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Ohinemuri catchment – river and streams ecosystem services assessment

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Brenda R. Baillie, Richard T. Yao and David J. Palmer

Karangahake Gorge

Report information sheet

REPORT TITLE	OHINEMURI CATCHMENT – RIVER AND STREAMS ECOSYSTEM SERVICES ASSESSMENT
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Executive summary

Introduction

The Waikato Regional Council (WRC) is currently undertaking an assessment of ecosystem services (ES) of the freshwater resources in the Waikato Region. This project contributes to the WRC Regional Policy Statement to ensure that the range of ES associated with natural resources are recognised and maintained or enhanced to enable their ongoing contributions to the region's wellbeing. The first two phases of this project involved a desktop assessment of selected freshwater resources (rivers, streams, lakes and wetlands, including terrestrial geothermal areas) in the Waikato and Waihou River systems to identify, quantify and value (where possible) the freshwater ES. This information is contributing to the development of an on-line interactive map of freshwater ES in the region. This map provides a visual representation of the broader values of freshwater ecosystems, providing an informative and educational service to the general public and supporting policy discussions and planning for on-going improvements in the management of freshwater resources. This is a strategic contribution to the WRC's mission of "a healthy environment, a strong economy and vibrant communities."

This project

The objective of this study (Phase 3) was to undertake an in-depth freshwater ES assessment of the rivers and streams within the Ohinemuri catchment, a tributary of the Waihou River. This involved a desktop assessment of the entire catchment, contact with relevant agencies and personnel to collate further information and data, and modelling of sediment, nutrient and water yield regulating services. Fifty-seven freshwater ES were assessed in the catchment; 22 provisioning ES classes, 21 regulating ES classes and 14 cultural ES classes.

Key results

Provisioning Services

The main provisioning service provided by the Ohinemuri River system was water supply for municipal, industrial (particularly mining) and agricultural use. The readily available, good quality water supply is an important contributor to the catchment's economy and the total direct use values for drinking water and non-drinking water, based on current surface water resource consents, were estimated at $3 million and $8,752 per year, respectively. Given that the available water consent data set is patchy, those approximations should be treated with caution. While there are costs associated with water treatment, including additional costs to treat the odour and taste from the Ohinemuri River at certain times of the year, we were unable to place an indicative economic value on this. Water yield modelling shows that the annual volume of water supply far exceeds the annual volume of water consumed (a better measure of demand) by the different land uses in Ohinemuri catchment with water consumption higher in dairy and livestock farms compared with forest areas. The Ohinemuri River system provides a range of freshwater food sources including eel (longfin and shortfin), trout and whitebait. The commercial eel fishery in the Ohinemuri catchment had an estimated annual total direct use value of $791,500.

Regulating Services

Flow regulation is an important ES provided by the Ohinemuri River, underpinning many of the other Provisioning, Regulating and Cultural ES in the catchment. The high rainfall across most of the catchment, along with land cover were key factors influencing the results from water yield modelling. These results suggest very high water yields across the catchment ranging from above 1,000 m^3/ha/year to greater than 3,000 m^3/ha/year. The catchment has a dynamic surface water dominated hydrological regime characterised by relatively low base flows and a high frequency of flood events. As a result, there are limits to the natural flood regulation ES that the river provides. A key regulating service provided by the Ohinemuri River system and its flow regime, is the natural ability of the water to assimilate, process and dilute contaminants (including sediment and nutrients) via a range of biological, chemical and physical processes. In addition, the physical characteristics of the river such as riparian margins and floodplains provide sites for storage and processing of contaminants. It was not possible to quantify the contribution of these individual processes to contaminant regulation; however, the importance of this regulating service should not be under-valued because of this.

Land-use activities were key sources of contaminants and provided additional pressure on the river's natural capacity to regulate contaminants. Contaminant sources included historic mining waste stored in floodplains and river channels, point source discharges such as urban stormwater and diffuse sources such as elevated sediment and nutrient concentrations from dairy and livestock land uses. Spatial modelling predicted low nitrogen leaching rate for native forests (0 to 5kg/ha/year), medium for livestock (10 to 30kg/ha/year) and relatively high for dairy (>40 kg/ha/year) with an average leaching rate from the entire catchment of 18kg N/ha/year. On average, annual sedimentation rates in dairy (1.42t/ha/year) and livestock (1.63 t/ha/year) areas in the catchment are more than three times as those in native (0.29t/ha/year) and exotic (0.39t/ha/year) forests.

We used water quality (WQ) data and WRC water quality and human health standards as an indicator of the river systems capacity to regulate contaminants. For those WQ parameters measured (including heavy metals), all were within human health & ecological health guidelines except for nitrogen concentrations and water temperatures for trout spawning. Heavy metal monitoring of sediments indicated lead concentrations exceeding guideline values at some locations in the river system. The Ohinemuri River system is providing a habitat regulating ES, including nursery habitat, for a range of aquatic organisms. However, both trout and native fish habitats are constrained by existing low flows while water quality characteristics such as high water temperatures are impacting on the trout fishery. These habitats could be further compromised if alterations to flow regimes (i.e. increased water takes) further impacted on low flow regimes and critical water quality characteristics.

Cultural Services
Recreational activities are a key cultural ES provided by the Ohinemuri River system and include trout fishing (although declining), walking, cycling, swimming and boating activities). The value of fishing was estimated at $74,569 per annum and walking at $1.754 million per annum. The historic mining remnants present in the catchment are considered nationally significant by the Department of Conservation (DOC). The Karangahake Gorge has high aesthetic values and is of national and regional significance with rising visitor numbers increasing pressure on existing infrastructure. Scientific and educational ES are also high in this catchment and the long-term water quality monitoring in the river system is of regional and national value, evident in the number of publications that have been produced. The Ohinemuri is of cultural and spiritual significance to Māori, including the Ohinemuri Waahi Tapu Area on the Ohinemuri River and provides a source of food and fibre (i.e. flax). In a separate research project, the WRC is undertaking an assessment of Māori cultural freshwater ES across the region (Hopkins, Kelepamu and Olubode-Awosola, 2019) and hopefully the Ohinemuri catchment will be covered shortly.

Conclusions

This assessment had identified a wide range of valuable freshwater ES in the Ohinemuri catchment that are benefiting local and wider communities. The main pressures on the freshwater ES identified in this assessment included current low flow regimes, along with water quality aspects such as high nitrogen concentrations and water temperatures. In combination, these factors are contributing to conditions that require additional water supply treatment costs to address taste and odour issues and a declining recreational trout fishery. Further reductions in low flows have the potential to exacerbate these conditions. The outcomes and information from this project will assist the WRC with its role and responsibilities under the Ministry for the Environment's (MfE) Action for healthy waterways programme, including the National Policy Statement for Freshwater Management and the MfE essential freshwater modelling project.

Further work

In view of the information gathered during this freshwater ES assessment, there is potential future work to expand the current assessment to include all freshwater resources in the catchment. Other opportunities include undertaking a more in-depth assessment of the seasonal variability in water supply, to consider a trade-off analyses of all ES in the catchment and to use the Ohinemuri catchment as a case study in the development of environmental accounts. Spatial economic accounting and economic valuation tools could also be used to assess the effect of governmental policies as such as the One Billion Trees Programme, various land-use changes or new freshwater management scenarios on freshwater ES in the catchment. The observation that water use is mostly less than the amount of water consented should be explored to understand any implications for the WRC's role of exploring potentials and identifying trade-off in its resource management and plan review process under the Resource Management Act.

Report title

Ohinemuri catchment – river and streams ecosystem services assessment

Table of contents

Introduction

The Waikato Regional Council (WRC) is currently undertaking an ecosystem services (ES) approach to identify, describe, quantify and value the freshwater ES in the Waikato Region. Ecosystem services refers to the benefits people obtain from ecosystems (MEA, 2005; TEEB, 2010; UKNEA, 2011). These include:

- provisioning services (such as food and water);
- regulating services (such as flood and disease control, nutrient regulation, water flow regulation);
- cultural services (such as spiritual, recreational, and cultural benefits); and
- supporting services (such as nutrient cycling) that maintain the conditions for life on earth.

Recognition of ES is an integral component of WRC's Regional Policy Statement, and Section 3.8 Ecosystem services states that 'The range of ES associated with natural resources are recognised and maintained or enhanced to enable their ongoing contribution to regional wellbeing' (Waikato Regional Council, 2016). The current freshwater ES assessment project also addresses Section 8.3.11 Advocacy and education - provide information on the value of freshwater resources and the ecosystem services they provide. In particular, the information from this project is contributing to the development of an interactive freshwater (rivers, streams, lakes and wetland) ES web map with underlying databases and reports showing the current and potential ES of freshwater resources (rivers, streams, lakes, wetlands) in the region. This map provides a visual representation of the broader values of freshwater ecosystems, providing an informative and educational service to the general public and supporting policy discussions and planning for on-going improvements in the management of freshwater resources. This is a strategic contribution to the WRC's mission of "a healthy environment, a strong economy and vibrant communities."

In Phase 1 of this project, a scoping study was undertaken in the Waikato River catchment that involved a desktop research to identify, quantify and value (where possible) the freshwater ecosystems services for a selection of lakes, wetlands, streams and rivers in the catchment. The Millennium Ecosystem Assessment (MEA) framework was used as the basis for this assessment (Olubode-Awosola, 2016). In Phase 2, the desktop evaluation of freshwater ES was extended into the Waihou River catchment in the Waikato region of New Zealand, covering a selection of streams and rivers (Baillie & Yao, 2018). A desktop evaluation was also completed for a wide range of terrestrial geothermal sites in the Waikato region (McQueen & Bycroft, 2018). These research activities have continued to provide refined estimates of the ecosystem services being assessed showing the spatial distribution of the services as well as trends over time. In addition, the efforts have been yielding an additional layer of information that reflects the values that community have for freshwater resources in the region.

For Phase 3, WRC commissioned Scion to undertake an in-depth freshwater ES assessment of the river and stream systems within the Ohinemuri catchment, applying the ES framework described in the Common International Classification of Ecosystem Services (CICES) (Haines-Young & Potschin 2018) along with the information from Phases 1 and 2 of this project. Unlike Phases 1 and 2 where we primarily employed a desktop application for selected sites within a catchment, this project involved assessing the freshwater ES of the entire catchment. The assessment included spatial modelling of the impact of existing land uses (e.g. dairy, livestock, planted forests and native forests) on selected regulating ecosystem services such as water regulation, avoided sedimentation of water ways and nutrient regulation. Figures 1 and 2 provide an overview of the Ohinemuri catchment within the larger Waihou Catchment, and surrounding areas, highlighting the river network, water quality locations, and land use.

