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Application of an ecosystem accounting framework for freshwater ecosystem services in the Waikato Region.

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Confidential Report

Application of an ecosystem accounting framework for freshwater ecosystem services in the Waikato Region

Waikato Freshwater Ecosystem Services Assessment - Phase 5

Richard T. Yao and David J. Palmer

Land use, land cover, and freshwater ecosystem services in the Waikato Region

Report information sheet

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Photo description and credits	• Pastoral dairy farming and exotic forestry are dominant productive land use in the Waikato and Bay of Plenty regions. https://www.waikatoregion.govt.nz/environment/land-and-soil/land-use-in-the-waikato/ https://www.boprc.govt.nz/environment/land/forestry • Coromandel Forest Park encompasses a lush temperate native forest https://nzjane.com/guide-to-coromandel-forest-park-what-to-see-and-do/ • Dairy farming has expanded significantly in the region over the past two decades. https://www.rnz.co.nz/news/national/465984/waikato-dairy-farmers-struggling-with-historic-dry-conditions

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Executive summary

The Waikato Regional Council (WRC) is undertaking a long-term project to assess ecosystem services (ES) from freshwater resources in the Waikato Region. This project contributes to the WRC Regional Policy Statement by ensuring that the range of ES associated with natural resources is recognised, maintained, and enhanced to contribute to human wellbeing in the region. The first two phases of this project involved a desktop assessment of selected freshwater bodies (rivers, streams, lakes, wetlands, and terrestrial geothermal areas) in the Waikato and Waihou river systems to identify, quantify, and value (where possible) the freshwater ES. The third phase assessed 57 ES provided by the rivers and streams in the region's Ohinemuri catchment. Phase four developed an ecosystem accounting framework and created two pilot ecosystem accounts for the Waikato River Catchment, accounting for approximately 34% of the Waikato region. To our knowledge, these ecosystem accounts are the first freshwater ecosystem accounts in New Zealand at a catchment level. This phase five project has further developed and applied the phase four framework to create ecosystem accounts for key freshwater ecosystem services supplied by freshwater resources throughout the region.

This project

The aim of this study (Phase 5) was to evaluate the impact of land use changes over time on freshwater-related ecosystem services (FWES) in the Waikato Region. Building on the capabilities developed for parameterising and running InVEST in Phase 4, and leveraging available data, spatial models, and expertise in water flow studies, we focused on assessing the region's ecosystems' capacity to provide the following FWES: (1) Water Yield, (2) Quick Flow, (3) Local Recharge, (4) Baseflow, and (5) Avoided Erosion. Our analysis involved distributing these ecosystem services across the eight Freshwater Management Units (FMUs) and categorising them according to 19 different land use and land cover categories (LULCs).

Ecosystem services are the benefits people obtain directly or indirectly from ecosystems. In this project, we utilised the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) suite of models to assess these key ecosystem services. Water yield was quantified using the InVEST Annual Water Yield model, which calculates the annual difference between precipitation and evapotranspiration, accounting for variability due to land use, soil conditions, and climate. It is measured in cubic metres of water within the region, by FMU or by LULC.

The InVEST Seasonal Water Yield model was used to analyse three additional ecosystem service indicators: Quickflow (QF), which measures rapid surface runoff during precipitation events, Local Recharge (LR) which indicates groundwater replenishment from local precipitation not absorbed by vegetation, and Baseflow (BF) which assesses a pixel's contribution to streamflow during dry periods.

The InVEST Sediment Delivery Ratio model was employed to evaluate Avoided Erosion (AE), which measures the role of vegetation in preventing soil loss—a crucial ecosystem service for local soil conservation. This metric quantifies the effectiveness of erosion prevention within the region or FMU and is measured in tonnes of sediment avoided per hectare.

Key results

Comparing the periods of 2001/02 and 2018/19, significant changes were observed in areas dedicated to primary production in the region. The data show that areas used for dairy cattle farming increased by 39%, while farms with a mix of sheep, beef, cattle, horses, and deer grew by 28%. Conversely, the areas designated for planted forests and those dedicated to beef cattle farming decreased by 22% and 40%, respectively.

Our analysis of land use allocation by Freshwater Management Unit (FMU) in the region indicated that, of the eight FMUs, seven experienced an increase in the area dedicated to dairy farming. The Upper Waikato FMU saw the most significant expansion, with dairy farm areas growing by 106%, from 85,728 ha to 176,490 ha. In contrast, the Coromandel FMU was the only one to witness a decline in dairy farming area, with a reduction of 3%.

Regarding planted forests, seven FMUs experienced a decrease in area, with the Middle Waikato and Upper Waikato FMUs showing the most substantial reductions of 44% and 39%, respectively. The West Coast FMU was the sole FMU to see an increase in planted forest area, with a gain of 17%. The Coromandel FMU exhibited the least change in land use, maintaining the most stable land use distribution among the eight FMUs.

Results from the InVEST models show how freshwater ecosystem services (FWES) indicators were impacted by the shift to more intensive land use over the 17-year period. The Annual Water Yield (AWY) model indicates that with an increase in intensive dairy farming and a reduction in planted forest areas, the overall water yield in the region increased by 24.3 million m^3 during the wet year (2001/02) and 30.5 million m^3 during the dry year (2018/19). Although these changes in volume are in the millions of cubic metres, the percentage increase is relatively small—less than 1%, with increases of 0.113% and 0.239% for the wet and dry years, respectively. This modest increase can be attributed to reduced tree interception following deforestation and decreased evaporation rates, as trees transpire more water vapour into the atmosphere through their leaves and branches, a process facilitated by solar radiation. These findings suggest that, accounting solely for biophysical factors mentioned above—and excluding water use for stock watering and milk processing, and other human activities—the shift from forestry to dairy farming has resulted in increased water availability.[1] Assuming this additional water could be utilised for irrigation, and with the value of irrigation water at approximately $0.16 per cubic metre based on Denne et al. (2011), the increased water yield during the wet year and dry year can be valued at $3.9 million and $4.9 million, respectively.

The team's careful construction of input datasets and rigorous parameterisation of the InVEST Seasonal Water Yield (SWY) model yielded significant insights; however, the outputs for Baseflow, Quickflow, and Local Recharge presented unexpected trends, as confirmed in consultation with our water flow scientist at Scion. It is therefore recommended that the input parameters for the SWY model be re-assessed in future analyses. Additionally, a comparative evaluation of the SWY model results against those from a complementary seasonal hydrological model would enhance validation and deepen understanding of these outcomes.

Results from the InVEST Sediment Delivery Ratio model reveal a pattern of reduction in the value of avoided erosion associated with land use change. Specifically, transitioning to more intensive agriculture, such as dairy farming, resulted in a 0.024% reduction in avoided erosion, equating to approximately 3.1 million tonnes of additional sediment. Assuming a value of $8.51 per tonne of sediment avoided, as calculated in Barry et al. (2014), this reduction corresponds to an estimated value of approximately $26.4 million for the region. While the region experienced an average gain of $4.4 million[2] in water yield value, this gain was outweighed by an average loss of $26.4 million in avoided erosion value, leading to a net loss of $22.0 million across two freshwater ecosystem services values.

Implications of results for the client

This study underscores the potential effects of land-use changes on the provision of freshwater (water yield) and the quality of freshwater (avoided erosion), which are essential ecosystem services in the region.[3] Estimates from the spatial modelling and InVEST models are presented in summary tables that are broken down into FMUs and LULCs. These tables and ecosystem accounts can be used to update the web map and related database on freshwater ecosystem services assessments on the WRC website.

This study highlighted how land-use change might impact the supply of water and the quality of water in the entire Waikato region. It demonstrates operationalisation of the concept of ecosystem services as

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[1] The calculations from the AWY model do not account for anthropogenic water uses like domestic water supply and livestock drinking water.

[2] The amount of $4.4 million represents the average of the water yield values of $3.9 million during the wet year and $4.9 million during the dry year.

[3] We should have also considered other freshwater ecosystem issues, such as nitrate leaching and *Escherichia coli* contamination, which are associated with dairy farming. However, addressing these requires the use of additional models that were not feasible due to resource constraints and intellectual property limitations.

being advocated for in Gardiner and Huser (2017). The Waikato web map with the associated database on freshwater ecosystem services assessments on the WRC website may be updated with this report.[4]

This report demonstrates the connection between the region's environment, economy and society, which may provide policy discussion points on sustaining and enhancing freshwater resources and their contributions to human well-being. The report could help inform the reporting of Waikato Progress Indicators (Huser & Killerby, 2021), as well as WRC's work with national government agencies on the healthy waterways programme and the National Policy Statement for Freshwater Management (New Zealand Government, 2020).

The recent review report by the Parliamentary Commissioner for the Environment (PCE) evaluated the 24 most widely used water models in New Zealand (Parliamentary Commissioner for the Environment, 2024). A significant challenge identified in the use of these models is their lack of transparency and accessibility, with many being opaque in their methodologies. Additionally, the models often yield divergent results and there is considerable competition among various modelling frameworks. The InVEST model, used in this project, was not included in the PCE report, reinforcing our belief that this is only the second application of InVEST in New Zealand. The InVEST models for water are open-access and user-friendly, with an enhanced modelling interface. Furthermore, the data used to operate InVEST can be made publicly available, promoting transparency and facilitating validation and cross-examination of the data and results.

WRC is one of the regional councils in New Zealand using freshwater models to assess water quality, water quantity or both to support water regulation and management (Parliamentary Commissioner for the Environment, 2024). The ecosystem accounts generated through this project have the potential to highlight trends and demonstrate the impacts of land use changes on freshwater quality and quantity in the region. Specifically, the modelled results of water quality and quantity presented in this document are organised by FMUs in the ecosystem capacity accounts. These figures may serve as a foundation for generating spatially explicit measured indicators of water quality (avoided erosion) and quantity (annual water yield). This aligns with the National Policy Statement for Freshwater Management 2020, Clause 3.29, which states that "Every regional council must operate and maintain, for every FMU: (a) a freshwater quality accounting system; and (b) a freshwater quantity accounting system."

Further work

This research has refined and extended the framework developed in Phase 4. In Phase 5, although we identified some issues with the results of the InVEST SWY model, we found the results from the InVEST AWY and SDR models to be robust. These robust results from Phase 5 will be used in the upcoming Phase 6 of this long-term project to incorporate the freshwater ecosystem service values into the Integrated Economic-Environmental Modelling (IEEM) framework. The IEEM framework is a computable general equilibrium (CGE) model, as described in Banerjee et al. (2019), that can be further developed and applied to model the links between freshwater ecosystem services and the economy and society in the Waikato region.

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[4] The Waikato Regional Council's freshwater online database can be accessed at https://waikatoregion.maps.arcgis.com/apps/webappviewer/index.html?id=cd512953486b430c8b0a18ee50c5467a.

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Introduction

Since 2015, the Waikato Regional Council (WRC) has led a series of projects to assess and enhance freshwater ecosystem services (ES) in the Waikato region. These initiatives have developed foundational frameworks, integrated Mātauranga Māori, evaluated ES within specific catchments, and advanced ES valuation methodologies, all to support sustainable freshwater management across rivers, lakes, geothermal sites, and catchments.

Summaries of Waikato Regional Council's ES projects from 2015 to present

- **Freshwater Ecosystem Services Project (FWESP) – Phase 1 (2016):** Conducted by Scion, Kessels Ecology and WRC in collaboration with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia, this foundational phase established a framework for assessing freshwater ES aligned with the objectives of the Waikato Regional Policy Statement. A spatially organised database was created to support structured monitoring and evaluation of ecosystem services across rivers, lakes, wetlands, and streams, providing an essential baseline for future assessments (Baillie & Yao, 2015; Olubode-Awosola, 2016).

- **FWESP Phase 2 (2018) – Waihou River Ecosystem Services Assessment:** In this phase, ecosystem services within the Waihou River catchment were assessed, examining their contributions to regional wellbeing. Conducted by Scion, this analysis informed land management practices, particularly within exotic grassland areas, to support sustainable resource use aligned with regional policy objectives (Baillie & Yao, 2018).

- **Assessment of Ecosystem Services from Terrestrial Geothermal Sites in the Waikato Region (2018):** In collaboration with Wildland Consultants, WRC assessed ecosystem services at 38 terrestrial geothermal sites, noting their significant cultural, recreational, and economic benefits. While certain ES values proved challenging to quantify, preliminary indicators highlighted the unique contributions of geothermal habitats, with recommendations for further comprehensive assessments focusing on cultural values and cost-effective evaluation methodologies (McQueen et al., 2018).

- **FWESP Phase 3 (2020) – Ohinemuri Catchment Ecosystem Services Assessment):** As Phase 3 of the broader freshwater ES project, this assessment focused on the Ohinemuri catchment, evaluating 57 ES types across provisioning, regulating, and cultural services (Baillie et al., 2020). Findings underscored pressures on water quality from factors such as elevated nitrogen levels and increased water temperatures, informing the Action for Healthy Waterways programme and the National Policy Statement for Freshwater Management.

- **Complementing Freshwater Ecosystem Services with Mātauranga Māori Knowledge (2019):** Conducted by Am^2 and Associates, this project expanded on the initial ES framework by integrating Mātauranga Māori. It focused on the cultural values associated with freshwater ecosystems in the Lower Waikato region (Hopkins & Kelepamu, 2019). Community surveys with mana whenua and local residents provided critical insights into the evolving cultural, social, and economic values within the ecosystem services framework.

- **SEV Applicability to WRC Freshwater Ecosystem Services Project (September 2020):** Streamlined Environmental Ltd. evaluated the applicability of the Stream Ecological Valuation (SEV) methodology to derive ES scores from WRC monitoring data (Eivers & Phillips, 2020). This proof-of-concept demonstrated that SEV could facilitate systematic ES mapping across diverse land uses, providing a scalable foundation for robust regional freshwater management.

- **FWESP Phase 4 (2022) – Framework for Developing an Environmental Accounting System for Freshwater Ecosystem Services:** In this phase, the Scion ES team developed an ecosystem accounting framework and created two pilot ecosystem accounts for the Waikato River Catchment, covering approximately 34% of the Waikato region (Yao & Palmer, 2022). These accounts are notable as the first freshwater ecosystem accounts at a catchment level in New Zealand.

