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Evaluation of scenarios for water-quality improvement in the Waikato and Waipa River catchments

Business-as-usual assessment

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The Technical Leaders Group approves the release of this report to Project Partners and the Collaborative Stakeholder Group for the Healthy Rivers Wai Ora Project.

Signed by:

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Evaluation of scenarios for water-quality improvement in the Waikato and Waipa River catchments

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1. Introduction

The Healthy Rivers: Plan for Change/Wai Ora He Rautaki Whakapaipai (HRWO) project sets out to progressively improve freshwater quality in the catchment of the Waikato and Waipa River catchments, through reducing the concentrations of four contaminants (microbes, nitrogen, phosphorus, and sediment) and improving associated values of water clarity and suspended algae (chlorophyll-a). A key part of this project has been the provision of technical assessment, directed by a Technical Leaders Group (TLG), to meet the information needs of a Collaborative Stakeholder Group (CSG). Modelling has been utilised throughout the process to identify the economic and water-quality implications of attribute limits consistent with a wide range of futures for the catchment (Doole et al., 2016a, b). Additionally, it has been used to retrodict the level of water quality present throughout the catchment in 1863 (Doole et al., 2016c) and evaluate the policy mix proposed by the CSG (Doole et al., 2016d). Nevertheless, it is important to establish a "without policy" reference point, to which the "with policy" scenario is compared (Doole et al., 2016e). The provision of this counterfactual—what would happen if no management policy were implemented—is critical because the benefit of introducing a management option is the change in values generated as a result.

The primary objective of this report is to outline the potential implications of what would happen in the absence of the proposed policy mix—the prediction of outcomes associated with moving forward according to a "business-as-usual" scenario. More information regarding the proposed policy mix and its predicted effects are described in Doole et al. (2016d). The proposed policy mix focuses on changes that would occur across a 10-year plan period (Doole et al., 2016d). Accordingly, the focus of this modelling effort is on predicting what would be the likely economic and environmental implications of not implementing the proposed policy mix across the same 10-year period.

The structure of the document is as follows. An overview of the model is provided in Section 2. Key assumptions regarding changes to land use, point sources, contaminant yield, sector profit, and mitigation uptake are outlined in Section 3. The results of the simulations are presented and discussed in Section 4. Section 5 presents conclusions.

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. (2015, 2016a, b, c, d). 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 that described a long-term future for the catchment (Doole et al., 2016a, 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 to identify optimal solutions to the posed mathematical problem (Bazaraa et al., 2006).

The assessment of the proposed policy mix involved the use of the model in "simulation" mode (Doole et al., 2016d). 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. In comparison, the assessment of the "business-as-usual" case primarily utilises an optimisation approach. The assumptions describing how the context is assumed to change over the next decade, in the absence of any concerted management action, are outlined in Section 3. These assumptions are defined in the model through the use of constraints within the mathematical-programming framework. The process of optimisation is then used to identify the solution that maximises profit, subject to the context described within the set of constraints incorporated in the model.

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 because 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, Farm Environment Plans 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, 2016a).

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 (2016a).

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 FMUs are included in the model, but is not studied independent of the others in this report.
2. 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. 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 #3 was based initially on that generated by the Economic Impact Joint Venture (EIJV) program of work that preceded the HRWO process. 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 project has been the extension of the EIJV economic model to consider the loss and mitigation of phosphorus, sediment, and *E. coli* loadings to water.

A key addition to the HRWO economic model has 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 visual clarity 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 decade, 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.

3. Assumptions used in the business-as-usual modelling

The business-as-usual scenario evaluates the economic and environmental outcomes of continued intensification within the HRWO catchment. Intensification typically occurs along two dimensions: within a fixed land use, and with land use change. Using more supplement and nitrogen fertiliser on a dairy farm is an example of intensification within a fixed land use. Converting an area of forest to dairy production is an example of intensification with land-use change. Assumptions around contaminant loss arising from intensification in fixed land uses are discussed in Section 3.1, while those regarding intensification with land-use change are discussed in Section 3.2. Increases in microbial, phosphorus, and sediment losses with intensification within fixed land uses are difficult to estimate. Thus, these are kept constant at their baseline levels in the model – this represents a conservative approach. In contrast, the loss of all contaminants (microbial, nitrogen, phosphorus, and sediment) is modified with land-use change, given that richer data is available for inclusion in the model. A more-detailed justification of these assumptions is provided for fixed land uses and with land-use change in Sections 3.1 and 3.2, respectively.