Ohinemuri catchment

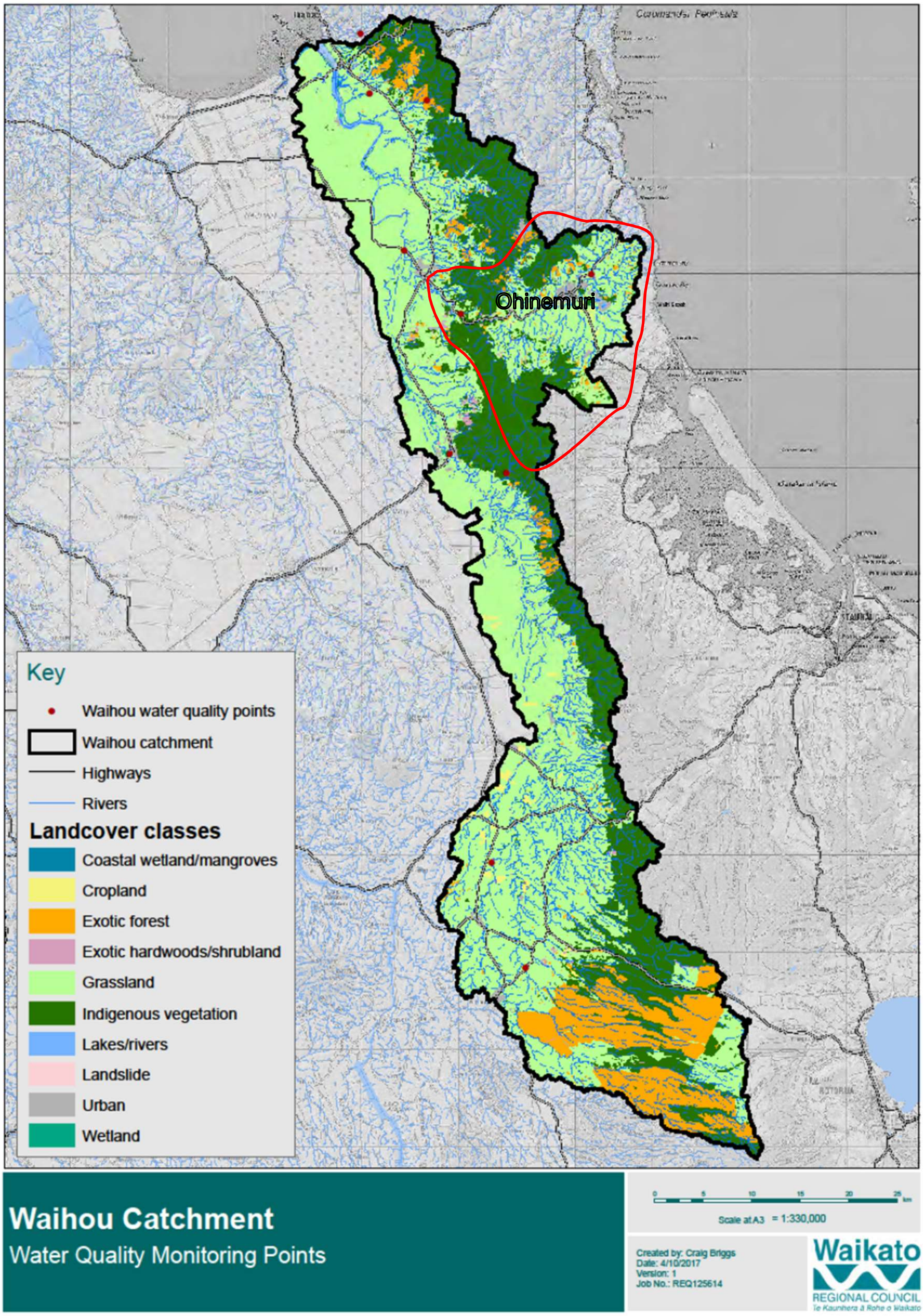

Figure 1: Location of the Ohinemuri catchment within the Waihou River system.
Source: Waikato Regional Council

The Ohinemuri catchment is located in the Hauraki District of the Waikato Region. The headwaters of the Ohinemuri catchment originate in western hill-country (Figures 1 & 2), north-east of Waihi. The Ohinemuri River is approximately 28km in length and flows in a westerly direction, draining steep hill country to the north (the southern end of the Coromandel Range) and to the south (northern end of the Kaimai Range). The river flows through the Karangahake Gorge and across floodplains to its confluence with the Waihou River near the township of Paeroa. The Ohinemuri has a catchment area of 34,803ha. The predominant land cover is dairying (34%), along with indigenous forest (30%) located primarily in the steeper areas of the catchment. Another 16% of the catchment is in livestock farming. The land uses that were grouped into the “Other” category included fruit growing, lifestyle block, idle land, plant nurseries, poultry, saleyards, tourism, urban, vegetable and wetland. This category accounted for about 5% of the total area of the Ohinemuri catchment. Paeroa and Waihi are the two largest townships in the catchment. There are four water quality monitoring sites within the river system (Figure 2):

1. Ohinemuri River @ SH25 Bridge (water quality, ecology)
2. Ohinemuri River @ Queens Head (water quality, flow)
3. Ohinemuri River @ Karangahake (water quality, flow)
4. Waitekauri River @ Up-Stream Ohinemuri confluence (water quality)

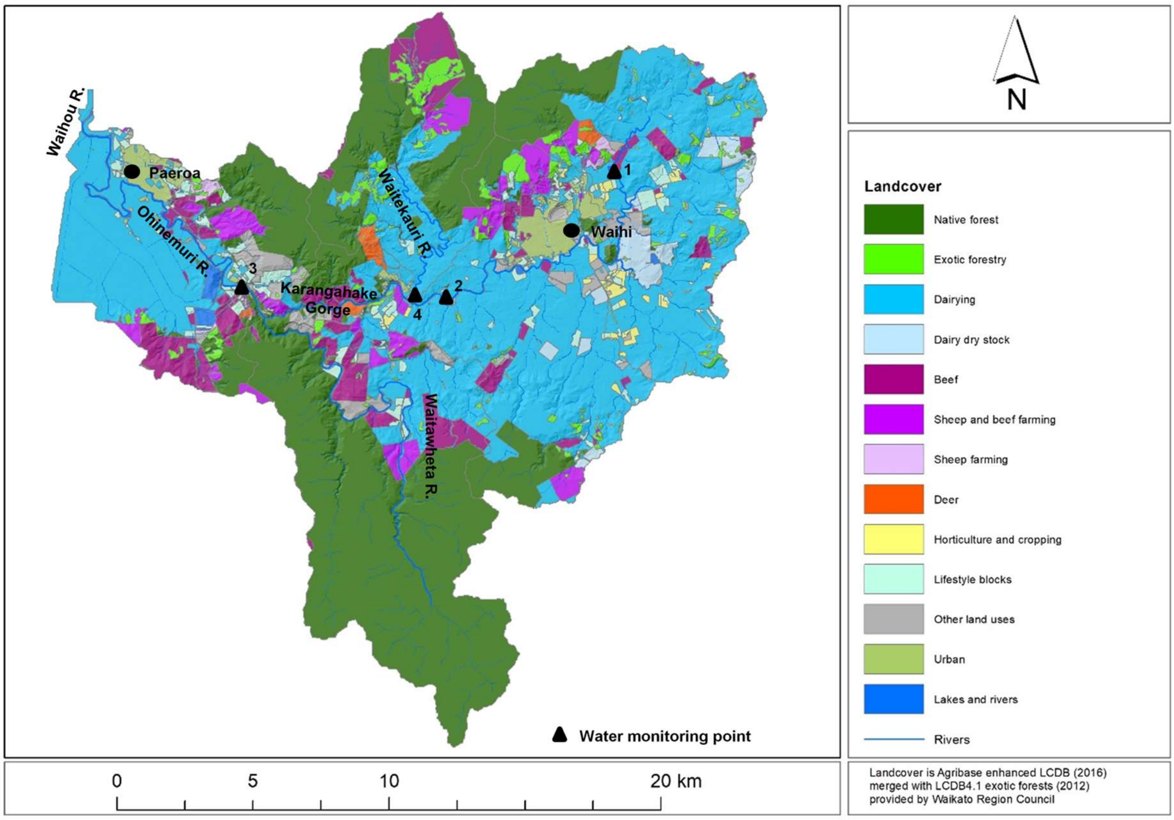

Figure 2: Features of the Ohinemuri catchment

Methods

Project Implementation and scope

In an initial meeting between WRC and Scion, the outcomes from Phases 1 and 2 of this project, research activities for Phase 3 and the scope of the Phase 3 freshwater ES assessment were discussed.

The Ohinemuri catchment was selected for the Phase 3 freshwater ES assessment because:

- it has a mixed land-use: high producing exotic grassland & indigenous forest along with mining activities,
- there is rainfall, river level & flow, suspended sediment, water quality, & ecological/biological/habitat data,
- there are consents for both water supply/extraction and discharge to water in the catchment,
- there are noticeable recreational activities relating to the Ohinemuri River,
- there are sites of scientific research,
- it contains a number of historical ES values,
- there are pressures of intensified land-use and flood risk and their potential impacts on freshwater ES,
- it is of a suitable size to undertake a more in-depth assessment than the desktop assessments in phases 1 and 2.
- it is also assumed there are cultural/Māori values

The aim was to undertake a more in-depth assessment of the freshwater ES in the Ohinemuri catchment to identify, describe and where feasible, quantify, model and provide an economic valuation of the freshwater ES present in the catchment. ES assessments were undertaken at the reach or catchment scale, whichever scale was most appropriate for the ES being assessed. Where possible and appropriate, reach ES information was 'scaled up' to provide an assessment for total catchment.

We applied the Common Classification of Ecosystem Services (CICES) V5.1 (Haines-Young and Potschin, 2018) framework to assess freshwater (streams and rivers) ES associated with the Ohinemuri catchment. The CICES uses a classification system that allows translation between different ecosystem service classification systems, such as those used by the Millennium Ecosystem Assessment (MEA) and the Economics of Ecosystems and Biodiversity (TEEB). CICES V5.1 uses a five-level hierarchical structure (Figure 3).

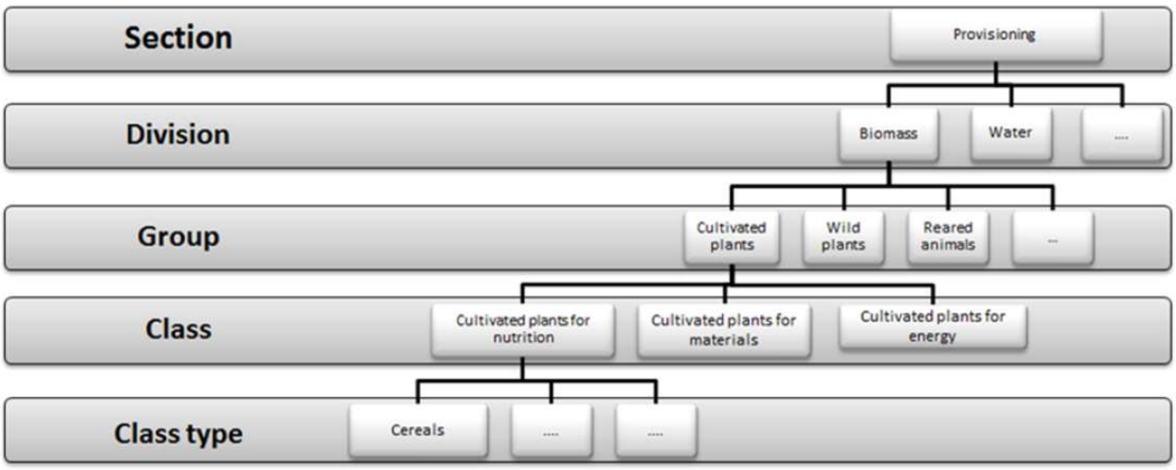

Figure 3: The hierarchical structure of CICES V5.1, illustrated with reference to a provisioning service 'cultivated plants' (Haines-Young and Potschin, 2018)

Under the CICES framework, provisioning, regulating and cultural ES have been divided into biotic and abiotic ES. Classes can, where appropriate, be aggregated, and there is the option to include additional classes when required. Further information and guidance on CICES V5.1 is available in Haines-Young and Potschin (2018).

