision problem faced by individual farmers in the catchment but are, nonetheless, an abstract representation of reality. Please refer to the farm modelling technical report for a complete description (Fenemor, et al., 2015). Important limitations from the farm modelling analysis relevant to this case study are listed below.

3.4.1 Risk of tree death and flow-on on impact resulting from prolonged cease-take restrictions

Farm modelling did not include:

- an assessment of the likelihood of immature trees dying under prolonged periods of cease-take restrictions; and
- consideration of impacts from prolonged cease-take restrictions on production in the following season due to lower plant carbohydrate reserves.

There is limited information to accurately quantify these risks specifically for the Waimea Plains. However, it is understood this would mainly be an issue for young (that is, less than two-year-old) and developing (that is, between three- and five-year-old) apple trees on Ranzau soils. More than half of all apples are on Ranzau soils. Apple orchards on the Waimea Plains are replaced on 15-year cycles on average, so about 20% of the apple crop could be vulnerable to these risks under prolonged cease-take restrictions each year.

Assuming risk of tree death would only eventuate after a period of about 30 days of continuous cease-take restrictions, the risk is not significant given that only four years in the analysis period had such prolonged continuous periods of cease-take restrictions. Flow-on impacts after prolonged restrictions could result in a 20% to 25% reduction in production the following season, depending on the length of cease-take restrictions and the level of soil moisture before the restrictions kicked in. It is believed flow-on impacts would only apply for one year, unless there is an ongoing drought.

These issues have also been observed for viticulture in other regions (for example, Marlborough) but, because of the timing of restrictions in the analysis period and the fact that there are few young vineyards in the study area, the risks are not believed to be applicable to viticulture in this case study.

Irrigators can mitigate these risks by, for instance, prioritising irrigation of young trees under restrictions or bringing in water from other sources by truck (though this would be costly).

Although difficult to quantify, as noted above, the impact of these limitations is that the analysis may be slightly underestimating the impact of limited reliability and clawback and, thus, the benefits from the dam in relation to these situations (Andrew Fenemor and Greg Dryden, pers. comm. 20 August 2015).

3.4.2 Market gardening rotations

As described above, market gardening was modelled as the combination of three seasonal rotations of winter lettuce and either summer pumpkin, summer cabbage or summer lettuce. In reality, market gardening profits would be based on the combination of those three, and any other, vegetable rotations. Price information for vegetables was limited, compared with price information available for other crops.

It is uncertain which consent-holders would be operating under each rotation at any particular point in time. Under the catchment model, it is assumed that each hectare of market gardening land is divided equally among the three rotations. Under the clawback analysis, it is assumed that each market gardening consent-holder would be operating under the same rotation for the entire period. Although this is not realistic, the analysis assumes there would be a roughly even split of rotations across different soil types to prevent predominance of one rotation having an undue impact on the analysis.

3.4.3 Stage 4 restrictions

As described above, stage 4 restrictions under the TRMP reduce allocated amounts by 70%, but TDC may issue further water shortage directions beyond these restrictions or even before stage 4 restrictions apply (for example, in the event of saltwater intrusion in the aquifers). For this reason, the farm modelling analysis assumed that stage 4 restrictions would actually be cease-take (that is, 100% reduction in allocated amounts). Consequently, this assumption may be over-estimating the impact of stage 4 restrictions.

Stage 4 restrictions apply when flow of the Waimea River (at Appleby Bridge) drops below 800 litres per second. The Appleby Bridge flow recorder is downstream from most abstractions. It is therefore expected that if abstractions decrease as a result of clawback, the frequency of stage 4 restrictions may be slightly lower. This analysis, however, assumes that the frequency of stage 4 restrictions will remain the same over the analysis period, which may be slightly over-estimating the frequency of such restrictions following clawback.

4 Catchment modelling

4.1 Methodology

An economic optimisation model was constructed to assess the potential of water permit transfers and the dam to maximise the value of available fresh water. These impacts were assessed by comparing estimated land use distribution and annual catchment-level profit under the following scenarios:

a) current allocation (baseline);

b) flat-rate clawback to meet TRMP allocation limits;

c) flat-rate clawback to meet TRMP allocation limits, with transfers of water permits allowed;

d) development of dam, without expansion of irrigated area;

e) development of dam, with expansion of irrigated area; and

f) development of dam, with expansion of irrigated area and a 20% cut in baseline nitrogen leaching.

The scenario involving a 20% cut in baseline nitrogen leaching was developed to study the implications of a limit being placed on nitrogen loss within the study area. This degree of reduction was not drawn from any stakeholder discussions or recommendations but, rather, was generated based on past experience in other New Zealand catchments in which water quality has been compromised by land use intensification. For these reasons, it is only indicative and should not be construed as a recommendation for any purpose.

4.1.1 Theoretical background

This section provides a broad outline of the economic modelling approach used to conduct the evaluation of the six scenarios listed above. The model is an optimisation model; that is, an iterative search process is utilised to identify how land management can best change from the current state to maximise total catchment profit.

A particular type of optimisation, linear programming, is used here (Vanderbei, 2007). This involves the definition of a model in which both the profit specification and constraints contain linear expressions. It is not possible to achieve the exact solutions identified by the model in reality, due to practical constraints that cannot be considered in a model. Nonetheless, the use of optimisation is valuable because it allows the use of a consistent and structured objective to select between multiple alternative outcomes within a complex decision problem.

The structure of the optimisation model is loosely based on that of the Land Allocation and Management (LAM) catchment framework (Doole, 2015). The flexibility of this model is demonstrated in its broad utilisation across a number of non-point pollution contexts, both nationally (Doole, 2013; Holland and Doole, 2014) and internationally (Beverly et al, 2013; Doole et al, 2013). Important benefits associated with the application of the LAM framework are (Doole, 2015):

- Its flexible structure allows its broad adaptation to diverse circumstances, for example, the contrast between its application in this case study and in Beverly et al (2013), which concerned water quality in south-eastern Australia.
- The complexity of the model can be altered, depending on the quality and quantity of resources available. For example, this application involves a large linear programming application, but the LAM framework has been applied previously in a model involving millions of non-linear constraints.
- The model can be efficiently coded in popular non-linear optimisation software, such as the General Algebraic Modelling System (Brooke et al, 2014), that allows matrix generation.

The LAM framework applied in this study is particularly suited to the problem at hand. Despite being linear, the model integrates a wide range of functional relationships from diverse fields (for example, hydrology, economics). The use of linear programming restricts the degree to which non-linear relationships can be defined but, at the same time, allows monthly assessment of a high number of discrete spatial units over a 40-year period given the high efficiency of the solvers present for this type of optimisation (Vanderbei, 2007; Doole and Pannell, 2012).

An important facet of the analysis is the presence of annual variability in the amount of water demanded and supplied in each month of the year. The standard approach to dealing with this problem in the economic analysis of irrigation management involves stochastic optimisation. This can be done in various ways.

Stochastic-search approaches use random-search processes to identify superior solutions in simulation models that do not fit the standard form required for mathematical programming (Doole and Pannell, 2008). These models are difficult to apply in practice because they do not deal naturally with system constraints and can converge to different solutions, depending on the random-search process adopted (Deb, 2000). Accordingly, mathematical programming methods are applied in this case study to investigate the stochastic problem at hand.

This can be done using a number of approaches. Stochastic programming involves defining a mathematical model for each realisation of a discrete random variable (Kingwell et al, 1993). These models are most popular in the dynamic study of risk management because they allow users to understand how best to respond to uncertainty that unfolds over time. In contrast, robust optimisation concerns the definition of resource constraints according to the most-pessimistic realisation of uncertain parameters (Doole and Kingwell, 2010). An example is maximising profit subject to the lowest expected water availability to an individual farm. This approach increases the resilience of system design but has a high cost in terms of foregone value due to the extreme conservatism evident in model solutions (Bertsimas and Sim, 2004; Doole and Pannell, 2011).

Another alternative is the full-factorial model in which a single realisation of the decision model is defined for every realisation of the random variables. This involves representing each individual month and year, rather than discrete bins describing aggregated, more generalised, “types” of variability typically experienced across time. For example, general stochastic programming would involve the development of a model in which optimal decisions are determined for “wet”, “medium” and “dry” months or season (Adamson et al, 2007). Crop production and profitability is usually characterised within these models, based on data drawn from historical observations.

For example, production and profit can be determined for each land use during “wet”, “medium” and “dry” months, based on data drawn from a 40-year period. In contrast, a full-factorial model would involve the determination of the optimal management decision in each month across each individual year within the 40-year period. Thus, the use of the full-factorial approach means that data is not lost through aggregation of information into representative weather types (for example, “wet” and “dry”). However, the use of this approach does place greater demands on computing resources and makes it more difficult to report model output in full.

4.1.2 Application to this case study

The full-factorial approach is utilised in this case study. This is due to the availability of data for individual months and years from SPASMO, the greater precision offered by describing each year rather than less-descriptive “types of years” and the capacity to consider them all in one model, given the powerful optimisation solver (CPLEX, see below) and computing resources available. Consistent with stochastic programming in the general sense, the model represents 40 realisations of a steady-state outcome. That is, each year is treated independently and trajectories of soil moisture are not linked across time between years. This assumption is appropriate in a New Zealand context because soil reserves typically fill over the extended autumn–winter period (John Bright, pers. comm., 14 January 2015).

The model is based on the delineation of the catchment into a large number of areas. These areas concern the hectares available on a given soil type in a certain surface water and groundwater WMZ. It is important to represent the primary combinations of both surface water and groundwater WMZs because many farms have access to water from more than one WMZ. No land area is available in some of these partitions, given that records show, for example, that a certain soil type may not be present in a given WMZ. Land use areas were derived using Geographic Information Systems analysis, with primary data shown in maps presented in Section 3.2.