3.1 Assumptions pertaining to rates of increase in contaminant yields

Intensification of land use is likely to express itself most markedly through changes to nitrogen loads arising from pastoral agriculture (PCE, 2013; Doole, 2015a). Dairy-farm nitrogen-leaching rates in the Waikato catchment are estimated to be increasing at an annual linear rate of 1.3% (Hudson, 2015), while drystock nitrogen-leaching rates are estimated to be increasing at an annual linear rate of 0.4% (Hudson, 2015). These estimates are used as an estimate of the likely rate of intensification within these sectors over the next 10 years. In contrast, no increases in intensity are predicted to occur in the plantation-forestry sector in the near future (PCE, 2013), so estimated contaminant losses to water for this land-use in the baseline are held constant in this application.

The horticultural industry in the Pukekohe/Pukekawa region is important, given that it helps to fill an important gap in the vegetable supply-chain nationally. However, there is little scope to increase horticultural area in this region, due to increasing competition for land for housing development near Auckland, such as outlined by Franklin Local Board (2014). An increase in nitrogen loss in the absence of the proposed policy mix is estimated at a linear increase of 2.5% per year in the horticultural sector. This is higher than those rates estimated for livestock enterprises, given that intensification could follow increased competition for land allocation from urban use. This assumption was generated through discussion with Chris Keenan, the HortNZ representative within the CSG for the HRWO project.

There is assumed to be no increasing trend in terms of sediment losses to water. Hicks et al. (2001) estimated that sediment yields could increase by around 15% across 2001–2036 due to climate change. However, there will be high spatial variation and it is difficult to identify what proportion could be expected to occur over the next decade. Additionally, recent empirical evidence suggests that there was no trend in terms of sediment losses from the most-erosive sub-catchments within the Waikato region across 1985–2011 (Hoyle, 2013). For these reasons, changes to the losses of sediment and particulate phosphorus within fixed land uses are not simulated in the business-as-usual case.

Changes in dissolved reactive phosphorus loss from farm land are difficult to predict. Recent hydrological and land-use modelling indicated that phosphorus loads are expected to exhibit no change in the Waikato region across 2008–2020, in line with broad expectations at the national level (PCE, 2013; Wilcock et al., 2013; Ballantine and Davies-Colley, 2014). This is consistent with a broad understanding that dairy expansion and intensification will generally increase the loss of nitrogen to water (Doole, 2015a), but this will be much less evident for phosphorus (Doole, 2013; PCE, 2013). Additionally, even if intensification is observed, extrapolating these trends to the receiving environment is difficult because the changes may not relate to phosphorus loss directly, but other scale-specific processes (e.g. phosphate retention) (Richard McDowell, AgResearch, pers. comm.). Indeed, Dymond et al. (2013) demonstrated that there is significant spatial heterogeneity in estimated dissolved reactive phosphorus loss, due to wide-scale diversity in farming intensity, climate, and soil properties. For these reasons, changes to the losses of dissolved reactive phosphorus within fixed land uses are not simulated in the business-as-usual case.

Changes in microbial loadings to water that will occur over the next decade—as indicated by *E. coli* yields—are problematic to assess. These loads are typically more difficult to estimate than nutrient or sediment losses, due to a lack of knowledge regarding key elements of their generation and transport from farming systems (Muirhead, 2015). Stocking rates have increased on New Zealand dairy farms over the last twenty years; for example, the average national stocking rate for dairy cows increased by 18% from 2.44 cows ha^{-1} to 2.87 cows ha^{-1} over 1994–2014 (LIC, 2014). This is likely to increase the amount of faeces deposited by livestock—a primary source of *E. coli* contamination (Muirhead et al., 2011)—because a higher stocking rate is generally associated with a higher feed intake, *ceteris paribus* (Romera and Doole, 2015). Nevertheless, the relationship between stocking rate and microbial loadings to water is tenuous and is difficult to relate to the approach being used for the catchment modelling of microbes (Richard Muirhead, AgResearch, pers. comm.). Accordingly, the losses of microbes to water arising from intensification within fixed land uses are not altered in the business-as-usual scenario.

This sub-section has described how microbial, phosphorus, and sediment losses are assumed to stay at their baseline level within fixed land uses across the next decade. This potentially understates the contribution of intensification to the environmental footprint of agriculture in the catchment. Indeed, if these contaminant losses do increase with intensification, then the change in water quality outlined below will be conservative and this will undervalue the degree of water-quality improvement estimated to accrue to WRPC1. A conservative view is taken, given the lack of data and the need for precaution when designing environmental policy (Pearce et al., 2006; Doole and Pannell, 2011). Nonetheless, the implications of changing these assumptions can easily be ascertained in the HRWO economic model, if there is deemed to be sufficient information to estimate how these contaminant losses change with intensification.