Current Phase – FWESP Phase 5: The current Phase 5 project builds on the frameworks (particularly the ES accounting framework in Phase 4) and findings from the preceding FWESP phases to establish ecosystem accounts for freshwater resources across the Waikato region, taking into account the region's seven freshwater management units (FMUs).

Rationale for Assessing Freshwater ES in The Region

The Waikato Regional Council (WRC), in alignment with other regional councils and government bodies both in New Zealand and internationally, has identified a significant gap in the monitoring and reporting on the state of the natural environment. In response, the WRC is intensifying its efforts to collect data and report on the status of both pristine and transformed ecosystems within its jurisdiction. This effort is framed within the ES framework, which recognises ecosystems as crucial assets that deliver wide-ranging benefits to the economy, the environment, and society at large. WRC places a particular emphasis on freshwater, considering it the region's most vital resource, now facing significant threats from pollution and overuse. The region houses the longest river in New Zealand, the Waikato River, and over 100 lakes, including the nation's largest, Lake Taupo. The demand for agricultural land has resulted in the reduction of the size and depth of waterways, particularly wetlands (Myers et al., 2013). Land use change to a more intensive farming systems has increased the flow of nutrients and sediments into these water bodies, adversely affecting water quality (Elliott et al., 2016). Land use change also influences the quantity of water in the region and with climate change, extreme weather events are making water flow regulation service more important to both the environment and society.

Freshwater ES are essential for human well-being and have garnered more focus than other ES types, as highlighted in studies by Guerry et al. (2015), Polasky et al. (2015) and Bagstad, Ancona, et al. (2020). Freshwater ecosystems offer a broad array of services to society, both through direct uses such as drinking, household, agricultural, and industrial purposes, and indirect uses, including power generation and transportation, as noted by Baillie and Yao (2018). However, the delivery of these freshwater-related ES is influenced by the land use and vegetation cover around these ecosystems, as discussed by Esse et al. (2021) and Yao and Palmer (2022).

Building on the accomplishments of Phase 4, this long-term project's Phase 5 aims to further refine and apply the framework developed in the previous phase. This framework quantifies the values of freshwater that may be impacted by changes in land use. Moreover, Phase 5 endeavours to integrate these values into policy discussions and assist in the establishment of a comprehensive freshwater environmental or natural capital accounting system for the entire Waikato Region.

To achieve these goals, the following activities were undertaken during Phase 5:
a) A scoping literature review was conducted to explore the value of freshwater ecosystems to society, emphasising the spatial quantification of these values.
b) Data were collected, and spatial layers constructed, to support the operation of spatial models. These models quantify the values of ecosystem services (ES) affected by land-use and land cover changes.
c) Key trends in water availability and water quality within the study area were identified, focusing on how these are influenced by the rate of land-use change. This analysis was segmented by the region's eight Freshwater Management Units (FMUs).
d) Results from spatial modelling were utilised to create ecosystem accounts. These accounts are segmented by 12 LULCs.

Phase 4 of the project focused on the Waikato River catchment, which includes the region's hydro lakes, and divided the area into eight overlapping sub-catchments for hydropower generation (Yao & Palmer, 2022). Building on this foundation, the current Phase 5 project extends to encompass the entire Waikato region, which is already organised into eight distinct Freshwater Management Units (FMUs) as previously defined by the Waikato Regional Council (WRC) in accordance with the National Policy Statement for Freshwater Management 2020.

Background

The Waikato Region, like other regions in New Zealand, faces a significant challenge: balancing the maximisation of social, cultural, and economic benefits derived from natural resources in a sustainable manner that preserves the quality and quantity of freshwater resources.

A noticeable trend towards economic growth in the region involves intensifying land use, transitioning from less intense forestry and pasture to more productive dairy farming, which yields significantly greater revenue. However, with the imposition of carbon prices (currently just above NZ$54.25 per tonne of CO2 equivalent) and the development of policies limiting further expansion of dairy farming (e.g., Healthy Rivers Plan Change 1), landowners are considering reverting their pastoral agricultural farms to forest tree plantations. The literature has also indicated a growing support for valuing ecosystems to help conserve the planet (Nature - Editorial, 2021).

Given these circumstances, it is crucial to assess the impacts of land use change on our important freshwater resources using modelling tools. The 2024 PCE report underscores the importance of utilising water biophysical models to analyse how changes in land use affect both water quality and quantity. The recent review published by the Parliamentary Commissioner for the Environment evaluates the 24 most commonly used water models in New Zealand (Parliamentary Commissioner for the Environment, 2024). One significant challenge noted is the lack of transparency and accessibility in many models, as they are often opaque. Furthermore, different models yield divergent results, and there is competition among various modelling frameworks.

The InVEST model used in this project was not mentioned in the report, which supports our belief that this is only the second application of InVEST in New Zealand. The InVEST open-access models for water are accessible to everyone, and its recently improved modelling interface makes it easy to use (Natural Capital Project, 2024). InVEST has been integrated with established economic models to enhance the representation of the value of natural ecosystems in decision-making processes (Banerjee et al., 2020; Johnson et al., 2023). The data used to run InVEST can also be made publicly available, providing transparency and allowing for validation and cross-examination of the data and results. InVEST could be a valuable addition to the mix when evaluating specific environmental issues at the landscape level, such as the impacts of land use change at the FMU, catchment, regional, or national level. One drawback of InVEST is that it is simplistic and is limited to annual and seasonal water modelling, while water data can now be available on an hourly or real-time basis.

WRC is one of the regional councils in New Zealand using freshwater models to assess water quality, water quantity or both to support water regulation and management (Parliamentary Commissioner for the Environment, 2024). The ecosystem accounts generated through this project have the potential to highlight trends and demonstrate the impacts of land use changes on freshwater quality and quantity in the region. Specifically, the modelled results of water quality and quantity presented in this document are organised by FMUs in the ecosystem capacity accounts. These figures may serve as a starting point for generating spatially explicit measured indicators of water quality (avoided erosion) and quantity (annual water yield). This aligns with the National Policy Statement for Freshwater Management 2020, Clause 3.29, which states that "Every regional council must operate and maintain, for every FMU: (a) a freshwater quality accounting system; and (b) a freshwater quantity accounting system." (New Zealand Government, 2020).

Methods and Data

Methods

Impacts of land use in the region was measured for 2001/02 and 2018/19 and the value of the flow of selected freshwater ecosystem services were quantified. The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) platform was used to explore the potential impacts of land use change on water availability and water quality. InVEST is an open-source platform that provides a suite of spatial models for exploring how changes in ecosystem quality and features are likely to alter the flow of ES that are realised by society (Natural Capital Project, 2024).

In this Phase 5 project, we applied three models from the InVEST platform: Annual Water Yield (AWY), Seasonal Water Yield (SWY), and Sediment Delivery Ratio (SDR).

To run the three InVEST models, we undertook several activities. These included the construction of geospatial layers for climate, land use/land cover classes, hydrological soil groupings, rainfall, and evapotranspiration. Additionally, we parameterised the InVEST models based on the literature and expert opinions.

Annual Water Yield

Water yield refers to the amount of water generated by a watershed or catchment area. It is typically calculated as the difference between precipitation and evapotranspiration. Precipitation includes any form of water released from clouds, such as rain, freezing rain, sleet, snow, or hail. Evapotranspiration encompasses two related processes: (1) the movement of water from the soil through plants to the atmosphere (transpiration), and (2) the direct movement of water from the soil to the atmosphere (evaporation). When the soil is sufficiently wet, the rate of evaporation is governed by atmospheric conditions.

To calculate the annual water yield for the entire study catchment and its sub-catchments, we used the InVEST Annual Water Yield (AWY) model (Natural Capital Project, 2024). The AWY model also includes an extension called the Hydropower Valuation model, which quantifies changes in water yield, consumptive water use, and hydropower generation. We used this extension model in Phase 4 to cover the Waikato catchment, which includes hydro lakes. However, in Phase 5, where we covered the entire region, we chose not to use this hydropower model, to manage the scope of the study, as a large proportion of the region (66%) does not have hydro dams, making it unnecessary.

Spatial analysis in InVEST was conducted on a per-pixel basis, with each pixel representing a 100m x 100m area, forming a one-hectare grid. The AWY model calculates water yield based on the runoff from each pixel. Water yield is determined by subtracting the proportion of water lost to evapotranspiration from the total rainfall. The model does not differentiate whether the water originates from surface, subsurface, or baseflow sources, but generally assumes that water yield for each pixel is derived from one of these channels (Natural Capital Project, 2024). It then aggregates all water yield estimates per pixel for each sub-catchment. This pixel-based approach allows for the consideration of variations in climatic and biophysical factors across the study area, such as soil type, rainfall, land cover, and vegetation. The calculations from the model (without the Hydropower Valuation component) do not account for anthropogenic water uses like domestic water supply and livestock drinking water. This is therefore a limitation of the AWY model, as the impact of water use for both animal and human consumption can be substantial.

In Figure 1, we highlight the key components of the AWY model, which is configured using vegetative data such as plant type, rooting depth, evapotranspiration coefficient by crop type, and plant-available water. We also developed spatial layers for rainfall and major land use/land cover classes. However, as depicted in Figure 1, the AWY model does not incorporate factors such as leaf type, seasonality, fog, and subsurface flow, since these data are often not readily available or accessible. For further details of the AWY spatial equations, please refer to the latest version of the InVEST Manual (Natural Capital Project, 2024).

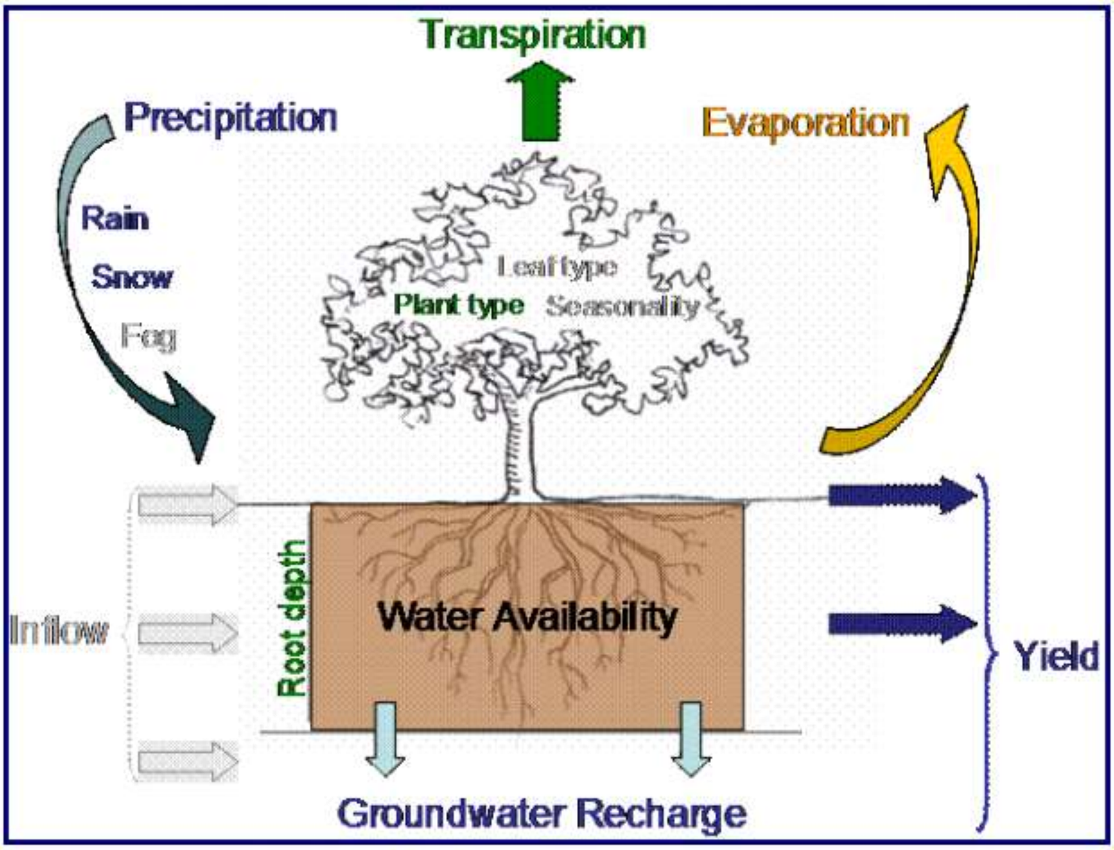

Figure 1. Conceptual diagram illustrating the simplified water balance method utilised in the Annual Water Yield model (Source: Natural Capital Project 2024). The elements of the water balance shown in colour are incorporated into the model, while those in grey are excluded.

Nine datasets were developed to implement the InVEST AWY model in the entire Waikato region (Table 1). The format for constructing the annual average precipitation and potential evapotranspiration (PET) datasets was based on the long-term average climate data method by Wratt et al. (2006). These datasets were reprojected from the New Zealand Map Grid (NZMG) to the New Zealand Transverse Mercator (NZTM) and resampled to a 100-metre cell size resolution. Rainfall and PET data for the years 2001/02 (July to June) and 2018/19 (July to June) were obtained from NIWA’s daily Virtual Climate Network (VCN) Station data, which provides daily data on a five-kilometre point grid across New Zealand. We extracted VCN data for the region, averaged it across the year, and spatially interpolated it using Inverse Distance Weighting (IDW) to a 100-metre cell size resolution. This process supplies the AWY model with both long-term average rainfall and PET, as well as specific rainfall and PET data for 2001/02 and 2018/19, all in consistent 100-metre cell size resolution rasters.

Table 1. Data sets constructed for running the InVEST Annual Water Yield model.

