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Simulation of the proposed policy mix for the Healthy Rivers Wai Ora process

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1. Introduction

The Healthy Rivers Plan for Change: Waiora He Rautaki Whakapaipai (HRWO) Project (www.waikatoregion.govt.nz/healthyrivers) will establish targets and limits for nutrients (N and P), sediment, and *E. coli* in water bodies across the Waikato and Waipa River catchments. Different targets and limits for these contaminants in waterways within this catchment will have diverse impacts on economic outcomes observed throughout the greater Waikato region. Accordingly, a central contribution of the Technical Leaders Group (TLG) to the HRWO project has been the development and utilisation of an economic model that integrates diverse information such that the size and distribution of abatement costs—across farm, catchment, regional, and national levels—associated with alternative limits and targets is predicted (Doole et al., 2016a, b).

The Collaborative Stakeholder Group (CSG) has proposed a policy to initiate improved water quality across the region, with most actions tied to reducing contaminant loss by the rural sector. The draft Waikato Regional Plan Change No. 1—Waikato and Waipa River Catchments (Proposed) (WRPC1) presented at CSG meeting #27 on 9 May 2016 sets out policies that aim to progressively reduce the concentrations of the four contaminants to meet Freshwater Management Unit (FMU) specific targets and associated values of water clarity and suspended algae (chlorophyll-a). The time frame for meeting these ultimate targets for water-quality improvement is 80 years, whereas the current Plan Change aims to ensure that the actions necessary to make a 10% step towards bridging the gap between the current and target states are implemented over the next decade. The target states that the Plan Change seeks to move towards are set out in what is referred to as "Scenario 1" in this report. Scenario 1 is a key output of the HRWO process and defines goals of substantial improvement in water quality for swimming, taking food, and healthy biodiversity. This involves an improvement in water quality at all sites in the catchment, even if it is already meeting the minimum acceptable state.

The policy mix contained in WRPC1 involves a number of diverse elements (Ritchie, 2016), given the size of the catchment, diversity of land-use sectors, number of contaminants considered, broad heterogeneity in contaminant loss, diversity of mitigation efficacy and cost, and spatial differences in water-quality limits. An additional consideration is that some gains in water quality brought about by this policy may potentially be offset through a proposed policy that would allow for some future development of iwi land. The complexity of this context emphasises the importance of using predictive modelling to assess the implications of implementing WRPC1.

The primary objective of this analysis is to employ the HRWO economic model to simulate the policy mix associated with WRPC1 under several different situations, to assess its impact on economic and water-quality outcomes within the Waikato River and Waipa River catchments. This report outlines the key assumptions that have been made to replicate the policy mix, discusses model output associated with a range of explorative scenarios and sensitivity analysis performed with respect to key input data, and then draw conclusions based on these results. Some material is also included that outlines the relationship between policy enactment, the adoption of various actions, and how long it may take for concomitant water-quality improvement to be observed.

The components of the policy mix have been developed based on extensive discussions among the CSG. The HRWO economic model (Doole et al., 2015a, b) provided input to this process, but was not the sole factor utilised to generate the individual elements of the aggregate policy. A key focus of this document is hence to outline what assumptions have been used to replicate the given policy mix within the model, particularly where an inconsistency exists between what the CSG have proposed as elements of the policy mix and what is represented within the HRWO framework (Doole et al., 2015a, b).

2. Model

This section presents a concise description of the economic-modelling approach used in this analysis. More detailed information about the modelling framework is presented in Doole et al. (2015a, b, c). The first part describes the structure of the catchment-level model, while the second part outlines specific details regarding its application to the Waikato and Waipa River catchments.

2.1 Structure of the catchment-level model

The catchment-level model was initially developed as an optimisation model–that is, it determined the least-cost combination of mitigation measures (land management, land-use changes, and point-source treatments) required to meet the water-quality attribute limits set for each scenario (Doole et al., 2015a, b). Within this approach, an iterative process is used to identify how different mitigations could be implemented to minimise the cost associated with achieving a set of given limits (Doole, 2015). The term "optimisation" conveys how the iterative process seeks to *minimise* the cost of a change, and contrasts a simulation approach in which a model user evaluates different scenarios involving pre-defined management activities across the landscape of interest. This particular optimisation model uses a method known as mathematical programming (Bazaraa et al., 2006). However, in this analysis, the model is used in simulation mode. Here, the components of the policy mix are fixed in the model—rather than being determined using an optimisation process—and the economic and water-quality implications computed using the structure of the standard HRWO framework.

The model structure is loosely based on that of the Land Allocation and Management (LAM) catchment framework (Doole, 2012, 2015). The flexibility of this model is demonstrated in its broad utilisation across a number of nonpoint-pollution contexts, both nationally (Doole, 2013; Howard et al., 2013; Holland and Doole, 2014) and internationally (Beverly et al., 2013; Doole et al., 2013). Key benefits associated with the application of the LAM framework are (Doole, 2015):

1. Its flexible structure allows it to be adapted to diverse circumstances.
2. The complexity of the model can be altered, depending on the quality and quantity of resources available.
3. The model can be efficiently coded in popular nonlinear-optimisation software, such as the General Algebraic Modelling System (GAMS) (Brooke et al., 2016), that allows matrix generation.
4. The structure of the model allows the use of a broad range of calibration techniques.
5. Models of substantial size can be constructed (Doole, 2010).

The flexibility of the modelling structure has been particularly critical to the development of the model utilised in the HRWO project, as it contains broadly-diverse relationships between land use, land management, contaminant loss, mitigation activity, pollutant attenuation, groundwater flows of nitrogen, and links between loads and concentrations.

Key mitigation costs included in the model are those associated with stream fencing, upgrading of effluent management on dairy farms, erosion control on dairy and drystock farms, enhanced point-source treatment, transition costs associated with the replacement of one type of farming activity with another, and edge-of-field mitigations (examples of edge-of-field options include wetlands and sediment traps). The efficacy of these mitigations and their costs has been gathered from a variety of literature sources, individual experts, and expert-panel workshops convened by the TLG (Doole, 2016).

Alongside these costs associated with mitigation, costs may also accrue through a decrease in farm profit associated with de-intensification or transition into a new land use. Transition costs to dairy or drystock do not consider the tax implications of this shift, given broad heterogeneity in the tax situations of different producers. However, these could have a significant impact on the value proposition accruing to forest-to-pasture conversion across the catchment (Forest to Farming Group, 2007). Changes to farm profit associated with different mitigation activities are computed using FARMAX for pastoral enterprises, farm budgeting for horticultural enterprises, and the Forest Investment Finder (FIF) for plantation forest. Inputs have been developed through interaction with technical experts within these sectors and industry organisations. A detailed discussion of these data is also described in Doole (2016).

The LAM framework is characterised by delineation of the catchment into a number of partitions. Accordingly, the HRWO model involves:

1. Partitioning of the catchment into the four Freshwater Management Units (FMUs) agreed to by the CSG. These are Upper Waikato (Taupo Gates to Karapiro), Middle Waikato (Karapiro to Ngaruawahia), Lower Waikato (Ngaruawahia to Port Waikato), and Waipa. The area contained within the Lakes FMU is included in the model, but is not studied independent of the others in this report.
2. Further partitioning of the area within each FMU into sub-catchments, many associated with their own monitoring site for a set of water-quality attributes.
3. Additional division of these 74 sub-catchments within the catchment into zones that represent farming systems of a consistent type (in terms of contaminant loss).

The information utilised in step (c) was based initially on that generated by the Economic Impact Joint Venture (EIJV) program of work that preceded the HRWO process. Nonetheless, the information generated by the EIJV was mainly focused on the dynamics of nitrogen leaching. Thus, a key focus of subsequent work within the HRWO process has been the extension of the EIJV economic model to consider the loss and mitigation of phosphorus, sediment, and *E. coli* loadings to water (Semadeni-Davies et al., 2015a, b; Yalden and Elliott, 2015; Doole, 2016).

A key addition to the HRWO economic model has also been the integration of diverse hydrological models that relate contaminant losses within and across sub-catchments to pollutant concentrations at the various monitoring sites represented within the catchment. These models concern *E. coli* (Semadeni-Davies et al., 2015a), sediment (Yalden and Elliott, 2015), nitrogen (Semadeni-Davies et al., 2015b), and phosphorus (Semadeni-Davies et al., 2015b). The integration of these models into the economic model allows the depiction of an explicit relationship between land management, point-source management, and concentrations of chlorophyll *a*, Total Nitrogen, Total Phosphorus, nitrate, *E. coli*, and black disc measurements at different sites across the catchment. A key feature of these hydrological models are estimated fate-transport matrices, which specify the flow and attenuation of contaminants between linked sites in the monitoring network. Importantly, these consider the impact of groundwater lags between the loss of nitrogen from farms and its subsequent delivery to surface-water bodies where it contributes to monitored levels of Total Nitrogen and nitrate. This is particularly an important feature of management in the Upper Waikato FMU, where groundwater lags are significant and there is a substantial load of nitrogen to come given recent development.

In keeping with standard practice (e.g. Hanley et al., 2007; Doole, 2010; Daigneault et al., 2012), the time path of adaptation is not included in the HRWO model, because:

1. The scarcity of data related to many relationships represented in the model is compounded when variation over time in key drivers of management behaviour (e.g. output price, input price, productivity, climate, innovation) is high and difficult to predict. An example is attempting to predict milk-price variation over the next few years, and how this influences mitigation costs for dairy farmers and related industries.

2. Dynamic models are difficult to develop and utilise because of their size and the demands they place on information gathering (Doole and Pannell, 2008).
3. Output from intertemporal models is heavily biased by the starting and endpoint conditions defined during model formulation (Klein-Haneveld and Stegeman, 2005).

Overall, these issues provide a strong justification for the employment of a steady-state modelling framework.

2.2 Application of the catchment-level model

The modelling application involves an analysis of 74 sub-catchments, which are further disaggregated into representative farms for dairy, dairy support, drystock, and horticulture sectors according to the characteristics of land and land management within these zones. Furthermore, 24 point sources are represented across the catchment, consisting of both industrial and municipal sources. Data from point sources was obtained from OPUS International Consultants (2013) and was modified following further consultation with the dischargers. The economic and environmental characteristics of plantation forest across the entire catchment are also estimated utilising information from Scion, expert opinion, and past studies.

The number of representative farms contained within a catchment-level economic model can, in principle, range from a single farm representing the entire catchment to representing each specific farm individually (Doole and Pannell, 2012). Realistically, a shortage of data of a sufficient quality and quantity restricts our capacity to represent individual farms with any precision (Doole, 2012); this is particularly problematic in New Zealand due to confidentiality restrictions. Aggregation into representative farms is a pragmatic “half-way house” that is likely to introduce some prediction error, in terms of estimating both contaminant losses and mitigation costs. However, larger errors can often accompany representations of individual farms, given a paucity of data available at that scale (Doole, 2012). Moreover, it removes the ability to study the movement of contaminants across the catchment, as the subsequent model is sufficiently large and unwieldy that the complexities involved with attenuation relationships and flow paths cannot be considered. Additional justifications are that the model becomes more difficult to interpret (Holland and Doole, 2014), while there is also the fact that mean trends remain the most-relevant anyway, since trends for farms on one side of the average offset the impact of those on the other (Doole, 2012). Issues of spatial aggregation and scale are common in natural-resource modelling approaches of this kind, and it is important to remain cognisant of these limitations when interpreting the model outputs.

Some mitigation practices involve the establishment of enduring assets; for example, the development of stand-off pads or riparian fences. The inclusion of their establishment costs as a lump sum would bias expense estimation because their cost is typically financed across time. Therefore, according to standard practice (e.g. Howard et al., 2013), capital costs are converted to annual equivalent payments at an interest rate of 8% over a payback period of 25 years. Maintenance costs for these assets have also been considered. Forest profits have been annualised and it is important to recognise that, in reality, the returns associated with this activity will only be borne after harvest when trees are 28 years of age.

3. Method

This section describes the assumptions that are made to simulate the policy mix contained in WRPC1.

3.1 Nitrogen policy for farms based on the 75th percentile

A part of the proposed policy states that all dairy farmers with a leaching rate currently above the 75th percentile, assessed per Freshwater Management Unit (FMU), must reduce their nitrogen-leaching level to that consistent with the 75th percentile by 2026. This restriction would also apply to any drystock producer whose nitrogen-leaching level is above that proposed threshold.

Detailed nitrogen-loss levels exist for individual dairy farms throughout the catchment. However, these are held by Fonterra and are unavailable for the purposes of policy simulation due to privacy restrictions. Three different methods are therefore utilised to estimate the effect that this policy would have on the mean leaching rate across each FMU. This multi-method approach is appropriate given the high level of inherent uncertainty that exists. Its suitability to this application is demonstrated in the consistency in results obtained utilising these alternative methods.

The primary method utilised is based on the fact that requiring all dairy farmers currently above the 75th percentile to reduce their nitrogen loss rate to that consistent with the 75th percentile leads to a censoring of the distribution of loss rates across the population. Censoring involves an aggregation of different members of a population at a given minimum and/or maximum value within a distribution (Pindyck and Rubinfeld, 1998). The 75th percentile policy leads to censoring because it leads to the aggregation of all of those farmers above this level of leaching to be at the 75th percentile, once the policy is enacted. This 75th percentile threshold represents the maximum value of the distribution when the policy mechanism is introduced; indeed, no censoring is likely to occur on the left-hand tail of the distribution under this policy instrument.

It is important to distinguish this from the statistical case of one-sided truncation. In comparison to censoring, the 75th percentile policy represented as a one-sided truncated distribution would involve paring the distribution to a given percentile, but then allocating the removed probability mass across the whole population. The case of censoring—in which the mass is accumulated at the 75th percentile—is more realistic, as it assumes producers do not mitigate more than they have to under this policy. This is consistent with a precautionary approach to policy evaluation and also the broad understanding that the mitigation of nitrogen on New Zealand dairy farms is generally costly (Doole and Kingwell, 2015; Doole et al., 2015a, b).