3.2 Assumptions pertaining to land-use change

The primary land-use change that is occurring in the study region presently is the ongoing conversion of forestry land in the Upper Waikato to intensive dairy production. A total of 10,000 ha of dairy conversion from plantation forest in the Upper Waikato Freshwater Management Unit (FMU) is permitted to occur over the next 10 years in the business-as-usual scenario. This estimate of land-use change is based on expert opinion, Hudson et al (2015), and Margules Groome (2015).

More than 40,000 ha of land has received Certificates of Compliance for such conversion. However, a lower level is evaluated since not all of this land is expected to be converted over the next decade due to market volatility, especially in the dairy industry, and because of water scarcity. The Upper Waikato area—where most forest-to-dairy conversion is occurring within the Waikato River catchment—is currently near to or already over-allocated in terms of water quantity. That is, no additional water is available for a farm that does not already have a consent. This may not represent an absolute constraint necessarily—due to technical innovation, transfers, the availability of groundwater, or specific parcels of forest already having water-take consents. Nevertheless, it is recognised that there is a limited availability of water for allocation to pastoral uses, and this could be expected to constrain conversion above the level of 10,000 ha. Hence, this estimate allows for some change in existing land use to occur, but only on the basis of more-efficient utilisation of consented water takes. This estimate of conversion is a possible future that is used to inform the scenario modelling, but should not be interpreted as a prediction or an indication of what should occur.

The estimated loadings arising from a hectare of land are altered as a result of forest-to-dairy conversion. Dairy farming can increase the losses of many contaminants, relative to those from plantation forest, even though the most-significant increases usually occur for nitrogen (McDowell and Wilcock, 2008; Dymond et al., 2013; PCE, 2013; Wilcock et al., 2013). Accordingly, changes are represented for all contaminants. The magnitudes of the changes in load occurring as a result of forest-to-dairy conversion are drawn from Semadeni-Davies et al., 2015a (*E. coli*), Yalden and Elliott (2015) (sediment), Semadeni-Davies et al., 2015b (nitrogen), and Semadeni-Davies et al. (2015b) (phosphorus).

3.3 Assumptions pertaining to point-source discharges

Significant changes in populations are predicted to occur within the key municipal centres in the Waikato region over the next 10–20 years (Jackson, 2013). However, it is assumed that municipal growth will not lead to increases in contaminant discharges because of technical innovation and since current losses are often well below consented limits. This has been observed in Hamilton in recent years, and has allowed the increased waste-water burden arising from population growth to be absorbed without further degrading water quality.

3.4 Assumptions pertaining to farm profit

Intensification within land-use sectors will affect farm profit. The model runs performed thus far in the HRWO process predict the medium-term economic costs associated with water-quality improvement. Input information regarding farm profit is held constant in these evaluations, given uncertainty around by how much sectoral profit can be expected to change in the short- to medium-term. It is also consistent with the employment of expected biophysical and financial conditions when computing the profitability measures in each land use (Doole, 2016). The use of average conditions in the computation of these quantities means that they remain generally valid, even though some volatility in climate and/or prices will be observed over time (Doole et al., 2015).

An assumption that farm profit should be held constant is also justified by empirical evidence. Anastasiadis and Kerr (2013) estimate that dairy production in the Waikato will increase by 14% across 2008–2020. Total Factor Productivity is a measure of the gains in production that are not associated with higher input use. This has been declining at an annual rate of 3.6% over the last decade in the New Zealand dairy industry (Jiang, 2011; DairyNZ, 2015). Thus, the increases in production estimated by Anastasiadis and Kerr (2013) will likely arise from increased input use. This is problematic in terms of improving farm returns, in that input prices have been rising at a rate that is 57% higher than the rate of inflation (DairyNZ, 2015) and output prices are highly volatile, as observed in recent years (Doole and Kingwell, 2015). Additionally, there is empirical evidence that intensification will change little across the drystock (Anastasiadis and Kerr, 2013) and plantation forestry (PCE, 2013) sectors. Nonetheless, Beef and Lamb New Zealand have recently outlined that the sheep-and-beef sector is expected to intensify within the HRWO catchment over the next decade, hence questioning the validity of this earlier assertion (Doole, 2016b).