Data set number	Data set title*	Developed using	References
1	Annual average precipitation	NIWA's daily Virtual Climate Network (VCN) Station data	Wratt et al. (2006)
2	Annual average potential evapotranspiration	Same as above	Same as above
3	Depth to root restricting layer	Fundamental Soil Layers (FSL)	LRIS (2010)
4	Plant available water content	Same as above	Same as above
5	Land use/land cover	Land Cover Database v5.0 (LCDB5) layer and Agribase enhanced LCDB	Landcare Research (2020); Assure Quality (2022)
6	Shape file of the sub-catchments	River Environment Classification (REC); Digital Elevation Model (DEM); InVEST DelineateIT model	Snelder et al. (2004); Columbus et al. (2011); Sharp et al. (2020)
7	Biophysical table (Plant evapotranspiration coefficient (Kc); Vegetation cover; Rooting depth)	We initially used Moderate Resolution Imaging Spectroradiometer (MODIS), then expert opinion of Don White with his key references	Running et al. (2019); Beets and Oliver (2007); White (2022); Zhang et al. (2001); Zhang et al. (2004)
8	Seasonality constant	Seasonal distribution of precipitation derived from data based on related literature	Donohue et al. (2012); Hamel and Guswa (2015)

* Note: For the detailed information on each InVEST data set, please refer to the Natural Capital Project (2024).

The root restricting layer and plant available water content (PAWC) were developed using the Fundamental Soil Layers (FSL) (LRIS, 2010). PAWC values, ranging from zero to one, were also based on the FSL. The root restricting layer was derived from the Potential Rooting Depth (PRD) layer, which defines the minimum and maximum depths at which root growth may be impeded by factors such as penetration resistance, poor aeration, or low available water capacity. Detailed descriptions of these rooting depth categories are provided in Webb and Wilson (1995) and Griffiths (1985).

The LULC rasters for the years 2001/02 and 2018/19 were created using data from the Land Cover Database v.5.0 (LCDB5) (Landcare Research, 2020) and enhanced land cover and land use information from Agribase provided by WRC (Agribase: https://www.asurequality.com/our-solutions/agribase/), which represents the summer periods of 2001/02 and 2018/19. To enhance the detail of the LULC classes, we integrated specific categories such as dairy dry stock, dairying, deer, sheep, and sheep and beef from the surveyed data of Agribase into LCDB5. This process resulted in the creation of hybrid LULC maps for the two study periods, 2001/02 and 2018/19.

Alongside the LULC data, the biophysical table forms the foundation for estimating water yield. This table is in spreadsheet format and includes columns for land cover types, the plant evapotranspiration coefficient (Kc) associated with each land cover type, and the maximum rooting depth for each.[5] These parameters were determined by aligning broad habitat classes with descriptions found in Madgwick (1994), Canadell et al. (1996), Allen (1998), and Sharp et al. (2020). The initial Kc factors were derived using 8-day averaged data from the Moderate Resolution Imaging Spectroradiometer (MODIS) at 500-metre resolution (MOD16A2GF) for PET and ET (Running et al., 2019). This data was averaged annually, and specific LULC polygon classes were used to capture PET and ET values for each class. Kc was calculated as the ratio of PET to actual evapotranspiration (AET) for each LULC class.

Using these parameters, we conducted initial test runs of the InVEST AWY model and summarised the results by LULC. These findings were then presented to Dr. Don White, an experienced water flow modelling researcher at Scion, who noted that the AWY model results did not align with expectations based on previous studies (Aguilos et al., 2021; Wang et al., 2012). Consequently, he reviewed the monthly Kc factors by LULC and advised recalculating and adjusting them based on his insights. Drawing on relevant biophysical data, literature, and Dr. White's expert guidance, we collaboratively developed a revised set of monthly Kc factors tailored to the 19 different LULCs for both the wet year (2001/02) and the dry year (2018/19). We averaged the 12 monthly Kc values for each year across the 19 different LULCs, enabling us to convert the Kc parameter per LULC for use in the AWY model. Additionally, the datasets of monthly Kc values were utilised to run the InVEST Seasonal Water Yield model, which will be

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[5] The changes in land use between the years 2001/02 and 2018/19 are, for the most part, due to dairying and planted forests. As such, land uses like native forests, peatlands, and shrublands are unlikely to be influencing the differences in the model between these two years.

discussed in the next section. Dr. White's rationale behind the development of these new sets of Kc parameters is explained in Appendix A.

Similar to the Phase 4 project, we estimated the seasonality constant (Z) as 0.2 * N, where N represents the average annual count of rain-days (> 1 mm) during the study period (Donohue et al., 2012; Hamel & Guswa, 2015). This calculation resulted in a value of 28 for Z during the wet year 2001/02 and 25 for Z during the dry year 2018/19.

In contrast to what we did in Phase 4 of this long-term project, where we delineated sub-catchments using hydro dams with the InVEST DelineateIT package, Phase 5 relied on shape files provided by the WRC for the eight FMUs in the region to calculate AWY results per FMU. We loaded these shape files into the Watersheds boundary input raster of the InVEST AWY model. This inclusion facilitated the generation of AWY outputs per FMU that we presented in ecosystem account distributed across the 8 FMUs.

We present in Table 2 the list of the rooting parameter values per LULC and the crop evapotranspiration coefficients used in the biophysical tables for running the AWY model.

Table 2. Parameters and coefficients in InVEST Water Yield's biophysical tables.

Land use code	Land use description	Vegetation code (1=yes, 0=no)	Rooting depth* (mm)	Plant evapotrans-piration coefficient (Kc 2001/02)	Plant evapotrans-piration coefficient (Kc 2018/19)
1	Dairy	1	600	0.882	0.780
2	Sheep, beef, horse & deer	0	550	0.882	0.780
3	Native forest	1	1600	0.889	0.814
4	Planted forest	1	1200	0.909	0.823
5	Generic pasture	1	550	0.882	0.780
6	Beef cattle	1	550	0.882	0.780
7	Shrubland	1	1000	0.895	0.801
8	Lake	1	-1	0.973	0.971
9	Livestock grazing	1	550	0.882	0.782
10	Urban landscape	1	-1	0.676	0.647
11	Freshwater wetland	0	150	0.928	0.875
12	Barren landscape	0	-1	0.676	0.647
13	Deciduous hardwood	1	1100	0.889	0.814
14	Tussock grassland	1	400	0.889	0.790
15	Cropping	1	400	0.882	0.780
16	River	0	-1	0.961	0.961
17	Market garden	1	300	0.895	0.801
18	Orchard	0	1000	0.899	0.818
19	Saline vegetation	1	-1	0.906	0.902

*Note: InVEST considers the rooting depth value of '-1' as not applicable.

Using the AWY model, the impacts of land use change on water yield were assessed through four spatial simulation scenarios:

1. Land use/land cover from 2001/02 combined with climatic and hydrological data from 2001/02
2. Land use/land cover from 2018/19 combined with climatic and hydrological data from 2001/02
3. Land use/land cover from 2001/02 combined with climatic and hydrological data from 2018/19
4. Land use/land cover from 2018/19 combined with climatic and hydrological data from 2018/19

The impact of land use change during a representative wet year (2001/02) was determined by calculating the difference in water yield volumes (m³) between Scenarios 1 and 2.

Likewise, the impact during a representative dry year (2018/19) was evaluated by comparing the water yield volumes between Scenarios 3 and 4.

Quantification of water flow regulation services using InVEST SWY

The InVEST SWY module uses the above-mentioned spatial data to calculate spatially explicit measures of water flow regulation services in the catchment. These measures include *Quickflow*, *Local Recharge,* and *Baseflow*. While SWY accounts for the variation in rainfall and evapotranspiration rates across the different months, the three measures are reported as spatial indices on a per pixel per year basis (Sharp et al., 2020). Spatially explicit outputs from InVEST SWY model were processed using ArcGIS Pro version 3.3 (ESRI, 2024) to produce digital maps (tif files) that are then used to calculate the above measures for the full catchment, across the FMUs and across LULC classes.

Water runoff refers to "the movement of water under the influence of gravity in channels of various sizes" (McConchie, 2001). Quickflow (QF) is water runoff that occurs during or shortly after rain events (Sharp et al., 2020). It is also referred to as "flood flow" (Duncan & Woods, 2013). QF is a runoff measure that indicates how the landscape's capacity for rainfall infiltration and flood regulation are changing over time. It is calculated with a Curve Number (CN)-based approach, which captures soil and land cover properties. Larger CN values have greater runoff potential (e.g. clay soils and low vegetation cover), while lower CN values have lower runoff potential (e.g. sandy soils and dense vegetation cover) (Sharp et al., 2020).

Baseflow (BF) refers to water reaching streams later when there is no rainfall, e.g. between rain events during the dry season. Local recharge (LR) is the water that becomes available as BF that supports dry-season river flows. LR is calculated by subtracting actual evapotranspiration (AET) plus QF from the amount of rainfall (Sharp et al., 2020). The LR index is computed on an annual time scale but uses values derived from monthly water budgets.

We present in Figure 2 a simple diagram illustrating the spatial calculation of QF, BF and LR in the InVEST SWY model. These three measures of water flow regulation services are influenced by land use change (Bagstad, Ingram, et al., 2020; Esse et al., 2021; Fahey et al., 2010), and in this study, we evaluate the impacts of land use change on each of them in the study region. Like the InVEST AWY model that we used in this project, the InVEST SWY model only accounts for climatic and biophysical factors and not anthropogenic water use (i.e., human extraction of water for irrigating farms and other purposes).

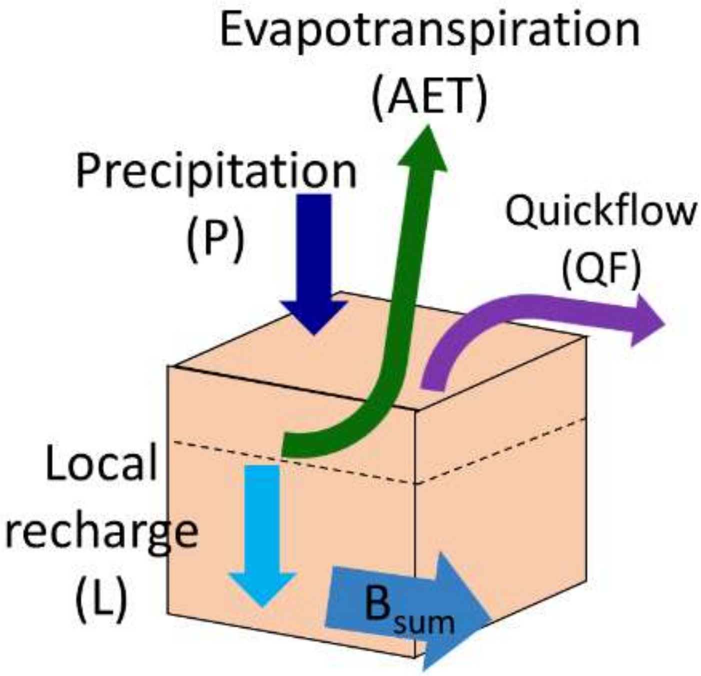

Figure 2. Pixel-scale water balance calculation for Local Recharge, with Bsum indicating the Baseflow, which is the flow that reaches the stream. (Source: Natural Capital Project, 2024).

In applying the SWY model, we used monthly spatial data to capture the seasonal effects. The data we used for running the SWY model, such as average precipitation, PET, Kc, shape file for sub-catchments, and DEM, were collected from the same sources as the AWY model. The 100m-by-100m cell size resolution DEM was also used for the SWY model. The LULC rasters for the 2001/02 and 2018/19 periods used in the AWY model was also used for the SWY model.

In contrast to AWY, the SWY model requires additional data sets such as hydrological soil groups (HSG), a different biophysical table and a rainfall events table. We constructed the HSG data set based on the Fundamental Soil Layer (FSL) and its soil series field and assigning the HSG from S-map online.[6] The final map was converted to a 100-m cell size resolution raster. The biophysical table for SWY was developed by assigning curve numbers to the LULC classes using curve number examples from the USDA Part 630 Hydrology Nation Engineering Handbook, Chapter 9: Hydrologic Soil-Cover Complexes, 2004. The monthly Kc coefficients by LULC class were developed from eight-day averaged Modus[7] 500-m resolution data (MOD16A2GF) for PET, and ET. Data were averaged across each month, and the LULC polygon classes used to capture the PET and ET values for each class. Kc was calculated as the ratio of PET to AET per LULC class. These data were assigned to each LULC class biophysical table.

The rainfall events table was developed using precipitation data where monthly rain day above 0.1mm rainfall were identified and assigned to a .csv table (Wratt et al., 2006). A flow accumulation thresholds value was developed by calculating flow direction and flow accumulation across the 100-m cell size resolution DEM for the study catchment. A series of stream networks was also developed and compared with New Zealand LINZ river vector data[8]; we estimated that somewhere between 500 and 1000 cells contributing toward a stream was normal for the catchment. Therefore, a threshold flow accumulation of 750 cells was assigned to the SWY model.

The SWY model produced preliminary results for three freshwater-related ecosystem services: QuickFlow (QF), Local Recharge (LR), and Baseflow (BF). Dr Don White reviewed these results and identified inconsistencies with the existing literature on water flow, highlighting opportunities for further refinement and analysis. Specifically, with land use changes from forestry to dairy, QF values are expected to increase, while BF and LR values should decrease. This prompted the team to re-examine the spatial data used in the model. After careful scrutiny, we confirmed that the spatial data were correctly derived and specified, and the monthly Kc values used were the adjusted ones provided by Dr White. We suspect there may be an issue with the data derived from S-map or a potential incompatibility of the constructed spatial data with the SWY model.

Sediment Delivery Ratio

The Sediment Delivery Ratio (SDR) model is an InVEST module that aims to measure and map the generation of overland sediment and its delivery to streams (Figure 3). SDR does not model gully, bank or mass erosion. Although SDR generates various outputs, our project specifically focuses on one ecosystem service: i.e., avoided erosion. Avoided erosion indicates how vegetation helps reduce erosion from a specific area, and this is measured in either tonnes per hectare per year or tonnes per square kilometre per year.