The estimation of the impact of the 75th percentile policy on the mean leaching rate in each FMU is performed as follows:

1. Compute the mean leaching rate (μ) for dairy farms in each FMU.
2. Identify the standard deviation (σ) through the relationship $\sigma = 0.28\mu$.
3. Estimate the upper quartile (the 75th percentile or *Q3*) through the relationship $Q3 = \mu + 0.67\sigma$, given μ and σ.
4. Compute the expected value of the censored distribution, where the censoring occurs at the 75th percentile, through $E[y] = \Phi a + (1-\Phi)(\mu + \sigma\lambda)$ (Greene, 2012). This relationship holds if $y^* \sim N(\mu, \sigma^2)$ and $y = a$ if $y^* \leq a$ or else $y = y^*$. In this equation, $\Phi\left[(a-\mu)/\sigma\right] = \Phi(a) = \Pr(y^* \leq a) = \Phi$ and $\lambda = \phi/(1-\Phi)$.

The relationship employed in Step 2 is identified from Doole (2012). Doole (2012) estimated nitrogen-leaching rates for 410 individual farms on three soil types through the Waikato region. It remains the best available data that is publically available to guide estimation of the requisite information. The mean and standard deviation from this sample are used to compute the coefficient of variation ($c = \sigma / \mu$), a measure of spread, for leaching rates among the dairy-farming population in each FMU. This identifies c = 0.28. The equation for the coefficient of variation is then reformulated with the mean and standard deviation set as unknowns; this yields $0.28 = \sigma / \mu$. This equation is then solved for the standard deviation, which yields $\sigma = 0.28\mu$. This allows the generation of the standard deviation as a function of the estimated mean.

Step 3 draws on standard statistical theory developed for a normal distribution (Mittelhammer et al., 2000). An assumption that nitrogen leaching is normally distributed within each FMU is justified by the fact that it cannot be rejected that the data for 410 individual farms generated by Doole (2012) is consistent with a normal distribution, at a 5% level of statistical significance. Outliers will exist in reality; nevertheless, removing those outcomes that have the greatest influence on the mean will be pared if standard rules for removing these observations are utilised.

Step 4 utilises standard theory for the censoring of a normal distribution (Greene, 2012). This is implemented in MATLAB software (Chapman, 2016). This method identifies that a 75th percentile policy will decrease average leaching by around 5% in each FMU.

A second method was also utilised to confirm these results were consistent with other data sets. An appendix to Doole (2016) presents two probability distributions of nitrogen loss from dairy farms in the study region: one for the Waipa/Franklin district [Figure 8 in the appendix of Doole (2016)], and one for the Upper Waikato [Figure 12 in the appendix of Doole (2016)]. These distributions were estimated by DairyNZ and indicate mean leaching levels of 30.3 kg N ha^{-1} in the Waipa/Franklin region, and 39.6 kg N ha^{-1} in the Upper Waikato region.

Maximum entropy (ME) is a Bayesian statistical technique that can be employed to estimate detailed probability distributions from sample statistics of different resolution (Golan et al., 1996). It distinguishes between alternative solutions based on their relative-information content (Golan and Gzyl, 2012). When information content is measured using entropy (Golan, 2012), the maximum-entropy principle (Jaynes, 1957) guides the selection of the probabilities within the distribution that could have been generated by the data set in the greatest number of ways.

Maximum entropy is employed to estimate the distribution of nitrogen-leaching loss for each district for which data is available. It would be preferable to do this for each FMU, but distributions like those presented by DairyNZ that are consistent with a more-refined spatial scale are unavailable. The maximum-entropy estimation for each district is coded in the General Algebraic Modelling System (GAMS) software (Brooke et al., 2016), using nonlinear-programming methods to identify the proportion of the population that leaches each single kilogram of leaching between the minimum and maximum levels defined by DairyNZ for each district. The program is defined such that the level of entropy is maximised, subject to conditions stating that the mean level of nitrogen loss and the (coarse) distribution described by DairyNZ is observed. In effect, this approach allows a more-detailed depiction of the probability distribution presented by DairyNZ, to be generated, while presenting equivalent information.

This information allows the identification of the rate of nitrogen loss consistent with the 75th percentile and also the estimation of the mean leaching level once the policy is enacted. The outcomes are very consistent with those identified using the first method, with reductions for mean leaching in the Waipa/Franklin and Upper Waikato districts associated with the enactment of the 75^{th} percentile policy being estimated at 4% and 5%, respectively.

Graham McBride (NIWA, Hamilton) also used the @Risk software (Nersesian, 2015) to fit empirical distributions to the DairyNZ data presented in Doole (2016), using the Bayesian Information Criterion to select the most-informative distribution. These distributions were then used to estimate the effect on mean leaching of shifting all farmers above the 75^{th} percentile down to this level. The magnitude of estimated decreases from the baseline mean arising from this work were 6% and 4% in the Waipa/Franklin and Upper Waikato districts, respectively.

Overall, the three methods show remarkable consistency, with an average rate of decrease in total leaching across each FMU of 5% when this aspect of the policy is considered independently of other effects.

This policy may also affect high-leaching drystock farms. A lack of information precludes the estimation of this effect. Nevertheless, it justifies a focus on achieving meaningful nitrogen reductions in this sector, a factor which is discussed in more detail below.

3.2 Stream fencing

The WRPC1 outlines that by 2026 all stock will be excluded from streams on land that has a slope less than or equal to 25 degrees. In contrast, all streams on land that has a gradient greater than 25 degrees will not be fenced. Sanjay Wadhwa (NIWA) used Geographic Information Systems (GIS) to partition the catchment according to land-use type, rainfall, slope, and soil type. This information was used to identify those stream lengths present in each land parcel that met the requirements set out by WRPC1. These streams were fenced, with each fence built to omit cattle but not sheep.

Riparian buffer strips are defined as 1 m on flat land (<15^{o}) and 3 m on slopes of 15^{o}–25^{o}. These buffers are simulated for all fenced streams of land in these slope classes. The establishment of broad riparian zones following livestock exclusion can help to mitigate nitrogen through denitrification and plant uptake. However, while some research has indicated the efficacy of buffers for nitrate removal (Zhang et al., 2010), there is a well-established concern that these areas will likely act as a source of nitrogen if vegetation is not regularly cut and removed (e.g. through silage cutting) (Collier et al., 2013), which can be difficult to perform in reality. Riparian zones can also help to mitigate phosphorus through phosphorus becoming bound to soils as water passes through this zone, plant uptake, and by preventing the collapse of the stream margin (Zhang et al., 2010). Nevertheless, this margin will not act as a long-term sink for phosphorus as none is lost permanently from the system (McDowell et al., 2008); unless, of course, the riparian vegetation is harvested and removed. For these reasons, the conservative assumptions surrounding the mitigation capacity of riparian buffers adopted in the previous round of modelling are used (Doole, 2016). This is also consistent with a precautionary approach to modelling the effects of the policy mix defined in WRPC1.

3.3 Farm Environment Plans

Farm Environment Plans are a core part of the proposed WRPC1. These are based on the concept that extension services can be used to work with farmers to reduce their environmental footprint, as well as improve their economic performance. This is a pragmatic policy that allows for a property-by-property risk assessment, and application of the most-appropriate set of mitigations for that situation above the specified minimum standards. Indeed, it explicitly recognises and deals with the heterogeneity present between producers across the catchment, particularly in terms of land-use type, land-use mix, management ability, production intensity, soil type, and slope (Doole and Kingwell, 2015). This approach is challenging to simulate and by necessity, assumptions need to be made in the simulation modelling. Some input to these assumptions was provided by industry representatives, members of the CSG, and Waikato Regional Council; however, this stopped short of prescriptions of what activities would be generally applicable within the proposed Farm Environment Plans. Indeed, the baseline assumptions were updated iteratively with the CSG in response to an examination of the impacts of various assumptions on economic and water-quality outcomes. The assumptions that are utilised are outlined in further detail throughout this section.

A number of two-pond systems still exist in the catchment. Also, low-rate effluent application is still not fully adopted on soil types to which is suited. The implementation of farm plans is assumed to promote the adoption of these technologies. This is particularly justified given rapid improvement of effluent management by the dairy industry, especially in the Waikato region specifically, and technical improvement observable in the associated technologies (Brocksopp et al., 2015).

The improved management of applied phosphorus is a key strategy to reduce phosphorus loss from New Zealand farms. There are three key strategies involved in this aggregated mitigation option in the model. First, there is an opportunity for farmers to optimise their application of phosphatic fertiliser in response to measurements of plant-available phosphorus levels (McDowell and Nash, 2012). Second, there is an opportunity to reduce rates of phosphorus loss through the use of less-soluble forms of phosphatic fertiliser, such as Reactive Phosphate Rock (RPR) (McDowell, 2010; McDowell and Smith, 2012). Last, there is the opportunity to employ best management practice for applying phosphatic fertiliser; for example, applying these only when surface runoff is unlikely (McDowell and Nash, 2012). At least one of these strategies is generally available to producers within the catchment, and this would be a key element of initial focus in many farm-planning exercises. Indeed, in general, they are highly adoptable since they are relatively cost-effective and introduce little complexity to ongoing management of the farm system (Monaghan et al., 2015). Thus, it is assumed in the following that all producers that utilise a farm plan adopt improved phosphorus management as part of their approved strategy.

Cost-effective edge-of-field mitigation options exist, with previous modelling in the HRWO process highlighting the combined value of detention bunds (without and with wetlands), sediment traps, small constructed wetlands, and large constructed wetlands (Doole, 2015a, b). This emphasises the need to examine their likely adoption over the next decade, within the context of the WRPC1. Large constructed wetlands are omitted from this analysis—that is, their level of adoption is fixed at zero—because their cost and large scale mean that they are unlikely to be broadly used across the catchment.

Diffusion describes the speed at which the use of an innovation spreads across space as a function of the time elapsed since it was introduced or encouraged. The logistic function is the classical description of a diffusion process for a broad range of technologies (Figure 1). Both the speed and the maximum level of adoption achieved are key elements of the diffusion curve for a given technology (Figure 1). As demonstrated in the seminal work of Griliches (1957), the logistic function describes a rate of diffusion that builds to a peak and then declines as the capacity for diffusion among a population is met. This shape represents different propensities for risk and innovativeness (Rogers, 2003), diversity in income that affects willingness to innovate (Golder and Tellis, 1997), and because adoption rates benefit from learning by doing (Park, 1994). Various analogues of this relationship exist (Meade and Islam, 2006), but the logistic function is the most common (e.g. Rogers, 2003).

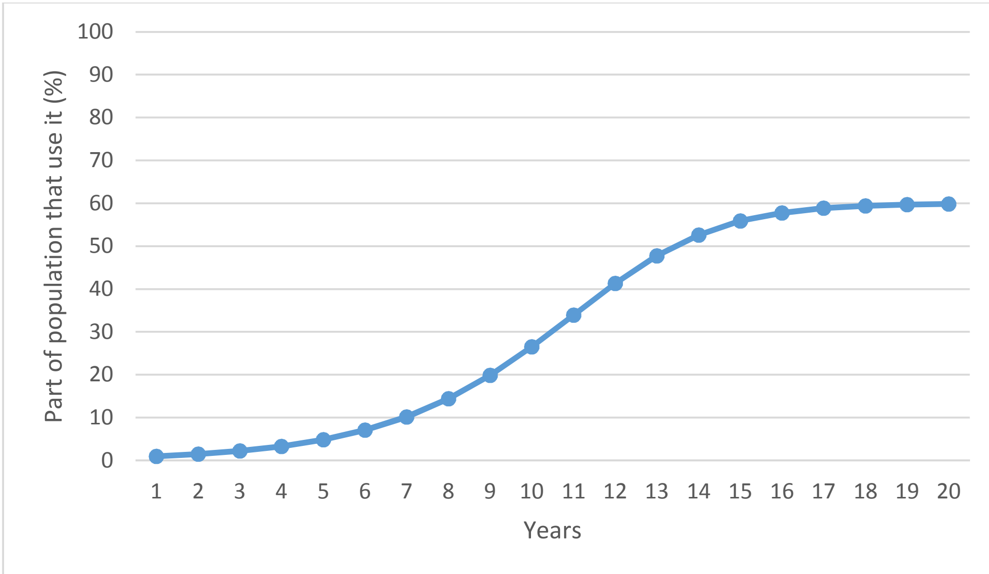

Figure 1. An example of a diffusion curve for a given technology. This curve describes that it takes around 20 years for the maximum proportion of the population (60%) to adopt this technology in its current form.

The ADOPT tool—as described by Kuehne et al. (2013)—identifies the diffusion curve that best fits a certain technology, based on answers to a set of pre-defined questions that together help to determine how rapidly and to what level adoption is expected to occur. The ADOPT tool is used here to identify the likely level of adoption over the next decade for detention bunds (without and with wetlands), sediment traps, and small constructed wetlands. The (rounded) level of adoption for detention bunds (without and with wetlands) and sediment traps after ten years of diffusion is 20%, reflecting how they are relatively cost-effective mitigation options and introduce little complexity to the farming operation. In contrast, the (rounded) level of adoption for small constructed wetlands after ten years of diffusion is 10%, reflecting how their high cost is predicted to limit their value to many producers in the Waikato region, in line with conventional adoption theory (Rogers, 2003; Pannell et al., 2006).

There is little information available to predict the level of reduction in nitrogen loss that will occur on individual farms in response to the use of Farm Environment Plans. Thus, an activity- or input-based approach is simulated. The practices that are selected are consistent in that they involve changes to the farming operation, but do not involve large up-front capital costs and are more focused on the refinement of an existing system. Overall, they share a concerted focus on tuning the existing farming system, based on their particular management system and biophysical resources, to promote nutrient-use efficiency. This approach is a key goal of extension for reducing the environmental footprint of New Zealand farms; thus, the simulation provides a reasonable description of what could transpire with a broad roll-out of a well-resourced, farm-planning program. Moreover, Section 4 highlights that this general focus is sufficient to achieve key environmental goals across the catchment. The following text describes their selection in more detail.