3.5 Assumptions pertaining to mitigation use

The economic model utilised within the HRWO process contains a wide range of mitigation practices, each associated with a given cost and efficacy in terms of its capacity to reduce the loss of a given contaminant. A conservative view is taken with respect to the degree that voluntary adoption of these mitigations will occur over the study period. This is justified for several reasons:

- A broad range of relatively-effective mitigation options exist for New Zealand land uses, but most of these are costly (AgFirst, 2009; Doole, 2012; Wilcock et al., 2013; Ridler et al., 2014; Doole, 2015a, b; Doole and Kingwell, 2015; Monaghan et al., 2015). Profitability is a key driver of the advantage that new agricultural practices offer, relative to the *status quo* (Batz et al., 1999; Pannell et al., 2006). This relative advantage is the most-important determinant of the uptake of new practices (Rogers, 2003; Pannell et al., 2006). Accordingly, it is appropriate to take a conservative view of voluntary adoption rates for mitigation practices, given that their use will likely impose costs on producers relative to their current position.
- Adoption is often slow for agricultural innovations, especially those for which the principal benefits are experienced off-farm, given barriers to uptake that are not considered during standard financial evaluations (Olmstead and Rhode, 2002). Such barriers can be related to risk, uncertainty, adjustment costs, system impacts, incompatibility with lifestyle and values, and complexity (Pannell et al., 2006, 2014).
- Some managers are unwilling to deviate from established management plans, given a strong drive to repeat learned actions, even in the presence of new opportunities or

> constraints (Gonzalez and Dutt, 2011). This is identified in the case of water-quality improvement in New Zealand by AgFirst (2010), who found that the adoption of “win-win” solutions identified in AgFirst (2009) was marred in several circumstances because of risk aversion and perceived limitations in the economic assessment of these practices (AgFirst, 2010).

The following assumptions are made with respect to the individual mitigations represented in this analysis.

Stream fencing is continued to increase at rates observed over the last decade. These are annual average rates of 3.5% per year for dairy farms and 0.2% for drystock (John Quinn, NIWA, pers. comm.).

The Waipa Catchment Plan (Waikato Regional Council, 2014) dictates a number of key actions for soil conservation. These include, but are not limited to:

1. The development and implementation of farm plans for all farms in the Moakurarua above Ormsby Road bridge sub-catchment and the Kaniwhawha above Te Pahu Road bridge sub-catchment.
2. The implementation of riparian enhancement programmes on the Mangapiko Stream between Te Awamutu and Pirongia, Waipa River between Toa’s bridge and Mangaorongo Stream confluence, Waipa River between Kaniwhaniwha Stream and Waikato River confluence, and the Mangapu sub-catchment.

Item 1 in this list is modelled through assuming that all farm land in these two sub-catchments are subject to soil-conservation plans.

Item 2 in this list is difficult to describe precisely within the economic model. Accordingly, it is approximated through all waterways in these respective sub-catchments being subject to streambank fencing, with the use of 5-metre wide riparian buffers.

A number of mitigation practices represented in the model impose no cost or allow increases in farm returns (Doole, 2016). Practices that are assumed to impose no cost are the remediation of 2-pond systems and improved phosphorus management. Accordingly, these options are assumed to be fully adopted in the business-as-usual case. In addition, a number of alternative farm-management options allow farm profit to increase, relative to the current state. It is assumed that producers in each sector can recognise and subsequently attain these through learning and behaviour change over the time frame considered within the business-as-usual case.

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 dis-equilibrium 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 full load-to-come is considered in the evaluation of the environmental impacts of the proposed policy mix in Doole et al. (2016d). Accordingly, an equivalent assumption is also made for the business-as-usual assessment in this study. Both approaches are broadly consistent with a precautionary approach to the evaluation of the implications of environmental management (Pearce et al., 2006). Moreover, the implications of different assumptions regarding load-to-come are explored in sensitivity analysis within both the main assessment of the proposed policy mix (Doole et al., 2016d) and here (see below).

3.7 Model runs

The primary objective of this analysis is to investigate the potential implications of what would happen in the absence of the proposed policy mix—the prediction of outcomes associated with moving forward according to a "business-as-usual" scenario. Doole (2016d) provides more information regarding the proposed policy mix and its predicted effects. For ease of comparison with the policy mix, the key outputs reported in Doole (2016d) are repeated here.