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[6] https://smap.landcareresearch.co.nz/maps-and-tools/factsheets/

[7] https://modis.gsfc.nasa.gov/about/

[8] https://data.linz.govt.nz/

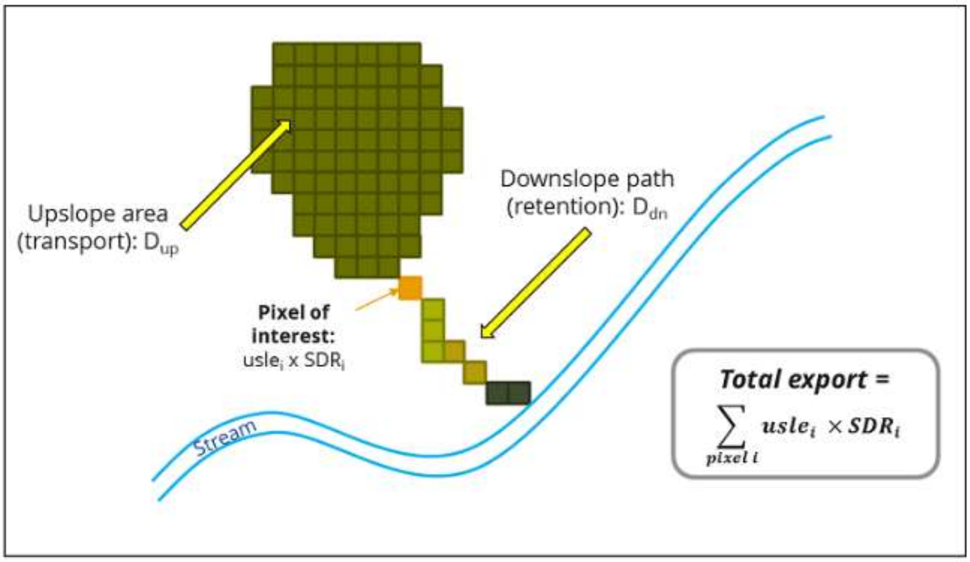

Figure 3. Conceptual method in the sediment delivery ratio (SDR) where each pixel is based on the upslope area and the downslope flow path. (Source: Natural Capital Project 2024)

To implement the InVEST SDR model across the entire Waikato region, three spatial datasets were developed (Table 3). The first dataset is the rainfall erosivity factor (Erosivity R), which measures the impact of rainfall on soil erosion. This parameter, commonly used in the Revised Universal Soil Loss Equation (RUSLE), is expressed in megajoule millimetres per hectare per hour per year. The dataset was created using NIWA rainfall climate normals (Wratt et al., 2006) and model coefficient estimates from Klik et al. (2015).

The second dataset is the soil erodibility factor (Erodibility K), which assesses how different soil properties influence a slope's susceptibility to erosion (Renard et al., 1997). This dataset was constructed using the formulas outlined in (Benavidez et al., 2018), incorporating spatial data on soil organic matter percentage, soil structure, and profile permeability. These data were derived from s-map and FSL, following the method of (Donovan & Monaghan, 2021). Larger K-factor values indicate greater soil susceptibility to erosion, and standard practice typically results in K-factor values ranging between zero and one.

The third data set is the biophysical table which includes three columns: Land Use Land Cover (LULC), soil cover and management factor (usle_c), and support practice factor (usle_p). The usle_c factor represents the ratio of soil loss from a field with specific cover and management practices compared to a field with "clean-tilled continuous fallow" (Wischmeier & Smith, 1978). The support practice factor (P) is defined as the ratio of soil loss under a particular soil conservation practice (e.g., contouring, terracing) to that of a field with conventional upslope and downslope tillage. The P factor accounts for management practices that affect soil erosion by altering the flow pattern, such as contouring, strip cropping, or terracing (Renard et al., 1997). The more effective the conservation practice in reducing soil erosion, the lower the P factor (Bagherzadeh, 2014). To parameterise usle_c and usle_p by land use and land cover classification, we utilised the data and methods from Benavidez et al. (2018).

Table 3. Data sets constructed for running the InVEST Sediment Delivery Ratio model.

Data set number	Data set title[a]	Developed using	Reference
1	Erosivity	NIWA's daily Virtual Climate Network (VCN) Station data	Klik et al. (2015)
2	Soil Erodibility	Same as above	Donovan and Monaghan (2021) Benavidez et al. (2018)
3	Biophysical table	S-map[b], Fundamental Soil Layer	Benavidez et al. (2018)

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[a] Note 1: For the detailed information on each InVEST data set, please refer to the Natural Capital Project (2024).

[b] Note 2, S-map data: Sand, silt, clay, and organic matter as a percentage, profile permeability (K values), Soil Hydrologic Group (HSG), Potential Rooting Depth (PRD), Available Water Capacity (AWC), Plant Available Water (PAW).

Running the InVEST SDR model also requires the inclusion of the digital elevation model for the region, which accounts for slope variability and topography. Since the data used for the InVEST SDR model are based on long-term average rainfall data (Waikato rainfall normals), the outputs generated from the model runs should be interpreted as long-term average values. For example, the estimated value of avoided erosion is not specific to the hydrological conditions of the year 2001/02; rather, it represents the value of avoided erosion for an average year in the region. This avoided erosion value has been assessed by land use and by FMUs. The estimated values have been integrated with calculated avoided mitigation costs (such as sediment filtration for potable water) to compute the non-market value of avoided erosion in 2024 NZ$. This valuation methodology follows the research conducted by Barry et al. (2014), which employed a water filtration cost of $8.51 per cubic metre of sediment.[9]

Ecosystem Accounting Framework

The System of Environmental Economic Accounting (SEEA), developed by the United Nations, integrates economic and environmental data into a unified framework to measure environmental conditions, the economy's reliance on the environment, and its impact on ecosystems. It provides internationally agreed standards for concepts, definitions, classifications, and methods to ensure consistent and comparable statistics.

The SEEA has three components:

1) SEEA Central Framework (SEEA CF): Adopted in 2012 as the first global standard for environmental-economic accounting;
2) SEEA Ecosystem Accounting (SEEA EA): A framework for measuring ecosystem changes and connecting them to economic and other human activities; and
3) SEEA Applications and Extensions (SEEA AE): Demonstrates how SEEA data can inform decision-making, policy analysis, and research.

For this report, we focus on applying the recommendations in the SEEA-EA framework which offers an integrated approach to assessing ecosystems and quantifying the services they provide, which are crucial to economic and human activities. Despite the widespread use of Gross Domestic Product (GDP) as a primary measure of national development, it fails to account for the depletion of natural resources. From 1992 to 2014, while global GDP per capita increased, the per capita value of natural capital significantly declined, underscoring the need to evaluate the health and limits of our natural capital (Kumar, 2018). The SEEA-EA framework has gained global recognition for its ability to offer a more sustainable lens on economic development by incorporating the value of natural resources into decision-making processes (Edens et al., 2022).

This study focuses on evaluating selected ecosystem services related to freshwater resources in the Waikato region, which are vital to both the economy and society. Using spatial modelling approaches and InVEST models, we quantified freshwater ecosystem service flows by LULC class and FMU. The resulting data were used to create preliminary tables for developing ecosystem accounts under the water and land themes, providing a foundation for improved water management and adaptation to environmental challenges (Vardon et al., 2018). This approach aligns with the SEEA-EA's goal of shifting economic thinking towards sustainability by recognising the finite nature of natural resources and the importance of preserving them for future generations (UN-SEEA, 2021).

Spatial data and outputs from two InVEST models—Annual Water Yield and Sediment Delivery Ratio—were utilised to develop two types of ecosystem accounts: the Extent Account and the Capacity Account. The Extent Account, based on the approach proposed by Warnell et al. (2020), documents change in land use between the two study periods. The Capacity Account assesses the ability of each LULC class to provide water-related ecosystem services, such as water yield and erosion prevention, across the region. This account was developed in alignment with methods outlined by Bagstad, Ancona, et al. (2020) and La Notte et al. (2019).

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[9] The water filtration cost of $8.51 has been converted to 2024 NZ$.

Study Site and Land Use Data

The Waikato Region is New Zealand's fourth largest region by area, covering approximately 2.46 million hectares. In 2018, the region had a population of 458,202, accounting for 10% of New Zealand's population (Statistics New Zealand, 2024b). It boasts a wide variety of natural assets, including freshwater resources, that underpin economic growth while also contributing to human well-being. In terms of freshwater resources, the region is home to at least 100 lakes, 20 rivers and 1,420 streams. These water bodies include the nation's largest lake, Lake Taupō, and its longest river, the Waikato River.

Under the 2020 National Policy Statement for Freshwater Management (NPS-FM) in New Zealand, regional councils are responsible for classifying significant aquatic areas—like river catchments, catchment segments, or catchment collections—across each region into what are known as Freshwater Management Units (FMUs). These FMUs are designated at a specific scale that allows councils to work together with tangata whenua and local communities to set objectives and limits for freshwater, as well as to establish measurable targets.

The Waikato Regional Council (WRC) has divided the region into 8 FMUs as shown in Figure 4. At the southern end of the region lies the Lake Taupo FMU, which covers the entire lake and the area upstream to Huka Falls, including aquifers, wetlands, lakes, and rivers. Just above Lake Taupo is the Upper Waikato FMU, which encompasses the Waikato River from Huka Falls to Lake Karapiro, featuring lakes, wetlands, aquifers, rivers, and streams. Further details about these FMUs, along with the others, can be accessed via the following link: https://www.waikatoregion.govt.nz/council/policy-and-plans/freshwater-policy-review/fpr-freshwater-managment-units/

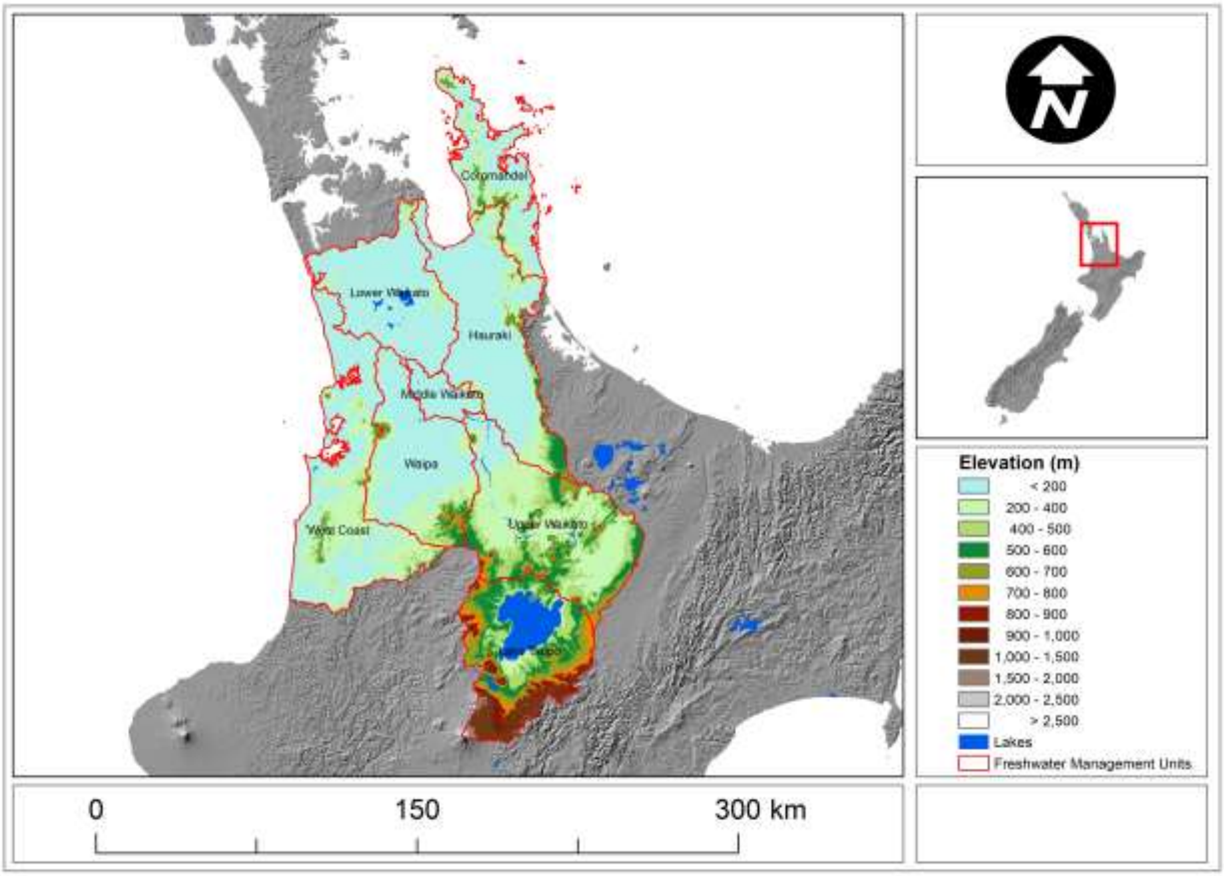


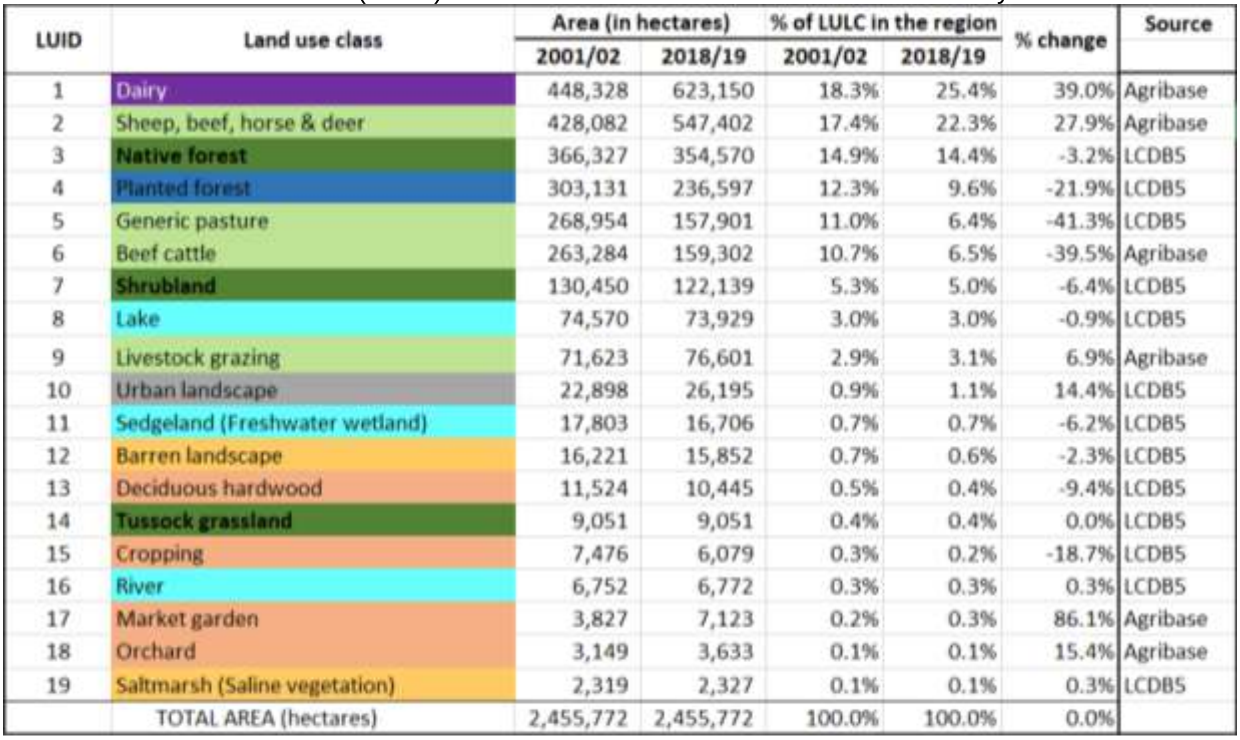
Figure 4. Map showing the location of the Waikato region, its eight (8) Freshwater Management Units (FMUs), and their respective elevations in metres above sea level.