For this project, as a first step, biotic and abiotic ES relevant to freshwater were extracted from the full CICES list along with components of the freshwater ES assessment template used in the Phases 1 and 2 to develop the template excel spreadsheet used in this Phase 3 assessment. Similar to Phase 1 and 2, we focused on the three groups of ES (provisioning, regulating and cultural), and did not include any items under the group of supporting services, to avoid double counting. The freshwater ES template used to collate the data for this project covered 22 provisioning ES classes, 21 regulating ES classes and 14 cultural ES classes. These classes are listed in Appendix I. A freshwater ES evaluation code was applied to each ES where: 1 = high level of certainty that the ES was not present in the catchment; 2 = ES may be present but no information found; 3 = ES highly certain to be present but no information found; 4 = ES present and qualitative information located; 5 = ES present, quantitative information located; 6 = ES present, quantitative and economic data available. For some ES, more than one evaluation code was applicable (Appendix I). For those ES where an economic evaluation was possible (Evaluation Code 6) Appendix II provides details of the costings used.

In Phase 2, the desktop research on freshwater ES assessment was confined to the vicinity of two water quality monitoring stations in the catchment. The desktop assessment of the Ohinemuri catchment was repeated in Phase 3 to cover the entire catchment from its headwaters to its confluence with the Waihou River. Relevant agencies (i.e. WRC, MPI, Hauraki District Council, Fish & Game, Department of Conservation) and personnel were contacted by both phone and e-mail to collate further information on the freshwater ES in the catchment.

Spatial Modelling of Regulating Services

The MEA (2005) broadly defines regulating services as the benefits obtained from the regulation of ecosystem processes. This ES category includes freshwater ES such as erosion control, water purification and water storage, provided by the Ohinemuri River system. However, the type of vegetation or landcover in the landscape plays a crucial role in soil retention, prevention of landslides, water flow regulation and nutrient retention. Landcover also influences the magnitude of runoff, flooding and aquifer recharge in the catchment, strongly influencing the freshwater ES in the river system itself. Hence, we undertook catchment scale modelling of soil erosion, nutrient leaching and water yield to improve our understanding of how these different land uses in the catchment affect freshwater resources and the ecosystem services they provide in the Ohinemuri catchment. This information is useful for planners and practitioners.

As we did not look at the changes in the provision of ecosystem services due to potential land use change or afforestation, we are unable to estimate the monetary value of the ecosystem services. However, this method enables the demonstration of trends or patterns of biophysical processes across land uses in the catchment.

Spatial analysis of soil erosion

To analyse the erosion rate in the Ohinemuri catchment, we used the New Zealand Empirical Erosion Model (NZEEM). NZEEM is a spatial environmental model that enables the estimation of erosion rates of woody (e.g. native forests and planted forests) and non-woody (e.g. bare land, pasture) vegetation across the landscape (Dymond, et al., 2010). NZEEM calculates the amount of sediment generated under the current woody vegetation in tonnes of sediment per square kilometre per year, and the sedimentation rate associated with non-woody land use. In this assessment, NZEEM was used to provide an indicative long-term mean erosion rates under current land cover in the Ohinemuri catchment.

Nutrient analysis

Under a five-year research programme at Scion, called the Growing Confidence in Forestry's Future, the team has developed an initial avoided nutrient function within the spatial economic tool called the Forest Investment Framework (FIF) (Yao et al. 2016; Yao et al. 2019a). The avoided nutrient analysis utilises spatial information on leaching from Dymond et al. (2013). To provide an overview, the OVERSEER® model was used to predict nitrate leaching rates per animal for every soil and climate combination across New Zealand. These data were combined with maps of animal numbers to produce a national map of nitrogen leaching (Dymond et al. 2013)". FIF utilises nitrogen leaching (kg nitrate-N/ha/year) as a baseline to compare current land use and the establishment of a plantation forest.

In this FIF application, we did not assume any land use change, so we cannot assign a monetary value for avoided nutrients. Instead we used the N leaching layer to provide area weighted values of leaching across each land use class. To achieve this, we used the land cover spatial information (Agribase) provided by WRC. Because the forestry class was not well represented in the Agribase layer, we merged the exotic forest class from LCDB4.1 into the Agribase layer for completeness and this layer was used to summarise N leaching per land use class using the zonal sum function in ArcGIS as a table. The summary table was joined with the original spatial information for the calculation of N leaching per land use class on an area basis (area weighted).

Annual water yield

Water yield is broadly defined as the amount of water "produced" by a watershed or a catchment. It is usually referred to as the difference between precipitation and evapotranspiration. However, there are several factors to consider when modelling water yield. To estimate the annual water yield in the catchment by land use and by sub-catchment, we used the InVEST Water Yield model (Sharp et al. 2018). The model is part of the InVEST set of spatial tools that map and value a wide range of ES (e.g. carbon storage and sequestration, habitats and pollination). The InVEST annual water yield module calculates annual water yield from a catchment and can be extended to calculate hydropower production. We utilised the InVEST water yield module to spatially quantify water yield and consumptive water use for each land use/landcover type across the Ohinemuri catchment. This model estimates the total annual water yield for each grid cell of the study area. For calculation details and the water yield equations refer to Sharp et al, (2018). Nine data sets are required for the water yield module to operate, namely: (1) annual average precipitation; (2) annual average potential evapotranspiration; (3) depth to root restricting layer; (4) plant available water content (AWC); (5) land use; (6) watersheds; (7) biophysical table; (8) the seasonality factor; and (9) water demand table. The biophysical table in conjunction with the spatial landcover data provides the basis for estimating water yield, which includes landcover types, the plant evapotranspiration coefficient (K_c) factor related to each landcover, and the maximum rooting depth for each landcover.

The data required for running the water yield model came from different sources. Specifically, annual average precipitation and potential evapotranspiration data (Wratt et al., 2006) from NIWA was projected from New Zealand Map Grid (NZMG) to New Zealand Transverse Mercator (NZTM) and resampled to a 25-m cell size resolution. Root restricting layer, and available water content (AWC), was developed from the fundamental soil layers (LRIS, 2010). Root restricting layer was developed from the Potential Rooting Depth[1] layer. Potential rooting depth describes the minimum and maximum depths to a layer that may impede root extension. Such a layer may be defined by penetration resistance, poor aeration or very low available water capacity. These classes are described more fully in Webb and Wilson, (1995), and Griffiths (1985). Fundamental Soil Layers (FSL) were also used to develop AWC with values from zero to one. Land use/land cover (LULC) was developed from Agribase[2] data provided from WRC. Watersheds were developed from River Environment Classification (REC) data (Snelder et al, 2004), that identifies sub-catchments across the Ohinemuri catchment. A biophysical table was developed from the LULC spatial layer that corresponds with each land use. This table includes information on whether the landcover class was vegetated or not, rooting depth, and the plant evapotranspiration coefficient (Kc). We estimated these parameters and coefficients from broad habitat classes by matching these classes descriptions with those in Madgwick, (1994); Canadell et al. (1996); Allen et al. (1998), and Sharp et al. (2018). The seasonality constant (Z) was estimated as 0.2 * N, where N is the average number of raindays (> 1-mm) per year over the study period (Donohue, 2012, Hamel, 2015), giving a value of 28 for Z. We present in Table 1 the list of parameters and coefficients used in the water yield biophysical model and the water demand model.

[1]PRD: https://lris.scinfo.org.nz/layer/48110-fsl-potential-rooting-depth/
[2]Agribase: https://www.asurequality.com/our-solutions/agribase/

Table 1: InVEST parameter values and coefficients for the annual water yield model. (Sources detailed in the above paragraphs)

Land-use (LU) code	Landcover (LC) description code	Landcover description	Water demand (m^3/ha/year)	LULC description	LULC vege-tation	Rooting depth (mm)	Kc*
1	ALA	Alpaca and/or Llama Breeding	28.1	Closed grassland	1	1200	0.7
2	BEF	Beef cattle farming	51.5	Open grassland	1	1100	0.6
3	DAI	Dairy cattle farming	155.9	Closed grassland	1	1200	0.7
4	DEE	Deer farming	37.1	Closed grassland	1	1200	0.7
5	DRY	Dairy dry stock	97.3	Closed grassland	1	1200	0.7
6	FOR	Forestry	0.0	Exotic forestry	1	3500	0.78
7	FRU	Fruit growing	6.2	Perennial cropland	1	2600	0.52
8	GOA	Goat farming	84.9	Closed grassland	1	1200	0.7
9	GRA	Grazing other people's stock	103.5	Closed grassland	1	1200	0.7
10	HOR	Horse farming and breeding	26.5	Closed grassland	1	1200	0.7
11	LIF	Lifestyle block	34.6	Closed grassland	1	1200	0.7
12	NAT	Native Bush	0.3	Dense native forest	1	3700	0.82
13	NEW	New Record – Unconfirmed Farm Type	2.1	Closed grassland	1	1200	0.7
14	NOF	Not farmed (i.e. idle land or non-farm use)	0.0	Shrubland	1	1600	0.5
15	NUR	Plant Nurseries	15.7	Other	0	0.1	0.1
16	OTH	Enterprises not covered by other classifications	0.0	Other	0	0.1	0.1
17	POU	Poultry farming	93.5	Other	0	0.1	0.1
18	SHP	Sheep farming	34.1	Open grassland	1	1100	0.6
19	SLY	Sales yard	0.0	Closed grassland	1	1200	0.7
20	SNB	Mixed Sheep and Beef farming	30.7	Open grassland	1	1100	0.6
21	TOU	Tourism (i.e. camping ground, motel)	0.6	Other	0	0.1	0.1
22	UNS	Unspecified (i.e. farmer did not give indication)	0.0	Other	0	0.1	0.1
23	VEG	Vegetable growing	0.0	Annual cropland	1	2000	0.69
24	Undefined	Undefined	0.0	Undefined	0	0.1	0.1

*Plant evapotranspiration coefficient (Kc)

Limitations

- The assessment of freshwater ES in the Ohinemuri catchment was confined to the river and stream network and did not cover lakes, wetlands or groundwater.
- While Māori cultural services were outside the scope of this assessment and are being addressed separately, any pertinent information identified during the ES assessment was noted in the template spreadsheet.
- In Class Code 2.1.3.1 which covers scientific research in the catchment, Google Scholar and a search of the WRC technical reports was used to compile a list of scientific publications and reports along with any other pertinent references found while undertaking this project. This is not an exhaustive list of scientific publications on the surface freshwaters (rivers and streams) of the Ohinemuri catchment.
- The level of effort applied to each ES class depended on the quality and quantity of information available, the importance/relevance of the ES class to the Ohinemuri catchment and financial constraints of the project.

Results

Of the 57 freshwater ES classes assessed in the Ohinemuri catchment, those ES identified as 'not' present' in the catchment related to in-situ aquatic plant and animal aquaculture and hydro-power (Appendix I). The ES that were assessed as 'not likely to be present in the catchment', mainly applied to a range of provisioning ES (i.e. provision of genetic material for a range of purposes), whereas those ES highly likely to be present in the catchment, even though no information was located, were all regulating services (Appendix I). Some type of information was located for just under half the freshwater ES assessed (Table 2), most of the information was qualitative, followed by quantitative data (Appendix III). Economic data was identified for commercial eel fisheries, drinking and non-drinking water, and the recreational activities of fishing and walking (Appendix III).

Table 2: Summary of the type of information found on the freshwater ES in the Ohinemuri catchment

ES Evaluation Code*	Number of ES classes*
1 - not present	6
2 – may be present	10
3 – highly likely to be present	14
4 – present, qualitative information	18
5 – present, quantitative information	14
6 – present, quantitative & economic data	5

*See Appendix I for full details on the evaluation code and ES class details. Note that the total number of classes (67) is greater than the number assessed (57) as some classes had more than one evaluation code.