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

1. Simulation of the current state. This scenario is denoted as "Current" in the following.
2. Simulation of the Waikato Region Plan Change policy mix with *no* development of iwi land. This scenario is denoted as "WRPC (no)" in the following.
3. Simulation of the Waikato Region Plan Change policy mix with *low* development of iwi land. This scenario is denoted as "WRPC (low)" in the following.
4. Simulation of the Waikato Region Plan Change policy mix with *moderate* development of iwi land. This scenario is denoted as "WRPC (medium)" in the following.
5. Simulation of the Waikato Region Plan Change policy mix with *high* development of iwi land. This scenario is denoted as "WRPC (high)" in the following.
6. Simulation of what is predicted to occur without the Waikato Region Plan Change policy mix. This scenario is denoted as "BAU" or business-as-usual in the following.

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 assumptions described above in the rest of Section 3, rather than optimising management actions to achieve certain water-quality outcomes, as done by Doole et al. (2016a, b).

Section 4 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 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.

The baseline assessment involves a standard assumption that the entire nitrogen load-to-come in groundwater is considered when computing attribute levels associated with the business-as-usual case (Section 3.6). The implications of varying the proportion of the load-to-come that is expressed in surface water is therefore explored. This is particularly valuable given that not all of the load-to-come may enter the groundwater over the subsequent decade. The nutrient modelling performed within the HRWO process has estimated this load-to-come (Semadeni-Davies et al., 2015b); however, the time that different loads are expressed varies across sub-catchments. It is non-trivial to vary these factors such that the load-to-come for each sub-catchment caters specifically for the time period expressed in the business-as-usual scenario. Accordingly, three general cases are explored: these involve 0, 50, and 100% of the estimated nitrogen load-to-come being considered across the catchment. The 100% scenario represents the baseline, in the following.

4. Results and Discussion

Table 1 reports the predicted level of profit for each of the primary scenarios that are evaluated. The "WRPC (no)" 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. The results associated with low, medium, and high levels of development on iwi land are reported in the "WRPC (low)", "WRPC (medium)", and "WRPC (high)" columns, respectively. Total dairy and drystock profit increase with the development of iwi land, while returns to plantation forestry decline. Nevertheless, this development does impose some conversion costs that erode the economic benefits accruing to land-use transition at the catchment level.

Catchment-level profit decreases in the business-as-usual (labelled "BAU") case in Table 1, relative to the current state. Dairy profit increases by 3%, relative to the current state. It is also greater than in the WRPC scenarios, even the scenario containing high conversion of forest to dairy production on iwi land. Likewise, profit increases in the drystock sector, relative to the current state, because of significant opportunities for producers to adopt win-win strategies in the short- to medium-term in this sector (Parsons et al., 2015). The horticulture sector is unaffected, while the profitability of forest declines somewhat given broad-scale harvest to open up land for dairy farming in the upper catchment. Notably, profit is higher in the "BAU" run than the "WRPC" runs; indeed, while the "WRPC" run reduces profit relative to the current state by 4%, they only decrease profit by 3% relative to the business-as-usual case. A key driver of this is that significant conversion costs are associated with converting forest land to dairy production in the "BAU" run (Table 1).

Table 1. Elements of catchment-level, annual profit earned at the current state; with the implementation of the "WRPC" policy mix with "no", "low", "medium", and "high" levels of development on iwi land; and under business-as-usual (labelled "BAU"). "Transition" denotes the costs arising from land-use conversion on iwi land. Changes in profit are computed relative to the current state.

Variable	**Units**	**Current**	**WRPC (no)**	**WRPC (low)**	**WRPC (med.)**	**WRPC (high)**	**BAU**
Sector profit							
Dairy	$m	617.53	604.13	611.78	618.50	626.18	633.38
Drystock	$m	210.15	210.99	213.89	216.09	217.74	218.51
Horticulture	$m	28.21	25.91	25.91	25.91	25.91	28.21
Forest	$m	58.86	58.86	57.71	56.56	55.43	56.07
Costs							
Transition	$m	0	0	9.53	18.54	28.40	31.00
Stream fencing	$m	0	2.84	2.86	2.88	2.90	2.22
Effluent update	$m	0	3.46	3.47	3.47	3.47	0
Erosion control	$m	0	8.32	8.36	8.37	8.43	0.39
Edge-of-field	$m	0	8.35	8.28	8.31	8.36	0
Total profit	*$m*	*914.76*	*876.91*	*876.81*	*875.51*	*873.71*	*902.56*
Change	*$m*		*-37.85*	*-37.95*	*-39.25*	*-41.05*	*-12.20*
Change	*%*		*-4*	*-4*	*-4*	*-4*	*-1*

Table 2 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 WRPC policy mix (denoted as "WRPC (no)" in Table 2). With the development of iwi land, the area allocated to dairy and drystock production increases, at the expense of plantation forest (Table 2). Dairy land increases substantially in the upper catchment, at the expense of forest, in the business-as-usual (labelled "BAU") scenario (Table 2, see Section 3.2 for further information). In contrast to the "WRPC" runs, no conversion to drystock is assumed to occur in the "BAU" runs.