Our assessment of freshwater ecosystem services (ES) covers the entire Waikato region, from Tūrangi in the south to the Coromandel Peninsula in the north (Figure 4). Using LCDB v.5 and Agribase-enhanced LCDB data for the years 2001/02 and 2018/19, we conducted a spatial analysis to determine the distribution of land across 19 key LULC categories. These categories include various pastoral areas such as dairy farming, dry stock (sheep, beef, horses, and deer), generic pasture, beef cattle, and grazing. The analysis revealed that, in both 2001/02 and 2018/19, the dominant land uses in the region were pastoral agriculture (comprising at least 60%), native forests and shrublands (comprising at least 19%), and planted forests (comprising at least 10%) (Table 4).

Between 2001/02 and 2018/19, the area under dairy farming increased by 174,822 hectares, whereas planted forests and dry stock areas decreased by 66,534 hectares and 90,737 hectares, respectively. Figure 5 illustrates the extent of land use change to dairying, showing that a significant portion of existing planted forests (depicted in blue) in 2001/02 was converted to dairy farming (depicted in purple) by 2018/19, particularly in the Upper Waikato FMU. Additionally, a substantial area of dry stock (depicted in green) in 2001 was predominantly converted to dairy farming by 2018/19. The changes in the distribution of key land uses between these two time periods are summarised in Table 5, indicating an increase in the proportion of dairying from 18% in 2001/02 to 25% in 2018/19, while the areas of planted forests and dry stock decreased by 22% and 9%, respectively.

Our analysis of freshwater resources reveals a reduction in freshwater wetlands and lakes in the region, with a decrease of approximately 1,097 hectares and 641 hectares, respectively. This represents a reduction of 6.2% for freshwater wetlands and 0.9% for lakes (Table 4). These findings are derived from our spatial analysis using LCDB v5 data. It is important to acknowledge that this dataset may have some accuracy limitations, as detailed in the LAWA factsheet.[10] Additionally, the observed reduction in freshwater resources may be attributed to the expansion of agricultural activities, which could have led to the contraction and shallowing of waterways (Waikato Regional Council, 2017).

Table 4. Land use/land cover (LULC) distribution in 2001/02 and 2018/19 in the study catchment.



LUID	Land use class	Area (in hectares)		% of LULC in the region		% change	Source
		2001/02	2018/19	2001/02	2018/19		
1	Dairy	448,328	623,150	18.3%	25.4%	39.0%	Agribase
2	Sheep, beef, horse & deer	428,082	547,402	17.4%	22.3%	27.9%	Agribase
3	Native forest	366,327	354,570	14.9%	14.4%	-3.2%	LCDB5
4	Planted forest	303,131	236,597	12.3%	9.6%	-21.9%	LCDB5
5	Generic pasture	268,954	157,901	11.0%	6.4%	-41.3%	LCDB5
6	Beef cattle	263,284	159,302	10.7%	6.5%	-39.5%	Agribase
7	Shrubland	130,450	122,139	5.3%	5.0%	-6.4%	LCDB5
8	Lake	74,570	73,929	3.0%	3.0%	-0.9%	LCDB5
9	Livestock grazing	71,623	76,601	2.9%	3.1%	6.9%	Agribase
10	Urban landscape	22,898	26,195	0.9%	1.1%	14.4%	LCDB5
11	Sedgeland (Freshwater wetland)	17,803	16,706	0.7%	0.7%	-6.2%	LCDB5
12	Barren landscape	16,221	15,852	0.7%	0.6%	-2.3%	LCDB5
13	Deciduous hardwood	11,524	10,445	0.5%	0.4%	-9.4%	LCDB5
14	Tussock grassland	9,051	9,051	0.4%	0.4%	0.0%	LCDB5
15	Cropping	7,476	6,079	0.3%	0.2%	-18.7%	LCDB5
16	River	6,752	6,772	0.3%	0.3%	0.3%	LCDB5
17	Market garden	3,827	7,123	0.2%	0.3%	86.1%	Agribase
18	Orchard	3,149	3,633	0.1%	0.1%	15.4%	Agribase
19	Saltmarsh (Saline vegetation)	2,319	2,327	0.1%	0.1%	0.3%	LCDB5
	TOTAL AREA (hectares)	2,455,772	2,455,772	100.0%	100.0%	0.0%	

Note: Land use data created using LCDB v.5 and Agribase Enhanced LCDB.

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[10] The Land Air Water Aotearoa (LAWA) factsheet on monitoring land cover in New Zealand is available at https://www.lawa.org.nz/learn/factsheets/land/monitoring-land-cover-in-new-zealand.

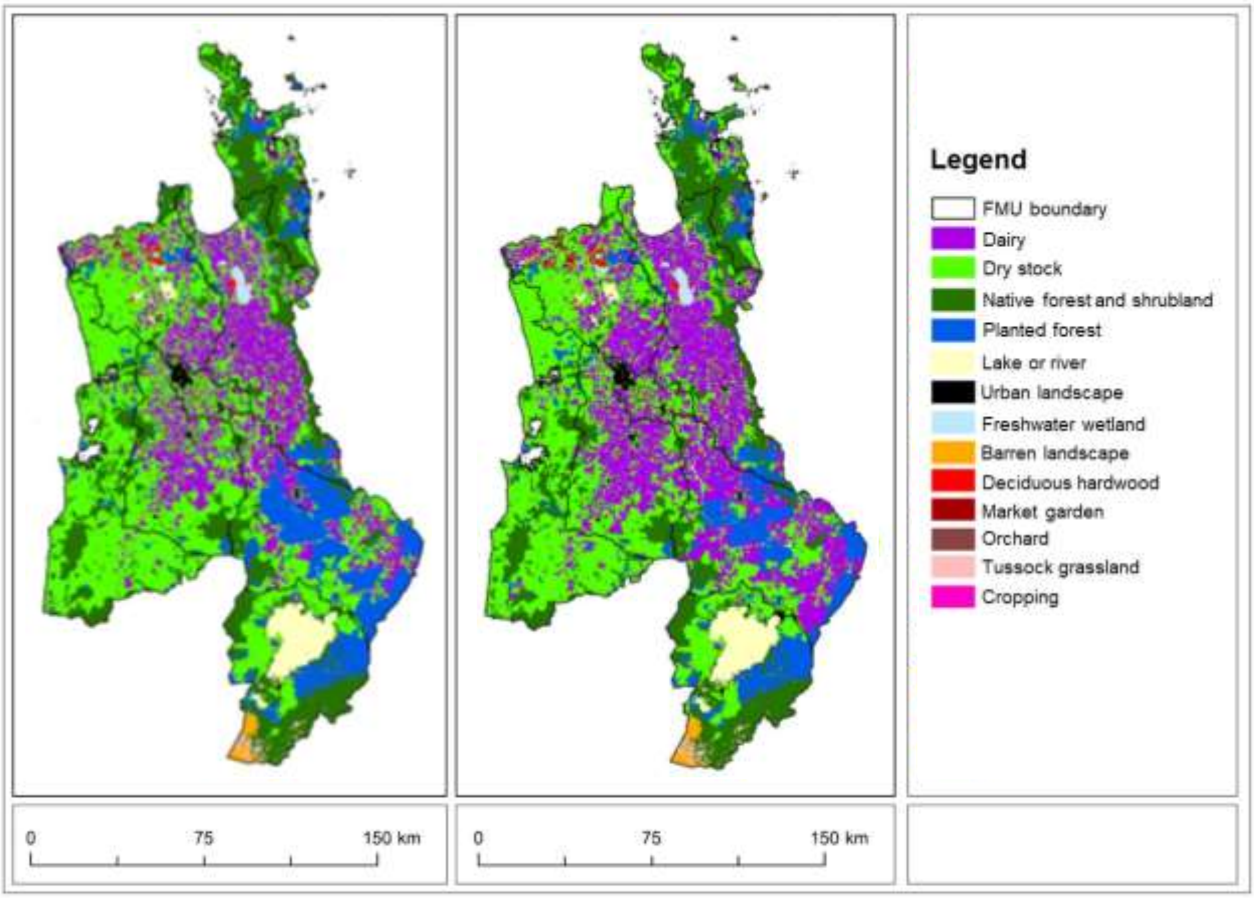


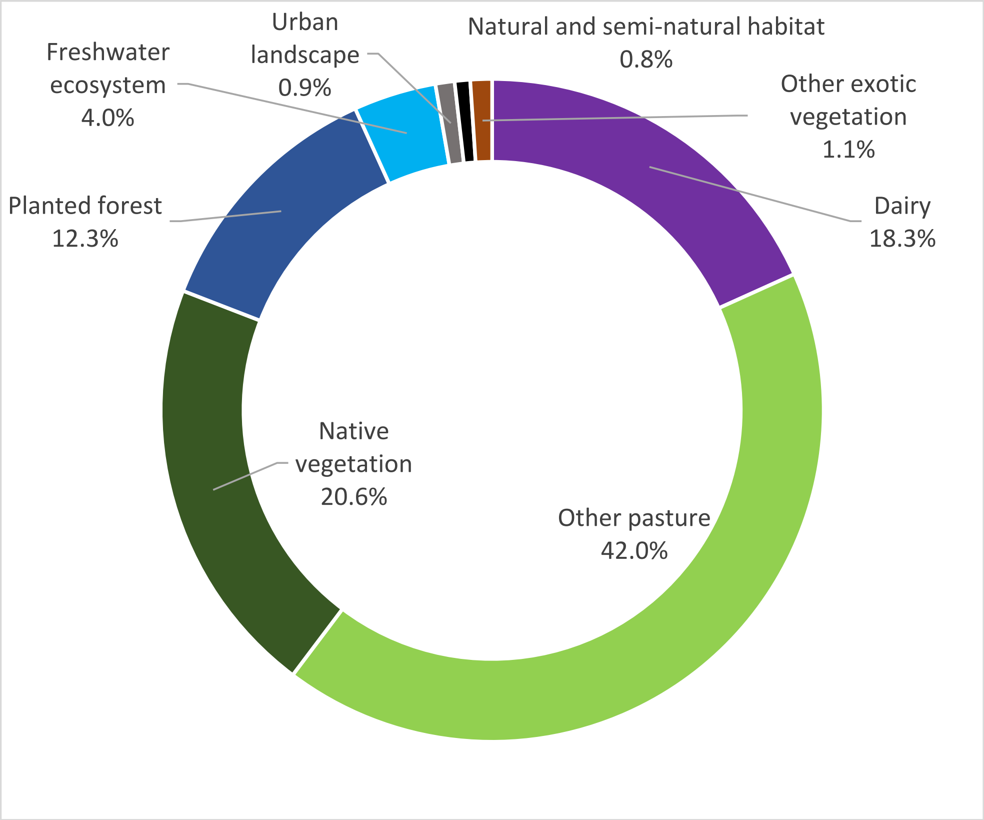
Figure 5. Spatial land use / land cover distribution in 2001/02 and 2018/19 in the study site.

To provide a simple illustration of land use changes within the region, we have aggregated several land use categories to streamline the classification process. Specifically, Land Use Identification Codes (LUIDs) 2, 5, 6, and 9, which denote various forms of less intensive pasture, have been combined into a single category termed 'Dry Stock' (Table 5). The category 'Native Forest and Shrubland' integrates the distinct classifications of 'Native Forest' and 'Shrubland'. Similarly, 'Natural and Semi-Natural Habitat' merges 'Barren Landscape' with 'Saltmarsh'. The category 'Other Exotic Vegetation' encompasses LUIDs 13, 15, 17, and 18, while 'Freshwater Ecosystem' includes lakes, rivers, and sedgelands (freshwater wetlands).

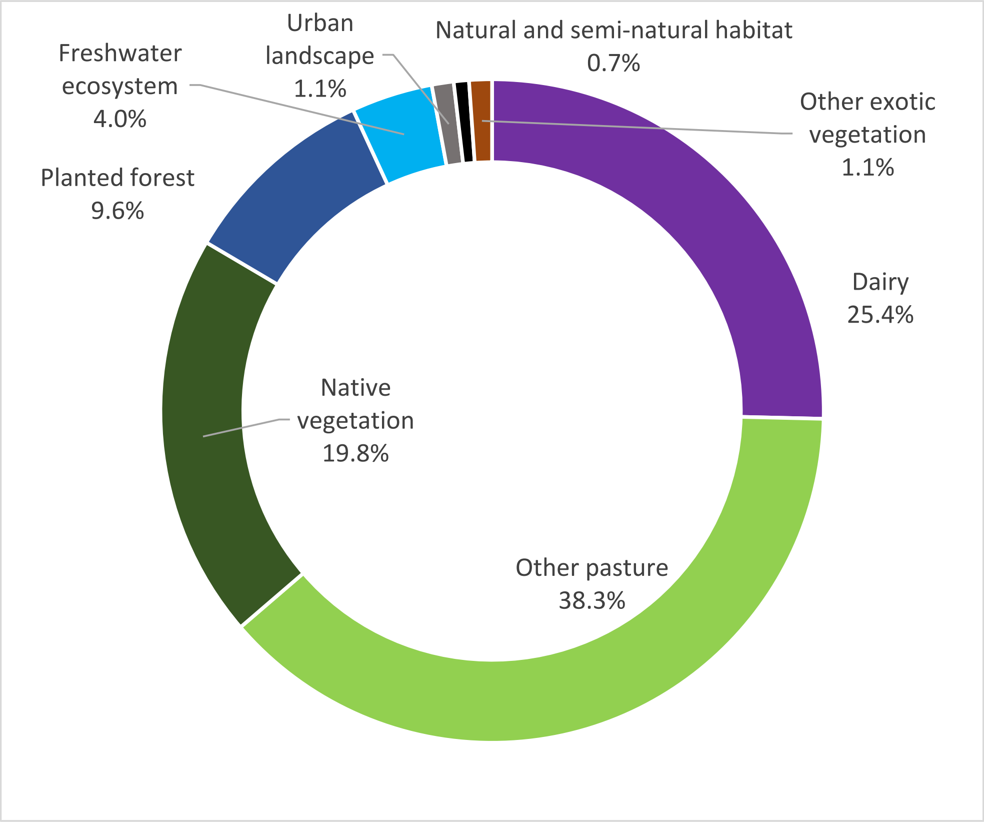
Table 5. Streamlined land use/land cover (LULC) distribution in 2001/02 and 2018/19.