Significant decision variables in the model concern the amount of land allocated to a given land use with a given level of water allocation within each of the areas described above. Irrigated land use is typically fixed in the current land use but can switch to other land uses in some runs of the model. In contrast, unirrigated pasture can be (a) converted to irrigated production or (b) converted to forest. Option (a) is pertinent with dam development but incurs a transition cost that is considered in the determination of catchment-level profit. In comparison, option (b) is pertinent when water quality targets pose potential limits to expansion (that is, scenario (f) above). Indeed, forest conversion on unirrigated pasture land is represented solely as a means to create headroom for more intensive enterprises, if and as required. In reality, water availability or nutrient discharge constraints are likely to drive land use away from productive uses to rural residential or residential uses. However, that form of land use change was outside the scope of the analysis.

The amount of land allocated to a given land use with a certain level of water use determines the level of profit earned by that activity in that area. Overall, these relationships strongly reflect the shape of the profit functions derived for the crops with respect to the amount of water available (as illustrated in Figure 6). Primary costs represented in the model are those associated with land use transition (conversion), penalties associated with reduced production in years during which expected amounts of water do not eventuate, the cost associated with dam development and the cost of additional infrastructure associated with expansion of irrigable area (Fenemor and Bealing, 2009).

Significant balance equations are required for water use by each crop in the optimisation model. SPASMO outputs identified the irrigation demand for each land use with a given water allocation on each soil type in each month across 1972–2012 (Section 3). This irrigation demand must be satisfied in each month across each year over this period; otherwise, a penalty is imposed on production and hence the profitability of this land use. Each land use is allocated a given amount of water, but this can be downscaled depending on the amount of water available to all users (for example, due to flow-based restrictions or regional water allocation policy). Water availability may also decrease for a given user who decides to transfer some of their allocation to other irrigators within their respective WMZ.

Water supply is augmented through several means, including: (a) rainfall, (b) water allocation, (c) transfer from other irrigators in the same "surface" WMZ and (d) transfer from other irrigators in the same groundwater WMZ. The amount of water allocated depends on the simulated policy instrument, while the ability to transfer water under items (c) and (d) differs according to the scenario. Water transfers are balanced through equilibrium conditions requiring that the outward and inward transfers of water quantities must equal one another in each month in each year in each WMZ.

Equations also determine nitrogen-leaching loads for each area. SPASMO is used to estimate the amount of nitrogen loss associated with a given level of water use by a given crop in a given year on each soil type in the catchment. These are aggregated based on the scale and intensity of land use observed within each area. Bounds are placed on their aggregate level in some runs performed with the model (specifically under scenario (f)), to investigate how water quality limits may impact on the relative advantages of alternative management plans.

The model is solved through linear programming using the Mathematical Programming System formulation with the CPLEX solver (IBM, 2010). The model consists of around 100,000 equations and 350,000 decision variables. The high dimensionality of the model arises from the representation of the full factorial combination of individual spatial areas across each month across a 40-year period. However, the high efficiency of the CPLEX solver and the linear structure of the model mean that optimal solutions can be identified reliably and efficiently.

4.1.3 Model data

A broad range of land uses are represented in the model. Irrigated land uses include market gardening (lettuce, cabbage and pumpkin rotations), viticulture, apples and dairy production. It is assumed that each hectare of market gardening land is divided equally among the three rotations. Unirrigated land uses include pasture (non-dairy) and forest. Unirrigated pasture is represented as the baseline land use for areas without irrigation, while forest is represented as an alternative in some model runs, especially those requiring reduced nitrogen losses within the catchment. Four soil types are studied: Dovedale, Ranzau, Richmond and Waimea. Irrigated pasture, other than dairy (assumed to be mostly lifestyle properties), and any land with an unspecified soil type (see Figure 7b) are excluded from the analysis.

"Surface" WMZs are Delta, Golden Hills, Hope and Eastern Hills, Redwood, Reservoir, Waimea West, Upper Catchment, Wai-iti and the Wai-iti Dam Service. The last two are not part of the Waimea Plains zones but are where some of the areas identified for irrigation expansion with the dam are located (Fenemor and Bealing, 2009). Water transfers are not possible in some of these zones. Furthermore, groundwater WMZs are the Upper Confined Aquifer, the Lower Confined Aquifer and the area where both aquifers overlap.

The model contains a steady-state structure; thus, all costs are annualised over a 25-year period at an interest rate of 8%. The dam was assumed to cost $70 million, which was annualised to a value of $6.56 million. The cost of infrastructure expansion was $5,030 per hectare in Fenemor and Bealing (2009); thus, an annualised value of $471 per hectare is used throughout this application. The costs of land use transition were provided by Fruition Horticulture.

The annualised conversion costs are as follows:

- conversion to viticulture costs $4,000 per hectare;
- conversion to apples costs $6,000 per hectare;
- conversion to market gardening costs $125 per hectare; and
- conversion to dairy costs $2,810 per hectare.

The profitability and nitrogen-leaching rates of unirrigated land uses were drawn from past studies and expert opinion. The profitability of plantation forest was an annualised value of $375 per hectare, while the leaching rate was 3 kilograms of nitrogen per hectare. In comparison, the profitability of unirrigated pasture had an annualised value of $400 per hectare, while the leaching rate was 12 kilograms of nitrogen per hectare. Sensitivity analysis with the model shows that realistic changes to these point estimates have no significant impact on the main findings arising from the model.

4.2 Results

Figures 9a and 9b illustrate the results of the optimisation model in terms of average annual catchment profit and area devoted to each land use respectively. Land use is held constant at its baseline level in scenarios (a) to (d); however, irrigation expansion scenarios (e) and (f) allow unirrigated pasture to be converted to irrigated land uses.

Figure 9a disaggregates catchment-level profit; benefits are above the horizontal axis, while costs are below it. Catchment-level profit (or net benefits) are represented by the blue line. It can be seen that scenarios (a) to (c) do not include dam, conversion (that is, those associated with land use transition) or infrastructure (that is, those associated with expansion of irrigable area) costs. This promotes their value but also imposes an opportunity cost in terms of foregone profit arising from an increase in irrigable area and production in scenarios (e) and (f). In comparison, scenario (d) is a poor option because it imposes the cost of dam development but does not lead to a substantial increase in catchment-level profit because there is no increase in irrigable area.

In relation to the last point, it is important to bear in mind that, under the proposed amendments to the TRMP, irrigators that do not affiliate to the dam would face much lower levels of water supply reliability and thus significantly higher costs than under the status quo. If the dam and these proposed changes proceed, the dam is likely to have a much greater benefit for existing irrigators than those found in this case study because it does not take into account the proposed changes.

Furthermore, the analysis assumes that there would be no land use change following clawback (scenario (b)), which may be an optimistic assumption. In reality, some landowners may change land use (for example, to unirrigated uses or lifestyle properties) if the dam is not built. The impact of this is that the benefits of the dam are likely to be even higher than suggested here for existing irrigators.

As outlined in the following section, results in terms of catchment profit do not take into account other non-irrigation benefits associated with the dam.

Benefits from water permit transfers are discernible by comparing catchment profit between scenarios (b) and (c). The impact of the dam in terms of increased reliability for existing irrigators is discernible by comparing catchment profit between scenarios (b) and (d). Its impact in terms of enabling expansion of irrigated area and land use change is discernible from annual catchment profit in scenarios (e) and (f). The larger profit derived from apples under scenarios (e) and (f) is a result of the increased area devoted to that land use, as illustrated in Figure 9b.