There is broad anecdotal understanding that profit can increase or stay the same on dairy farms if reductions in nitrogen are low to moderate (Holland and Doole, 2014; Doole and Kingwell, 2015). Doole (2012) identified that a 10% reduction in nitrogen across a population of 410 actual dairy farms allowed a number of them to experience win-win outcomes. However, profits unequivocally fell for all farms when greater reductions in nitrogen-leaching were required. Additional evidence is observable in the Upper Waikato Sustainable Milk Project, an intensive farm-planning exercise that involved over 700 farms in the Upper Waikato catchment. In this project, it was highlighted that profit would generally increase or stay the same when up to 10% reductions in nitrogen leaching were required, given the scope for improving the efficiency of nutrient use. This is also consistent with the results of extensive farm-level modelling performed for the Waikato region and reported in DairyNZ (2014). A 5–10% reduction in nitrogen loss on dairy farms is simulated in this report through optimising the use of existing structures (e.g. stand-off pads and feed pads), reducing the use of high-leaching crops (both summer and winter), decreasing N fertiliser use (especially in autumn), and applying some strategic reductions in stocking rate if feed resources declined as a result of lower input use (Doole, 2016). These practices are consistent with promoting more-efficient use of nutrients utilising cost-effective mitigation measures.

Practices consistent with cost-effective improvements to drystock and horticulture land uses, based on a general strategy of improving the efficiency of nutrient use, are also drawn from previous research (e.g. Howard et al., 2013; Agribusiness Group, 2014; Olubode et al., 2014; Parsons et al., 2015) and discussion with sector representatives. A 5–10% reduction in nitrogen loss on drystock farms is attained through reducing stocking rate, stock age, cattle: sheep ratio, and crop area. The low rates of leaching observed on many drystock farms perhaps makes them an unlikely target for reducing nitrogen loss relative to high-leaching land uses, at least in principle. Nevertheless, these reductions are simulated given the broad distribution of drystock farms in the catchment and the presence of high-leaching farms in this sector. It is also consistent with the expectation that Farm Environment Plans will target all four contaminants at farm level. In addition, a 5–10% reduction in nitrogen loss on horticulture farms is attained through improving the timing of nitrogen-fertiliser application and reducing the total amount applied (by around 10–15%).

Doole (2016) outlined several options for sediment management across pastoral farms. These consist of streambank fencing (Section 3.2), edge-of-field technologies, and soil-conservation plans (Doole, 2016). The first two factors are described above. The remaining action is soil-conservation plans. Soil-conservation plans for pastoral land uses, as described in Doole (2016), are utilised in this study; however, in this report, these plans denote a farm-level approach and are not just focused at critical-source areas. The level of implementation for these farm plans is guided by the information in Table 1. This is consistent with the Farm Environment Plan approach outlined in the WRPC1.

In contrast, a range of mitigation activities exist for reducing sediment loss from horticultural farms. These are described in more detail in Barber (2014). The assumed levels of efficacy and cost used here are taken from this source, with midpoints representing any ranges presented by Barber (2014). See Doole (2016) for more information. These actions are introduced across sub-catchments according to the levels of implementation outlined in Table 1.

The Farm Environment Plan program will be rolled out according to a prioritisation strategy, primarily due to resource constraints. The Waikato catchment consists of 74 sub-catchments. The prioritisation strategy has been selected by the CSG, based largely on the current water-quality outcomes that are observed for the four contaminants in each sub-catchment. The current understanding is that Farm Environment Plans will be implemented to 25%, 50%, and 100% level in Tranche 3, 2, and 1 sub-catchments, respectively, over the next decade (Table 1).

Table 1. Expected level of implementation of actions within Farm Environment Plans across each HRWO sub-catchment by 2026.

Name of sub-catchments	Expected level of implementation of Farm Environment Plans
Pueto	25
Waikato at Ohaaki	25
Waikato at Ohakuri	25
Torepatutahi	100
Mangakara	50
Waiotapu at Homestead	100
Kawaunui	50
Waiotapu at Campbell	25
Otamakokore	50
Whirinaki	25
Waikato at Whakamaru	50
Waipapa	100
Tahunaatara	50
Mangaharakeke	100
Waikato at Waipapa	100
Mangakino	50
Mangamingi	100
Whakauru	50
Pokaiwhenua	100
Little Waipa	100
Waikato at Karapiro	25
Karapiro	25
Waikato at Narrows	25
Mangawhero	100
Waikato at Bridge St Br	100

Mangaonua	25
Mangakotukutuku	100
Mangaone	50
Waikato at Horotiu Br	100
Waitawhiriwhiri	100
Kirikiriroa	100
Waipa at Mangaokewa Rd	100
Waipa at Otewa	50
Mangaokewa	100
Mangarapa	100
Mangapu	100
Mangarama	100
Waipa at Otorohanga	100
Waipa at Pirongia-Ngutunui Rd Br	50
Waitomo at Tumutumu Rd	100
Waitomo at SH31 Otorohanga	50
Moakurarua	100
Puniu at Bartons Corner Rd Br	50
Puniu at Wharepapa	25
Mangatutu	25
Mangapiko	50
Mangaohoi	25
Waipa at SH23 Br Whatawhata	50
Mangauika	25
Kaniwhaniwha	50
Waipa at Waingaro Rd Br	50
Ohote	25
Firewood	50
Waikato at Huntly-Tainui Br	100
Komakorau	50

Mangawara	100
Waikato at Rangiriri	50
Awaroa (Rotowaro) at Harris/Te Ohaki Br	100
Awaroa (Rotowaro) at Sansons Br	50
Waikato at Mercer Br	25
Whangape	100
Whangamarino at Island Block Rd	100
Whangamarino at Jefferies Rd Br	100
Waerenga	100
Matahuru	100
Waikare	100
Opuatia	100
Mangatangi	100
Waikato at Tuakau Br	50
Ohaeroa	25
Mangatawhiri	25
Whakapipi	100
Awaroa (Waiuku)	25
Waikato at Port Waikato	50

3.4 Land-use change

Land use is held constant at its baseline levels (Doole et al., 2015a). The rules proposed will prevent further development occurring through land-use change. Additionally, farm planning will seek to support business resilience such that the policy should not drive large shifts towards less-intensive enterprises through land-use change. Consistent with the policy mix, it is also assumed that no farm can intensify from its current position.

An exception to this general approach is a focus on the development of iwi land (Section 3.7). Development is assumed to occur across two different types of iwi land:

1. Iwi land in the Central North Island currently in forestry; this is hereafter referred to as the "CNI" land. This involves areas of 2,167; 4,333; and 6,500 ha under the low, medium, and high levels of development predicted to occur over the next decade. These levels of development (derived through CSG discussion) each constitute individual scenarios of the model, as described in Section 3.7 below.
2. Iwi land held under multiple ownership; this is hereafter referred to as the "MO" land. This involves areas of 900; 1,800; and 2,700 ha under the low, medium, and high levels of development predicted to occur over the next decade. These levels of development (derived from examining past rates of change and agreed through CSG discussion) each constitute individual scenarios of the model, as described in Section 3.7 below.

The level of development (i.e. no, low, medium, or high) that is simulated *is always the same* on the CNI and MO land. This means that different levels of development between iwi land that is located in the Central North Island or is subject to multiple ownership are not investigated. Development for iwi land is assumed only to occur on land blocks that are above 4 ha in size.

Development of iwi land is assumed to consist of various actions:

- Areas of land use capability (LUC) class 1–4 are assumed to convert from forest to dairy. The new dairy activities that are simulated produce a level of leaching equivalent to the mean dairy farms found in the relevant FMU.
- Areas of LUC class 5–7 are assumed to convert from forest to drystock. The new drystock activities that are simulated produce a level of leaching equivalent to the mean drystock farms found in the relevant FMU.
- Areas of LUC class 8 are assumed to remain in plantation forest.

The following activities were performed to identify the potential areas of iwi land that could be developed. The model then determined where it was most profitable to convert existing land within the areas for development set in each scenario, given the implementation of the proposed policy mix.

Waikato Regional Council and Glen McIntosh (Tonkin and Taylor, Hamilton) identified key information for each of the CNI and MO land types. A spatial analysis was conducted by intersecting GIS layers for land use, land capability, soil drainage, and land ownership. The output of this intersection was then aggregated to give the total area for each sub-catchment of each combination of land use, land capability, soil drainage, and land ownership. The existing land use information was based on the CLUES layer that is aligned to Landcare Research's Land Cover Database 4 2012 and incorporates Asure Quality's AgriBase stocking information as an indicator of pastoral enterprise. This is the same dataset that has been used in other catchment prioritisation work (e.g. the Waikato Lite project). Potential land use was based on Landcare Research's Land Resource Inventory. Land drainage was categorised based on the soil-drainage field in the Fundamental Soils Layer published by Landcare Research.

The CNI and MO properties were identified using different processes. CNI ownership was based on a parcel match using Schedule 1 of the *Central North Island Forests Land Collective Settlement Act 2008*. To verify the parcel match, a comparison was made with information from New Zealand Forest Managers Ltd, which was supplied to Waikato Regional Council by Brough Resource Management. Discrepancies were found for four parcels, and these were manually verified against the ownership details in the Waikato Regional Council rating database. MO parcels were initially selected based on the ownership indicator codes in the Waikato Regional Council rating database. These results were then manually checked against the online maps published by the Maori Land Court.

3.5 Point sources

Many point sources in the study region are currently emitting contaminant loads beneath the level that they are consented to discharge. However, these levels may either increase as populations grow throughout the Waikato region or decrease because of treatment plant upgrades. It is assumed that no change in point-source contaminant loss is experienced, given these opposing effects.

3.6 Groundwater lags

The dynamics of nitrogen in the Upper Waikato FMU are strongly impacted by groundwater lags. There is substantial uncertainty around historical leaching loads and the lag time in their delivery to surface water (Hadfield, 2015). Nevertheless, nitrogen concentrations are increasing in the surface water due to the entry of historical losses of nitrogen stored in the groundwater (Weir et al., 2013). Groundwater lags mean that the current concentrations observed for nitrogen attributes represent an incomplete picture of the response of the catchment to existing on-farm losses. There will be an increase in the loads of nitrogen reaching surface water in the future and this will increase concentrations at these sites—this is broadly referred to in the following text as the "load-to-come".

The presence of a nitrogen load-to-come in the Upper Waikato FMU is a key issue that the proposed policy mix must contend with. It means that while goals for a 10% step towards Scenario 1 are computed based on the current state, more nitrogen will be measured at these sites across time than is currently observed—even if land use and land-use management remain unchanged—because of the load-to-come. In effect, the current state represents a disequilibrium situation and the equilibrium situation will be characterised by higher levels of nitrogen evident in surface waters at sites at which groundwater lags are observed and those sites connected to them hydrologically.

Two sets of attenuation values were determined for the catchment during model development: one was generated for the situation of disequilibrium at the current state, and one was generated for the case where land use and land use management and the load-to-come are in equilibrium (Semadeni-Davies et al., 2015b). The difference between them accounts for the impact of groundwater lags. The load-to-come is considered in the assessment of the proposed policy mix presented in this report. However, the 10% step towards Scenario 1 is measured relative to the current state, as proposed by the CSG. The chief implication of this is that the generation of the 10% step does not consider the nitrogen load-to-come, while the modelling assessment does. This places an increased burden on the proposed policy mix in terms of its capacity to improve water quality, relative to the current state.

3.7 Model runs

The modelling investigation is based around the simulation of four primary scenarios:

1. Simulation of the CSG policy mix with *no* development of iwi land.
2. Simulation of the CSG policy mix with *low* development of iwi land.
3. Simulation of the CSG policy mix with *medium* development of iwi land.
4. Simulation of the CSG policy mix with *high* development of iwi land.

Water-quality outcomes are computed outside of the model, with model output being compared to proposed targets. No constraints are therefore placed within the model in order for any scenarios to achieve any particular water-quality outcomes of any kind. Indeed, the focus is on simulating the proposed policy mix in a "what if" format, rather than optimising the components of the policy mix in order to achieve certain water-quality outcomes, as is performed in Doole et al. (2015a, b).

Section 4.1 presents the results of the baseline assessment of the proposed policy mix. However, these results are conditional on the baseline assumptions presented throughout Section 3. Uncertainty and knowledge gaps are unavoidable realities in policy evaluation. The implications of uncertainty are therefore explored in Section 4.2 through the use of sensitivity analysis (Pannell, 1997; Doole and Pannell, 2013). This is a formal process of identifying how model output changes as inputs to the model are varied away from their standard (i.e. baseline) levels. Table 1 shows how the implementation of farm plans will vary across the catchment, based on the prioritisation framework developed by the CSG. The implications of lower and higher levels of implementation are explored within the sensitivity analysis, to highlight the effects of less-structured prioritisation and what may occur if lower or higher levels of implementation are achieved.

4. Results and Discussion

4.1 Model output

Table 2 reports the predicted level of profit for each of the primary scenarios that are evaluated. The "Sector profit" rows mainly represent change in farm profit as a result of farm management strategies that reduce losses of nitrogen and phosphorus. The "Costs" rows focus on the costs of converting land and additional mitigation strategies that are less embedded within the management of farm systems. The "WRPC1 (none)" scenario represents the results of the plan change with no further development of iwi land. The profitability of the dairy and horticultural sectors declines by 2% and 8%, respectively. In contrast, drystock profit improves, albeit slightly. Table 2 highlights that the costs of improving nutrient-use efficiency on pastoral farms is minimal at the catchment level, in line with previous work (Monaghan et al., 2015; Parsons et al., 2015). In contrast, the impact on the horticultural sector is significant, highlighting the key importance of nitrogen-fertiliser use within this industry. Additionally, there are substantial mitigation costs associated with other facets of the policy mix, especially soil-conservation activities and edge-of-field strategies.

The results associated with low, medium, and high levels of development on iwi land are reported in the "WRPC1 (low)", "WRPC1 (medium)", and "WRPC1 (high)" columns, respectively. With the development of iwi land, total dairy and drystock profit increase, while returns to plantation forestry decline. Nevertheless, this development does impose some conversion costs that seek to erode the economic benefits of land-use transition at the catchment level. Thus, overall, annual catchment profit declines by around 4%, irrespective of the degree to which iwi land is developed (Table 2).

Table 2. Elements of catchment-level, annual profit earned with the implementation of the WRPC1 policy mix with no, low, medium, and high levels of development on iwi land. Transition denotes the costs arising from land-use conversion on iwi land.