Streamlined LULC category	2001/02 (ha)	2018/19 (ha)	Change in area (ha)	% change
Dairy	448,328	623,150	174,822	39.0%
Dry stock	1,031,944	941,205	-90,739	-8.8%
Native forest and shrubland	505,829	485,760	-20,069	-4.0%
Planted forest	303,131	236,597	-66,534	-21.9%
Freshwater ecosystem	99,126	97,408	-1,718	-1.7%
Urban landscape	22,898	26,195	3,297	14.4%
Natural and semi-natural habitat	18,540	18,178	-362	-2.0%
Other exotic vegetation	25,976	27,280	1,304	5.0%
TOTAL AREA (hectares)	2,455,772	2,455,772		

We present in Table 5 a summary of the streamlined land use categories. Between 2001 and 2018, there was a significant 39% increase in areas under dairy farming, causing the proportion of dairy land in the region to rise from 18% to 25%. Concurrently, the areas under planted forests and other pasture decreased, with their respective proportions falling from 22% to 9% and from 42% to 38% over the same period (refer to Table 5 and Figure 5). This reduction in planted forests and other pasture resulted in a decline in their combined share of the region's total land area, decreasing from 12% and 42% in 2001 to 10% and 38% by 2018.



2001/02



2018/19

Figure 6. Statistical LULC distribution in 2001/02 and 2018/19 in the Waikato region.

Bar charts have been created to illustrate the distribution of streamlined LULC categories by FMU and across the entire Waikato region (Figure 7). The analysis shows that between 2001/02 and 2018/19, the proportion of land under 'Dairy' farming increased in seven FMUs. The most substantial increase occurred in the Upper Waikato FMU, where the proportion of dairy land rose from 20% to 41%. Although the proportion of dairy land did not show a noticeable increase in the bar charts in Figure 7 for most FMUs, the spatial data indicate that dairy areas expanded in all FMUs, with increases ranging from 14% in Hauraki to 106% in Upper Waikato (Figure 8). Urban landscapes grew in seven FMUs, except for the West Coast, which saw a 1% decrease. Additionally, the area of other exotic vegetation, including cropping and market gardening, increased in four FMUs while decreasing in the remaining four.

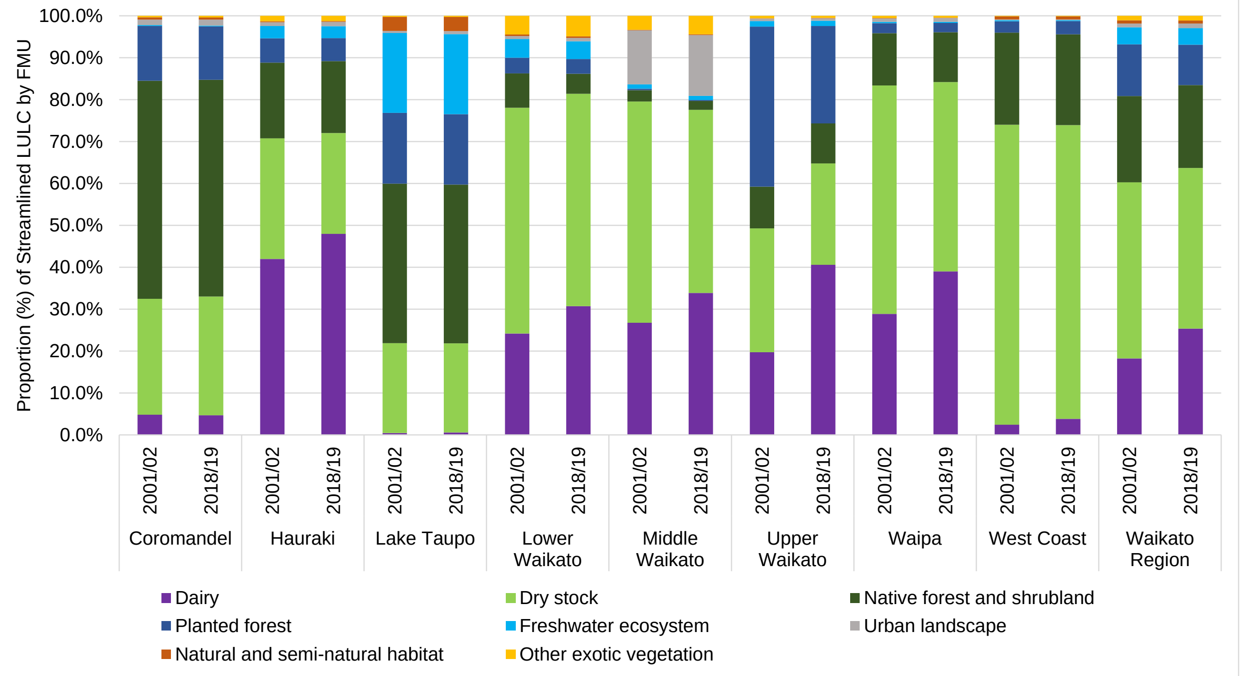


Figure 7. Distribution of streamlined LULC by FMU in 2001/02 and 2018/19.

The area of planted forest across the Waikato region decreased by 22% (Figure 8). This reduction was observed in six FMUs, with the Middle Waikato and Upper Waikato experiencing the most substantial decreases of 44% and 39%, respectively. Notably, the West Coast FMU was an exception, with a 17% increase in planted forest.

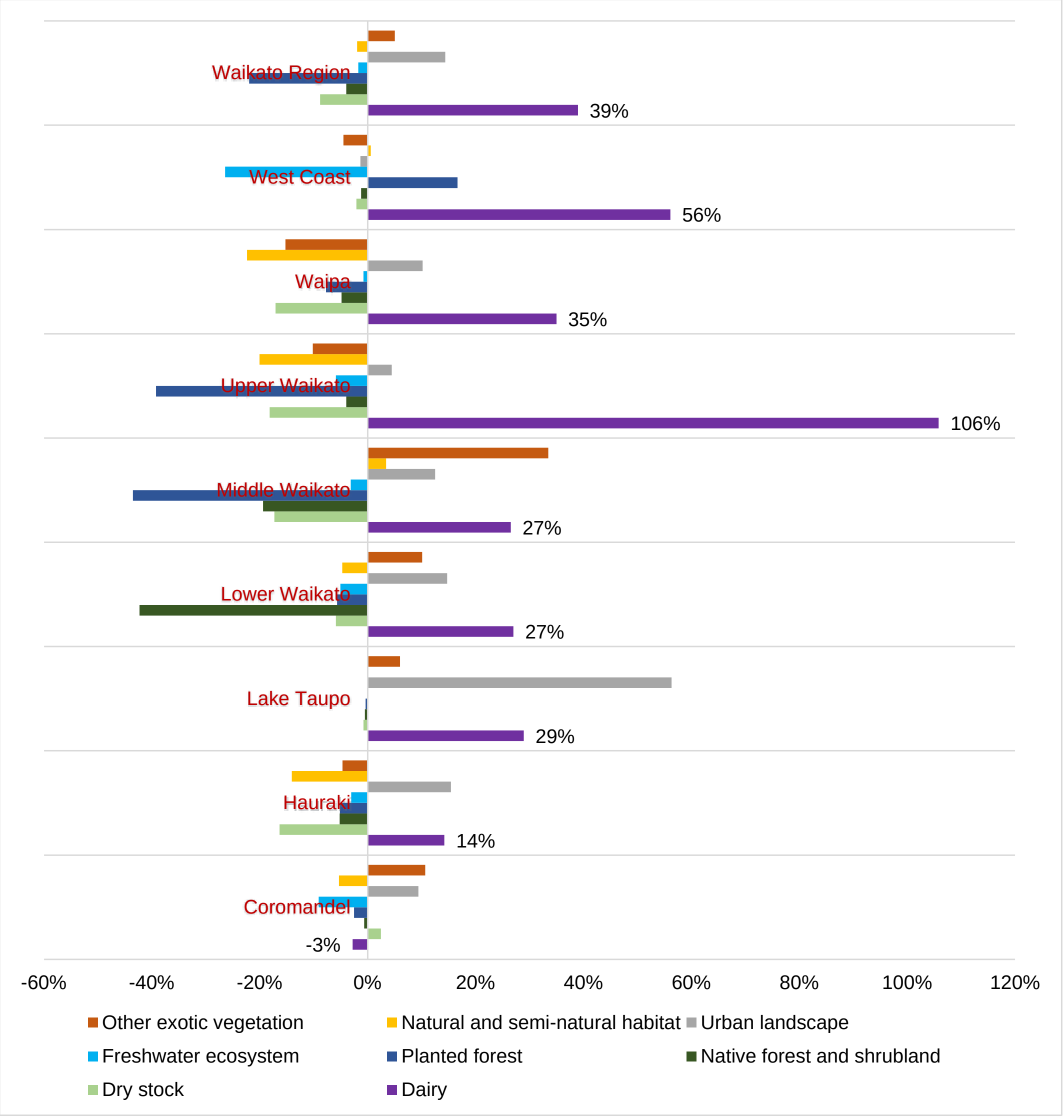


Figure 8. Percentage change in Land Use/Land Cover (LULC) area by Freshwater Management Unit (FMU).

Results

We present the results from the InVEST Annual Water Yield, Seasonal Water Yield, and Sediment Delivery Ratio models in two formats: (1) by FMU, which facilitates comparison of ecosystem service flows based on the extent of land use changes from forestry to dairy, and (2) by land use classification, which represents the two ecosystem accounts. These accounts include the extent account and the ecosystem capacity account.

InVEST Annual Water Yield

Results from the InVEST models show how freshwater ecosystem services (FWES) indicators were impacted by the shift to more intensive land use over the 17-year period. Annual Water Yield (AWY) model results from the simulation scenarios suggest that with an increase in intensive dairy farming and a reduction in planted forest areas, the overall water yield volume in the region increased by 24.3 million m^3 during the wet year (2001/02) and 30.5 million m^3 during the dry year (2018/19). Although these changes in volume are in the millions of cubic metres, the percentage increase is relatively small—less than 1%, with increases of 0.113% and 0.239% for the wet and dry years, respectively. This increase can be explained by the reduction in evaporation rates, as trees transpire more water vapour into the atmosphere through their leaves and branches, a process aided by solar radiation. Assuming this increase in available water in the region can be used for irrigation, and with the value of irrigation water at $0.16 per cubic metre based on Denne et al. (2011), the increased water yield during the wet year and dry year can be valued at $3.9 million and $4.9 million, respectively (Appendix B1). Please note that this water yield assessment focuses solely on the impacts of biophysical characteristics, particularly land use and land cover, which influence evapotranspiration rates. It does not account for the increased water use associated with the conversion from forestry to dairy farming (e.g., stock water and irrigation). Additionally, it does not include anthropogenic ecological values, such as the provision of habitats for native species like blue ducks, eels, and other freshwater species. However, changes in the quantity of water use due to land use change, as well as biodiversity conservation values, will be incorporated into the environmental-economic model to be developed in Phase 6 of this long-term project.

Disentangling the annual water yield results by FMU, we find some variation in the change in water yield. The Upper Waikato FMU which has the greatest reduction of forestry area and highest increase in dairy area, has the highest increase in water yield of 20.7 million m^3 and 25.4 million m^3 of water during the wet and dry years, respectively (Appendix B1). We can then multiply these increases in water availability in the FMU by the price of irrigation water of $0.16/$m^3$ where we find that the highest value in the Upper Waikato FMU of approximately $3.3 million and $4.1 million for the wet and dry years, respectively. Converting this increase on a per hectare basis, the three FMUs with the largest increases in water yield during the wet year are Upper Waikato (48 m^3/ha), Middle Waikato (24 m^3/ha) and Lower Waikato (12 m^3/ha). All these three FMUs experienced significant increase in the area of dairy farms (106%, 27% and 27%, respectively) and substantial decrease in planted forest area (-6%, -44% and -39%, respectively).

InVEST Seasonal Water Yield

Despite the team's careful construction of the input datasets and parameterisation of the InVEST Seasonal Water Yield (SWY) model, the results for Baseflow, Quickflow, and Local Recharge do not align with the expectations from the literature, as discussed with our water flow scientist at Scion.
It is advisable to re-evaluate the inputs for the SWY model in future analyses. Moreover, further investigation is needed to compare the SWY results with those from another established complementary seasonal hydrological model, such as the revised Soil and Water Assessment Tool (SWAT+).[11] SWAT+ is a model that provides a more flexible spatial representation of interactions and processes within a catchment or a watershed.

Given that the results from the SWY model are not consistent with the global literature, we have decided not to present them in this report. The purpose of running the InVEST SWY model was to assess the impacts of land use change on two freshwater-related ecosystem services in the region: flood mitigation during the wettest months (June, July, and August) and drought mitigation during the driest months (January, February, and March). Unfortunately, estimates of Quickflow, Local Recharge and Baseflow

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[11] https://swat.tamu.edu/

from our InVEST SWY runs are not coherent. We hope estimates from future spatial modelling exercises will be robust enough to provide insights into these two critical ecosystem services so that they can be integrated into the region's freshwater ecosystem accounting system.