For ease of reporting, ES classes have been combined where appropriate in the results section below. For example, CICES separates ES into biotic and abiotic ES. This arbitrary separation does not always align well with assessing freshwater ES in a river system where biotic and abiotic processes are synergistic and cannot be easily separated. In these instances, the biotic and abiotic ES have been grouped together and discussed as a single ES. For example, CICES has five regulatory ES covering the mediation of waste, toxics and other nuisances by living and non-living processes:
-Biotic, Class Code 2.1.1.1. Bio-remediation by micro-organisms, algae, plants, and animals
-Biotic, Class Code 2.1.1.2 Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals
-Biotic, Class Code 2.2.5.1 Regulation of the chemical condition of freshwaters by living processes
-Abiotic, Class Code 5.1.1.1 Dilution by freshwater and marine ecosystems
-Abiotic, Class Code 5.1.1.3 Mediation by other chemical or physical means (e.g. via Filtration, sequestration, storage or accumulation)
As these processes will be occurring simultaneously as the water flows down the river system and no data was found on these individual processes, they have been grouped together for the purposes of this report.

Provisioning ecosystem services

Biotic

Division: Biomass
Groups: Cultivated in-situ aquatic plants/ reared aquatic animals for nutrition, materials or energy.
Class Codes: 1.1.2.1, 1.1.2.2, 1.1.2.3, 1.1.4.1, 1.1.4.2, 1.1.4.3
No in-situ plant or animal aquaculture operations for the purposes of providing nutrition (food), fibre and materials, or energy were found in the Ohinemuri catchment.

Group: Wild plants (aquatic) for nutrition, materials or energy
Class Codes: 1.1.5.1, 1.1.5.2, 1.1.5.3
There is anecdotal evidence that watercress is collected for nutrition (food) in the Ohinemuri catchment, but no quantitative information was found. In the past, flax has been planted along the lower reaches of the Ohinemuri River approximately 15 km upstream from its confluence with the Waihou River. A local marae uses this site to harvest flax for fibre (e.g. weaving).

Group: Wild animals (aquatic) for nutrition, materials or energy

Class Codes: 1.1.6.1, 1.1.6.2, 1.1.6.3
Wild aquatic animals in the Ohinemuri catchment are providing a nutrition (food) resource. For example, white-baiting occurs from the confluence of the Ohinemuri with the Waihou River upstream to just below Mackaytown (Barrier, 1994) and there is a current resource consent for a whitebait stand in the lower Ohinemuri River. However, no quantitative information was found on the amount of whitebait catch. The Ohinemuri River system is popular for trout fishing (rainbow and brown), particularly the section of the river that runs through the Karangahake Gorge and the Waitawheta River (a tributary of the Ohinemuri). While trout will be providing a food source, we were unable to identify any quantitative data on this. The recreational aspects of trout fishing are covered under the Cultural ES 6.1.1.1.

There is a commercial eel fishery in the Ohinemuri catchment for both longfin and shortfin with a fishing event intensity of 2.1-3.0 fishing events per year in the lower part of the river, and less than one fishing event per year in the upper reaches or tributaries (Figure 17, Bentjies et al. 2016). Figure 4 shows somewhat a stable catch of both shortfin and longfin eel over the past six years (2013 to 2019).

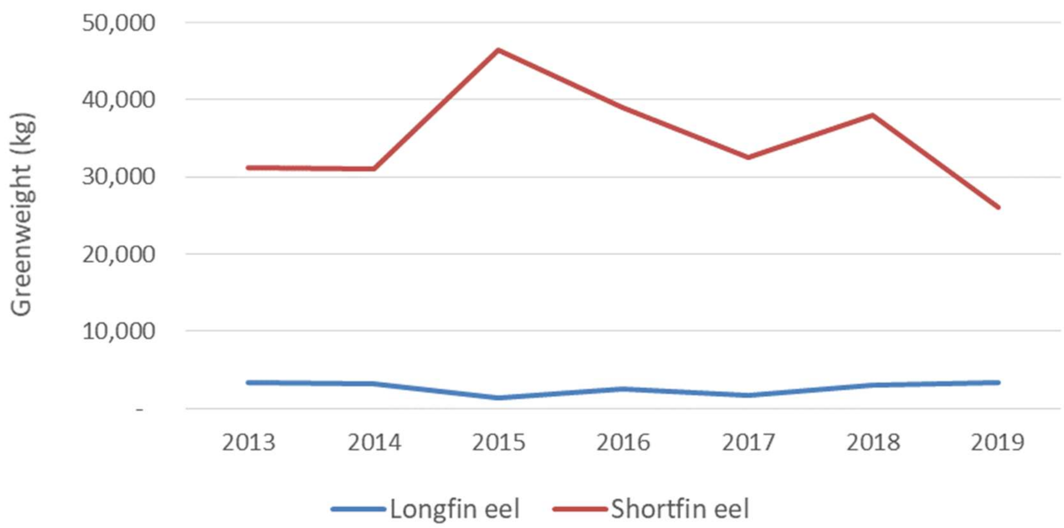

Figure 4: Commercial eel catch in the Ohinemuri catchment (Source: MPI 2019 via the Official Information Act)

Based on the data collected on the eels caught in the Ohinemuri sub-catchment via the Official Information Act, the average quantity of eel catch in kilograms per year was about 38,848kg in green weight. Assuming that 90% of the total weight of the catch was sold in the market and using the price of $22.64 per kg (Appendix II), the annual value of eels caught in the Ohinemuri was about NZ$791,500 (Appendix III). Although the eel industry in New Zealand is quite small relative to many other industries, it has been estimated the total revenue generated from export of eels in 2011/12 reached more than $10 million (Ministry for Primary Industries, 2013). In addition to this market value of the provisioning benefit, eels are also considered as a valued taonga species in New Zealand. Despite the limited information available, there has been some claims of marginal recreational fishing in eels as well.

Division: Genetic material
Groups: Genetic material from plants, algae or fungi collected for maintaining or establishing a population, used to breed new strains or varieties, Individual genes for the design and construction of new biological entities

Class codes: 1.2.1.1, 1.2.1.2, 1.2.1.3
While freshwater plants, algae or fungi and their genetic material may be contributing to the maintenance or establishment of populations, breeding new strains or varieties or the development of new genetic entities, no evidence was found for these ES in the Ohinemuri catchment.

Division/Group: Other types of provisioning service from biotic sources
Class: Wild plants (aquatic, including fungi, algae) used for medicinal/pharmaceutical/health purposes; Code 1.3.1.1.
While there is the potential for aquatic plants to be used for health benefits i.e. gel from flax plants for skincare products, whether flax or any other freshwater plant material is being used for health and/or pharmaceutical purposes in the Ohinemuri catchment is unknown.

Abiotic

Division: Water
Group: Surface water used for nutrition, materials or energy
Class: Surface water for drinking and non-drinking purposes; Codes 4.2.1.1, 4.2.1.2
There are three current resource consents in the Ohinemuri catchment for the surface water extraction for domestic/municipal water supply and 10 surface water non-drinking water consents primarily for dairy and horticultural use (Table 3; Figure 5). All three water takes for domestic and municipal supply are located upstream from known discharge consents (Figure 5). Two are in the headwaters of the Ohinemuri where land use is dominated by horticulture and cropping. The third site is in the Waitawheta catchment dominated by native forest. The remaining surface water takes are primarily for agricultural and horticultural activities (Table 3).

Table 3: Current surface water take consents in the Ohinemuri catchment

	Authorisation ID	**Applicant/ Holder**	**Activity Description**	**Annual total take(m^3)**	**Water use Primary**	**Water use Secondary**
No*	**Domestic and municipal**					
1	130392.01.01	Hauraki District Council	Take water from the Walmsley Stream (Waihi water supply)	1056000	Domestic & Municipal Water Supply	Drinking water supply - Domestic, rural or urban
2	130392.03.01	Hauraki District Council	Take water from the Ohinemuri Stream (Waihi water supply).	1054000	Domestic & Municipal Water Supply	Drinking water supply - Domestic, rural or urban
3	AUTH101995.01.02/APP140228	Hauraki District Council	Take water from Waitawheta River for Paeroa Public water supply	2506460	Domestic & Municipal Water Supply	Drinking water supply - Domestic, rural or urban
	Non-drinking water					
4	120591.01.01	Menefy Family Trust	Take up to 250 m^3 water per day from the Ruahorehore Stream for frost protection purposes	10000	Horticulture/ market gardening	Irrigation
5	122956.01.01	Paeroa Golf Club	To take water from Kuaoiti Stream	10000	Recreation/ amenities/ sport	Irrigation
6	124954.01.01	Suraj Horticulture Services Limited	To take water for use on kiwifruit orchard	22000	Horticulture/ market gardening	Frost protection
7	125093.01.01	SN Fleming	To take water from an unknown tributary of Doherty Stream	85259.8	Industry (Food processing)	Bottling
8	125648.01.01	Macedonian Properties Limited	To take surface water - Homunga Stream	11497.5	Agricultural farming - dairy	Shed wash
9	125719.01.01	Waihiki Holdings Limited	To take water from an unnamed tributary of the Ruahorehore Stream	5723.2	Agricultural farming - dairy	Stock water and shed wash
10	125825.01.01	Langeveld Farms Limited	To take surface water from the Taieri Stream	10220	Agricultural farming - dairy	Shed wash

11	134184.01.01	Dairy Properties (2006) Ltd.	To take water from an unnamed tributary of the Ohinemuri River	6694.1	Agricultural farming - dairy	Shed wash
12	136485.01.01	Laneway Resources Limited	To take Surface Water	0**	Industry - quarry/mining -gold/precious metals	Drilling and testing (non-geothermal)
13	139689.01.01	Rahu Resources Pty Limited	Take water from surface water sources	Unknown	Mining - gold/precious metals	-

*Reference number for the locations of the consents in the catchment in Figure 5.
**The annual take for this consent is zero as the take is intermittent and water used during drilling is returned to the waterbody.

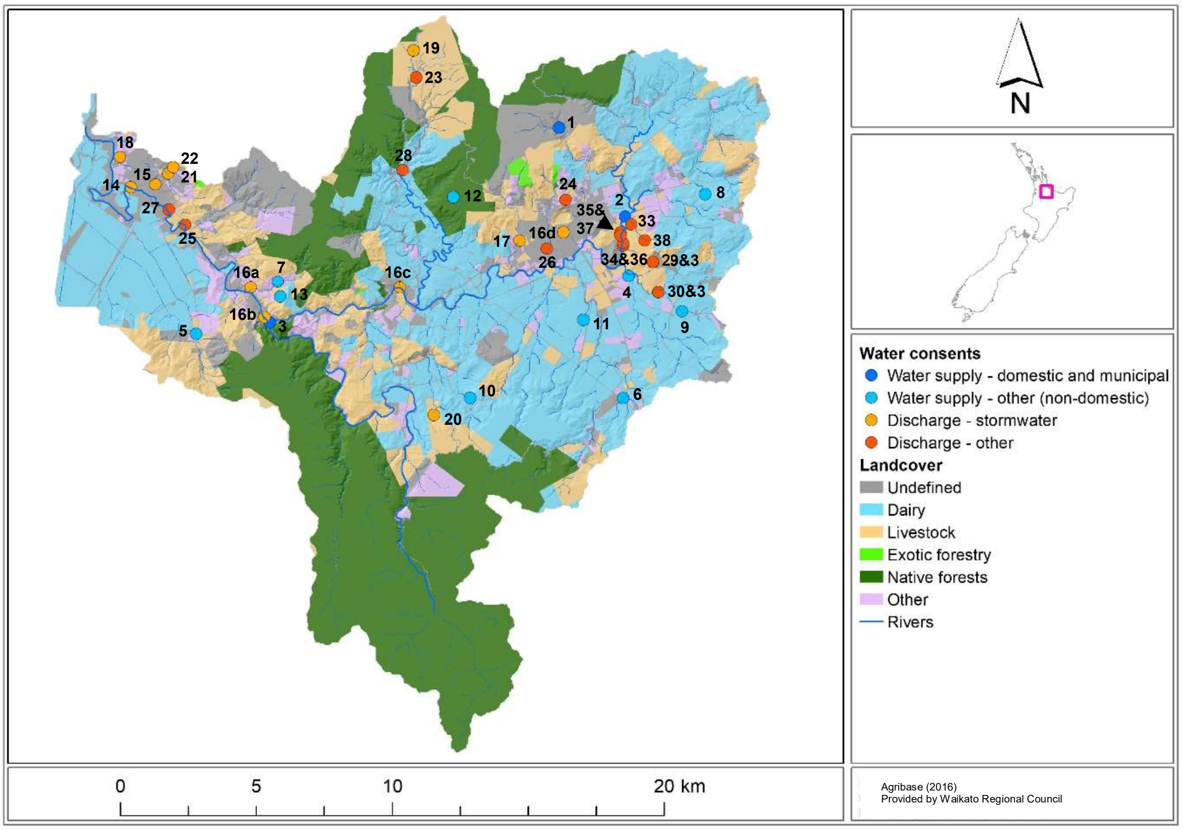

Figure 5: Location of current resource consents for water takes and discharges in the Ohinemuri catchment. See Table 3 and Appendix IV for details of the water take and discharge consents