Table 2. Catchment-level land allocation for the current state; with the implementation of the "WRPC" policy mix with "no", "low", "medium", and "high" levels of development on iwi land; and under business-as-usual ("BAU").

Variable	**Units**	**Current**	**WRPC (no)**	**WRPC (low)**	**WRPC (med.)**	**WRPC (high)**	**BAU**
Dairy	Ha	308,008	308,008	310,461	312,654	315,206	318,008
Drystock	Ha	370,355	370,355	370,939	371,781	372,357	370,355
Horticulture	Ha	6,103	6,103	6,103	6,103	6,103	6,103
Forest	Ha	169,478	169,478	166,442	163,406	160,278	159,478
Total	*Ha*	*853,945*	*853,945*	*853,945*	*853,945*	*853,945*	*853,945*
New dairy	Ha	-	-	2,453	4,646	7,198	10,000
New drystock	Ha	-	-	583	1,426	2,002	-
Total	*Ha*	-	-	*3,036*	*6,072*	*9,200*	*10,000*

Table 3 reports the level of output of key products in each industry, within each scenario. Dairy production increases in all scenarios, relative to the current state. This arises from a combination of improvements in productivity, as farmers gain an ability to move away from their baseline management plan in the model, and the conversion of forest land. The elements of drystock and horticultural production also stay the same or increase in the business-as-usual scenario. Nonetheless, there is some fall in forest production with conversion occurring in the upper catchment, though this decrease is minor in absolute terms.

Table 3. Catchment-level, annual production at the current state; with the implementation of the "WRPC" policy mix with "no", "low", "medium", and "high" levels of development on iwi land; and under business-as-usual ("BAU").

Variable	Units	Current state	WRPC (no)	WRPC (low)	WRPC (med.)	WRPC (high)	BAU
Milk solids	t	238,988	240,570	243,422	246,066	249,136	254,315
Wool	t	7,976	7,957	7,968	7,968	7,971	8,048
Mutton	t	17,806	17,723	17,754	17,754	17,763	17,988
Lamb	t	12,331	12,326	12,327	12,327	12,327	12,334
Beef	t	23,877	24,180	24,208	24,258	24,297	24,230
Bull beef	t	15,115	15,055	15,198	15,392	15,524	15,115
Hort. crops	t	244,809	245,147	245,147	245,147	245,147	251,452
S1 logs	M m^3	18	18	18	18	17	18
S2 logs	M m^3	49	49	48	47	46	46
S3 logs	M m^3	52	52	51	50	49	49
Pulp	M m^3	33	33	33	32	32	32
Waste	M m^3	2	2	2	2	2	2

Table 4 shows the number of sites that degrade in water quality relative to the current state, within each scenario. It highlights that the policy mix achieves substantial improvement in water-quality outcomes, relative to the current state. Most degradation is observed for those attributes related to nitrogen concentrations, given that the baseline evaluation of the policy mix involved an assumption that all of the load-to-come was expressed across the decade of interest (Doole et al., 2016d).

Under the business-as-usual case, water-quality outcomes are predicted to degrade significantly, relative to the current state (Table 4). This is also observed chiefly in those attributes related to nitrogen losses from intensive agriculture (i.e. the Total Nitrogen, median nitrate, and 95th percentile nitrate concentrations). However, the scale is much more significant than is observed under the proposed policy mix (Table 4). All sites degrade for Total Nitrogen, while 82–98% of sites degrade for median and 95th percentile nitrate, depending on the load-to-come that is considered in the evaluation. If the full load-to-come is considered—as done for the proposed policy mix in Doole et al. (2016d)—then all sites degrade for Total Nitrogen and all but one site degrade for median and 95th percentile nitrate (Table 4). If appropriate data could be identified that related intensification within land uses to microbial, phosphorus, and sediment losses, then the level of water-quality degradation identified in Table 4 would obviously change.