Figure 9a: Average annual catchment profit under different scenarios

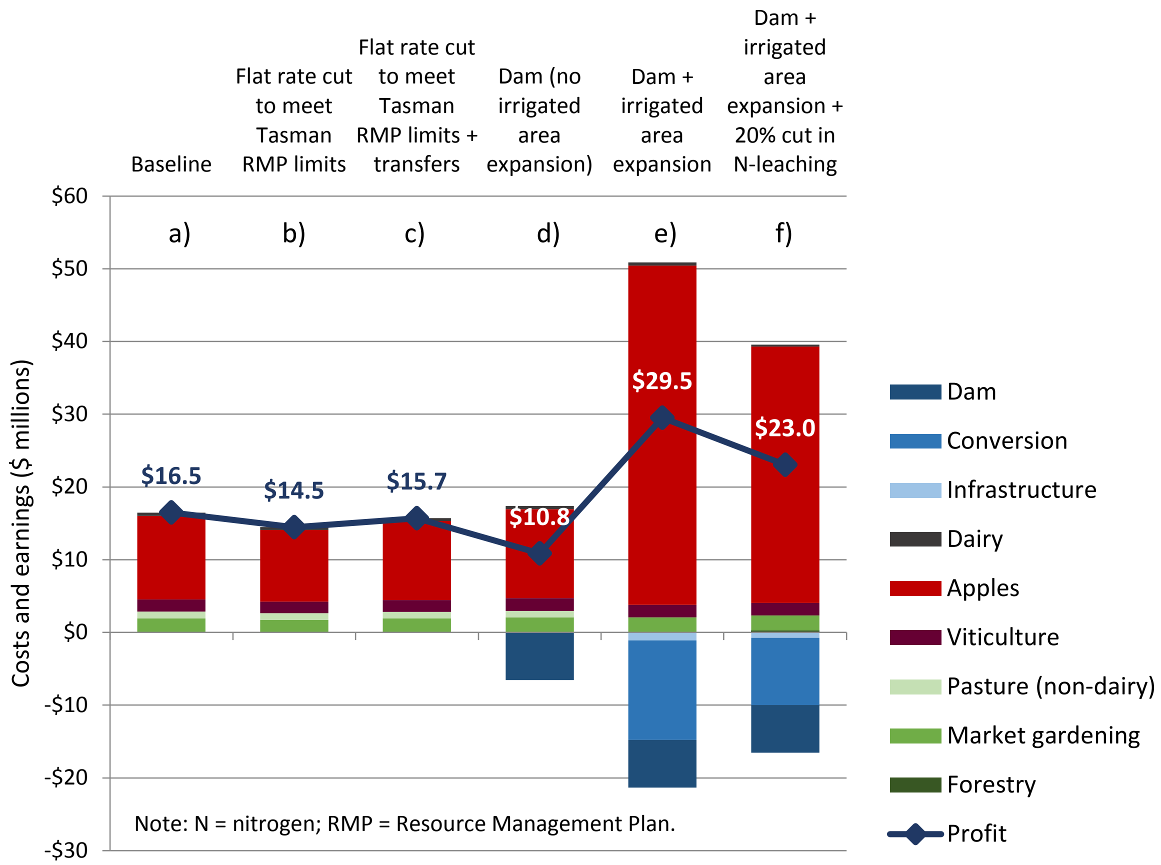
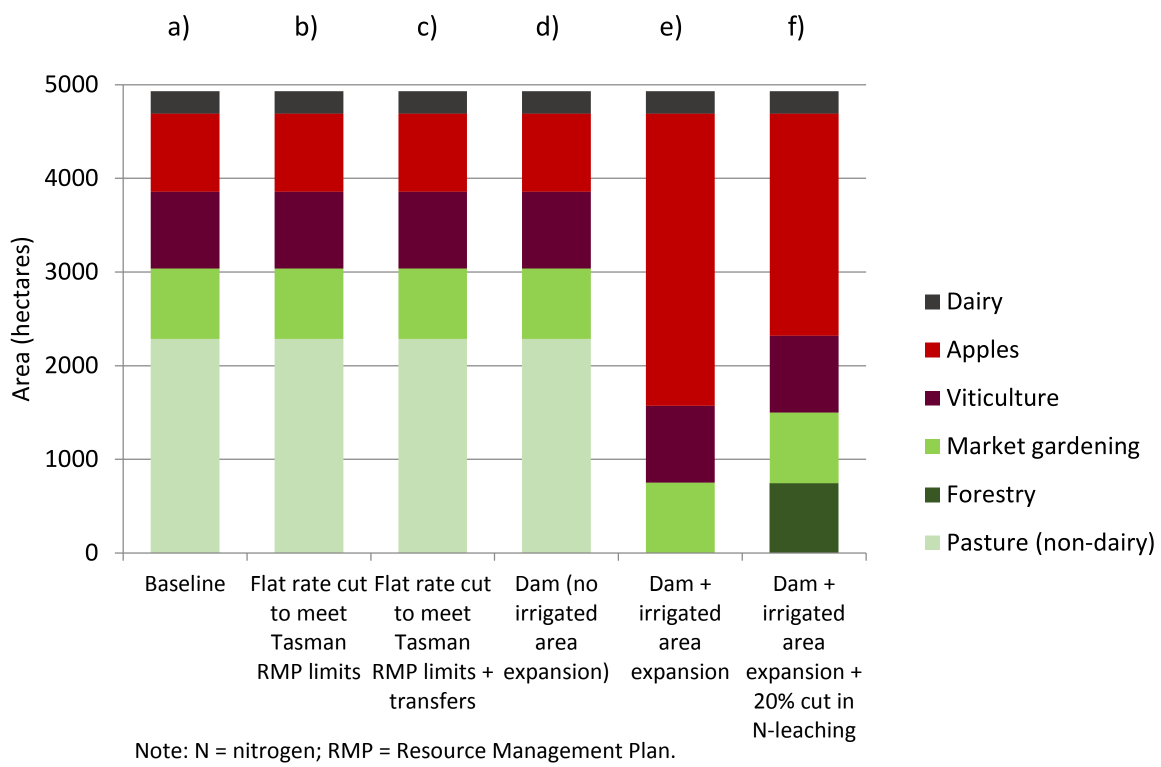


Figure 9b: Land use under different scenarios



4.2.1 Benefits from water permit transfers

Water permit transfers allow water to move to higher value uses. The Resource Management Act 1991 provides for transfer to another site, provided both sites are within the same catchment and transfer is expressly allowed under the regional plan or a new consent is granted.

The results show that water permit transfers would have moderate benefits in this case. In the absence of the dam, transfers would result in an increase of 8.6%, or $1.2 million in average annual catchment profit, once over-allocation is phased out. These benefits relate primarily to short-term transfers in dry years, with a maximum increase of 46% in annual catchment profit compared with the no trade scenario in one particularly dry year.

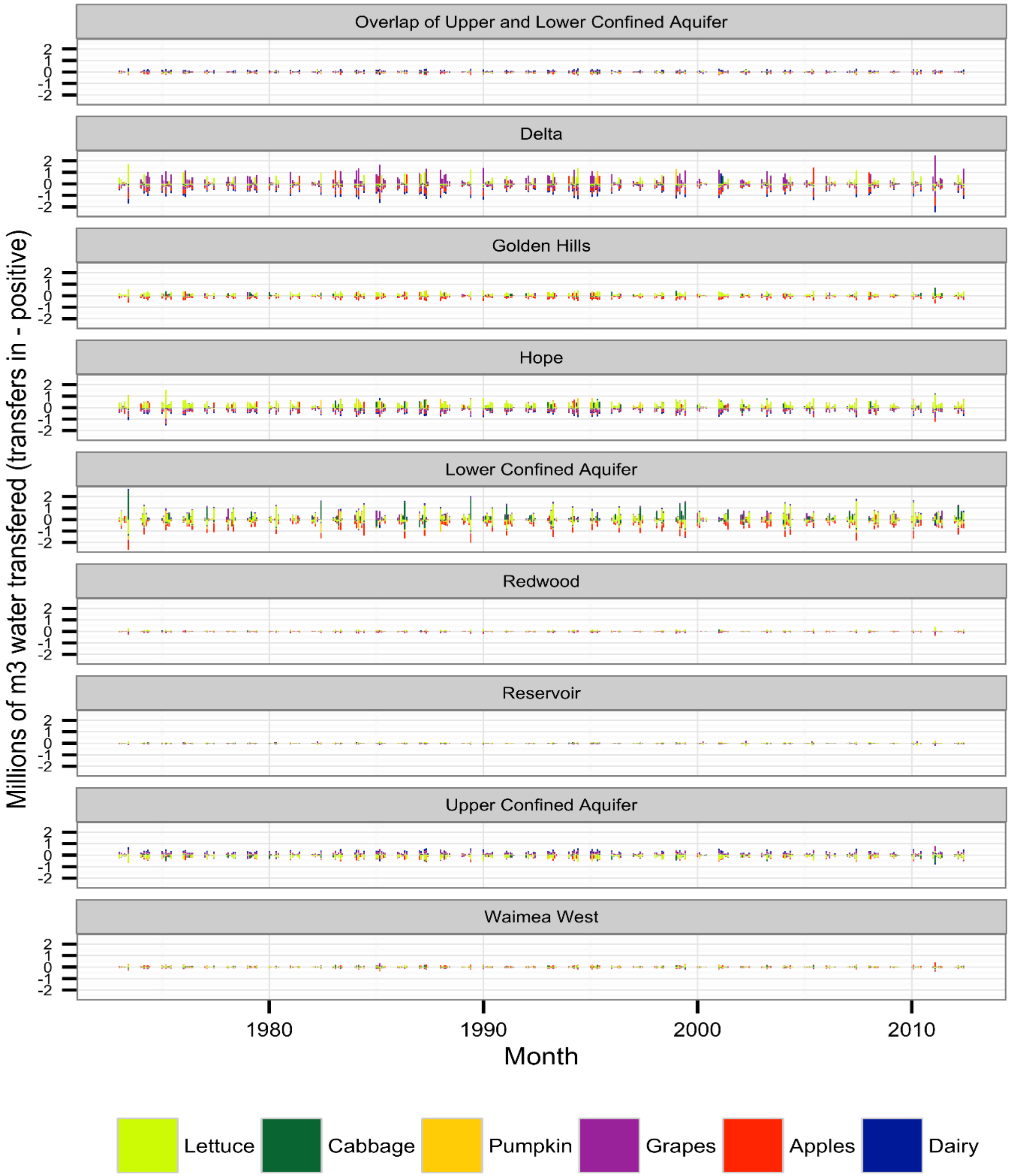
The value of transfers increases markedly with increasing water scarcity. This can be seen in Figure 10, which shows that the volume of water traded varies markedly throughout the year and between years. Negative values are outward transfers while positive values are inward transfers.

If the dam goes ahead, transfers would have no impact given there would no longer be water scarcity until the water is fully allocated. The dam is expected to meet water needs for current and expected future users in a 1-in-50 year drought.

In theory and under the model, water users would transfer water permits as long as the marginal benefit of doing so is greater than the forgone benefit (or marginal cost) of keeping those allocations (either for irrigation or, in this case, as a buffer against flow restrictions).

Transfers of water permits are limited by the fact that all irrigation users need water during the drier months. Furthermore, the catchment is fragmented into nine WMZs, limiting the size of the market and users' ability to transfer water as it is assumed transfers are not permitted between WMZs.

Figure 10: Monthly water transfers by Water Management Zone



4.2.2 Benefits from the dam

The dam would enable the expansion of irrigated areas and would provide a close to fully reliable water supply. This would result in significant net benefits: 103% or $15 million increase in average annual catchment profit, once over-allocation is phased out, and an unregulated 10% decrease in nitrogen leaching. This is an example of land use intensification resulting in environmental benefits; here, the availability of a low-leaching, high-value crop allows both economic and environmental improvement to accompany irrigation development.

These benefits relate primarily to the expansion of irrigated areas and the conversion of land use from unirrigated pasture to apples (scenario (e)). Figure 6 illustrates that apples are by far the most profitable of the land uses modelled in the catchment, returning around $15,000 per hectare per year on average under current allocation rates compared with about $400 for unirrigated pasture.