Where water is extracted from the Ohinemuri and Waitawheta Rivers for the Waihi and Paeroa town water supply, the river is unable to attenuate the water smell & taste. The suspected cause is warm water temperatures (approx. November to March) and dying algae and other bacteria[3] . While water is treated to meet drinking water standards, we were unable to obtain costs on this. Actual water extraction data was provided to the project team by WRC. This data set covered two extraction sites for drinking/municipal use (Waitawheta and Walmsey streams) and seven non-drinking sites (Doherty's Stream Tributary, Homunga Stream, Ohinemuri River, Ohinemuri River Tributary, Ruahorehore Stream 1, Ruahorehore Stream 2 and Kuaoiti Stream). The data provided was patchy with the Ruahorehore site having 8 months (in 2018) of actual water extraction data while the Waitawheta Stream had a 16-year drinking water extraction data. We have extrapolated based on the data at hand and arrived at an average annual drinking water extraction rate of 1,681,119 million m^3 and non-drinking rate of 58,345 m^3. Assuming that these volumes of water have been distributed to the residents and non-drinking water users, and assuming that the price per m^3 of water is \$1.80/m^3

[3] https://www.stuff.co.nz/waikato-times/news/88676542/waihi-water-no-longer-smells-like-teenage-boys-socks

for drinking and $0.15 for non-drinking (Appendix II), the total potential revenue values would be approximately $3 million and $8,752, respectively (Appendix III).

We present in Figures 6 and 7 the maps of the water supply and water consumption that were generated using the InVEST Annual Water Yield model. Comparing Figures 6 and 7, we can find that on an annual basis, the volume of water supply far exceeds the volume of water consumed by the different land uses in Ohinemuri (Tables 3a & 3b). By juxtaposing Figure 7 with the catchment's land cover map in Figure 5, we can see a pattern that the water consumption is higher in dairy and livestock farms than forest areas. While the InVEST Annual Water Yield model provides an estimate of total annual water yield in the catchment, decision making processes and policy discussions would need information on the impacts of seasonal flows, especially during the dry season. To account for seasonality flows (high and low flows), a future exercise can be the application of the InVEST Seasonal Water Yield model. The Seasonal Water Yield model computes spatial indices for quantifying the relative contribution of land spatial units to the generation of both baseflow and quick flow across the catchment (Sharp et al., 2018).

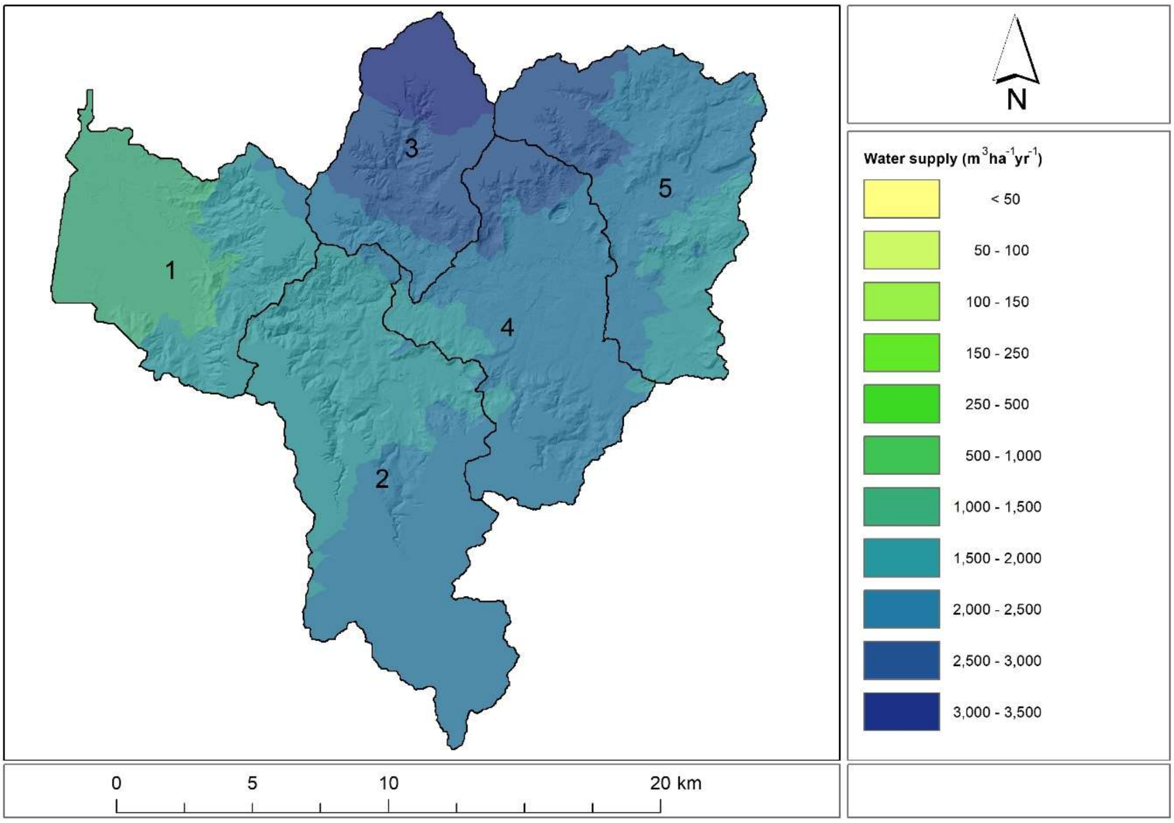

Figure 6: Simulated water supply using the InVEST annual water yield model with the 5 sub-catchments (numbered) used to produce statistics in Table 4a

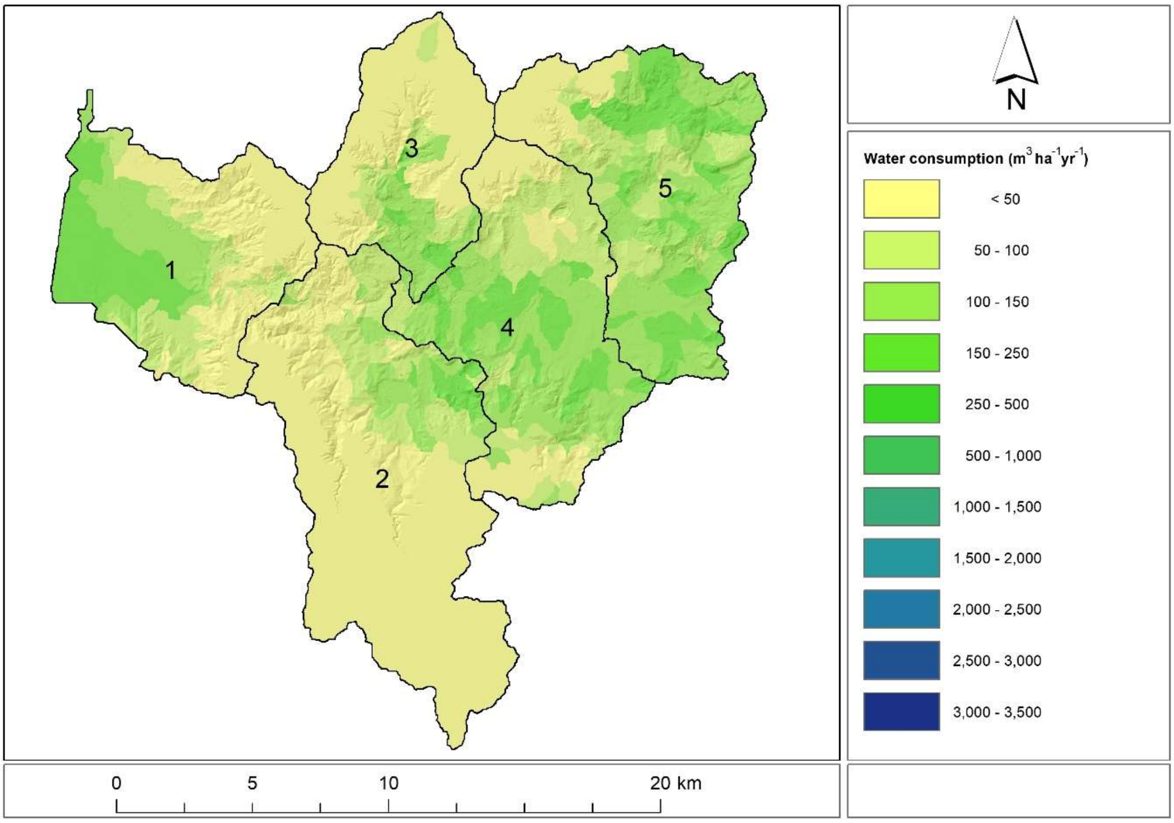

Figure 7: Simulated water consumption using the InVEST annual water yield model using the spatial data provided by WRC. Note that the 5 sub-catchments (numbered) were used to produce statistics in Table 4a

Regulating ecosystem services

Biotic & Abiotic

Division: Transformation of biochemical or physical inputs to ecosystems
Groups: Mediation of wastes or toxic substances of anthropogenic origin by living processes
Mediation of waste, toxics and other nuisances by non-living processes
Water conditions
Class Codes: 2.1.1.1 (bio-remediation by micro-organisms, algae, plants, and animals); 2.1.1.2 (filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals); 2.2.5.1 (regulation of chemical processes by living processes); 5.1.1.1 (dilution), 5.1.1.3 (mediation by other chemical or physical means, e.g. filtration, sequestration, storage or accumulation)

Rivers and streams have a natural ability to dilute, assimilate and process contaminants (including sediment and nutrients) via a range of biotic and abiotic processes. The rate at which these processes occur will be dependent on a wide range of factors including temperature, light availability, composition of biological communities, water chemistry, sediment composition and flow regimes (Allan & Castillo, 2009; Fono et al., 2006; Moore et al., 2012). The flow regime of the Ohinemuri River system provides a natural dilution ES (Class Code 5.1.1.1) which increases down the river system (upper SH25 flow site, mean flow = 1.22 m^3/sec; lower Karangahake flow site, mean flow = 12.2 m^3/sec; data provided by WRC). Changes to natural flow regimes such as increased water takes may compromise natural dilution processes in the river system, particularly during periods when there are likely to be higher concentrations of contaminants in the waterways, for example, during periods of low flow. Biological, chemical and physical processes such as bio-remediation, adsorption, absorption, chemical transformation, filtration and sequestration (Class Codes 2.1.1.1., 2.1.1.2, 2.2.5.1, 5.1.1.3) also provide a natural contamination regulation ES, although we are unable to find quantitative information on the amounts of contaminants removed via these processes.