The business-as-usual case is characterised by a moderate level of intensification and a concerted effort to address highly-localised sediment and microbial losses in a number of priority sub-catchments. In contrast to the proposed policy mix, there is no integrated approach taken to reducing the losses of a broad range of contaminants to water. Additionally, intensification both within existing land uses and through land-use change is allowed to occur. This leads to a concomitant increase in nitrogen losses from farms throughout the catchment. This is particularly likely to occur in the upper catchment given the expected level of conversion (Section 3.2); high losses of nitrogen from dairy farms (McDowell and Wilcock, 2008), relative to plantation forest (Davis, 2014); and the presence of fine-textured soils in this region that have high-leaching rates under dairy farming (Doole, 2010, 2012). Nevertheless, degradation is not only observed for those attributes related to nitrogen losses. Clarity and microbial attributes also degrade at some sites, relative to the current state (Table 4). However, as outlined above, greater degradation may be observed if changes in microbial, phosphorus, and sediment losses related to intensification within land-uses was able to be modelled.

There is a significant amount of empirical data that supports these assertions that water quality will further degrade in the catchment, in the absence of the policy mix. In an analysis of long-term records of water quality in the Waikato region, Vant (2013) identified that more than half of the analysed sites were deteriorating in terms of Total Nitrogen concentration, primarily due to increasing nitrate concentrations. Based on these results, Vant (2013) goes on to state that, “areas of pastoral farming probably account for much of this deterioration” (p. 25). This is in strong agreement with the results reported in Table 4 below, where the business-as-usual case is characterised by significant deterioration in these attributes. Several other studies of regional and national water quality highlight the strong link between agricultural intensification and the decline of water quality in New Zealand freshwater environments (Larned et al., 2004; Parfitt et al., 2012; Dymond et al., 2013; Hudson et al., 2015). Additionally, a recent historical study reinforces that clearance of the catchment and subsequent agricultural and horticultural development have led to severe water-quality deterioration throughout (Doole et al., 2016c).

Table 4. The number of sites that degrade, relative to current state. This is reported for the proposed policy mix ("WRPC") with "no", "low", "medium", and "high" development of iwi land and for the business-as-usual ("BAU") scenario with no nitrogen load-to-come considered ("no LTC"), 50% of the nitrogen load-to-come considered ("half LTC"), and all of the nitrogen load-to-come considered ("full LTC"). The "full LTC" scenario is the baseline "BAU" assessment studied in this analysis.

Attribute	**WRPC (no)**	**WRPC (low)**	**WRPC (med.)**	**WRPC (high)**	**BAU (no LTC)**	**BAU (half LTC)**	**BAU (full LTC)**	**Total sites**
Median chlorophyll-a	0	0	0	0	0	0	0	9
Maximum chlorophyll-a	0	0	0	0	0	0	0	9
Total Nitrogen	3	3	3	3	9	9	9	9
Total Phosphorus	0	0	1	1	0	0	0	9
Median nitrate	1	1	1	1	50	56	60	61
95th percentile nitrate	1	1	1	1	50	56	60	61
Median *E. coli*	0	0	0	0	1	1	1	61
95th percentile *E. coli*	0	0	0	0	1	1	1	61
Clarity	0	0	0	0	1	1	1	58

Table 5 reports the number of sites that meet their targets set under Scenario 1. 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 (Doole et al., 2016a, b). This involves an improvement in water quality at all sites in the catchment, even if it is already meeting the minimum acceptable state. The number of sites that meet their targets set under Scenario 1 is reported for current state; under the proposed policy mix with no, low, medium, and high iwi-land development; and for the business-as-usual case. 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 5). It also more than doubles the number of sites that reach their goal for the 95th percentile *E. coli* concentration. These outcomes do not change with different levels of iwi-land development (Table 5).

The business-as-usual scenario—that contains no broad-ranging focus on water-quality improvement—generally reduces the number of sites that reach their Scenario 1 target, relative to the policy-mix assessments (Table 5). This is observed for all attributes, except that for Total Nitrogen for which only site meets the Scenario 1 target across all scenarios recorded in Table 5. Relative to current state, degradation is observed for median chlorophyll-a, maximum chlorophyll-a, Total Phosphorus, median nitrate, and 95th percentile nitrate concentrations. An additional eleven sites meet the Scenario 1 target for clarity under business-as-usual; in addition, one more site meets the Scenario 1 goal for median *E. coli* concentration and an additional two sites meet their target for 95th percentile *E. coli* concentrations in this set of circumstances (Table 5). These improvements in clarity and microbial contamination under BAU highlight the value of a concerted effort to address highly-localised sediment and microbial losses in a number of priority sub-catchments (Section 3.5). Additionally, they also reflect the effects of the steady increases in stream fencing that are predicted to continue occur across the pastoral industry, especially in the dairy sector, over the next decade.