InVEST Sediment Delivery Ratio

Results from the InVEST Sediment Delivery Ratio (SDR) model include estimates of long-term sediment export for the region over two time periods. These estimates are compared with long-term soil erosion rates in the region, as estimated using the New Zealand Empirical Erosion Model (NZEEM) (Statistics New Zealand, 2024a). The methodologies employed by the two models differ considerably. NZEEM is an empirical model based on long-term suspended sediment data collected between 1960 and 1990 (Dymond et al., 2010; Hicks et al., 2011), whereas the InVEST SDR simulation results in this study are based on available data from the fiscal years 2001/02 and 2018/19.

Table 6 displays the erosion rates estimated by both models. The InVEST SDR estimates are higher by 7.5% for 2001 and 13.6% for 2018 compared to the NZEEM estimates. Despite these differences, the InVEST estimates, particularly for 2001, are reasonably close to the NZEEM values and are thus considered to be within an acceptable range.

Table 6. Estimated erosion rates by InVEST SDR and NZEEM.

Year	NZEEM estimate (tonnes of sediment per hectare)	InVEST SDR estimate (tonnes of sediment per hectare)	Difference in erosion rate (tonnes of sediment per hectare)	% difference
2001/02 (wet)	2.76	2.97	0.21	7.47
2018/19 (dry)	2.76	3.14	0.38	13.56

We utilised the InVEST SDR model to estimate the value of avoided erosion. The findings reveal a reduction in the overall value of avoided erosion in the region due to land use changes. Specifically, the shift from forestry and dry stock pasture to more intensive agriculture, such as dairy farming, resulted in a 0.024% decrease in the value of avoided erosion, corresponding to a loss of approximately 3.1 million tonnes of sediment retention in the Waikato Region. Assuming an avoided erosion value of $8.51 per tonne, as calculated in Barry et al. (2014), this equates to an approximate cost of $26.4 million for removing these sediments from freshwater resources. Although the region saw a gain of about approximately $4.0 million in water yield value, it incurred a loss of $26.4 million in avoided erosion value, resulting in a net loss of $22.4 million in freshwater ecosystem service supply values.

The InVEST SDR results summary in Appendix B2 indicates that, at the FMU level, the Lower Waikato, Upper Waikato, and Middle Waikato experienced the most significant reductions in avoided erosion value ($14.1 million, $8.0 million, and $4.0 million, respectively), while only Coromandel showed a gain. On a per hectare basis, the order shifts to Middle Waikato, Lower Waikato, and Upper Waikato, with reductions of $67.90/ha, $48.53/ha, and $15.71/ha, respectively. Despite the Upper Waikato covering an area of 434,772 ha, which is more than seven times larger than the Middle Waikato (56,573 ha), the latter exhibited a more substantial increase in erosion rate due to land use changes.

The values reported here should be regarded as indicative, as there may be potential omitted variables in the model. However, the SDR model estimates provide a starting point for incorporating non-market environmental values into planning and policy discussions. Furthermore, they are anticipated to serve as a basis for future research aimed at achieving more precise assessments of the impacts of land use changes on the supply and demand of ecosystem services.

Ecosystem accounting

We constructed the ecosystem extent account of land uses in the Waikato region following the frameworks described in Warnell et al. (2020) and Yao and Palmer (2022) (Appendix C). The LULC classes have been colour-coded consistently with the map of the Waikato region in Figure 5. To simplify the ecosystem account, we reduced the LULC categories (in Figure 5) to 12 by combining water bodies (such as lakes, rivers, and freshwater wetlands) and deciduous hardwood into a single category, Other LULCs.

The ecosystem extent account presents the distribution of the 12 LULC classes between 2001/02 and 2018/19 (Appendix C). The most prominent changes during this period are the gains in the area of dairying (+174,584 ha), urban landscape (+3,302 ha) and market garden (+3,285 ha); and the losses in the area of dry stock (-90,478 ha), exotic planted forest (-66,499 ha), native forest (-11,871 ha), and shrubland (-8,316 ha). While market garden only account for less than 0.4% of the land area in the region, it demonstrated the greatest percentage change in area increase of 85%, almost doubling between the two periods. Only tussock grassland did not experience a change in area among the 12 LULCs in the extent account.

We then constructed the ecosystem capacity account for the region following Bagstad, Ingram, et al. (2020) and La Notte et al. (2019). The capacity account is presented in Appendix D in one table with two sets of freshwater related ecosystem services: water yield and avoided erosion. This allows the presentation of the capacity of the key ecosystems or LULCs in the region to supply freshwater and quantity (water yield) and quality (avoided erosion).

The first eight rows of the ecosystem capacity account illustrate the potential impacts of land use change on water yield in the region during a wet year (2001/02) and a dry year (2018/19) (Appendix D). As expected, the water yield volume during the wet year (~21 billion m^3) is significantly greater than during the dry year (~12 billion m^3). Notably, with land use change, the overall increase in water yield volume in the region was 0.01% during the wet year and 0.24% during the dry year. Although these percentages may seem negligible, they correspond to increases of 24.3 million m^3 and 30.5 million m^3 in the catchment's water volume, respectively. Given the growing importance and demand of water for agriculture and other industries in the region, this additional volume of water is generally beneficial (Waikato Regional Council, 2023). However, it is crucial to assess this additional water on a monthly basis to determine whether it contributes positively (e.g., drought mitigation) or negatively (e.g., increased flood risk). Unfortunately, the results from the InVEST SWY model were not consistent with the global literature and do not allow us to ascertain whether the additional water is advantageous or disadvantageous.

Although there may be no direct connection between the % change in LULC in the extent account with those in the capacity account, we describe here some weak correlation between the two. We can see that a 39% increase dairy land corresponds to approximately 42% increase in water yield and a 38% increase in avoided erosion value (Appendix D). While a 22% reduction in planted forests corresponds to approximately 19% reduction water yield and a 10% reduction in avoided erosion.

The ecosystem capacity account also provides an illustration of the impacts of land use change on the long-term average avoided erosion values in the region. Like the % change in water yield in the entire region, the % change in avoided erosion value is negligible, only -0.02%. However, the sign is negative which indicates a reduction in avoided erosion value. This sign reflects the soil erosion protection provided by planted forests and with land use change to more intensive agriculture, we get an increase of 3 million tonnes of sediments that will likely end up in waterways, impacting water quality.

The extent and capacity accounts presented here may be used as starting points to construct the supply and use tables as well as the ecosystem services flow monetary accounts. The capacity account provides the link between the condition account and the supply and use tables in the SEEA-EA framework.

Summary, discussion and future directions

Summary and discussion

To the best of our knowledge, this Phase 5 project represents the second application of two InVEST models—Annual Water Yield (AWY) and Seasonal Water Yield (SWY)—in New Zealand, and the first application of the InVEST Sediment Delivery Ratio (SDR) model in the country. Consequently, this project extends and refines the freshwater ecosystem assessment framework initially developed in Phase 4.

When comparing the water yield results from Phase 4, which focused on the Waikato River catchment (representing approximately 34% of the Waikato region) to those from Phase 5, where a new method was utilised for parameterising crop coefficients by LULC, we observed divergent estimates from the Annual Water Yield (AWY) model. In Phase 4, the emphasis was on developing the capability to operate the InVEST model and the development of a pilot ecosystem accounts. Conversely, Phase 5 included validation of the modelling results through consultation with water flow and biophysical modellers at Scion. This has improved the robustness of our findings, enabling us to identify and highlight instances where results are inconsistent with the literature.

Discussions with biophysical modellers at Scion, who reviewed our InVEST model runs, particularly the InVEST SWY model, have revealed potential issues related to the parameters used and unresolved concerns regarding vegetation maps (e.g., MODIS vegetation map) that we used. It is possible that some data are not fit for purpose for running InVEST at the scale of 100m. The MODIS vegetation map was captured at a coarse resolution of 1 km, requiring downscaling to a 100 m cell size. While more recent remote sensing data, such as Sentinel-2, offer finer resolutions (e.g., 10 m), they do not cover the 2001/02 period relevant to this study and therefore do not align with our study timeframe. As a result, we created our set of Kc parameters using Dr White’s expert opinion on hydrology.

In Phase 4, the AWY model results indicated a decrease in water yield due to land use changes from forestry to dairy, with a more pronounced reduction during the dry year compared to the wet year. However, in Phase 5, our findings showed that water yield increases with land use changes in the wet year, and that the increase in available water is more significant during the dry year. After consulting with a water flow expert, we have determined that the results from Phase 5 are more realistic compared to those from Phase 4. However, the magnitude of the difference between Phases 4 and 5 is not directly comparable, as Phase 4 focused solely on the Waikato River catchment and its associated hydro dam catchments, while Phase 5 encompassed the entire region, including its eight FMUs.

Phase 5 AWY results were also presented by FMU where we find the greatest increase in water yield in the Upper Waikato FMU, the FMU with the largest land use change from forestry to dairy. But in terms of reduction in avoided erosion value, it is exhibited the third greatest reduction in value, with Middle Waikato FMU and Lower Waikato FMU being first and second. This demonstrates a trade-off pattern in freshwater ecosystem services values due to land use change. This is essentially what the InVEST model is about: a model that explains the trade-offs in ES values. We have also expressed these supply of ES values in monetary form and found a ratio in water yield and avoided erosion value in the Upper Waikato FMU where an average gain of approximately $8/ha in water yield value corresponds to an average reduction of $16/ha in avoided erosion value. This indicates that on average we incur a net loss of approximately $8/ha with changing to a more intensive land use in the Upper Waikato region. In the case of the Coromandel FMU which experienced minimal land use change, it resulted in increases in water yield value of approximately $0.15/ha and avoided erosion value of approximately $2.23/ha.

Phase 5 results from the AWY model were also analysed by FMU. The Upper Waikato FMU, which experienced the most significant land use change from forestry to dairy, showed the greatest increase in water yield. However, in terms of reduction in avoided erosion value, the Upper Waikato FMU ranked third, following the Middle Waikato and Lower Waikato FMUs, which had the largest reductions. This pattern highlights the trade-offs in freshwater ecosystem service values resulting from land use changes. The InVEST model effectively illustrates these trade-offs in ecosystem service values.

We present an ecosystem accounting framework designed to evaluate and describe the multiple values of freshwater-related ecosystem services to support planning and policy decision-making. The numerical results provided should be regarded as indicative rather than absolute, due to potential estimation errors.

Future work should focus on developing and employing more comprehensive hydrological models and estimating anthropocentric freshwater values using primary data, such as surveys of households, industries, and stakeholders in the Waikato region.

This study has refined and applied an ecosystem accounting framework to quantify the impacts of land use changes on freshwater-related ecosystem services. The analysis covered the entire region, individual FMUs, and LULC categories. A flow diagram of this assessment framework is provided in Appendix E.

This study addresses two key actions outlined in the Waikato Freshwater Strategy (Waikato Regional Council, 2017):

- “Continue to improve the regional freshwater quantity database in conjunction with external agencies.”
- “Develop and implement a freshwater quality database to enable quality accounts to be developed for each Freshwater Management Unit.”

The spatial inputs used to run the three InVEST models were submitted to the Waikato Regional Council on 1 July 2024. We also provided a detailed overview of the methodology employed in running the InVEST models and described the spatial outputs generated. As a result, the Council now has the capability to rerun these models using the open source InVEST suite of models. This process ensures that the Council fully understands how the project team applied the InVEST models, aligning with the transparency principles outlined in the recent review of freshwater models by the Parliamentary Commissioner for the Environment (2024).

Future directions

The quantified freshwater ecosystem service values from this completed project will serve as one of the major data sets for running the Integrated Economic-Environmental Modelling (IEEM) model in Phase 6. The IEEM model requires outputs from the InVEST Water Yield model for water quantity. For the water quality component, we will utilise the avoided erosion output from the InVEST Sediment Delivery Ratio (SDR) model, that we produced in this Phase 5 project.

Phase 6 will include assessing water demand across various sectors, such as domestic consumption, agriculture (specifically irrigation), hydropower generation, and other industrial uses. The computable general equilibrium (CGE) modelling framework that will be employed in Phase 6 will address the limitations of this Phase 5 project by accounting for the increased water use from land use changes, such as the shift from forestry to dairy. This aspect was not included in Phase 5 due to its focus on biophysical spatial analysis of water flow regulation using InVEST.

By analysing both the supply and demand of freshwater ecosystem services and using a regional input-output table (I/O) in conjunction with a social accounting matrix, we will lay the groundwork for conducting a CGE analysis. The team will build on the IEEM framework developed by Banerjee et al. (2019), which is supported by publicly available programming code on the General Algebraic Modelling System (GAMS) platform (Banerjee & Cicowiez, 2020). Following methodology described in Banerjee et al. (2020), the IEEM framework will be employed to integrate water yield values estimated using the InVEST AWY model into a CGE model, thereby connecting the value of these freshwater ecosystem services with various sectors of the economy in the Waikato Region.

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Appendix A - Development of the new sets of monthly crop coefficients (Kcs) and InVEST water balance model results

Don White[12]

Annual water balance

The primary land use change in the region during the study period was the conversion of planted forest areas to pasture. There is a large global literature showing a decrease in catchment yield under the multi-year planted forests compared to annual pastures and dryland crops. This was summarised in a meta-analysis from (Zhang et al., 2001). Using a simple top-down water balance model (see (White et al., 2022) for a recent description of the method), assuming no change in storage, Zhang et al. 2001 also concluded that evaporation from these catchments was greater from planted forests than from pastures. This was the average effect and there was enormous variability.

Planted forests are deeper rooted than pasture systems and they are aerodynamically rough. These differences give rise to the differences observed by Zhang et al 2001 and by many others (Aguilos et al., 2021; Shi et al., 2012; Wang et al., 2012). More water is stored in the root zone of planted forests, and this buffers the difference between evaporation and rainfall so that they are water limited less often than pastures. The deeper roots also create a deeper zone of dry soil so that more rainfall may be required to replenish soil water stores and generate baseflow via the groundwater. Planted forests' aerodynamic roughness increases potential and actual evaporation by increasing turbulence and transfer of water vapour from within the forest to the atmosphere.