The morphological features of the river system provide additional sites for contamination processing and storage. Low flow areas provide in-stream storage sites for sediment and other contaminants and during higher flows riparian margins and floodplains (Figure 8) provide storage sites for flood waters, sediment and debris. Riparian margins also filter sediment, nutrients, and contaminants coming off the land before they reach the waterway. While the quantities of contaminants removed or stored in these locations is unknown, a notable exception is the historic mining waste that has been discharged into the Ohinemuri River and its tributaries (Clement et al., 2017). The volume of mine waste stored in the Ohinemuri floodplain is estimated at 1.13 M m^3 and mine waste stored in the floodplains and along the river channel contains elevated quantities of heavy metals such as lead, arsenic and zinc that still pose a risk to the environment (Clement et al., 2017).

Figure 8: Ohinemuri floodplains

The main sources of contaminants reaching the river system (point-source and diffuse), come from land-use activities in the catchment. As discussed above, historic mining waste is one source of contamination. Discharge resource consents provided information on point source discharges into the Ohinemuri river. We located 25 current resource consent discharge permits (Figure 5 and Appendix IV). There is a cluster of discharge consents held by Oceana Gold Ltd. in the upper part of the catchment, in relation to mining activities, along with another cluster in the lower section of the river near Paeroa (Figure 5; Appendix IV). Stormwater discharges for the main townships in the catchment are distributed along the main stem of the Ohinemuri River.

Diffuse sources of contaminants such as nutrients (Vant, 2016) and sediment (Haddadchi & Hicks, 2016; Hoyle, 2014) provide additional pressure on the rivers natural capacity to regulate contaminants. Of particular concern in many waterways across New Zealand, including the Ohinemuri, is nitrogen leaching. Using a spatial nitrogen leaching function loosely coupled with FIF, we simulated the nitrogen leaching in the catchment (Figure 9). Juxtaposing the nitrate leaching map below with the landcover map in Figure 5, we can see a pattern that leaching rate is low under native forests (0 to 5 kg/ha/year), medium under livestock (10 to 30 kg/ha/year) and high under dairy (>40 kg/ha/year).

Based on the nitrogen leaching spatial model, the entire catchment had an average leaching rate of 18 kgN/hayear. Amongst the four major land uses, dairy had the highest average nitrogen leaching (36kg N/ha/year) followed by livestock (16kg N/ha/year), exotic forestry (0.3kg N/ha/year) and native forests (0.3 kg N/ha/year) (Table 4b). Sub-catchment 2, which had the largest proportion of native forests (66%), had the least amount of leaching (6kg N/ha/year) while sub-catchment 5 with 56% dairy had the highest average leaching rate of 33kg N/ha/year (Table 4b).

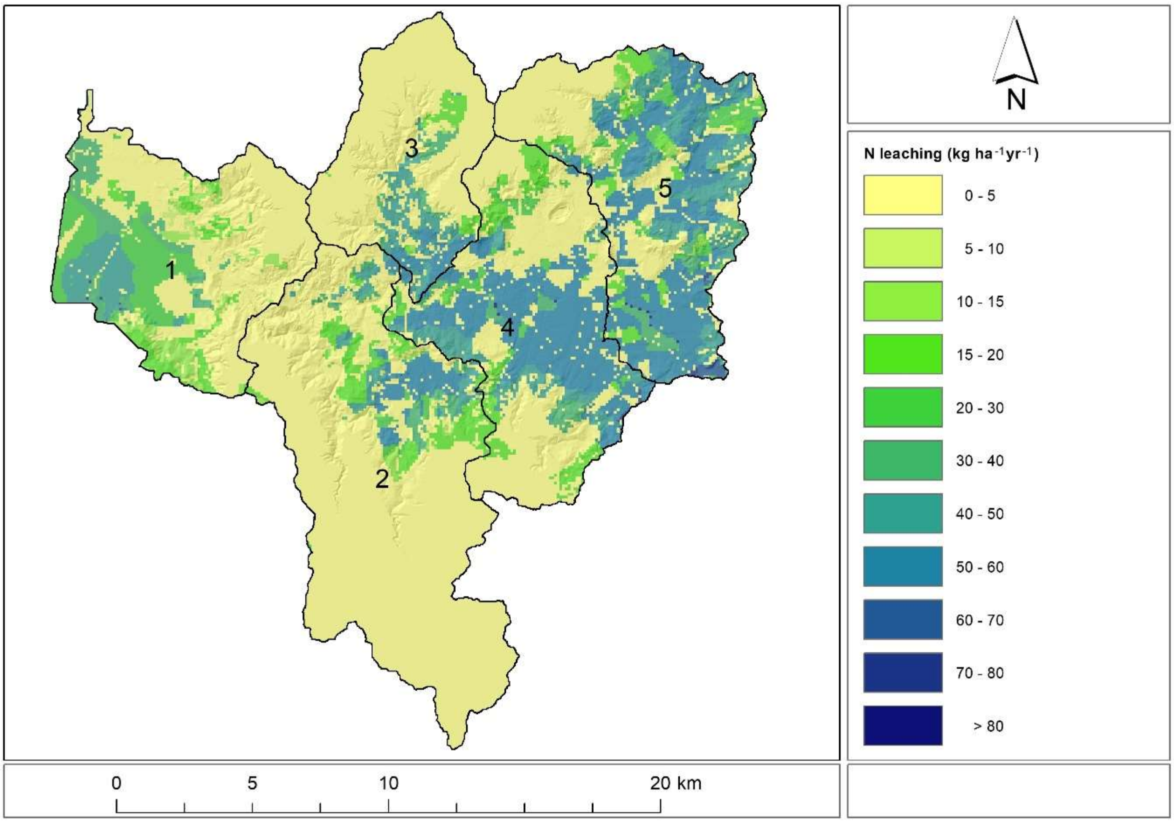

Figure 9: Simulated spatially explicit nitrogen leaching across the Ohinemuri catchment using a spatial model. Note that the 5 sub-catchments (numbered) were used to produce statistics in Table 4a.

Table 4a: Summary of the quantified regulating service values across the major land uses in the five Ohinemuri sub-catchments using NZEEM, InVEST and Nitrogen Leaching Models

	Area	Dairy	Livestock*	Exotic forestry	Native forest	Other land use	NoData	Nitrate leaching	Sedimentation	Water yield	Consumptive water use	Realisable water supply
	(ha)	(%)	(%)	(%)	(%)	(%)	(%)	(kg N/ha /year)	(m^3/km/year)	(m^3/ha/ year)	(m^3/ha/year)	(m^3/ha/year)
Sub-catchment 1	6,315.9	34.0	20.2	0.1	7.2	9.6	28.8	15.7	78.5	601.4	78.2	523.2
Sub-catchment 2	10,127.8	11.2	13.0	0.0	66.1	4.1	5.6	5.9	70.4	793.7	24.0	769.7
Sub-catchment 3	4,312.7	26.8	20.4	-	43.0	0.6	9.3	9.5	145.3	1,090.4	63.0	1,027.4
Sub-catchment 4	7,093.5	49.0	15.2	1.0	10.7	4.8	19.3	27.7	137.5	922.7	96.3	826.3
Sub-catchment 5	6,926.5	55.7	16.0	0.0	7.3	5.9	15.1	33.2	109.2	911.4	113.5	798.0
No data	26.6	-	-	-	-	-	-	-	-	-	-	-
Ohinemuri	34,802.9	33.9	16.3	0.2	29.5	5.2	14.9	17.5	102.2	839.0	66.9	772.1

* Includes dairy dry stock, beef farming, sheep and beef farming, deer farming, goat farming and grazing other people's stock.

Table 4b: Quantified regulating service values across the major land uses in the Ohinemuri catchment using NZEEM, InVEST and Nitrogen Leaching Models

	Area	Area	Nitrate leaching	Sedimentation	Water yield	Consumptive water use	Realisable water supply
	(ha)	(%)	(kg N/ha/year)	(t/km^2/year)	(m^3/ha/year)	(m^3/ha/year)	(m^3/ha/year)
Dairy	11,766	33.8	36.5	141.8	823.0	125.2	697.8
Livestock*	5,658	16.3	13.1	163.2	868.6	58.6	810.1
Exotic forestry	86	0.2	1.4	39.1	1160.9	20.3	1140.6
Native forest	10,271	29.5	0.3	28.6	831.0	7.6	823.4
Other**	1,799	5.2	6.2	75.4	879.2	48.2	831.0
No data	5,223	15.0	-	-	-	-	-
Ohinemuri catchment	34,803	100.0	17.5	102.2	853.4	63.2	790.1

* Includes dairy dry stock, alpaca and llama, beef farming, mixed sheep and beef farming, farming, goat farming, grazing other people's stock, sheep farming
** Includes fruit growing, lifestyle block, idle land, plant nurseries, poultry, saleyards, tourism, urban, vegetable and wetland

If the load of a contaminant is too high, the capacity of a water body to store, assimilate and/or process the contaminant may be exceeded (as in the case of mining waste discussed above). This can result in a degradation of water quality and, if effect thresholds are exceeded, would result in adverse effects on aquatic organisms, recreational and cultural values, human health and downstream receiving environments such as lakes and estuaries[4] . Water quality monitoring data was used as an indicator of Ohinemuri river systems natural capacity to assimilate and regulate contaminants inputs by assessing against WRC water quality guidelines and standards[5] (Table 5). However, we acknowledge that these median indicator values do not cover seasonality and intra-annual variations where water quality conditions may fall below thresholds for human and ecological health at critical times of the year or during critical periods within an organism's life cycle.

Table 5: Median water quality characteristics along the main stem of the Ohinemuri River (S.H.25, Queens Head, Karangahake) and the Waitekauri sub-catchment. Colour code for rating against WRC water quality guidelines and standards: **Excellent**, **Satisfactory**, **Unsatisfactory**. No rating data available for TON and DRP.

	Human use - recreation			**Ecological health**									
	E. coli	Clarity		Turbidity	TN	TON	Amm-N	DRP	TP	DO	pH	Temp	Temp
Site	n/100ml	m		NTU	g/m³	g/m³	g/m³	g/m³	g/m³	%sat		°C*	°C**
S.H. 25	105	3.21		1.04	0.59	0.46	0.005	0.004	0.011	102	7	16	16
Queens Head	70	3.22		1.10	1.23	0.95	0.051	0.002	0.0095	101	7.1	15.9	15.9
Karangahake	52	3.02		1.25	0.57	0.40	0.017	0.002	0.009	100	7	13.6	13.6
Waitekauri	80	3.31		0.76	0.23	0.11	0.005	0.002	0.006	100	7.1	15.4	15.4

Source: Data from LAWA (Downloaded 7th June 2019; 5-year median) or Tulagi 2018 (median values for 2017 data). TN = total nitrogen, TON = Total Oxidised Nitrogen, Amm-N = Ammoniacal Nitrogen, DRP = Dissolved Reactive Phosphorus, TP = Total Phosphorus, DO = Dissolved Oxygen, Temp = Water Temperature. * rating against fish spawning temperature requirements; ** rating against fish health temperature requirements.

For most water quality variables in Table 5, the Ohinemuri River system can regulate contaminants to a satisfactory or excellent rating for human and ecological health. The two notable exceptions where catchment pressures are exceeding the regulatory capacity of the main stem of the Ohinemuri catchment are TN concentrations, which are at unsatisfactory levels at the three monitoring sites along the main stem of the river, along with temperature requirements for fish spawning. With regard to heavy metals, Oceania Gold NZ Ltd monitor their treated water discharge for heavy metals as part of their resource consent requirements. Results indicate heavy metal concentrations are below compliance limits based on USEPA criteria (Boffa Miskell Limited, 2018). However, some heavy metals tend to accumulate in sediment. Sediment samples from the Ohinemuri and Waitekauri Rivers indicate concentrations of zinc and copper below toxicant default guideline values (DGV) with lead exceeding DGV in some sections of the Ohinemuri River (Australian & New Zealand guidelines for fresh & marine water quality, 2018; Sabti et al., 2000).