Illustrated by the results under scenario (d), the dam would effectively provide full water supply reliability for existing irrigators. The benefits from this amount to $2.9 million per annum on average (or 20% of earnings after clawback). As described in the following section, these values do not take into account environmental and other non-irrigation benefits of the dam.

As noted above, if we take into account that scenario (b) (clawback and no dam) is likely to be worse than presented here due to some irrigators changing land use (for example, to unirrigated uses or lifestyle properties), the benefits from the dam are likely to be higher than estimated.

Sensitivity analysis, summarised in Table 1, shows that there would still be net benefits compared with scenario (b) (clawback and no dam) under the most pessimistic scenario evaluated. Indeed, the average earnings from the catchment after clawback are estimated to be around $14.5 million (Figure 9a), and a higher value ($18 million) is predicted to be earned even if there were a 20% drop in apple profit and a $10 million overrun in dam construction costs.

Table 1: Total catchment profit associated with the dam plus irrigated area expansion scenario (e), as dam costs and apple profit are altered

		Dam costs		
		Low ($60m)	Medium ($70m)*	High ($80m)
Apple profit	–20%	$20m	$19m	$18m
	As modelled*	$31m	$30m	$28m
	+20%	$39m	$38m	$37m

** Original assumptions*

Farm modelling was based on apple prices over the past five years, which are understood to have been relatively favourable for apples. Apple profits have been volatile in the past and more drastic drops in apple profit were not tested. However, if there were more drastic drops in apple profit, Table 1 infers that it is likely the value of the scenario containing dam development could drop below the value earned under current management. If that was the case, though, other land uses may be favoured over apples, for example, market gardening, viticulture or other high-value crops not considered in this analysis.

Under scenario (f), if nitrogen discharge limits are set at a level 20% below the current rate for the catchment, benefits from the dam would decrease by 22% or $6.5 million (Figure 9a) and would require the conversion of some of the area to a very low leaching land use such as forestry (Figure 9b) or other extensive on-farm mitigation.

An additional scenario was tested in which all suitable areas available for irrigation expansion were converted to dairy farming rather than apples. This scenario provides some insight into the relative value of this option, given that dairy conversion has been performed widely across New Zealand over the past 25 years. The outcome of such a conversion would be significantly inferior, both economically and environmentally. Average annual catchment profit would be $16 million lower than the optimal scenario, and nitrogen leaching would be 92 tonnes higher than under conversion to apples. The results of this additional scenario and of scenarios (e) and (f) are summarised in Table 2.

Table 2: Implications of fixing dairy conversion on all Richmond and Waimea soils (approximately 1,650 hectares), following the development of a dam and infrastructure expansion

	Scenario		
	e) Dam with expansion of irrigated area – *conversion to apples*	f) Dam with expansion of irrigated area – *conversion to apples and 20% cut in baseline Nitrogen leaching*	Dam with expansion of irrigated area – conversion to dairy
Catchment earnings ($m)	50.87	39.57	29.2
Infrastructure costs ($m)	1.08	0.73	1.08
Conversion costs ($m)	13.72	9.24	8.41
Dam costs ($m)	6.56	6.56	6.56
Total value ($m)	*29.51*	*23.04*	*13.15*
Nitrogen (tonnes)	76	69	168

This highlights a critical finding – that the positive environmental and economic outcomes associated with dam development identified for the Waimea Plains in this analysis are unique to this individual catchment and that it is difficult to extrapolate to other areas without careful assessment. Indeed, it is the unique characteristics of the Waimea Plains – principally, their capacity to support high-value and low-leaching crops – that underlies this conclusion. There is a risk that changing market conditions in the future may create incentives for land use change towards higher leaching uses (for example, dairy, market gardening); this risk would need to be managed.

4.3 Limitations and uncertainties

A number of key limitations are associated with the catchment modelling performed in this case study.

4.3.1 Land use change and transition

The model focuses on the identification of steady state solutions across 40 independent years and, therefore, does not address the complex intertemporal topics of adaptation and optimal transition. It also does not account for more sophisticated and nimble management responses that may be available to irrigators, such as water sharing arrangements.

An optimisation approach is used to determine optimal land allocation. This allows the use of a consistent way of comparing different solutions, hence avoiding the arbitrary nature of trial-and-error search. However, it does mean that land use change is more elastic than may be expected in reality.

Land use change is a temporal process influenced by many factors, including input and output price trends, innovation, expectations, productivity, landowner skills and experience, existing capital investment and environmental policy. A particular complicating factor in the Waimea Plains is the high value of non-productive land used for lifestyle and/or rural–residential purposes, which competes with productive land uses.

Sophisticated methods are available to richly represent these dynamics, based on historical trends (Heckelei et al, 2012). A limitation of this analysis is that it does not deal with land use change at this level of sophistication. However, a scenario-based approach is deemed to be more valuable, because it bypasses technical difficulties involved with representing land use change in optimisation models (Doole and Marsh, 2014), it allows the identification of key concepts regarding land use change, and it is consistent with the fact that it is problematic to estimate future land use change based on historical data, given that the availability of new water sources and potential water quality limits together provide new evolutionary forces that will ultimately influence the trajectory of land use change in this catchment.

4.3.2 Impacts on nitrogen leaching and water quality

A rich definition of the likely mitigation–cost relationships that exist for individual enterprises within the catchment was outside the scope of the analysis. The main abatement strategies available are farm management practices, irrigation, nutrient management and land use change. These are important drivers of reduced nitrogen loss in this environment, but others exist and may be worthy of consideration. Attenuation of nitrogen losses within the catchment has not been considered.

Construction of the dam will allow higher stream flows and aquifer recharge during the drier summer months, in particular, reducing the concentration of nutrients (for example, total nitrogen and nitrate levels) in some water bodies provided the loads of nutrient reaching waterways do not increase. Relationships between irrigation level, stream flow and nutrient concentration are not considered here, but they potentially understate the benefits of dam development for water quality in some parts of the catchment.

4.3.3 Plan changes

The analysis is based on the TRMP rules as of May 2015. On 19 September 2015, TDC notified proposed amendments to the TRMP that would alter the “with dam” rules to provide for a higher level of water supply reliability to irrigators that affiliate to the dam and a much lower level to those that do not, amongst other changes. That lower level of reliability would have significant impacts on irrigators that do not affiliate to the dam, which are not considered in this analysis.

4.3.4 Other costs and benefits

The analysis does not include costs and benefits other than profit for apples, viticulture, market gardening, and dairy farming and financial costs associated with dam construction, land use conversion and infrastructure required to expand irrigated areas. The catchment model also makes assumptions about profit for unirrigated pasture and forestry. The dam would have other benefits (for example, environmental, recreational, hydroelectricity, urban supply) and costs (for example, environmental impacts associated with construction) that are not considered in this analysis.

Furthermore, the analysis does not consider impacts in terms of:

- other agricultural uses (for example, avocados, berries, nuts, olives, glasshouses, nurseries, hops, kiwifruit and so on) – although the per hectare value of some of these land uses is significant, all other land uses, except non-dairy pasture, cover only about 6% of the study area. A significant proportion of irrigated non-dairy pasture is under lifestyle properties, and it is assumed the impact of clawback on this land use would be minimal (as per anecdotal information relating to management of restrictions within the WEIS described in section 5.3.2 below);
- employment, flow-on impacts on the wider regional economy and anything else other than catchment profit are also excluded.

4.3.5 Other limitations

The use of a full-factorial modelling approach represents the variation in water demand and supply across individual months and years. However, in line with standard optimisation models of this kind (Conrad and Clark, 1987), the model contains implicit assumptions that the catchment manager has full knowledge of how climate conditions will unfold across time, how this will affect plant growth and how management will impact on both enterprise production and profitability. These assumptions potentially overstate the benefits associated with the temporary transfer of water entitlements, especially given that risk aversion can also impair the willingness of some producers to transfer water permits, even in the short-term. Nevertheless, these assumptions remain in line with standard practice, because a model gets too large to utilise when it incorporates all possible branches within a decision tree consisting of irrigation decisions across multiple months and multiple years (Kingwell et al, 1993).

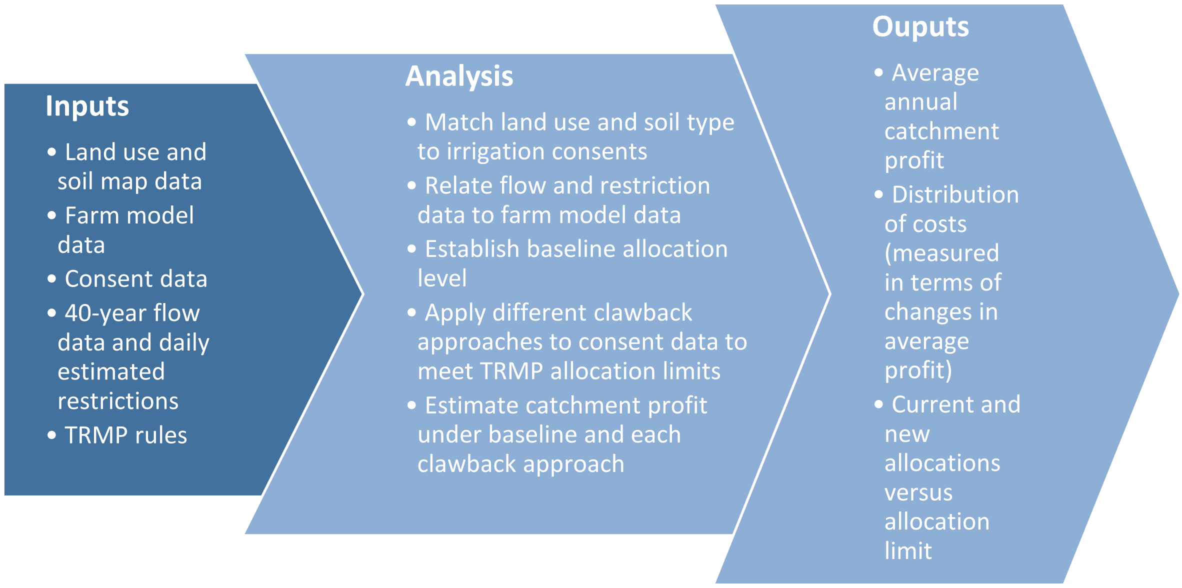
Aside from the apple profit sensitivity analysis, price variation is not studied. Distributional impacts across different farmers and growers are not evaluated specifically either.