Seasonal Patterns

Results from InVEST Seasonal Water Yield suggest that replacement of planted forests with pasture increases baseflow and decreases quick flow. These results differ from the global literature and the findings of paired catchment studies in New Zealand (Beets & Oliver, 2007). Results from the recently completed Forest Flows research programme at Scion are also consistent with the global literature and previous NZ catchment studies (Meason et al., 2024).

In paired catchment studies, quick flow is generally decreased by afforestation and increased by deforestation and establishment of pasture. The InVEST model used curve numbers as one of the parameters to predict infiltration rates.**[13]** Both InVEST and SWAT models assume that water moves through the soil. However, in forested catchments, most water moves through macropores, such as root channels, where bypass flow often dominates water movement. Adjustment of the curve numbers to reflect the real difference between forests and pastures is one option for fixing this problem. In the InVEST SWY model, base flow is rainfall minus quickflow and any change in storage because the model assumes conservation of mass.

Magnitude of Change

The change in streamflow caused by land use change is small relative to annual water yield. The volumes look large if expressed in m^3 but when converted to a rainfall equivalent they equate to only a few millimetres per year.

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[13] The InVEST Seasonal Water Yield model seems to be a variation of the Soil and Water Assessment Tool (SWAT) model described in G. Arnold, J., N. Moriasi, D., W. Gassman, P., C. Abbaspour, K., J. White, M., Srinivasan, R., Santhi, C., D. Harmel, R., van Griensven, A., W. Van Liew, M., Kannan, N., & K. Jha, M. (2012). SWAT: Model Use, Calibration, and Validation. *Transactions of the ASABE*, *55*(4), 1491-1508. https://doi.org/https://doi.org/10.13031/2013.42256 Accessed on 22 July 2024 at https://elibrary.asabe.org/abstract.asp?aid=42256

Evapotranspiration (transpiration + interception + soil evaporation) is an inherently conservative process. Climate is the main determinant – evaporation is water and energy limited. The next most important driver is hydrogeology (parent material, soil type and depth, topography, aspect). Land use comes next – it is a relatively weak determinant of water balance (Zhang et al., 2004), and this is reflected in the small size of the differences here.

The effect of vegetation on water balance varies with climate. The difference between vegetation cover peaks when the climate wetness is 1 (Rainfall = potential evaporation). It decreases above this (when rainfall is much more than evaporation) because energy becomes the main limit and below this because water becomes limiting (Zhang et al., 2004).

Appendix B1 - InVEST Annual Water Yield results by FMU

			Coromandel	Hauraki	Lake Taupo	West Coast	Middle Waikato	Waipa	Lower Waikato	Upper Waikato	Waikato
Water yield ('000 m3/year)	***BD 2001/02 (Wet year)***	*LULC 2001/02*	2,508,020	2,709,266	3,915,120	4,751,396	238,927	2,611,089	1,644,879	3,108,898	21,487,594
		LULC 2018/19	2,508,285	2,709,015	3,914,027	4,751,860	240,295	2,610,518	1,648,235	3,129,631	21,511,865
		Difference	265	-251	-1,093	463	1,368	-571	3,356	20,733	24,271
	BD 2018/19 (Dry year)	*LULC 2001/02*	1,154,123	1,634,618	2,309,868	2,969,586	172,312	1,681,045	1,166,724	1,674,813	12,763,089
		LULC 2018/19	1,154,287	1,635,000	2,308,538	2,970,041	173,109	1,680,578	1,171,858	1,700,216	12,793,629
		Difference	164	383	-1,330	455	798	-467	5,135	25,403	30,540
Water yield valuation (Wet year)	***BD 2001/02 (Value by FMU)***	*Difference (m3)*	264,934	-250,598	-1,092,501	463,410	1,367,723	-571,371	3,356,076	20,732,868	24,270,542
		Value ($)	42,389	-40,096	-174,800	74,146	218,836	-91,419	536,972	3,317,259	3,883,287
	BD 2001/02 (Value per ha)	*Difference (m3/ha)*	1.35	-0.63	-3.17	1.08	24.18	-1.85	11.56	47.69	9.88
		Value ($/ha)	0.22	-0.10	-0.51	0.17	3.87	-0.30	1.85	7.63	1.58
Water yield valuation (Dry year)	***BD 2018/19 (Value by FMU)***	*Difference (m3)*	163,591	382,567	-1,329,972	455,451	797,640	-467,035	5,134,539	25,403,447	30,540,227
		Value ($)	26,175	61,211	-212,796	72,872	127,622	-74,726	821,526	4,064,552	4,886,436
	BD 2018/19 (Value per ha)	*Difference (m3/ha)*	0.84	0.97	-3.86	1.06	14.10	-1.51	17.68	58.43	12.44
		Value ($/ha)	0.13	0.15	-0.62	0.17	2.26	-0.24	2.83	9.35	1.99

Appendix B2 - InVEST Sediment Delivery Ratio results by FMU

			Coromandel	Hauraki	Lake Taupo	West Coast	Middle Waikato	Waipa	Lower Waikato	Upper Waikato	Waikato
Avoided erosion ('000 m^3/year)	***Avoided erosion ('000 m3/year)***	*LULC 2001/02*	2,369,686	1,973,893	1,834,445	3,161,187	107,967	1,249,294	1,079,597	1,277,134	13,053,203
		LULC 2018/19	2,369,737	1,973,760	1,834,413	3,161,147	107,515	1,249,260	1,077,941	1,276,331	13,050,104
		Difference	51	-134	-31	-40	-452	-35	-1,656	-803	-3,099
Avoided erosion valuation	***Value by FMU***	*Difference (m^3)*	51,326	-133,512	-31,448	-39,899	-451,689	-34,859	-1,656,210	-802,606	-3,098,897
		Value ($)	436,784	-1,136,183	-267,626	-339,538	-3,843,870	-296,654	-14,094,348	-6,830,176	-26,371,611
	Value per ha	*Difference (m^3/ha)*	0.26	-0.34	-0.09	-0.09	-7.98	-0.11	-5.70	-1.85	-1.26
		Value ($/ha)	2.23	-2.87	-0.78	-0.79	-67.95	-0.96	-48.53	-15.71	-10.74

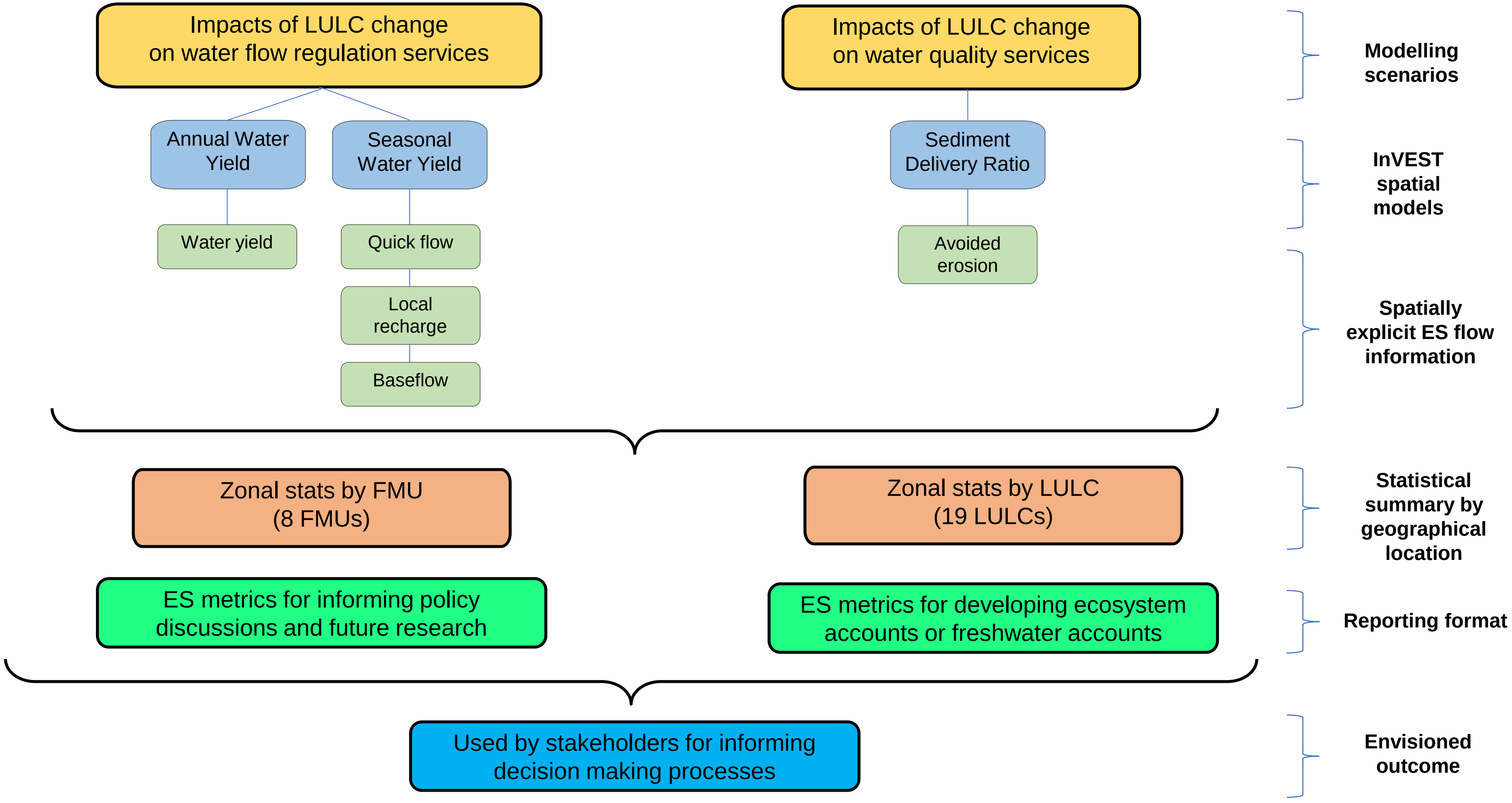
Appendix C - Ecosystem extent account

		Ecosystem Type (Land Use/Land Cover)												
		Dairy	Dry stock	Native forest	Planted forest	Shrubland	Urban landscape	Barren landscape	Tussock grassland	Cropping	Market garden	Orchard	Other LULCs	Total
Area (ha)	2001/02	448,342	1,030,746	365,952	303,036	129,921	22,739	15,657	9,033	7,438	3,831	3,130	109,354	2,449,179
	2018/19	622,926	940,268	354,081	236,537	121,605	26,041	15,317	9,033	6,043	7,116	3,626	106,586	2,449,179
	Area change (2018/19 less 2001/02)	174,584	-90,478	-11,871	-66,499	-8,316	3,302	-340	0	-1,395	3,285	496	-2,768	
% change [Area change ÷ (2001/02)]*100%		38.9	-8.8	-3.2	-21.9	-6.4	14.5	-2.2	0.0	-18.8	85.7	15.8	-2.5	

Appendix D - Ecosystem capacity account

			Ecosystem Type (Land Use/Land Cover)												
			Dairy	Dry stock	Native forest	Planted forest	Shrubland	Urban landscape	Barren landscape	Tussock grassland	Cropping	Market garden	Orchard	Other LULCs	**Total**
Water yield ('000 m3/year)	***BD 2001/02***	LULC 2001/02	2,823,699	8,968,216	4,818,454	2,459,142	1,549,819	150,920	325,206	209,901	44,491	24,662	20,359	22,133	21,487,594
		LULC 2018/19	4,020,849	8,424,553	4,710,871	1,990,391	1,474,273	168,425	321,146	209,981	35,872	47,283	22,826	22,105	21,511,865
	Change in WY (2018/19 less 2001/02)		1,197,150	-543,663	-107,583	-468,751	-75,546	17,505	-4,060	80	-8,618	22,621	2,467	-28	2,427
	% change = [Change ÷(2001/02)] X 100%		42.40	-6.06	-2.23	-19.06	-4.87	11.60	-1.25	0.04	-19.37	91.72	12.12	-0.13	0.01
	BD 2018/19	LULC 2001/02	1,745,585	5,488,636	2,743,842	1,296,755	860,907	99,369	256,318	157,086	29,014	16,051	12,196	10,597	12,763,089
		LULC 2018/19	2,473,344	5,121,611	2,679,775	1,056,793	819,404	111,624	253,131	157,000	23,107	31,242	13,636	10,576	12,793,629
	Change in WY (2018/19 less 2001/02)		727,760	-367,025	-64,067	-239,962	-41,503	12,256	-3,187	-87	-5,908	15,190	1,440	-22	30,540
	% change = [Change ÷(2001/02)] X 100%		41.69	-6.69	-2.33	-18.50	-4.82	12.33	-1.24	-0.06	-20.36	94.63	11.80	-0.20	0.24
Avoided erosion ('000 tonnes/ year)	**BD 2001/02 and LULC 2001/02**		661,415	4,916,891	5,081,191	1,076,206	1,142,617	36,268	70,650	55,475	3,129	3,519	4,687	1,690	13,053,203
	BD 2018/19 and LULC 2018/19		914,883	5,074,550	4,862,308	972,176	1,046,157	40,484	67,596	55,469	4,777	3,700	8,010	1,114	13,050,104
	Change in AE (2018/19 less 2001/02)		253,468	157,660	-218,883	-104,030	-96,460	4,216	-3,054	-6	1,648	182	3,323	-576	-3,099
	% change = [Change ÷(2001/02)] X 100%		38.32	3.21	-4.31	-9.67	-8.44	11.62	-4.32	-0.01	52.67	5.16	70.91	-34.06	-0.02

Appendix E – Freshwater ecosystem assessment framework



Impacts of LULC change on water flow regulation services

Annual Water Yield

Water yield

Seasonal Water Yield

Quick flow

Local recharge

Baseflow

Impacts of LULC change on water quality services

Sediment Delivery Ratio

Avoided erosion

Zonal stats by FMU (8 FMUs)

Zonal stats by LULC (19 LULCs)

ES metrics for informing policy discussions and future research

ES metrics for developing ecosystem accounts or freshwater accounts

Used by stakeholders for informing decision making processes

Modelling scenarios

InVEST spatial models

Spatially explicit ES flow information

Statistical summary by geographical location

Reporting format

Envisioned outcome