Variable	**Units**	**Current**	**WRPC1 (none)**	**WRPC1 (low)**	**WRPC1 (med.)**	**WRPC1 (high)**
Sector profit						
Dairy	$m	617.53	604.13	611.78	618.50	626.18
Drystock	$m	210.15	210.99	213.89	216.09	217.74
Horticulture	$m	28.21	25.91	25.91	25.91	25.91
Forest	$m	58.86	58.86	57.71	56.56	55.43

Costs						
Transition	$m	0	0	9.53	18.54	28.40
Stream fencing	$m	0	2.84	2.86	2.88	2.90
Effluent update	$m	0	3.46	3.47	3.47	3.47
Erosion control	$m	0	8.32	8.36	8.37	8.43
Edge-of-field	$m	0	8.35	8.28	8.31	8.36
Total profit	*$m*	*914.76*	*876.91*	*876.81*	*875.51*	*873.71*
Loss in profit	*$m*	-	*37.85*	*37.95*	*39.25*	*41.05*
Loss in profit	*%*	-	*4*	*4*	*4*	*4*

Table 3 reports the allocation of land across the catchment, under each scenario. Land-use patterns are fixed across the catchment at their baseline levels, under the simulation of the standard WRPC1 policy mix. Nevertheless, with the development of iwi land, the area allocated to dairy and drystock production increases, at the expense of plantation forest (Table 3).

Table 3. Catchment-level land allocation for the simulation of the WRPC1 policy mix, with no, low, medium, and high levels of development on iwi land.

Variable	**Units**	**Current**	**WRPC1 (none)**	**WRPC1 (low)**	**WRPC1 (med.)**	**WRPC1 (high)**
Dairy	Ha	308,008	308,008	310,461	312,654	315,206
Drystock	Ha	370,355	370,355	370,939	371,781	372,357
Horticulture	Ha	6,103	6,103	6,103	6,103	6,103
Forest	Ha	169,478	169,478	166,442	163,406	160,278
Total	*Ha*	*853,945*	*853,945*	*853,945*	*853,945*	*853,945*
New dairy	Ha	-	-	2,453	4,646	7,198
New drystock	Ha	-	-	583	1,426	2,002
Total	*Ha*	-	-	*3,036*	*6,072*	*9,200*

Table 4 reports the level of output of key products in each industry, under different levels of iwi-land development. Dairy production decreases for the no, low, and medium iwi-land development scenarios. However, the conversion of much land in the high iwi-land development scenario means that production increases in this case, relative to the current state. Sheep products decline in volume under WRPC1, though only marginally and this is offset with iwi land development. Beef production increases due to iwi-land development and through the reconfiguration of nutrient use in dairy and drystock systems. Horticultural production also increases in total volume, despite such increases being associated with a decline in value to farmers (Table 2). Wood products decrease in volume, though not by much in absolute terms.

Table 4. Catchment-level annual production for the simulation of the WRPC1 policy mix, with no, low, medium, and high levels of development on iwi land.

Variable	**Units**	**Current state**	**WRPC1 (none)**	**WRPC1 (low)**	**WRPC1 (med.)**	**WRPC1 (high)**
Milk solids	t	248,699	240,570	243,422	246,066	249,136
Wool	t	7,224	7,957	7,968	7,968	7,971
Mutton	t	15,194	17,723	17,754	17,754	17,763
Lamb	t	12,334	12,326	12,327	12,327	12,327
Beef	t	26,059	24,180	24,208	24,258	24,297
Bull beef	t	15,777	15,055	15,198	15,392	15,524
Hort. crops	t	251,452	245,147	245,147	245,147	245,147
S1 logs	M m^3	18	18	18	18	17
S2 logs	M m^3	49	49	48	47	46
S3 logs	M m^3	52	52	51	50	49
Pulp	M m^3	33	33	33	32	32
Waste	M m^3	2	2	2	2	2

Summaries of model output for the concentrations of the water attributes under current state and with implementation of the policy mix are compared in the Addendum—in general, significant water quality improvements are predicted. However, in terms of the CSG's "10% step towards scenario 1" aim, the specific test of the policy mix involves determining the percentage movement towards that aim for each attribute—Table 5 presents the relevant summary statistics. Sites that meet goals that are set under Scenario 1 are excluded from these calculations, given that further improvement is not required. Values for median *E. coli* concentration are excluded given that around 97% of sites meet goals set for this attribute under Scenario 1 (see later discussion related to Table 6). Hence, a positive magnitude for a site reported in this sample denotes a level of water-quality improvement towards Scenario 1; a 10% improvement is the target for each attribute at each site under the WRPC1 policy. For example, if the current state for median nitrate is 2 g m^{-3} and the Scenario 1 goal for median nitrate is 1 g m^{-3} and the model run achieves a concentration of 1.5 g m^{-3} at this site—consistent with water-quality improvement, relative to the target—then the associated level of improvement presented in Table 5 is equal to +50%. A magnitude beyond 100% highlights that a concentration better than that defined by Scenario 1 has been achieved. In contrast, a negative magnitude denotes that water-quality has declined, relative to the target. For example, if the current state for median nitrate is 2 g m^{-3} and the Scenario 1 goal for median nitrate is 1 g m^{-3} and the model run achieves a concentration of 2.5 g m^{-3} at this site—consistent with water-quality degradation, relative to the target—then the associated level of degradation presented in Table 5 for that site is equal to -50%.

Table 5 shows an overwhelming improvement in water quality brought about by the proposed policy mix, relative to the 10% step towards the Scenario 1 goal. This is indicated by the high, positive medians for each attribute under all scenarios (Table 5). For example, the lowest median improvement in an attribute, in the absence of iwi land development, is 31%. This is much higher than the goal of 10% improvements for all attributes across all sites, relative to Scenario 1. The median improvement declines with iwi-land development for a number of attributes, though these changes are generally small (Table 5). The median improvement values for median and maximum chlorophyll-a decline by 4% and 1%, respectively, going from no to high iwi-land development. The median improvement values in the sample for median and 95th percentile nitrate decline by 0% and 3%, respectively, going from no to high iwi-land development. Additionally, the median improvement values in the sample for median *E. coli* concentration, 95th percentile *E. coli* concentration, and clarity do not change under these circumstances. However, the median values for TN and TP improvement decline by 25% and 10%, respectively, going from no to high iwi-land development. The minimum value for TN is negative across all land-development scenarios, while the minimum value for TP also becomes negative for the case of medium- and high-development scenarios. The minimum level reported for median and 95th percentile nitrate levels is also negative across all cases of land development. These negative values highlight that water-quality degradation occurs at a number of sites under the proposed policy mix—primarily for attributes related to nitrogen loss—and those for TN and TP are exacerbated by iwi-land development (Table 5).

Table 5. Summary statistics for the percentage change in each water-quality attribute, relative to the relevant Scenario 1 goal, under the WRPC1 policy mix with no, low, medium, and high development of iwi land. "Med.", "Min.", and "Max." represent the median, minimum, and maximum values reported for each attribute under each development scenario.

Attribute	WRPC1 (none)			WRPC1 (low)			WRPC1 (medium)			WRPC1 (high)		
	Med.	**Min.**	**Max.**	**Med.**	**Min.**	**Max.**	**Med.**	**Min.**	**Max.**	**Med.**	**Min.**	**Max.**
Median chlorophyll-a	72	37	119	71	37	117	70	37	116	69	37	114
Maximum chlorophyll-a	94	76	>1,000	93	75	>1,000	93	74	>1,000	93	73	>1,000
Total Nitrogen	33	-40	41	30	-48	40	28	-53	41	25	-60	40
Total Phosphorus	31	27	67	29	22	64	28	-11	60	28	-11	57
Median nitrate	68	-33	344	68	-33	343	68	-33	343	68	-29	343
95th percentile nitrate	65	-162	>1,000	63	-162	>1,000	63	-162	>1,000	63	-145	>1,000
95th percentile *E. coli*	69	35	688	69	35	683	69	35	682	69	35	681
Clarity	175	29	>1,000	175	29	>1,000	175	29	>1,000	175	29	>1,000

Table 6 reports the number of sites that meet their targets set under Scenario 1. This is reported for current state and under the proposed policy mix with no, low, medium, and high iwi-land development. The proposed policy mix achieves appreciable improvements in water quality as defined by this measure, especially for clarity. The policy mix increases the number of sites that reach their Scenario 1 targets by 22% and 33% for median and maximum chlorophyll-a (Table 6). It also more than doubles the number of sites that reach their goal for the 95th percentile *E. coli* concentration. The largest achievement is evident for clarity; the number of sites that satisfy Scenario 1 targets for black-disc measurement goes from 3 to 44, with the implementation of the policy mix (Table 6). These outcomes also do not change with different levels of iwi-land development (Table 6).

Table 7 presents concentration data for those sites at which 10% steps towards Scenario 1 water-quality targets are not achieved. (These generally correspond to those sites for which negative minimum values are reported in Table 5.) The concentration target to be met under the 10% step is reported in the column labelled “10% step to Scenario 1”. Measured concentrations under different levels of development are presented in the columns labelled “WRPC1 (no)” to “WRPC1 (high)”. Across all instances of iwi-land development, Total Nitrogen concentration is above both that for the current state and that consistent with the 10% target at three sites: Waikato River at Ohakuri, Waikato River at Waipapa, and Waikato River at Whakamaru (Table 7). Additionally, the 10% steps for median and 95th percentile nitrate levels are not achieved at Waipapa under all iwi-land development scenarios. In comparison, the 10% step for Total Phosphorus is not met under the medium- and high-development scenarios. This is a result of significant scope for the development of iwi land in this sub-catchment and the high loss rates for phosphorus that are typically found on these free-draining, pumice soils (Doole, 2016). Nevertheless, the breach is miniscule in absolute terms (Table 7) and thus does not cause an increase in chlorophyll-a at this site or others downstream of it (Table 5).

The breaches reported for TN, median nitrate, and 95th percentile nitrate in Table 7 demonstrate the importance of projected additional nitrogen emerging from groundwater, as a result of past development, in the Upper Waikato FMU. The simulations outlined in this report consider this additional nitrogen when evaluating whether the proposed policy mix is able to achieve the 10%

steps towards Scenario 1 outcomes across all sites (Section 3.6). The nitrogen load-to-come makes it appreciably more difficult to achieve the 10% step. Concentrations for TN, median nitrate, and 95th percentile nitrate increase at sites where the load-to-come is most pronounced—and hence those downstream that are hydrologically connected also—once the load-to-come is accounted for. This is evident in Table 7 where there is an increase from the "Current state" concentration to the "Current + load-to-come" concentration for each attribute related to nitrogen. Previous research has highlighted the need for substantial afforestation in the Upper Waikato to offset the nitrogen stored in groundwater as a result of past intensification (Doole, 2013; Doole et al., 2015a). In line with this past analysis, this simulation of WRPC1 highlights that reductions in nitrogen in the Upper Waikato are too limited to achieve the target concentrations related to nitrogen loadings at a number of key sites, regardless of the predicted development of iwi land.

However, there are a number of reasons why the breaches occur, apart from the load-to-come. First, the goals determined for Total Nitrogen in the Upper Waikato FMU are indicative of high water quality ('A' band in the National Objectives framework), which make it easier for breaches to occur in the presence of productive agriculture. Second, improvements towards Scenario 1 are determined from current state and not the future concentration consistent with partial or full expression of the nitrogen load-to-come in surface water over the next decade. Thus, the proposed policy mix must achieve additional mitigation above that required for other attributes, given the need to offset this load-to-come alongside current contaminant loss. Nevertheless, the material implications for ecosystems of these observed breaches are arguably limited. The main implication of Total Nitrogen as a measure of water quality is its contribution to algal growth. Despite breaches being evident for Total Nitrogen in the Upper Waikato FMU (Table 7), targets for both median and maximum chlorophyll-a levels are achieved in all scenarios (Table 5) and many sites for these attributes meet the goals set for them under Scenario 1 too (Table 6). The improvement in median and maximum chlorophyll-a levels in all scenarios reinforces the importance of phosphorus as the key nutrient that currently limits algal growth in the lakes of the Waikato River (Yalden and Elliott, 2015).

Table 6. The number of sites that meet their Scenario 1 target under no, low, medium, and high development of iwi land.

Attribute	Current	WRPC1 (no)	WRPC1 (low)	WRPC1 (med.)	WRPC1 (high)	Total sites
Median chlorophyll-a	3	5	5	5	5	9
Maximum chlorophyll-a	4	7	7	7	7	9
Total Nitrogen	1	1	1	1	1	9
Total Phosphorus	2	2	2	2	2	9
Median nitrate	46	49	49	49	49	61
95th percentile nitrate	38	42	42	42	42	61
Median *E. coli*	57	59	59	59	59	61
95th percentile *E. coli*	12	25	25	25	25	61
Clarity	3	44	44	44	44	58

Table 7. Concentration data for sites that do not achieve 10% improvements under the proposed policy mix across cases of no, low, medium, and high iwi-land development. Shaded cells denote instances where reported concentrations fail to meet the 10% steps towards Scenario 1 that are the goal of the policy mix.

Attribute	Site[1]	Current	Current + load-to-come	Sc. 1	10% step to Sc. 1	WRPC1 (no)	WRPC1 (low)	WRPC1 (med.)	WRPC1 (high)
TN	EW-1131-107	0.215	0.281	0.16	0.210	0.237	0.241	0.245	0.248
	EW-1131-143	0.336	0.422	0.16	0.318	0.344	0.348	0.352	0.355
	EW-1131-147	0.271	0.354	0.16	0.26	0.291	0.295	0.298	0.301
TP	EW-1131-105	0.011	0.011	0.01	0.011	0.0105	0.0108	0.0111	0.0111
Median nitrate	EW-1202-007	1.210	1.77	1	1.189	1.280	1.280	1.280	1.272
95% nitrate	EW-1202-007	1.555	2.27	1.5	1.55	1.644	1.644	1.644	1.635

[1] Sites are as follows: EW-1131-107 is Waikato River at Ohakuri, EW-1131-143 is Waikato River at Waipapa, EW-1131-147 is Waikato River at Whakamaru, EW-1131-105 is Waikato River at Ohaaki, and EW-1202-007 is Waipapa.