5 Clawback analysis

5.1 Methodology

The clawback analysis looks at the impact of different approaches to phase out over-allocation on a consent-by-consent basis, should the dam not proceed. Conclusions about the impact of different approaches on catchment profit and the distribution of these costs are drawn. The methodology applied in this analysis is summarised in Figure 11.

Figure 11: Clawback analysis methodology



5.1.1 Inputs

Inputs to the analysis are:

a) **land use and soil type maps** described in section 3.2;

b) **farm model data** described in section 3;

c) **consent data** – obtained from TDC covering 299 individual consents for the Waimea WMZs (illustrated in Figure 2). Of these, 30 consents are for non-irrigation abstractions (for example, industrial, domestic, municipal use) and 269 consents are for irrigation;

d) **flow data and estimated restrictions** for a period of more than 40 years described in section 3.3; and

e) **TRMP** (as of May 2015) – in addition to setting out flow-based restrictions and the minimum flow for the Waimea River described above, it sets allocation limits for the nine WMZs in the Waimea area, illustrated in Figure 2 and Figure 3 (Upper Catchment WMZ is not shown).

5.1.2 Analysis

The analysis involved the following process.

i. **Match land use and soil type to irrigation consents:** Each irrigation consent was assigned a single land use and soil type based on their coordinates and overlap or proximity to each relevant land use and soil type.

   Market gardening was modelled as a seasonal rotation of winter lettuce and either summer pumpkin, summer cabbage or summer lettuce. Market gardening consents were split into three groups, and each group was arbitrarily assigned one of these rotations for the entire analysis period, assuming a roughly even split of rotations for each soil type. Although it is not realistic for individual consent-holders to operate under the same rotation for the entire period, the assumption of a roughly even split of rotations across different soil types is reasonable and prevents predominance of one rotation having an undue impact on the analysis.

   Given that there is a single consent for the WEIS area, which covers various land uses and soil types, this step did not apply to the WEIS consent. Instead, each combination of land use and soil type within the WEIS area was treated as an individual consent.

ii. **Relate flow and restriction data to farm model data:** A stepwise-regression analysis (Maechler, 2015) was applied to the farm model data and restriction data to generate functions that explain the impact of flow-based restrictions on profit for each land use, soil type and water allocation scenario.

   The resulting functions can be expressed as:

$$\Delta\pi = a + b \cdot [\log(1 - M_1)] + c \cdot [\log(1 - M_2)] + d \cdot \left[\log\left(1 - \frac{\sum_{i=3}^{12} M_i}{10}\right)\right]$$

$$\Delta\pi = \pi_{unrestricted} - \pi_{restricted}$$

   Where:

   $\Delta\pi$ is the difference in profit for each land use, soil type and allocation rate combination between when flow-based restrictions apply (that is, restricted or “without dam”) and when flow-based restrictions do not apply (that is, unrestricted or “with dam”).

   M_i is the average monthly restriction over the analysis period. Note that the statistical significance of average monthly restrictions varies for different combinations of land use, soil type and allocation levels. For example, for apples on Ranzau soils and 350 cubic metres per hectare per week allocation, only the average monthly restrictions in January (for example, M_1) and February (for example, M_2) are statistically significant, while for pumpkin and lettuce on Wakatu soils and 350 cubic metres per hectare per allocation, only November and February average restrictions are statistically significant.

The function for the lowest allocation level included in the efficiency-adjusted farm model output was used to estimate average profit for restricted allocation levels below the range included in that output.

iii. **Establish baseline allocation level:** Allocation limits for each WMZ in the TRMP are set in litres per second. All cubic metre per week rates for consents were converted into litres per second so that total allocation can be comparable to allocation limits, as summarised in Figure 3.

iv. **Apply different clawback approaches to consent data to meet TRMP allocation limits:** As illustrated in Figure 3, six of the nine WMZs are over-allocated (Upper Catchment WMZ is not shown). Across all zones, allocation is 64% above the combined allocation limit. The objective of this part of the analysis was to reduce allocations to meet the limit in each WMZ.

Allocations for non-irrigation (that is, municipal, domestic and industrial) consents were not reduced.[2] Likewise, allocations for the Lower Confined Aquifer were not reduced because that WMZ is not over-allocated. There are no relevant consents in the Upper Catchments or Redwood WMZs, so clawback was only applied to irrigation consents in the six WMZs that are over-allocated: Upper Confined Aquifer, Delta, Golden Hills, Waimea West, Reservoir and Hope and Eastern Hills.

The clawback approaches applied were:

A. Flat-rate cut: subject to the degree of over-allocation in each WMZ, as summarised in Table 3.

Table 3: Flat-rate clawback required for irrigation consents per Water Management Zone

Water Management Zone	Over-allocation percentage above limit (irrigation consents only)
Upper Confined Aquifer	30.2%
Lower Confined Aquifer	0.0%
Upper Catchments	0.0%
Delta	62.3%
Golden Hills	18.9%
Waimea West	45.9%
Reservoir	50.2%
Hope and Eastern Hills	25.5%
Redwood	0.0%

[2] Industrial consents are likely to be reduced to their reasonable needs while municipal and domestic supply consents (great majority of non-irrigation take) are not likely to be reduced. Non-irrigation takes within urban areas (Richmond and Brightwater) are already subject to volumetric service charges.

B. **TRMP "bona fide" use cut:** defined for the purpose of this analysis as the lowest of soil type rate, crop rate (as per TRMP tables 31.1D and 31.1DA respectively) or the maximum irrigation need for each land use, soil type and allocation combination from farm model data.[3]

C. **Stringent irrigation need-based cut:** for WMZs for which over-allocation is not completely phased out by B above, clawback to 90 percentile (or 9 years out of 10 years) irrigation need, and in WMZs where that is not sufficient, clawback to 80 percentile (or 8 years out of 10 years) irrigation need.

Given that farm modelling only covered apples, viticulture, market gardening and dairy, the following assumptions in Table 4 were made about irrigation need for other land uses.

Table 4: Assumptions about irrigation needs for other crops

Land use	Maximum irrigation need (m^3/ha/week)	90 percentile irrigation need (m^3/ha/week)	80 percentile irrigation need (m^3/ha/week)
Berries, hops, kiwifruit	Same as apple farm model		
Olives, hazelnuts	Same as viticulture farm model		
Glasshouses, nurseries, pasture (non-dairy)	250	180	145

v. **Estimate average annual catchment profit under baseline and each clawback approach:** this involved matching baseline and new allocations under each clawback approach to the modelled (or derived) profit for each land use and soil type combination for each consent.

"Irrigation need" is defined as water demand (from farm modelling described in Section 3) beyond rainfall to meet different crop growth–production needs given specific soil type properties and climatic conditions. Irrigation needs are greater during dry (low rainfall) years than during higher rainfall years. Therefore, irrigation need can be expressed in relation to variable demand, for example, to meet needs in 10 out of 10 years (maximum) or 8 years out of 10 years (80 percentile). For use in this analysis, irrigation need is expressed as cubic metres per hectare per week.

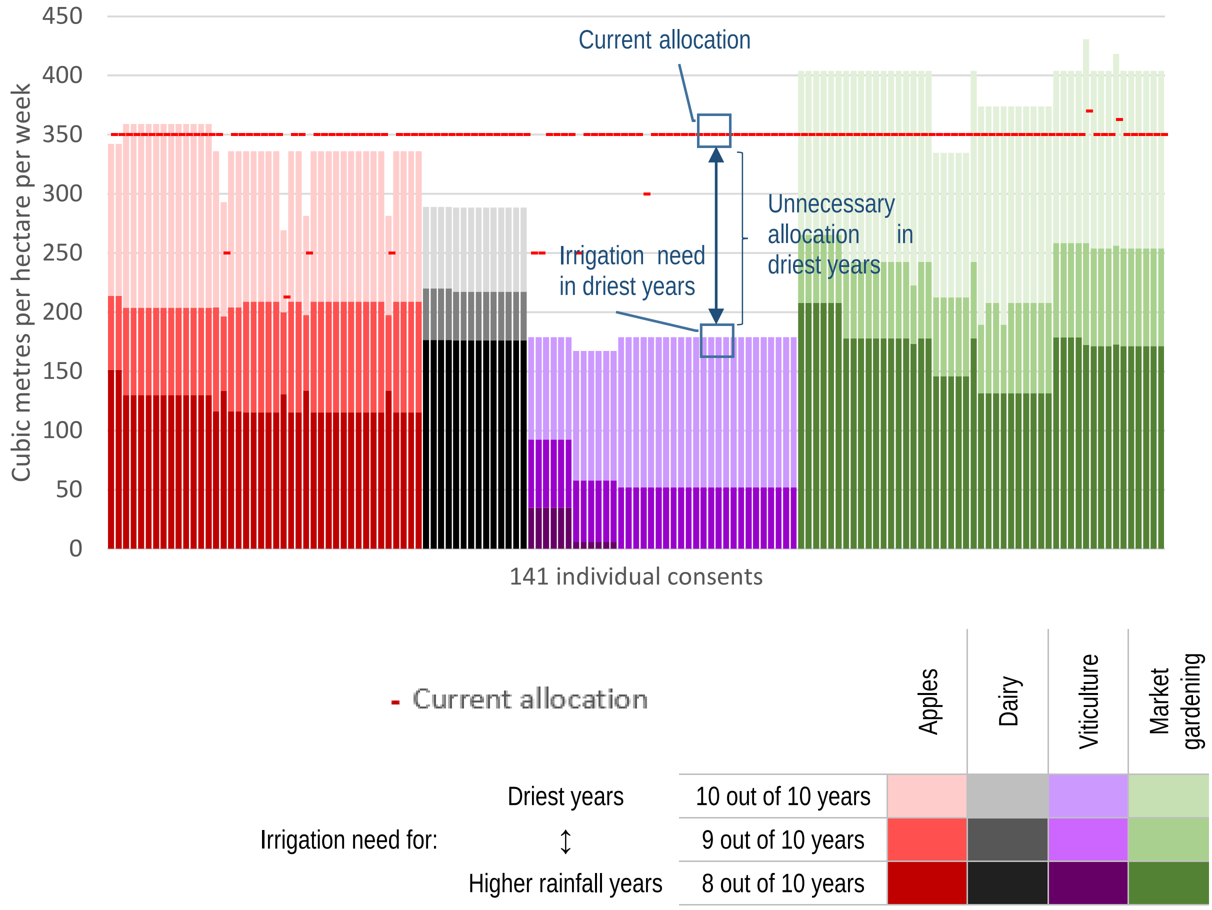
[3] TRMP "bona fide" use refers to actual metered use as opposed to modelled irrigation need. Although there is reasonably good actual metered use data for the Waimea Plains going back to 2003, this information is not complete for all consents, and actual use in that period would have been subject to different restrictions from those applicable under the current TRMP. Furthermore, there has not been a particularly dry year since 2003. To ensure a consistent approach, modelled irrigation need was considered instead.