Table 5. The number of sites that meet the Scenario 1 target at current state; under the policy mix ("WRPC") with "no", "low", "medium", and "high" development of iwi land; and with business-as-usual ("BAU").

Attribute	**Current**	**WRPC1 (no)**	**WRPC1 (low)**	**WRPC1 (med.)**	**WRPC1 (high)**	**BAU**	**Total sites**
Median chlorophyll-a	3	5	5	5	5	2	9
Maximum chlorophyll-a	4	7	7	7	7	2	9
Total Nitrogen	1	1	1	1	1	1	9
Total Phosphorus	2	2	2	2	2	1	9
Median nitrate	46	49	49	49	49	45	61
95th percentile nitrate	38	42	42	42	42	35	61
Median *E. coli*	57	59	59	59	59	58	61
95th percentile *E. coli*	12	25	25	25	25	14	61
Clarity	3	44	44	44	44	14	58

5. Conclusions

The Healthy Rivers: Plan for Change/Wai Ora He Rautaki Whakapaipai (HRWO) project sets out to progressively improve freshwater quality in the catchment of the Waikato and Waipa River catchments, through reducing the concentrations of four contaminants (microbes, nitrogen, phosphorus, and sediment) and improving associated values of water clarity and suspended algae (chlorophyll-a). A number of mathematical models have been developed and applied to provide information—chiefly pertaining to the economic and water-quality implications of proposed policies—to a Collaborative Stakeholder Group (CSG) across the course of the project. A critical assessment has concerned the evaluation of the proposed policy mix generated by the CSG (Doole et al., 2016d). The primary objective of this analysis is to establish a "without policy" reference point, to which this "with policy" scenario can be compared (Doole et al., 2016e).

Evaluation of the business-as-usual case highlights several key findings. The projection of expected trends in land-use change and land management across the catchment highlights that economic outcomes will likely slightly decrease or stay the same if dairy prices remain around their long-term average. Expansion of dairy farming across the Upper Waikato Freshwater Management Unit is expected to occur, but the conversions costs accruing to this transition will be significant and serve to offset the economic gains associated with this activity. Intensification within existing farms and through dairy conversion means that attribute levels for Total Nitrogen, median nitrate, and 95th percentile nitrate will likely degrade, relative to the current state. Impacts on clarity and microbial concentrations are minimal, given continued investment in stream fencing and localised soil-conservation efforts in priority sub-catchments.

The business-as-usual scenario—that contains no broad-ranging focus on water-quality improvement—generally reduces the number of sites that reach their Scenario 1 target, relative to the policy-mix assessments (Table 5). This is observed for all attributes, except for that for Total Nitrogen.

Relative to current state, degradation is observed for median chlorophyll-a, maximum chlorophyll-a, Total Phosphorus, median nitrate, and 95th percentile nitrate concentrations. In contrast, some improvement is observed, relative to the current state, for *E. coli* concentrations and clarity due to ongoing investment in stream-fencing and soil-conservation efforts, particularly where promoted by industry and the Waikato Regional Council.

Increased nitrogen losses from intensive agriculture are identified as the main change in the absence of the proposed policy mix. This is intuitive given that the largest change in land use and land management, relative to the *status quo*, is likely to concern the expansion of dairy production. Dairy farming can increase the losses of many contaminants from pasture, but the most-significant increases—relative to those observed under plantation forest—usually occur for nitrogen (McDowell and Wilcock, 2008; Dymond et al., 2013; PCE, 2013; Wilcock et al., 2013). This is especially relevant in the fine-textured soils typical of the Upper Waikato Freshwater Management Unit (Doole, 2013, 2016). The extent of these changes are highly likely to be magnified if a greater area of dairy conversion was observed across the next decade.

A limitation of the modelling is the lack of data pertaining to how microbial, phosphorus, and sediment losses change as existing land uses are intensified, in the absence of land-use change. There is currently insufficient science to inform the development of meaningful estimates, especially across the range of diverse land uses present in the HRWO catchment. Nonetheless, the implications of changing the existing set of assumptions can easily be ascertained in the HRWO economic model, once there is deemed to be adequate information.

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