4.2 Sensitivity analysis

Table 1 shows how the implementation of Farm Environment Plans will vary across the catchment, based on the prioritisation framework developed by the CSG. Table 9 highlights how key model output changes when different levels of implementation are assumed constant across the entire catchment. For example, the 25% scenario assumes that Farm Environment Plans are implemented on a quarter of farms across all sub-catchments within the next decade. Total catchment-level cost increases at an increasing rate, with the 50% implementation level costing 3% of catchment income and the 100% implementation level costing around 10% of catchment income. This outcome is intuitive, reflecting the increasing cost of mitigation activity as farm plans are implemented to a greater degree. Indeed, it aligns strongly with the convexity of abatement-cost curves in the environmental-economics literature, given that it becomes costlier to perform additional mitigation when a lot of abatement activity has occurred previously (Hanley et al., 2007). The proposed policy mix represents an intermediate state relative to the other scenarios, achieving a balance between economic outcomes on one hand and water-quality improvement on the other. The benefit of this activity is improved water-quality outcomes across all attributes. The number of sites that meet Scenario 1 targets is quite responsive to an increase in the implementation of Farm Environment Plans, except for Total Nitrogen and median *E. coli*. Furthermore, the number of sites that fail to meet 10% steps towards Scenario 1 reduce as more farm plans are implemented, as expected. Nonetheless, it is evident in Table 9 that the three breaches reported for Total Nitrogen (see Table 6) remain even if all farms implement a Farm Environment Plan in the 10-year period. This reinforces the importance of the nitrogen load-to-come on the ability of management to influence water-quality targets at these particular sites.

Table 9. Key economic and water-quality outcomes when the level of Farm Environment Plan implementation is simultaneously fixed across all sub-catchments at 0, 25, 50, 75, or 100%.

	Item	Unit	WRPC1	Level of farm-plan implementation (%)				
			(no)	**0**	**25**	**50**	**75**	**100**
Economic outcomes	Dairy	$m	604.13	613.17	610.80	604.31	597.01	588.85
	Drystock	$m	210.99	218.54	218.06	213.95	209.08	203.65
	Horticulture	$m	25.91	28.21	28.19	27.15	24.56	21.71
	Forest	$m	58.86	58.86	58.86	58.86	58.86	58.86
	Stream fencing	$m	2.84	2.84	2.84	2.84	2.84	2.84
	Effluent update	$m	3.46	0	1.29	2.56	3.81	5.07
	Erosion control	$m	8.32	0	1.06	4.22	9.50	16.89
	Edge-of-field	$m	8.35	0	3.84	7.12	10.15	12.93
	Total	*$m*	*876.91*	*915.93*	*906.89*	*887.53*	*863.20*	*835.34*
Achievement of Scenario 1 limits	Median chlorophyll-a	No.	5	4	5	5	5	6
	Maximum chlorophyll-a	No.	7	6	6	7	7	7
	Total Nitrogen	No.	1	1	1	1	1	1
	Total Phosphorus	No.	2	2	2	2	3	3
	Median nitrate	No.	49	49	49	49	49	50
	95th percentile nitrate	No.	42	42	42	42	43	43
	Median *E. coli*	No.	59	59	59	59	59	59
	95th percentile *E. coli*	No.	25	24	24	24	26	26
	Clarity	No.	44	25	33	38	45	48
Fail 10% step	Total Nitrogen	No.	3	5	4	3	3	3
	Median nitrate	No.	1	3	1	1	1	0
	95th percentile nitrate	No.	1	3	2	1	1	0
	Clarity	No.	-	4	1	0	0	0

4.3 Timing of response

The purpose of this section is to explain the relationships between various mitigation actions included in the HRWO modelling/policy mix and the timing of response in terms of water quality in the receiving water bodies. This is important to address the issue of what the policy might be expected to achieve in the next 10 years, given that not all mitigation actions have an immediate effect on water quality and that many of these actions will be progressively implemented as the Farm Environment Plans are rolled out.

WRPC1 includes Policy 2a for reducing diffuse losses of the four contaminants on farms by managing farming activities through a tailored, property-specific approach, where mitigation actions on the land that will reduce nitrogen, phosphorus, sediment and *E. coli* leaving the property are specified in resource consents or through industry schemes. Doole (2016) describes the efficacy of the main mitigations that are likely to be applied in these Farm Environment Plans and earlier in this report we describe how they have been included in the modelling of the effects of the policy mix. Response time frames to the main edge-of-field and land-management mitigations included in the policy mix are summarised in Table 10.

Table 10. Summary of mitigation benefits and expected response times after implementation.

Mitigation	Benefits	Response time to close to full benefit
Livestock exclusion fencing from stream channel/bank	Reduced pathogens (*E. coli*)	Immediate to 6-month lag as reservoirs in stream sediments die off (Donnison et al., 2004).
Livestock exclusion fencing from stream channel/bank	Reduced suspended sediment from decreased faeces input and bank/bed damage	Immediate for faecal effects; 6 months for groundcover regeneration, 5 years for tree root development (Marden et al., 2005).
Livestock exclusion fencing from stream channel/bank	Reduced direct nutrient input	Immediate
Livestock exclusion from riparian areas	Reduced contaminant inputs due to decreased deposition in area most connected to waterway and increased plant growth and associated filtering	<1 year

Riparian planting	Reduced contaminants as above plus plant uptake of nutrients in shallow groundwater	5 years plus, depending on the depth of groundwater relative to tree/shrub rooting depth and thetime taken for plants to be effective
Riparian planting	Stream habitat (fish cover, litter input) and reduced temperature, control of instream vegetation	Varies with stream width: circa 7 years for 2-4 m wide streams; > 15 years for 6-8 m wide streams for full effect to be observed.
Livestock exclusion from wetlands	Reduced pugging, channelised flow, and direct inputs; reduced nutrients to waterways via increased plant uptake of nutrients and input litter as a carbon source, promoting denitrification	Immediate benefits for sedimentation of particulates. Nutrient uptake increasing to plateau after 2-3 years from plant growth. Later plant uptake declines as plants mature but compensated for by increasing denitrification as plant carbon input accumulates.
Treatment wetlands for surface flow drainage	Reduced nutrients (particularly N), *E. coli* and suspended sediments from sedimentation, nutrient uptake into plant biomass and denitrification	Immediate benefits for sedimentation of particulates. Nutrient uptake increasing to plateau after 2-3 years from plant growth. Later plant uptake declines as plants mature, but compensated for by increasing denitrification as plant carbon input accumulates. Denitrification response can be shortened by carbon addition (straw, wood chips) at setup. P uptake may decline as adsorption sites are saturated—this can be managed by addition of P

		sorption agents although efficacy can be quite variable in the first few years.
Treatment wetlands for subsurface drainage	Reduced nutrients (particularly dissolved N) from nutrient uptake into plant biomass and denitrification (Tanner and Sukias, 2011).	Nutrient uptake increasing to plateau after 2–3 years from plant growth. Later plant uptake declines as plants mature, but compensated for by increasing denitrification as carbon input from plants accumulates. Denitrification response can be shortened by carbon addition (e.g. straw, wood chips) at establishment. P uptake may decline as adsorption sites are saturated—this can be managed by addition of P sorption agents.
Sediment bunds (Clarke et al., 2013)	Reducing particulate sediment, N and P, and microbes from stormflow runoff	Immediately after construction
Sediment bunds plus lowflow wetlands	Reducing particulate sediment, N and P, and microbes from stormflow runoff and dissolved nutrients from baseflow.	Immediate benefits after construction of bund and and then increasing benefit up to a plateau at 2-3 years for wetland effects as above.
Land management change – with a focus on good management practice. Examples are reduced P use to match plant needs, lower N fertiliser application, changed frequency and timing of fertilizer, grazing	Reduced sediment, P and microbial runoff, reduced leaching of N to groundwater	Highly variable (<1 yr–decades), depending on pathway from soil to groundwater to surface water and legacy effects from previous high fertilizer use.

management to reduce pugging close to streams.		
Soil conservation works – e.g., plantings to stabilize hillsides, gullies and streambanks	Reduced N leaching; reduced microbes where livestock are removed; reduced P, particulate N and suspended sediment from reduced pugging of soil and, in longer-term, reduced erosion as trees establish and stabilize soils and increase rainfall interception	< 6 months for *E. coli* benefits for livestock removal and for surface soil disturbance; 5–10 years (+ groundwater lag) for N leaching as soil reserves are depleted (tree thinning likely to slow process); 6–8 years required for slope stability and canopy-closure benefits for surface erosion protection. Spikes in N, P, and suspended sediment losses are likely to be observed if areas are planted in trees for harvesting (Fahey et al., 2004; Fahey and Marden, 2006; Davis, 2014).

Water-quality response timeframes range from immediate to many decades depending on the mitigation, the contaminant, the location, and the receiving water body. A stylised representation of these water quality response patterns is shown below in Figure 2.

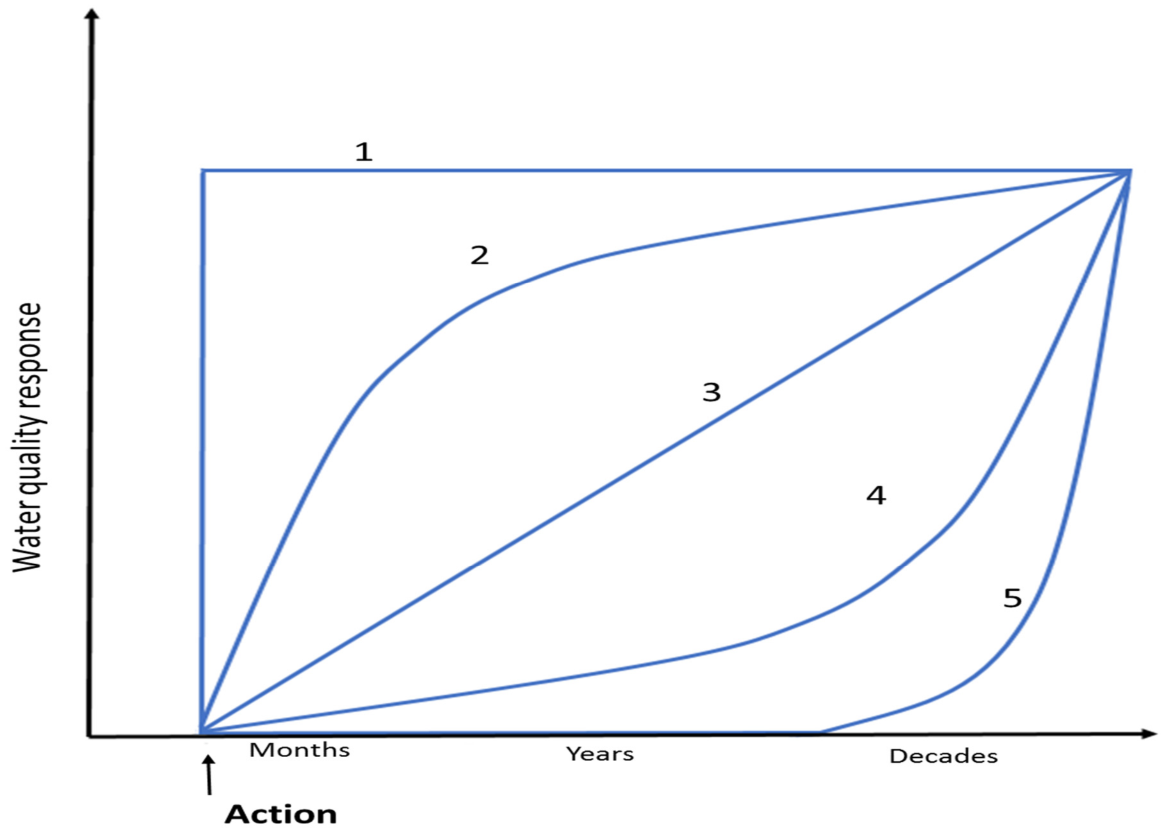

Figure 2. The relationship between the time of implementation for different mitigation actions and the time that a water-quality response is likely to be observed.

An immediate response (pattern #1 in Figure 2) may be expected from some mitigation actions. Some obvious examples include the switching of a point-source discharge to land application and fencing off a stream to prevent direct livestock excreta inputs to the waterway.

At the other extreme is a long delay between mitigation action and water quality response (pattern #5 in Figure 2). The most obvious example of this type of response is the lag effects related to groundwater nitrogen described earlier in this report. The TLG in the HRWO project commissioned a range of studies on groundwater in the Waikato and Waipa catchments to gain a better understanding of the time of travel of water and nitrate from the land, through the soil profile and groundwater, to emergence in surface waters (e.g. Hadfield, 2015). The mean age of surface water in the Waipa, mid-Waikato, and Lower Waikato FMUs during *summer base flows* (i.e., the time that groundwater-dominated flows are typically observed) is usually less than 15 years and averages about 10 years. In contrast, the mean age of surface waters during *summer base flows* in the Upper Waikato FMU tributaries are much older, with an average residence time of about 50 years (Hadfield, 2015). These distinct differences in mean water age demonstrate that, for nitrogen, the *full* effect of past changes in land use and intensification and the *full* effect of future mitigations implemented as part of the policy mix will be seen much earlier in the nitrogen concentrations of the Waipa, mid-Waikato, and lower Waikato tributaries (depicted as patterns #2 or #3 in Figure 2) than in the Upper Waikato tributaries.

For the Upper Waikato tributaries, the in-stream nitrogen response pattern to on-farm land management mitigations that will be observed will depend on the relative sources of the water (deep groundwater, shallow groundwater, rapid through flow, and surface runoff) and the nitrogen concentrations within each source. Patterns #4 or #5 shown in Figure 1 likely provide the best depiction of what could be expected to occur for those sub-catchments where deep groundwater is a large proportion of the surface-water input. While we have estimates of mean residence times under summer base flows, we are unable to determine the distribution of residence times for, and the hydrological sources of, all of the water leaving a sub-catchment. Because of that, apart from being able to conclude that full hydrological system responses to on-farm mitigations will be slow in these sub-catchments, we are unable to quantify the time-scale and shape of the nitrogen concentration response pattern in the surface water. This response pattern is further complicated by the dis-equilibrium that currently exists between observed water quality and recent changes in land-use and intensification. In summary, this slow system response has two future consequences over the HRWO Plan period and beyond:

1. The effects of past and recent land-use change and intensification will continue to influence nitrogen concentrations in receiving waters for decades to come (this regards the so-called "load-to-come").
2. The effects of on-farm nitrogen mitigations that are implemented as a result of the policy mix over the next 10 years will take decades to be fully reflected in receiving waters.