5.2 Results

5.2.1 Current allocation versus irrigation need

Figure 12 illustrates current allocation and irrigation need for each of the 141 irrigation consents analysed (excluding the WEIS consent). As described above, irrigation need is defined as water demand beyond rainfall to meet different crop growth and/or production needs given specific soil type properties and climatic conditions. The figure shows that current allocation, represented by red marks, is generally greater than irrigation need, represented by coloured bars. Lighter-colour bars show irrigation need in the driest years while darker-colour bars show irrigation need in higher rainfall years.

Figure 12: Current allocation and irrigation need by consent for apples, dairy, viticulture and market gardening



In summary, in the absence of restrictions:

a) 57% of consents are unlikely to be fully utilised, even during the driest years (current weekly allocation greater than maximum weekly irrigation need); and

b) the remaining 43% would fall short only in 1 year out of 10 years (current weekly allocation lower than maximum irrigation need but greater than irrigation need for 9 years out of 10 years).

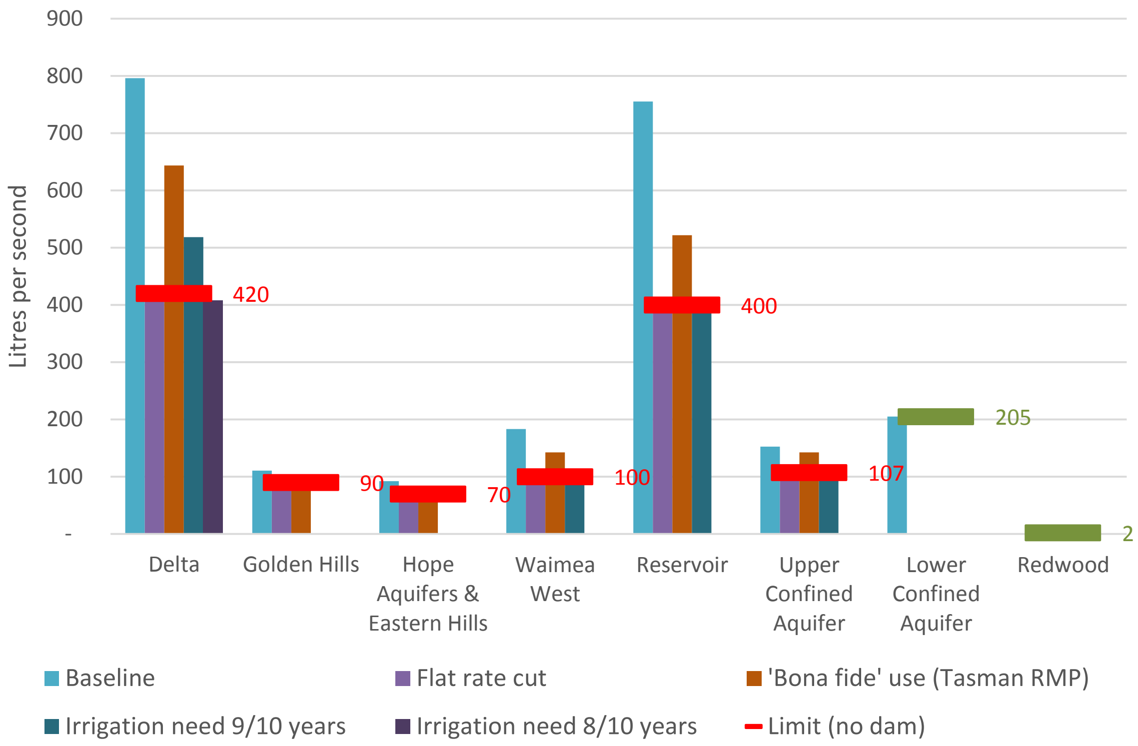
It is important to note that, because of flow-based restrictions, full allocations would often not be available to irrigators when required anyway.

5.2.2 Current and clawed back allocation versus allocation limits

Figure 13 shows current allocation and allocation under each of the clawback approaches evaluated in relation to the allocation limit for each WMZ. Flat-rate clawback, by definition, achieves the limit in all over-allocated WMZs. Under the TRMP, "bona fide" clawback would only reduce allocation to the limit in Golden Hills and the Hope and Eastern Hills.

For the other over-allocated WMZs, more stringent clawback based on irrigation need is required to reach the limit. In the Waimea West, Reservoir and Upper Confined Aquifer WMZs, clawback based on irrigation need for 9 years out of 10 years enables the allocation limit to be achieved. In Delta, the most over-allocated WMZ and the one with the highest volume of non-irrigation allocations (which are not reduced in this analysis), it is necessary to clawback based on irrigation need for 8 years out of 10 years to achieve the limit.

Figure 13: Waimea Water Management Zones: baseline and clawed back allocation versus allocation limit

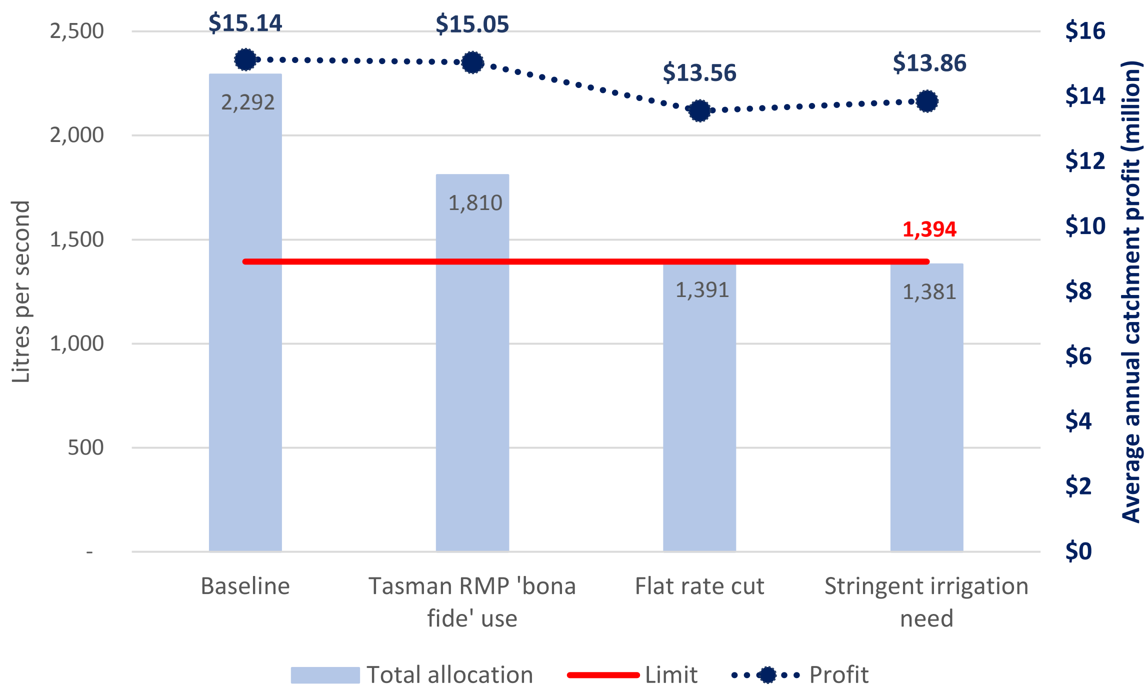


Note: RMP = Resource Management Plan.

5.2.3 Allocation and catchment profit

Outputs from the analysis in terms of average annual catchment profit, current and clawed back allocations (in comparison with the allocation limit) are summarised in Figure 14.

Figure 14: Total allocation and average annual catchment profit for apples, viticulture, dairy and market gardening under baseline and clawback scenarios



Note: RMP = Resource Management Plan.

Water permit cuts based on irrigation need[4] result in an 8.5% drop in average annual catchment profit, compared with a 10.4% drop under flat-rate cuts. As mentioned above, TRMP "bona fide" use cuts would not be sufficient to meet the allocation limit in all WMZs. Figure 14 also shows that, due to the current degree of over-allocation, headroom for new users would not be created by clawback without imposing additional costs on current irrigators.