Group: Mediation of nuisances of anthropogenic origin
Class Code: 2.1.2.1 (smell reduction)
While the river system will be providing an ES in reducing smell and the impact of odours on people, no quantitative information was available on this. At certain times of the year, there are sections of the river system that are unable to reduce the smell and taste of river water to an acceptable level for water supply (See Class Code 4.2.1.1 under Provisioning Services).

Class Code: 2.1.2.2, 2.1.2.3 (noise attenuation and visual screening)
There is a vegetated riparian margin along most of the length of the Ohinemuri River, supplemented by indigenous restoration plantings, particularly along the mid-section of the river (Figure 10) and the Waitete and Mangatoetoe streams (pers. comm. HELP (Habitat Enhancement and Landcare

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[4]https://www.niwa.co.nz/our-science/freshwater/tools/kaitiaki_tools/impacts/chemical-contaminates
[5] https://www.waikatoregion.govt.nz/environment/natural-resources/water/rivers/healthyrivers/how-we-measure-quality/

Partnership Waihi Inc.)). Sections of the river system will be providing both a visual and a noise screen. For example, tall riparian vegetation provides a visual screen between the river and the road and both riparian vegetation and the noise of the river will assist in reducing noise from passing traffic.

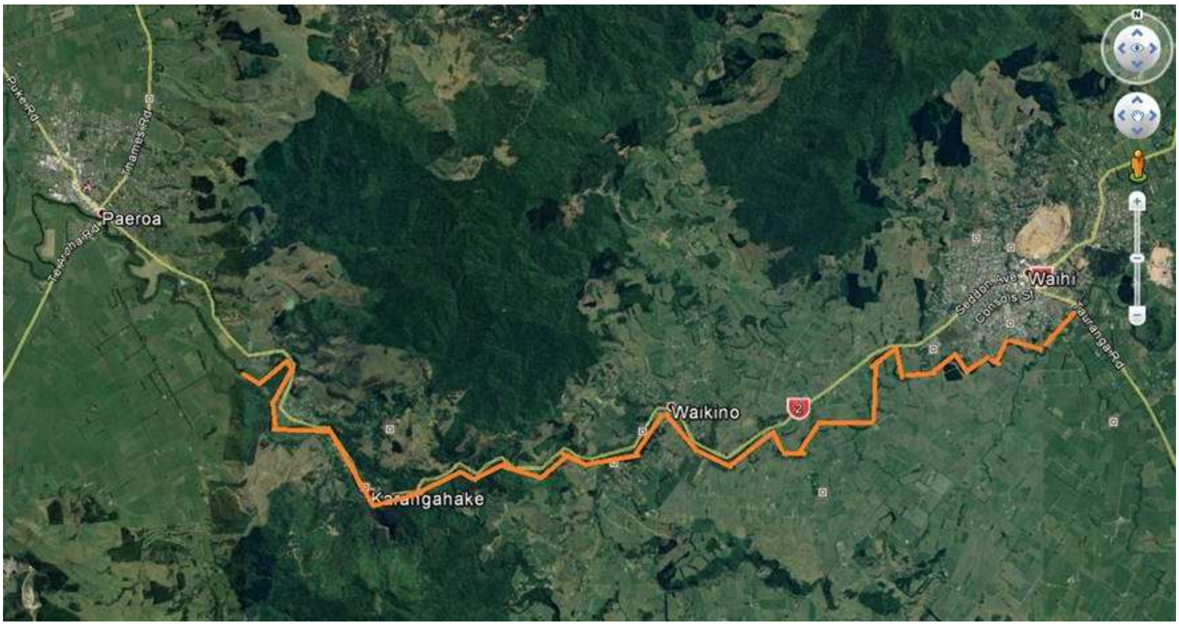

Figure 10: Section of the Ohinemuri River (marked in orange) where indigenous riparian planting has been undertaken

Division: Regulation of physical, chemical and biological conditions
Group: Regulation of baseline flows and extreme events
Class codes:
Biotic - 2.2.1.3 (capacity of the vegetation to regulate hydrology)
Abiotic - 5.2.1.2 (physical barriers to liquid flows i.e. flood protection)

The Ohinemuri River system has a surface water dominated hydrology and a dynamic hydrological regime characterised by relatively low base flows and a high frequency of flood events (Franklin and Booker 2009; Franklin 2015). The hydrological regime will be influenced by rainfall patterns, underlying geology, vegetation cover and water yield in the catchment. One of the key inputs of the InVEST water yield model is the annual total rainfall. We present in Figure 11a the average annual total rainfall (in millilitres) where northern locations receive the highest rainfall volumes while western locations received the lowest amounts of rainfall. Because rainfall is one of the main drivers in the InVEST annual water yield model it can potentially have a greater influence on model outcomes than vegetation cover or the types of land use in the catchment.

Results from the water yield model simulation in InVEST suggest very high water yields across the catchment ranging from above 1,000 m^3/ha/year to greater than 3,000 m^3/ha/year (Figure 11b). The northernmost tip, which predominantly consisted of sheep and beef farms, native forests and exotic planted forests, has been found to have the highest water yield (3,000 to 3,500 m^3/ha/year). When comparing water yield results by land use type, exotic forestry, which accounted for about 0.2% of the catchment's total area, provide the highest water yield compared to other land uses (e.g. dairy, sheep and beef, native forests) (Table 4b). This result is not consistent with previous New Zealand studies which pointed out that water yield was higher in pasture areas than planted forest areas (e.g. Dymond et al., 2012). We consider this result an exceptional case because the small areas of exotic forests (only occupying a combined area of 86 hectares, based on the spatial data provided) were located for the most part in high rainfall locations of the catchment and are surrounded by livestock farms.

By dividing Ohinemuri into five sub-catchments, sub-catchment 3 which had no exotic forests had the highest water yield (Figure 11b). This relatively high water yield was followed by sub-catchments 4 and 5 where dairy farms are a main part of the sub-catchment. These results suggest that these types of land use do impact greatly on water yield volume in the Ohinemuri catchment when compared with rainfall.

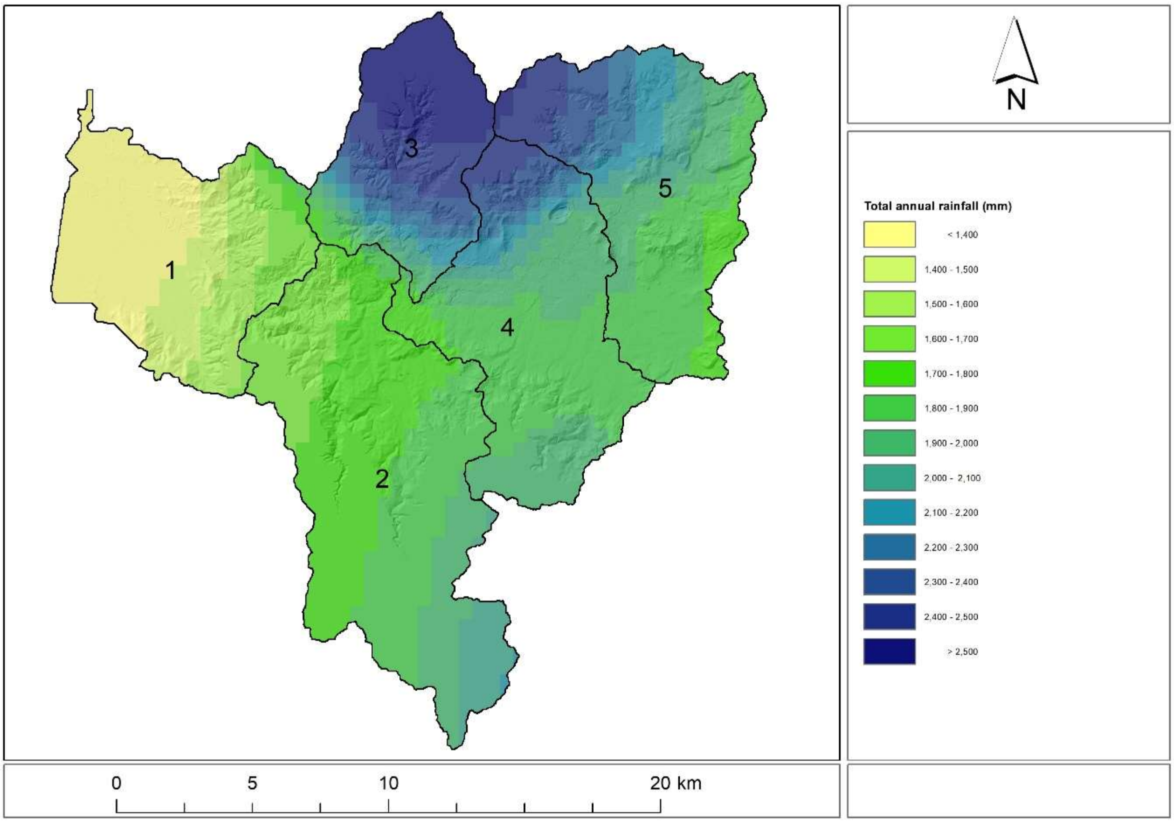

Figure 11a: Average annual rainfall (in mm) in the Ohinemuri catchment (Source: Wratt et al., 2006). Note that the 5 sub-catchments (numbered) were used to produce statistics in Table 4a

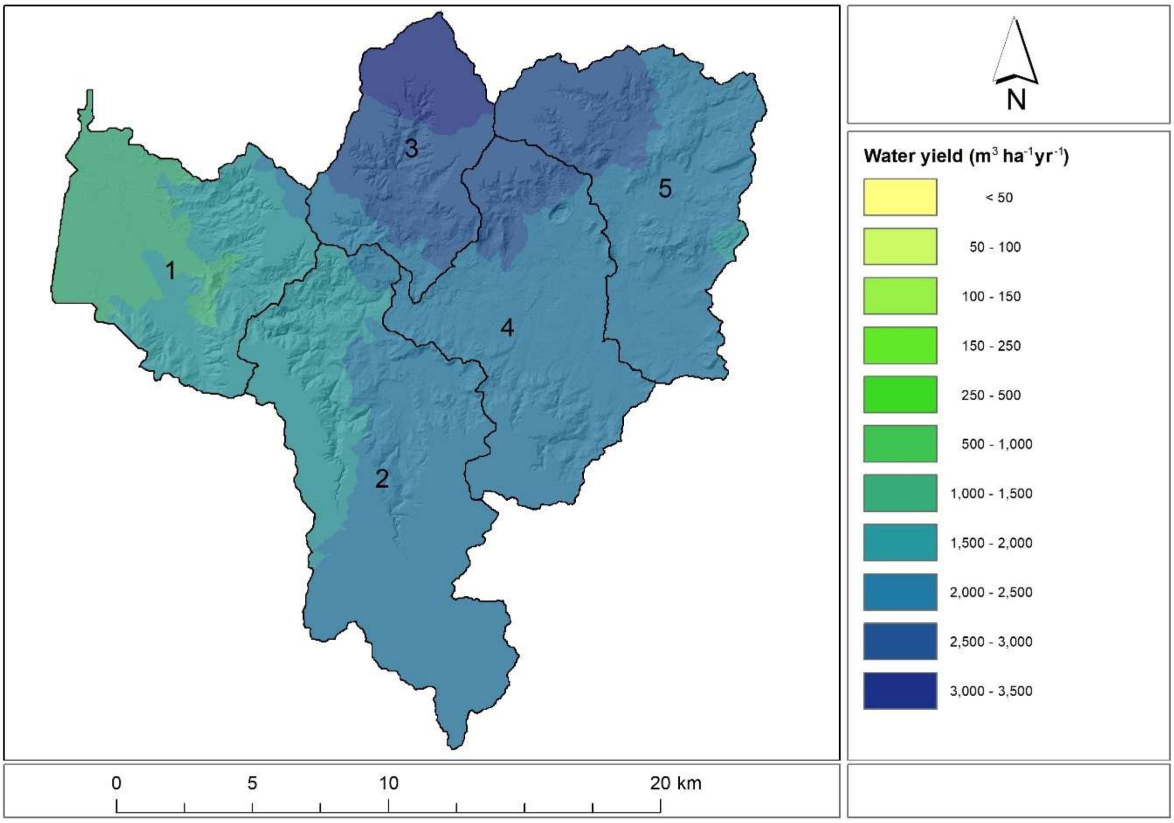

Figure 11b: Spatially explicit annual water yield volume per hectare in the Ohinemuri catchment. Note that the 5 sub-catchments (numbered) were used to produce statistics in Table 4a

Although the forested headwaters will assist in mediating flood flows, the Ohinemuri is prone to flooding, a combination of steep topography, frequent high rainfall events (Munroe, 2007) and a high proportion of the catchment in low vegetation cover (Figure 2), exacerbating run-off in high rainfall events. A flood alarm is sited at Karangahake and is particularly important for the downstream flood-prone township of Paeroa[6]. Paeroa is only 4-m above sea level and situated on the Ohinemuri floodplains close to the rivers confluence with the Waihou River (Munroe, 2007). Stopbanks to protect the township are currently being upgraded[7].