Over the next 10 years, it is therefore likely that nitrogen concentrations in surface waters will **increase** at some monitoring sites (predominantly in the Upper Waikato FMU), despite implementing on-farm mitigations that will lower nitrogen-leaching losses. In the longer-term, the model output presented in Sections 4.1 and 4.2 indicate that the new equilibrium state will be such that nitrogen concentrations will be higher in the Upper Waikato FMU main-stem despite the implementation of the policy mix (i.e. the load-to-come outweighs the effects of the policy mix). This is shown in Table 7, where even after the implementation of the proposed policy mix, concentrations increase above their level at current state at three main stem sites for Total Nitrogen and at one main stem site each for median and 95th percentile nitrate. This highlights the inability of the policy mix to attain its objective to maintain and improve water quality across the catchment. In contrast, further downstream—where the load-to-come is much less pronounced—the effects of the policy mix on tributary inputs (including the Waipa River) lead to a predicted decrease in main-stem equilibrium N concentration. Here, the impact of the policy mix is so considerable on N inputs from tributaries that this offsets the impact of higher loads of nitrogen emanating from upstream where the nitrogen load-to-come is quite dominant within some sub-catchments.

The other contaminants that will be mitigated through the implementation of Farm Environment Plans would be expected to show some receiving water-quality response within the 10 year HRWO Plan period (Table 10), but not always to their full extent, particularly if implemented towards the end of the period. In summary:

- Mitigation actions that reduce *E. coli* inputs to receiving waters are largely effective within a year, so we would expect to see implementation of the policy mix leading to significant improvements in this attribute across the Waikato-Waipa catchment within the HRWO Plan period (a combination of pattern #1 and #2 responses in Figure 2).
- Mitigation actions that reduce phosphorus inputs to receiving waters show a mix of timeframes for effectiveness (from months to up to 10 years), so we would expect to see implementation of the policy mix leading to some improvements in this attribute across the Waikato-Waipa catchment within the HRWO Plan period (a combination of pattern #2, #3, and #4 responses in Figure 2).
- Mitigation actions that reduce sediment inputs to receiving waters largely show responses over a 2- to 10-year timeframe with increasing efficacy through that time. We would therefore expect to see implementation of the policy mix leading to some improvements in

this attribute (clarity) across the Waikato-Waipa catchment within the HRWO Plan period (largely consistent with patterns #3 and #4 responses in Figure 2). This outcome is significant given that that the proposed policy mix is predicted to lead to a substantial improvement on clarity levels throughout the catchment (Table 6).

The variables associated with implementing the tailored Farm Environment Plans—that is, which actions will be implemented where at what time, and with what response being evident in the water—means that it is not possible to quantitatively determine the time path of water-quality improvement arising from the policy mix, only the expected end-point. For the reasons given above, we would expect *E. coli* to be most responsive and most likely to achieve its end-points earliest, followed by phosphorus and clarity, while nitrogen responses will likely be slowest and highly variable due to the overwhelming effects of the load-to-come in the Upper Waikato.

Although not the subject of this report, it is important to recognise that any assessment of water-quality improvement from implementing the policy mix will need to statistically discriminate such improvement from the natural temporal variability evident in water quality. The Southern Oscillation Index (SOI) has a major influence on inter-annual climate variation in New Zealand (Kidson and Renwick, 2002) and hence on contaminant runoff and resultant water quality. Negative SOI values (El Ninõ) are associated with cool, south-westerly conditions and below-normal rainfall in the north and east regions, but increased rainfall in the west of New Zealand. Positive values (La Ninã) are generally characterized by increased moist, rainy conditions to the north-east of the North Island, and reduced rainfall to the south and south-west of the South Island. This varying annual rainfall will alter runoff losses from land and may confound analysis of the effects of the policy mix. This implies that monitoring records should be long enough to discriminate the effects of mitigation actions from those induced by the 3–7 year SOI climate cycles.

4. Conclusions

The Collaborative Stakeholder Group (CSG) within the Healthy Rivers Plan for Change: Waiora He Rautaki Whakapaipai (HRWO) Project has proposed a policy mix to initiate improved water quality across the region, with most actions tied to reducing contaminant loss by the rural sector.

The draft Waikato Regional Plan Change No. 1—Waikato and Waipa River Catchments (Proposed) (WRPC1) presented at CSG meeting #27 on 9 May 2016 sets out policies that aim to progressively reduce the concentrations of the four contaminants to meet FMU specific targets and associated values of water clarity and suspended algae (chlorophyll-a). The target states that the Plan Change seeks to move towards are set out in what is referred to as "Scenario 1" in this report. Scenario 1 is a key output of the HRWO process and defines goals of substantial improvement in water quality for swimming, taking food, and healthy biodiversity. This involves an improvement in water quality at all sites in the catchment, even if it is already meeting the minimum acceptable state. The time frame for meeting the ultimate set of targets defined within Scenario 1 is 80 years, whereas the current Plan Change aims to take actions over a 10-year period that will, over time, make a 10% improvement towards bridging the gap between the current and target states.

The primary objective of this analysis is to employ the HRWO economic model (Doole et al., 2016a, b) to simulate the policy mix associated with WRPC1 under several different situations, to assess its impact on economic and water-quality outcomes within the Waikato River and Waipa River catchments. This report outlines the key assumptions that have been made to replicate the policy mix, discusses model output associated with a range of explorative scenarios and sensitivity analysis, and then draws conclusions based on these results.

The analysis indicates that the policy mix will likely reduce economic outcomes in the short-term, incurring a loss of around 4% of catchment profit relative to current conditions. Improvements in nutrient-use efficiency decrease the absolute economic impact of mitigation on farming systems, while other mitigation strategies (especially stream fencing and edge-of-field strategies) provide cost-effective mitigation of a broad range of contaminants. The development of iwi land increases dairy and drystock income; however, these gains are offset by substantial conversion costs associated with the establishment of productive agriculture on land that was previously afforested. This occurs to such a degree that a net loss of 4% is also observed under the iwi-land development scenarios that have been evaluated.

The analysis highlights that the proposed policy mix will achieve significant improvements in water quality across the catchment. It achieves improvements in water quality as defined by an increase in the number of sites that meet their Scenario 1 targets, especially for the clarity attribute. Additionally, the proposed policy mix is predicted to achieve greater than a 10% movement towards the goals set out for different attributes in Scenario 1 in 99% of the cases. This is indicated by the high, positive median levels of improvement towards Scenario 1 identified for each attribute, across all scenarios associated with different levels of iwi-land development. For example, the lowest median increase in an attribute—in the absence of iwi-land development—is 31%.

The only sites that fail to meet 10% steps towards Scenario 1 exist in the Upper Waikato FMU, as the policy mix does not provide for sufficient mitigation effort to offset substantial amounts of nitrogen in the groundwater that will eventually start to express itself in surface waters. This load-to-come means that attribute levels at some sites will likely worsen over the next decade, despite substantial efforts being enacted on farms to address nitrogen loss in response to the implementation of the policy mix. Indeed, the objective to maintain and improve water quality is predicted to be difficult to achieve with the proposed policy mix across a number of sites, when this load-to-come is accounted for. Nevertheless, these breaches affect only nitrogen attributes and do not have a predicted impact on chlorophyll-a levels due to the dominant influence of phosphorus on algal growth (Yalden & Elliott 2015). Nevertheless, the potential for nitrogen levels to control algal growth at certain times of the year indicates that seasonal responses to elevated nitrogen may occur.

Overall, the proposed policy mix constitutes an attractive value proposition in terms of the economic and water-quality outcomes that it achieves. However, these results are conditional on achieving rapid and significant levels of adoption of mitigation actions across the catchment. Moreover, nitrogen legacies evident in groundwater in the upper catchment make it difficult to maintain or improve all water-quality outcomes at a number of monitoring sites in this location.

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Addendum

Figure A1:

Comparison of modelled current state and predicted policy mix on chlorophyll *a* median concentrations along Waikato River main stem. Sites listed in downstream order from left to right.

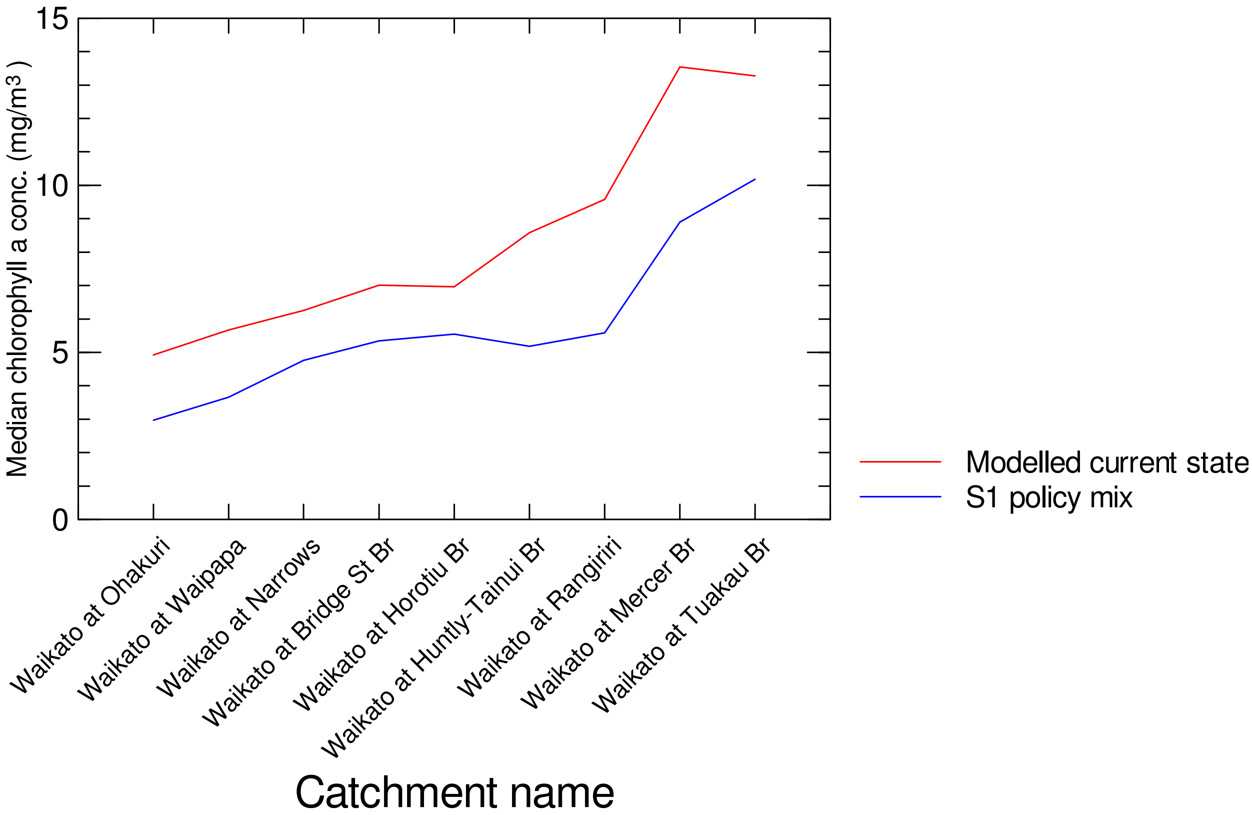

Figure A2:

Comparison of modelled current state and predicted policy mix on <u>chlorophyll *a* maximum</u> concentrations along Waikato River main stem. Sites listed in downstream order from left to right.

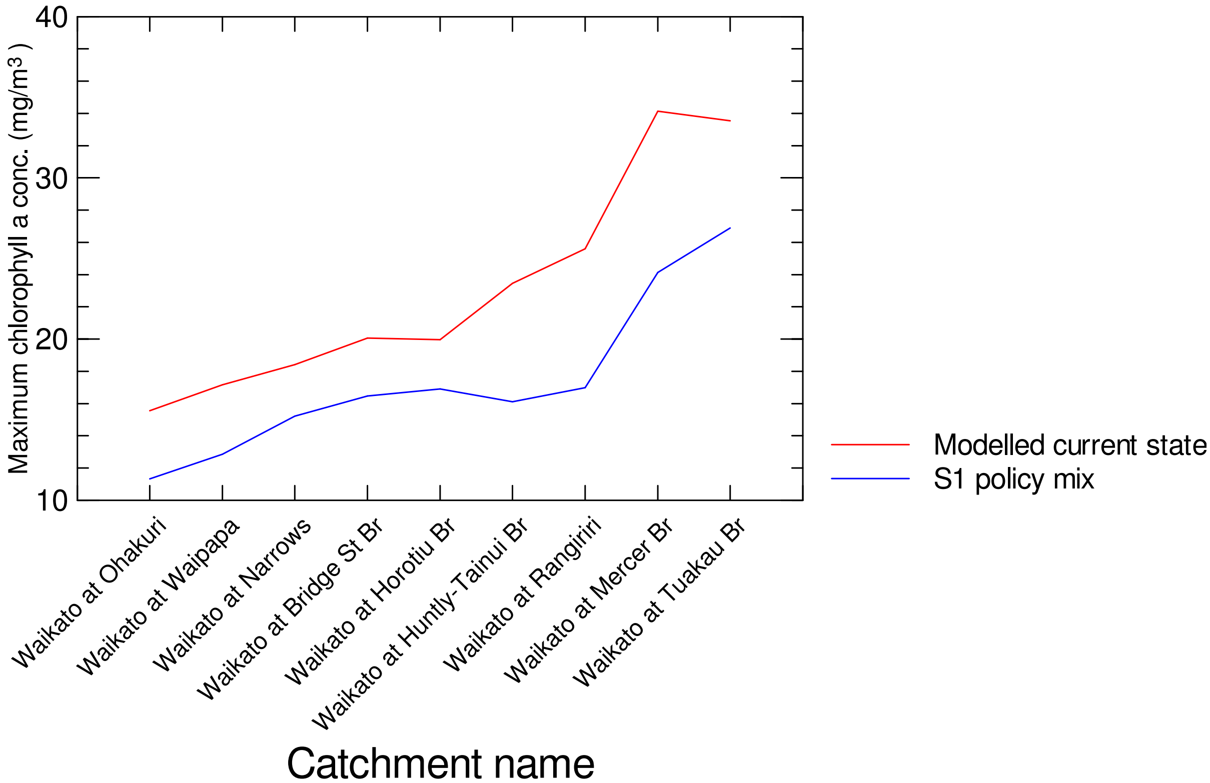

Figure A3:

Comparison of modelled current state and predicted policy mix on <u>median total nitrogen</u> concentrations along Waikato River main stem. Sites listed in downstream order from left to right.