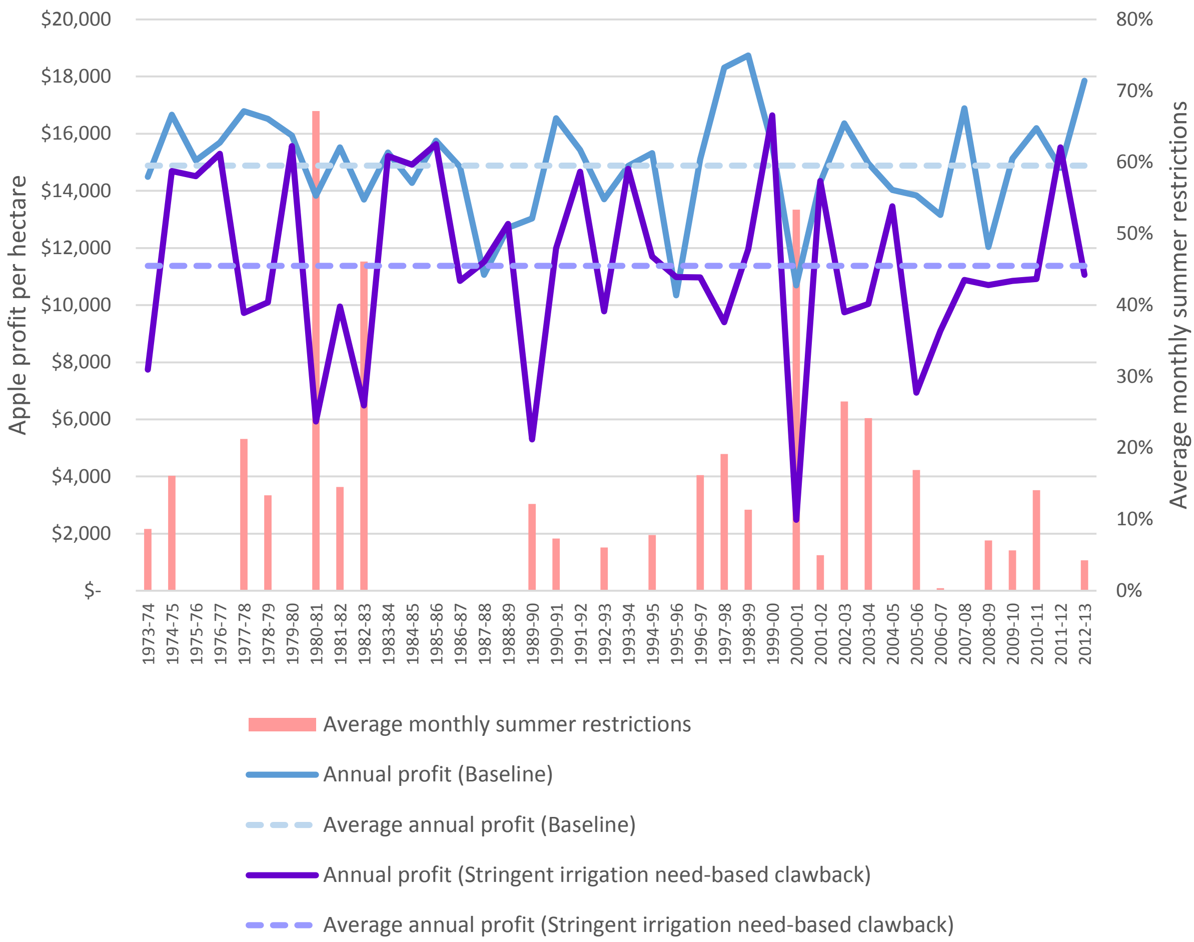
As noted under the catchment modelling discussion, the results presented here may be optimistic because the analysis assumes constant land use and ignores the likely possibility of landowners changing land use (for example, converting to lifestyle properties or unirrigated uses). The effect of this would be to reduce catchment profit further; therefore, the results may be underestimating the impact of clawback.

It is possible to disaggregate impacts of different clawback approaches by individual consent-holder, WMZ and by year. For example, Figure 15 shows profit (annual and average) for a hectare of apples in the Delta WMZ on Waimea soils throughout the analysis period. The figure

[4] As illustrated in Figure 13, a combination of different levels of irrigation need from a maximum 9 years out of 10 years and 8 years out of 10 years is required to meet allocation limits in all WMZs.

illustrates the high degree of variability in profit over the analysis period, with significant drops occurring when there are high levels of flow-based restrictions, particularly after allocations are clawed back.

Figure 15: Estimated apple profit and summer irrigation restrictions (Waimea soil, Delta WMZ) 1973/74–2012/13



5.2.4 Distribution of costs

Distribution of costs (in terms of impact on average catchment profit) is summarised in Table 5 and Figure 16.

Water permit cuts based on irrigation need would spread costs slightly more evenly among consent-holders. Irrigation need-based cuts would result in lower drops in profit compared with flat-rate cuts for all land uses, except viticulture, given the lower irrigation need of that land use. It is important to note that most consent-holders that would face drops in profit greater than 30% are market gardening consent-holders who are already making losses in the baseline scenario.[5]

Table 5: Distribution of costs under different clawback approaches

	Number of consent-holders affected by percentage drop in annual average profit*						Annual profit loss by land use				
Clawback approach	0%	0% to 5%	5 to 10%	10 to 20%	20 to 30%	>30%	Apples	Dairy	Viticulture	Market gardening	(WEIS)
Baseline	*142**	–	–	–	–	–	–	–	–	–	–
Tasman Resource Management Plan "bona fide" cut	*45*	*82**	*15*	*0*	*0*	*0*	*0.4%*	*0.0%*	*2.9%*	*1.2%*	*0.4%*
Flat-rate cut	15	53	23	2*	29	20	10.1%	18.9%	2.7%	15.5%	10.2%
Stringent irrigation need-based cut	19	23*	29	30	24	17	9.7%	13.0%	10.6%	11.9%	4.5%

* Waimea East Irrigation Scheme (WEIS) considered under a single consent

Of the consent-holders that started with a positive profit in the baseline scenario, the highest drops in profit are for market gardening (particularly under the lettuce–cabbage rotation), a 64% drop under flat-rate cuts and a 48% drop under stringent irrigation need-based cuts. This can be attributed to the generally greater irrigation needs of that land use. The distribution of market gardening consent-holders by percentage of profit loss is not significantly different between flat-rate and stringent irrigation need-based cuts.

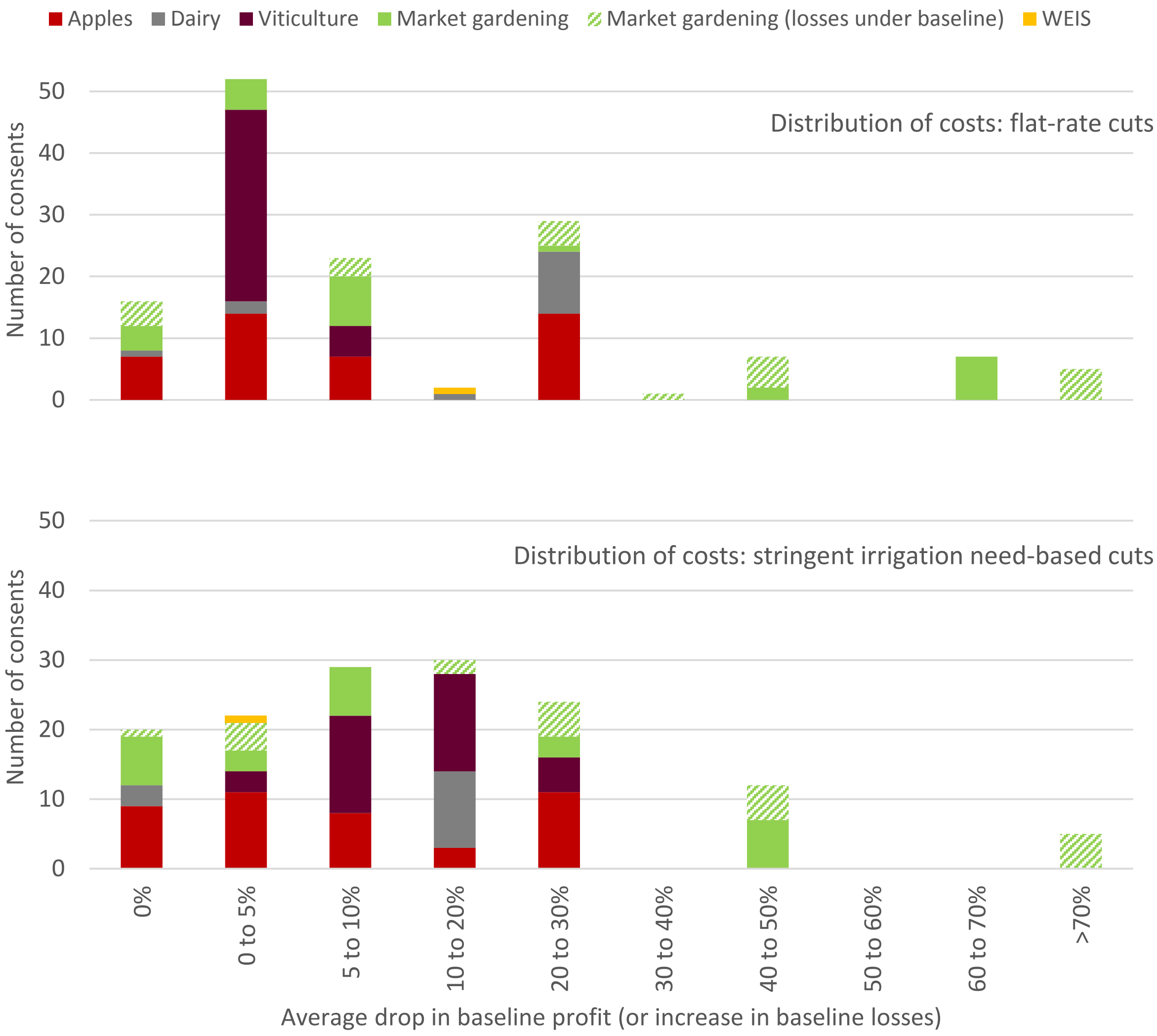
Because of their lower irrigation needs, most viticulture consent-holders face small (less than 5%) losses under flat-rate cuts but face higher losses under irrigation need-based cuts.