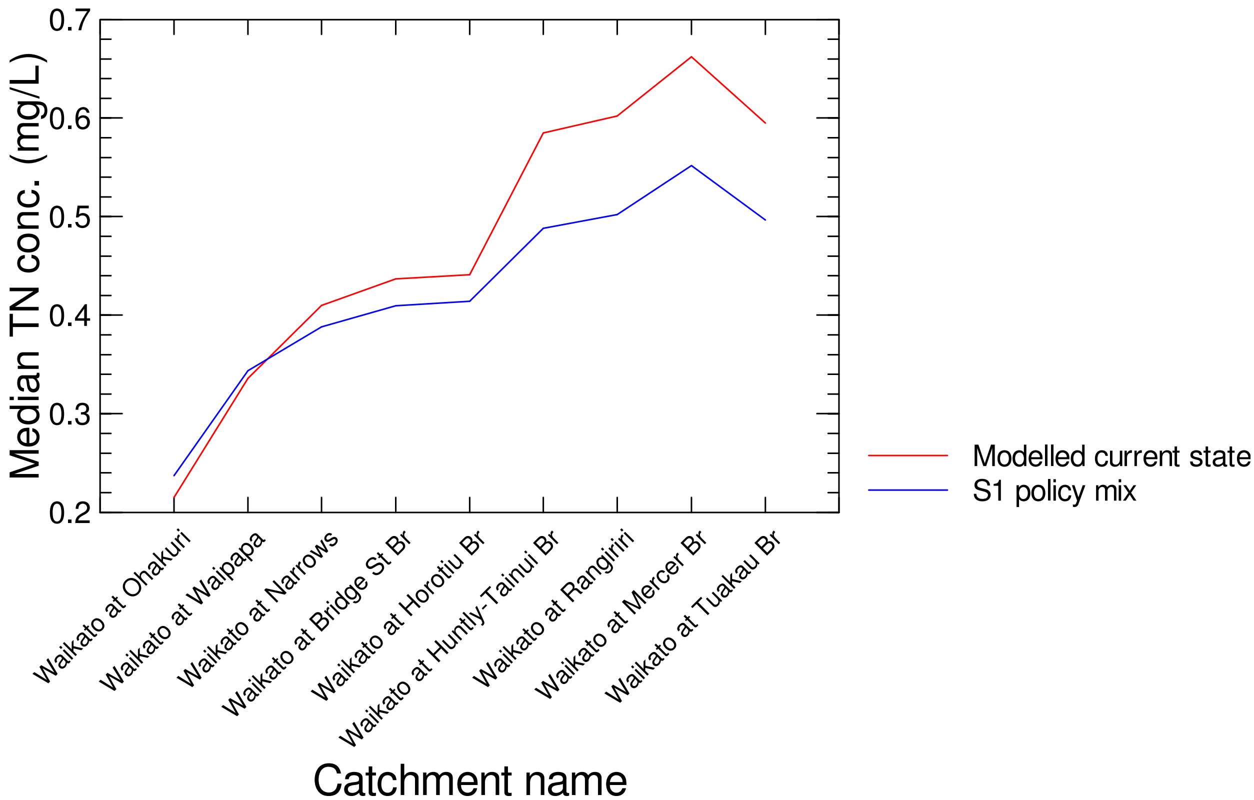

Figure A4:

Comparison of modelled current state and predicted policy mix on <u>median total phosphorus</u> concentrations along Waikato River main stem. Sites listed in downstream order from left to right.

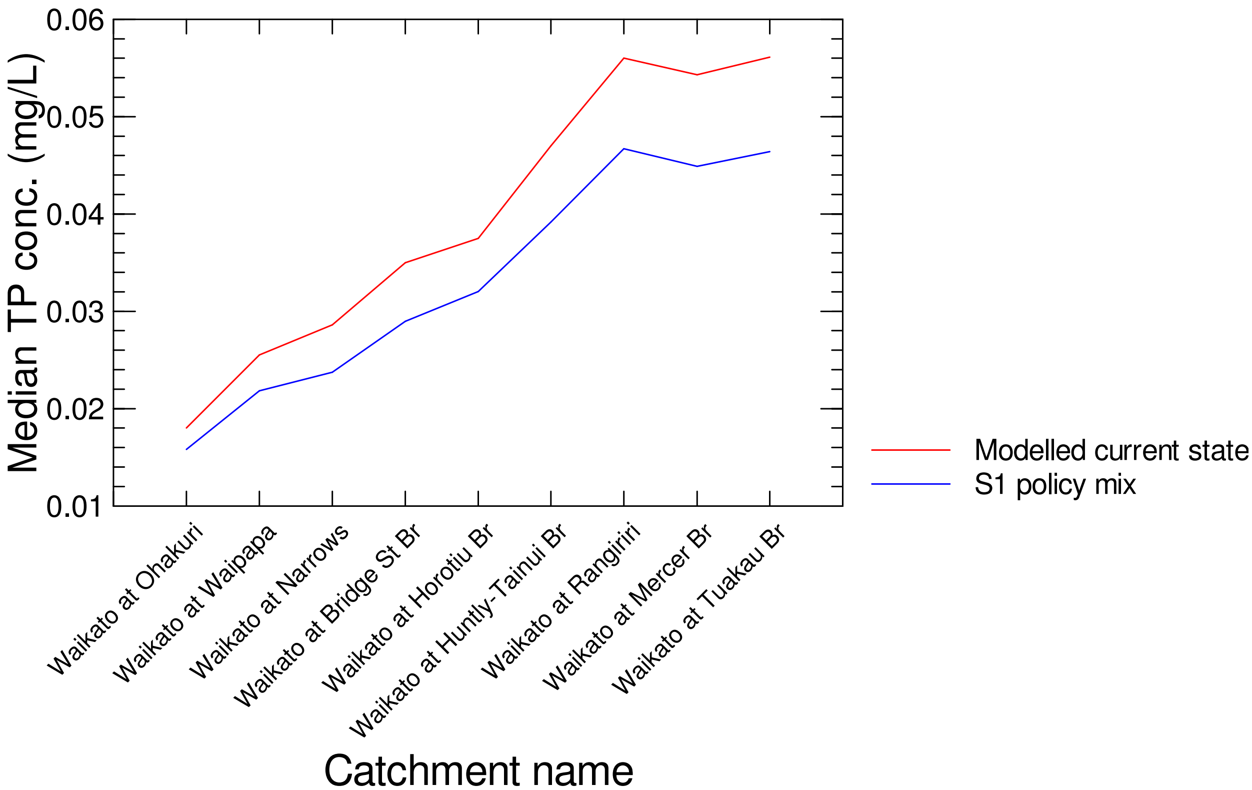

Figure A5: **Comparison of modelled current state and predicted policy mix on median nitrate nitrogen concentrations in the four Freshwater Management Units of the Waikato/Waipa catchment.**

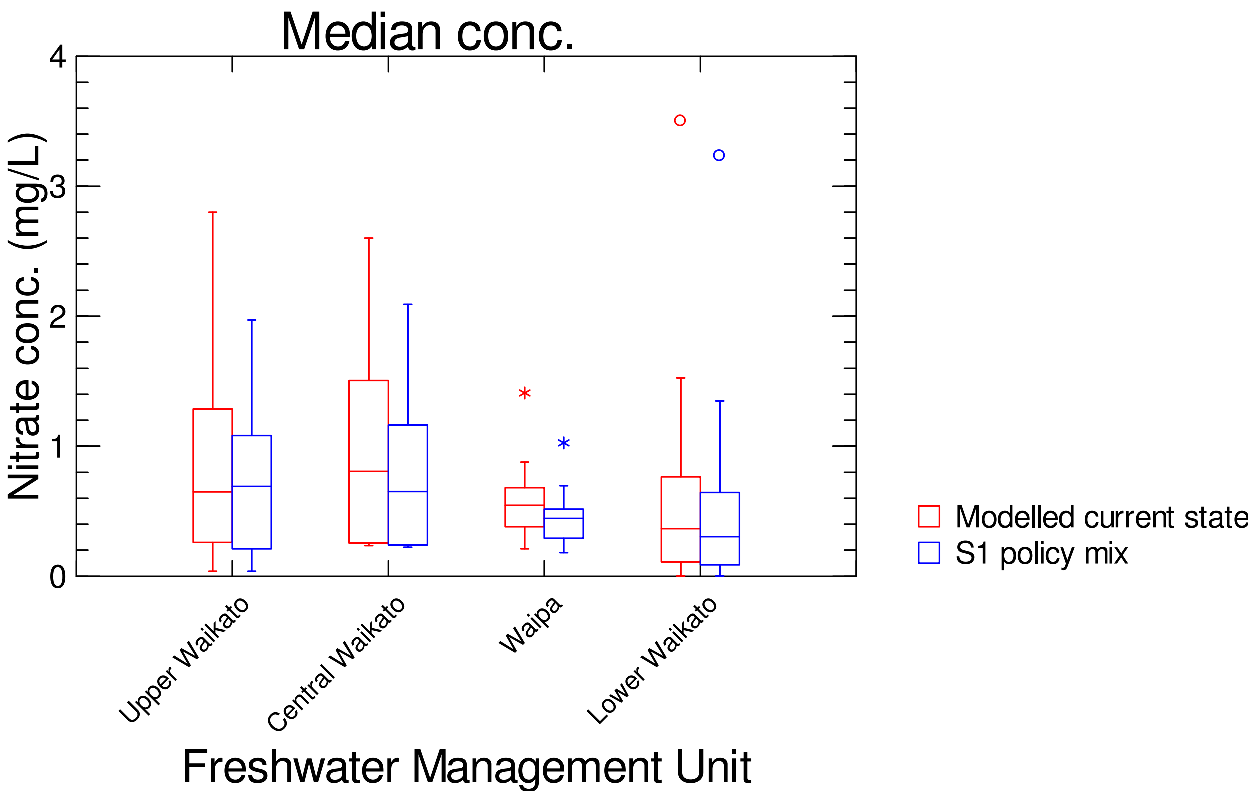

Figure A6:

Comparison of modelled current state and predicted policy mix on ninety-fifth percentile nitrate nitrogen concentrations in the four Freshwater Management Units of the Waikato/Waipa catchment.

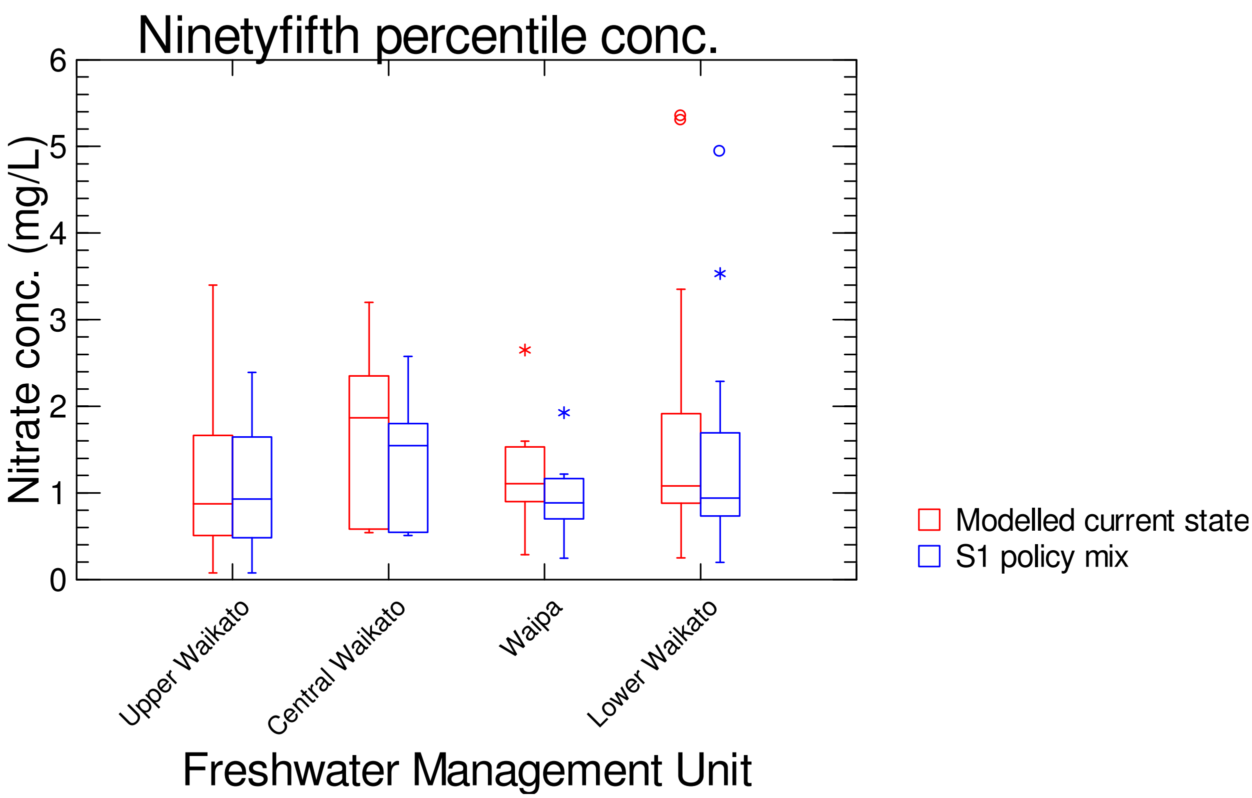

Table A1:

Summary statistics for modelled current state and policy mix <u>median nitrate nitrogen</u> concentrations according to Freshwater Management Unit.

Freshwater Management Unit	Statistic	Median nitrate-nitrogen concentrations (mg/L)	
		Modelled current state	S1 policy mix
Upper Waikato	Minimum	0.039	0.039
Upper Waikato	Maximum	2.8	1.97
Upper Waikato	Median	0.65	0.692
Central Waikato	Minimum	0.235	0.222
Central Waikato	Maximum	2.6	2.092
Central Waikato	Median	0.808	0.651

Waipa	Minimum	0.21	0.181
Waipa	Maximum	1.41	1.025
Waipa	Median	0.545	0.446
Lower Waikato	Minimum	0.001	0.001
Lower Waikato	Maximum	3.5	3.232
Lower Waikato	Median	0.365	0.304

Table A2:

Summary statistics for modelled current state and policy mix ninety-fifth percentile nitrate nitrogen concentrations according to Freshwater Management Unit.

Freshwater Management Unit	Statistic	Ninety-fifth percentile nitrate-nitrogen concentrations (mg/L)	
		Modelled current state	S1 policy mix
Upper Waikato	Minimum	0.075	0.076
Upper Waikato	Maximum	3.4	2.392
Upper Waikato	Median	0.875	0.929
Central Waikato	Minimum	0.54	0.507
Central Waikato	Maximum	3.2	2.574
Central Waikato	Median	1.868	1.546
Waipa	Minimum	0.285	0.247
Waipa	Maximum	2.65	1.926
Waipa	Median	1.105	0.883
Lower Waikato	Minimum	0.251	0.2
Lower Waikato	Maximum	5.35	4.94
Lower Waikato	Median	1.081	0.939

Table A3:

Summary statistics for modelled current state and policy mix nitrate nitrogen concentrations for the Waikato/Waipa catchment.

Statistic	Median nitrate-nitrogen concentrations (mg/L)		Ninety-fifth percentile nitrate-nitrogen concentrations (mg/L)	
	Modelled current state	S1 policy mix	Modelled current state	S1 policy mix
Minimum	0.001	0.001	0.075	0.076
Maximum	3.500	3.232	5.350	4.940
Median	0.595	0.508	1.108	0.970

Figure A7:

Comparison of modelled current state and predicted policy mix on <u>median *E. coli* concentrations</u> in the four Freshwater Management Units of the Waikato/Waipa River catchment. (Note y-axis has log_{10} scale).

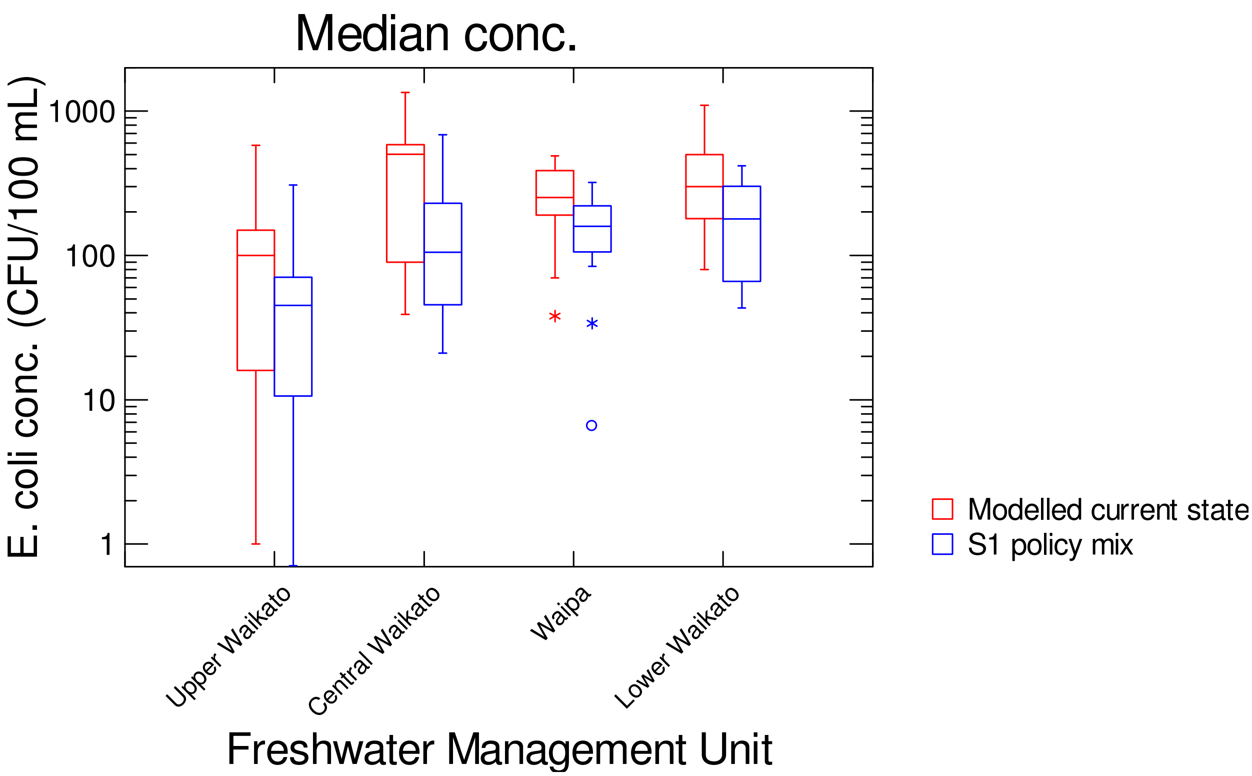

Figure A8:

Comparison of modelled current state and predicted policy mix on <u>ninety-fifth percentile *E. coli*</u> concentrations in the four Freshwater Management Units of the Waikato/Waipa catchment. (Note y-axis has log_{10} scale).

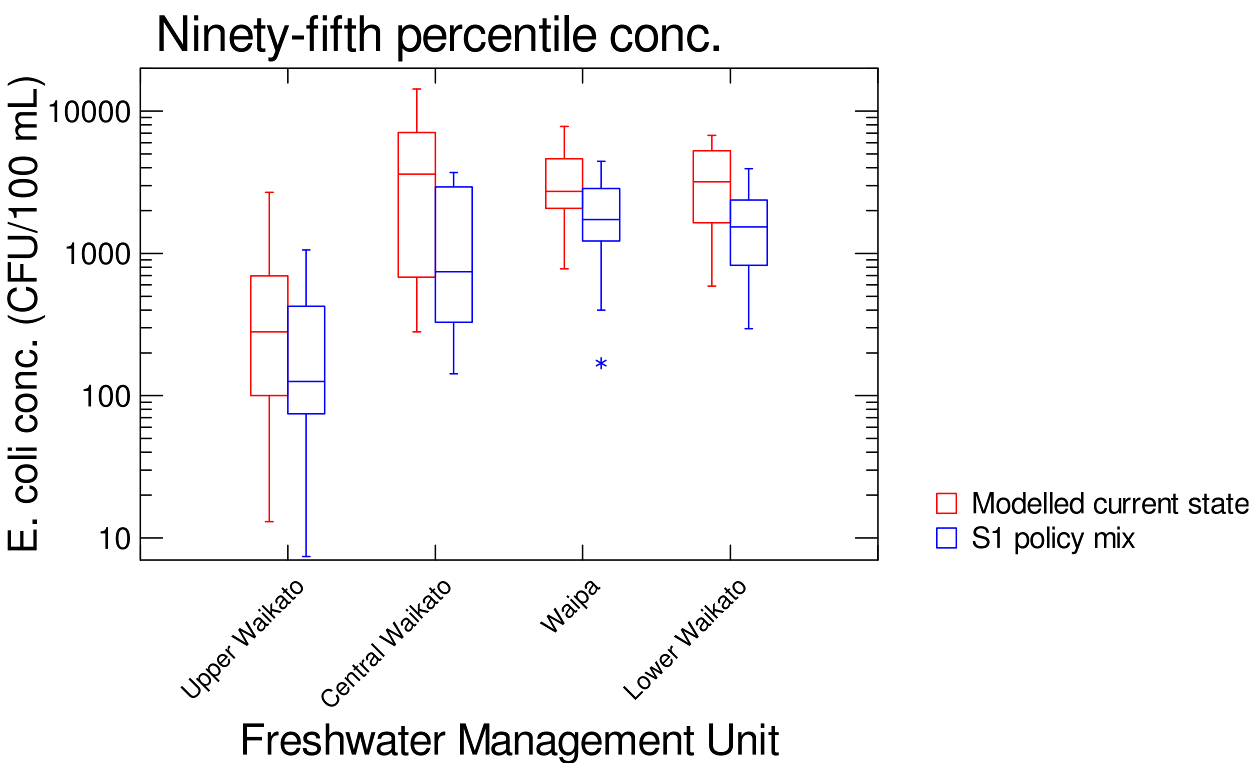

Table A4:

Summary statistics for modelled current state and policy mix *E. coli* concentrations for the Waikato/Waipa catchment.

Statistic	Median *E. coli* concentrations (CFU/100 mL)		Ninety-fifth percentile *E. coli* concentrations (CFU/100 mL)	
	Modelled current state	S1 policy mix	Modelled current state	S1 policy mix
Minimum	1	1	13	7
Maximum	1350	687	14300	4439
Median	221	105	2085	1018

Table A5:

Summary statistics for modelled current state and policy mix *E. coli* concentrations according to Freshwater Management Unit.

Freshwater Management Units	Statistic	Median *E. coli* concentration (CFU/100 mL)		Ninety-fifth percentile *E. coli* concentration (CFU/100 mL)	
		Modelled current state	S1 policy mix	Modelled current state	S1 policy mix
Upper Waikato	Minimum	1	1	13	7
Upper Waikato	Maximum	580	307	2685	1058
Upper Waikato	Median	100	45	281	126
Central Waikato	Minimum	39	21	280	142
Central Waikato	Maximum	1350	687	14300	3699
Central Waikato	Median	502	105	3612	774
Waipa	Minimum	38	7	780	169
Waipa	Maximum	490	321	7800	4438
Waipa	Median	252	160	2729	1727
Lower Waikato	Minimum	80	43	589	296
Lower Waikato	Maximum	1100	418	6770	3930
Lower Waikato	Median	300	179	3180	1536

Figure A9:

Comparison of modelled current state and predicted policy mix on <u>median visual clarity</u> in the four Freshwater Management Units of the Waikato/Waipa catchment.

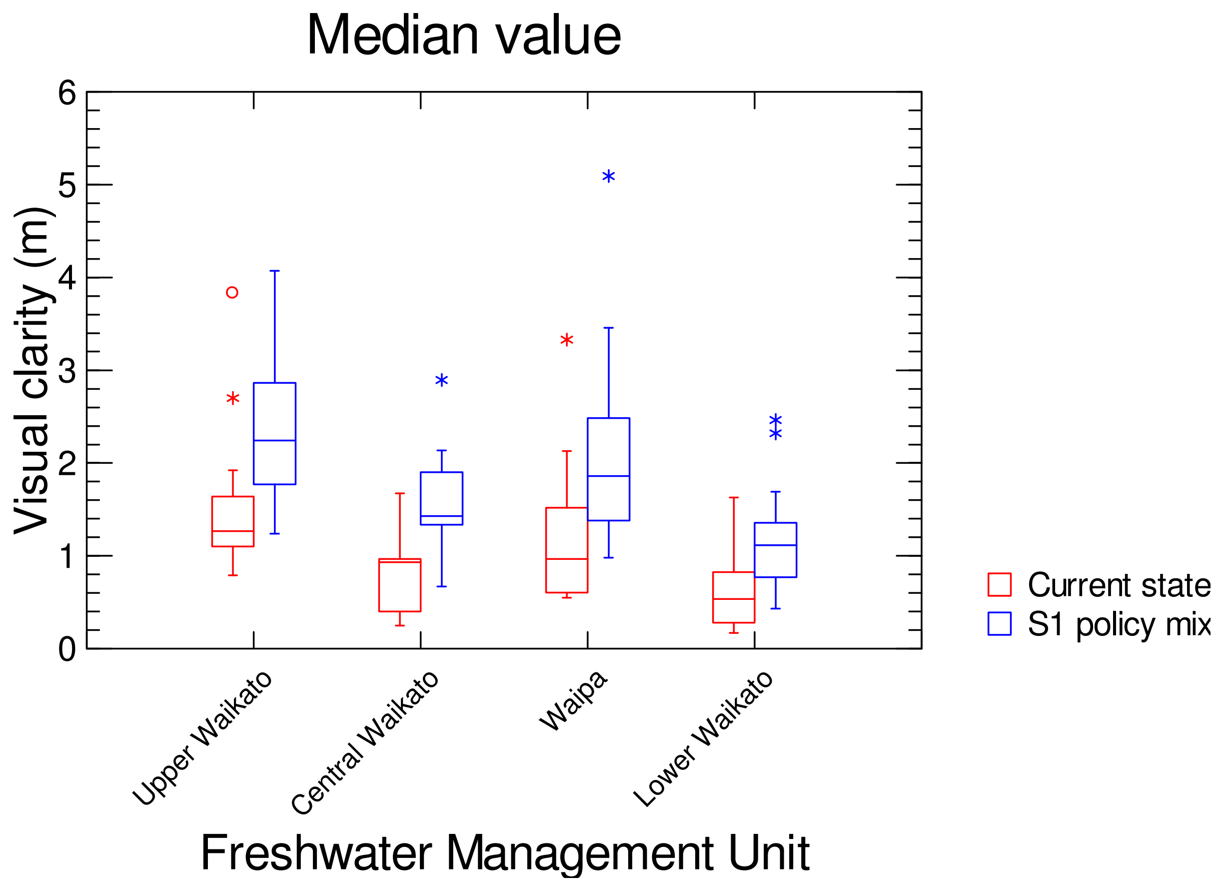

Table A6:

Summary statistics for modelled current state and policy mix visual clarity for the Waikato/Waipa catchment according to Freshwater Management Unit.

Freshwater Management Units	Statistic	Median clarity (m)	
		Current state	S1 policy mix
Upper Waikato	Minimum	0.79	1.24
Upper Waikato	Maximum	3.83	4.07
Upper Waikato	Median	1.26	2.24
Central Waikato	Minimum	0.25	0.67
Central Waikato	Maximum	1.67	2.89
Central Waikato	Median	0.93	1.43
Waipa	Minimum	0.55	0.98
Waipa	Maximum	3.33	5.09
Waipa	Median	0.97	1.86
Lower Waikato	Minimum	0.17	0.43
Lower Waikato	Maximum	1.63	2.46
Lower Waikato	Median	0.53	1.11

Table A7:

Summary statistics for modelled current state and S1 policy mix visual clarity for the Waikato/Waipa catchment; all sites

Statistic	Median visual clarity (m)	
	Current state	S1 policy mix
Minimum	0.17	0.43
Maximum	3.83	5.09
Median	0.87	1.66

Figure A10:

Comparison of modelled current state and predicted policy mix on <u>median visual clarity</u> along the Waikato River main stem. Sites listed in downstream order from left to right.