The distribution of apple and dairy consent-holders, by percentage drop in profit, is not significantly different under flat-rate and stringent irrigation need-based cuts but consent-holders would face lower drops in profit under the latter approach.

Profit for the WEIS area would drop by 10.2% under flat-rate cuts but only by 4.5% under stringent irrigation need-based cuts.

[5] As described in section 3.4.2, the clawback analysis assumes that market gardening consent-holders would be operating under the same rotation for the entire analysis period. In reality, market gardening consent-holders would change rotations every year, therefore, individual consent-holders would not actually be making losses for the entire period, but according to the model, some consent-holders would be making losses under certain rotations each time.

Figure 16: Distribution of costs under flat-rate clawback and stringent irrigation need-based clawback



Note: WEIS = Waimea East Irrigation Scheme.

5.3 Limitations and uncertainties

5.3.1 Matching land use and soil type with consent data

The process of assigning land use and soil type to each consent in the clawback analysis assumes that each consent is related only to one land use and soil type. In reality, there may be multiple land uses and soil types associated with each consent.

Irrigated area was determined from consent data but actual area irrigated under each consent is uncertain (for example, an irrigator could choose to apply a lower rate of irrigation than allocated to a larger area).

5.3.2 Management of allocations and restrictions within the Waimea East Irrigation Scheme

The WEIS covers about one-fifth of the study area (approximately 1100 hectares) and is the single largest water user. Although the WEIS is subject to the same allocation limit and flow-based restrictions as all other consent-holders, it would have a lot more flexibility about how water is allocated and restricted between individual irrigators within the scheme.

For example, anecdotal information indicates that, when flow-based restrictions apply, lifestyle block irrigators within the WEIS are the first ones to reduce abstractions to ensure commercial irrigators can continue to irrigate. In this analysis, it is assumed that all irrigators within the scheme are treated the same as those outside the scheme (that is, subject to the same clawback rules and restrictions). One exception to this assumption is in the case of stringent irrigation need-based clawback. In that case, apple growers within the WEIS were allocated rates slightly higher than 90 percentile irrigation need so that the total allocation limit for the Reservoir WMZ, from which water for the WEIS is abstracted, was reached.

5.3.3 General limitations

Limitations described in sections 4.3.1 (in relation to complexity of land use change decisions), 4.3.3 (plan changes) and 4.3.4 (other costs and benefits) also apply to the clawback analysis component of the case study.

6 Conclusions

6.1 Enabling water permit transfers

Benefits from water permit transfers are moderate, resulting in an average annual catchment profit increase of 8.6% or $1.2 million, once over-allocation is phased out, if the dam does not proceed. Most of this benefit occurs in dry years, 46% in a particularly dry year, and relates to short-term transfers. If the dam goes ahead, there would no longer be a shortage of water and, consequently, water permit transfers would have no impact until the additional water is fully allocated.

6.2 Water storage infrastructure

The dam would result in significant economic benefits, 103% or a $15 million increase in average annual catchment profit. This benefit relates mainly to the ability to expand irrigated areas and convert land use from unirrigated pasture to apples (a high-value export product). Furthermore, it potentially has environmental benefits in that apples have low nitrogen-loss rates, relative to alternative land uses, and dam development will increase river flows and recharge aquifers. The dam would also provide close to full reliability for existing irrigators, representing a $2.9 million (or 20%) increase in average annual earnings.

This particular positive impact for the economy and environment is not applicable in many other catchments given that the suitability of areas for high-value tree crops is limited due to, for instance, weather conditions, soil types, market constraints, water quality constraints or distance to markets and/or ports. Nonetheless, these results do highlight the positive impact that water storage infrastructure can have, both economically and environmentally, when it enables growth within environmental limits.

Average catchment profit estimates do not take into account other benefits from the dam (for example, environmental and urban use), the likelihood of land use change to less intensive uses (for example, unirrigated pasture or lifestyle properties) if the dam is not built and proposed changes to the TRMP that would introduce a different management regime. The impact of this is a likely underestimation of the benefits of the dam.

Although the approach taken in this case study is different from previous economic assessments of the dam, the conclusions about the value of the dam are generally consistent with those of previous assessments (Clough and Corong, 2014; John Cook and Associates, and Northington Partners, 2011).

6.3 Clawback

Freshwater resources in the Waimea Plains area are over-allocated, 64% above the combined allocation limit. Users face significant flow-based restrictions that would have a greater impact following clawback, if the dam does not go ahead.

In the absence of restrictions, current allocation is generally greater than irrigation needs: 57% of irrigation consent-holders would not use their full allocation, even in the driest years, and 43% would fall short only in 1 year out of 10 years. However, flow-based restrictions mean that, often, irrigators would not be able to take their full allocations when they most need them anyway.

Clawback based on irrigation needs would result in lower costs than flat-rate cuts (an 8.5% drop in average catchment profit compared with a 10.4% drop) and a slightly more even distribution of those costs. This is a logical conclusion, consistent with the approach already adopted by many regional councils. TRMP “bona fide” use allocation rules would not completely phase out over-allocation.

Finally, because the objective of the analysis was to reduce allocations to the allocation limit in each WMZ, clawback did not create headroom for new users (for example, iwi and/or hapū). Headroom for new users could be created if more stringent clawback approaches are adopted, which would result in additional costs for existing users.

7 References

Adamson, D; Mallawaarachchi, T; Quiggin, J (2007) Water use and salinity in the Murray-Darling Basin: A state-contingent model. *Australian Journal of Agricultural and Resource Economics* 51: 263–281.

Bertsimas, D; Sim, M (2004) The price of robustness. *Operations Research* 52: 35–53.

Beverly, C; Roberts, A; Stott, K; Vigiak, O; Doole, G (2013) Optimising economic and environmental outcomes: Water quality challenges in Corner Inlet, Victoria. *Proceedings of the 20th International Congress on Modelling and Simulation* (pp 2117–2123). Adelaide.

Brooke, A; Kendrick, D; Meeraus, A; Raman, R (2014) *GAMS – A user's guide.* GAMS Development Corporation; Washington, DC.

Clough, P; Corong, E (2014) *Waimea dam economic assessment: Review and update of economic impact assessment of Waimea Community Dam – Report to Nelson Economic Development Agency.* NZIER; Wellington.

Conrad, J; Clark, C (1987) *Natural resource economics: notes and problems.* Cambridge University Press; Cambridge.

Deb, K (2000) An efficient constraint handling method for genetic algorithms. *Computer Methods in Applied Mechanics and Engineering* 186: 311–338.

Doole, G (2013) *Evaluation of policies for water quality improvement in the Upper Waikato catchment: Client report.* University of Waikato; Hamilton.

Doole, G (2015) A modelling framework for determining cost-effective land allocation at the catchment level. *Computers and Electronics in Agriculture* 114: 221–230.

Doole, G; Kingwell, R (2010) Robust mathematical programming for natural resource modelling under parametric uncertainty. *Natural Resource Modelling* 23: 283–302.

Doole, G; Marsh, D (2014) Methodological limitations in the evaluation of policies to reduce nitrate leaching from New Zealand agriculture. *Australian Journal of Agricultural and Resource Economics* 58: 78–89.

Doole, G; Pannell, D (2008) Optimisation of a large, constrained simulation model using compressed annealing. *Journal of Agricultural Economics* 59(1): 188–206.

Doole, G; Pannell, D (2011) Evaluating environmental policies under uncertainty through application of robust non-linear programming. *Australian Journal of Agricultural and Resource Economics* 55: 469–486.

Doole, G; Pannell, D (2012) Empirical evaluation of non-point pollution policies under agent heterogeneity. *Australian Journal of Agricultural and Resource Economics* 56(1): 82–101.

Doole, G; Vigiak, O; Pannell, D; Roberts, A (2013) Cost-effective strategies to mitigate multiple pollutants in an agricultural catchment in North-Central Victoria, Australia. *Australian Journal of Agricultural and Resource Economics* 57(3): 441–460.

Fenemor, A; Bealing, J (2009) *Enhancing water distribution from the Waimea water augmentation project: Report prepared for Waimea Water Augmentation Committee.* Landcare Research; Nelson.

Fenemor, A; Green, S; Dryden, G; Samarasinghe, O; Newsome, P; Price, R; . . . Lilburne, L (2015) *Crop production, profit and nutrient losses in relation to irrigation water allocation and reliability: Waimea Plains, Tasman District*. Landcare Research; Nelson.

Heckelei, T; Britz, W; Zhang, Y (2012) Positive mathematical programming approaches: Recent development in literature and applies modelling. *Bio-based and Applied Economics* 1: 109–124.

Holland, L; Doole, G (2014) Implications of fairness for the design of nitrate leaching policy for heterogeneous New Zealand dairy farms. *Agricultural Water Management* 132: 79–88.

IBM (2010) *User's manual for CPLEX, IBM*. IBM; Paris.

John Cook & Associates and Northington Partners (2011) *Waimea Community Dam economic impact analysis: Report to Nelson Economic Development Agency.* Nelson.

Kingwell, R; Pannell, D; Robinson, S (1993) Tactical responses to seasonal conditions in whole-farm planning in Western Australia. *Agricultural Economics* 8: 211–226.

Maechler, M (3 September 2015) *Choose a model by AIC in a stepwise algorithm*. Retrieved from Statistical Data Analysis: R: https://stat.ethz.ch/R-manual/R-devel/library/MASS/html/stepAIC.html. Accessed 28 September 2015.

Vanderbei, R J (2007) *Linear programming: foundations and extension.* Springer: New York.