These hydrological characteristics indicate that the Ohinemuri River system provides a limited natural flooding regulation ES (2.2.1.3 & 5.2.1.2). Natural features of the Ohinemuri river system such as floodplains, riparian vegetation and river sinuosity contribute to flow and flood regulation in the catchment. In the Ohinemuri, the floodplains are mainly located in the lower section of the river system. These areas mediate flood intensity and provide natural storage sites for flood overflow. Flood waters are slowly released back into the river system, lost via evapotranspiration, or infiltrate and recharge ground water systems, maintaining flow regulation. Likewise, riparian margins can contribute to reducing the power and speed of the flood waters along with channel morphology characteristics such as sinuosity. While the flood stopbanks along the lower section of the river limit the natural flood regulation ES provided by the floodplains, they do provide some protection for the town and the highly productive agricultural activities in these low-lying areas (Figure 12).

Figure 12: Lower Ohinemuri River near Paeroa showing the riparian margin with flood stopbanks in the background (left) and flood stopbank along the town edge (right)

Biotic - 2.2.1.1 (capacity of the vegetation to control erosion)
Biotic - 2.2.1.2 (capacity of the vegetation to control mass movement)
Abiotic - 5.2.1.1. (physical barriers to mass flows i.e. landslides)

The steeper catchment areas in the Ohinemuri are at risk from terrestrial mass movement such as slips and landslides. The ability of riparian margins to provide an effective barrier is limited as events of this nature and scale are likely to pass through narrow riparian margins. Terrestrial mass

[6]http://www.waikatoregion.govt.nz/assets/PageFiles/16917/26305_A4%20Paeroa%20Flood%20Hazards.pdf
[7] https://www.waikatoregion.govt.nz/community/whats-happening/news/media-releases-recent/new-flood-gates-will-enable-faster-response-times/

movements can transform into debris flows if they connect with the waterway. River features such as sinuosity, floodplains and riparian vegetation can attenuate the power, speed, extent and damage of debris flows on downstream receiving environments (2.2.1.2; 5.2.1.1).

River sediment loads are influenced by catchment topography, geology and soils, climate and land-use practices (Hicks et al. 2004). Using NZEEM which accounts for the soil erosion terrain and the types of vegetation across the catchment, we simulated the soil erosion rates which are expressed in tonnes of soil per km^2 per year. We estimated low erosion rates (<50 t/km^2/year) in areas under forests (native and exotic) while medium to high erosion rates (>75 t/km^2/year) in pasture areas. On average, sedimentation rates in dairy (142 t/km^2/year) and livestock (163 t/km^2/year) areas in the catchment are more than three times as those in native (29 t/km^2/year) and exotic (39 t/km^2/year) forests (Table 4b). Areas in darker blue shade in the north, central and western sections of the catchment (Figure 13), that have the highest erosion rates, have the potential to reduce erosion rates in the longer term through afforestation.

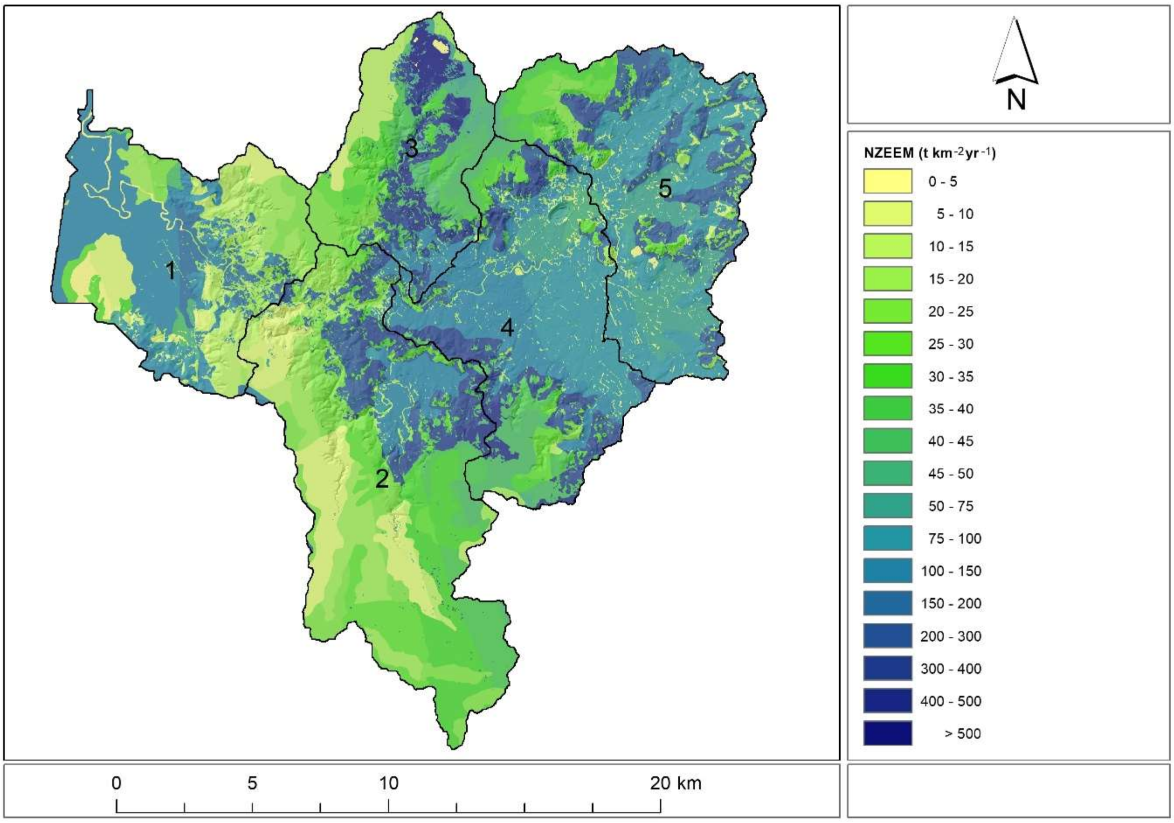

Figure 13: Simulated erosion rates in the catchment based on the New Zealand Empirical Erosion Model (NZEEM). Note that the 5 sub-catchments (numbered) were used to produce statistics in Table 4a

We illustrate in Figure 14 the values on sedimentation, water yield and nutrients across the major land uses that we expressed in index form. The index for each ecosystem service was derived by dividing each simulated number by the highest value in the ecosystem service column then multiplied by 100%. This illustration provides a simplified visualisation for ranking the ecosystem impacts of the major land uses. In terms of nitrate leaching, dairy provides the highest negative impact followed by livestock, while native forests are close to the index values. In terms of the contribution to the sedimentation of water ways, drystock farming predominates, closely followed by dairy farming, then native forests.

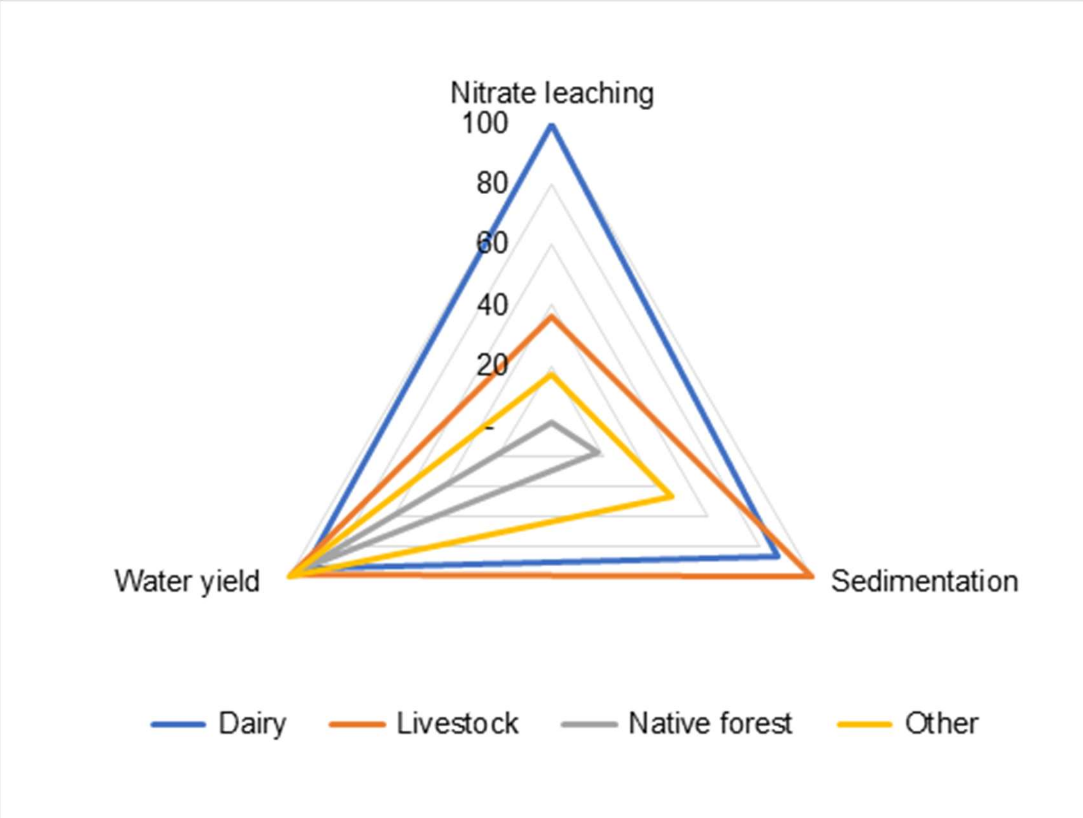

Figure 14: Environmental impact indices of the major land uses in the Ohinemuri catchment

These results describe the avoided erosion services provided by different vegetation types in the terrestrial environment of the Ohinemuri catchment. A large proportion of the surface water in a catchment flows into rivers and streams. The river system has a natural capacity to control erosion, and sediment inputs (2.2.1.1). The ability of riparian vegetation to filter out sediment before it reaches the river will be dependent on a range of factors including riparian vegetation composition, width and slope. Regardless, the riparian margins and floodplains have the potential to retain and store sediment exported by the river system, particularly during flood events, reducing the amount of sediment exported downstream and into the Thames estuary. Using turbidity as a surrogate indicator for suspended sediment, turbidity levels in the Ohinemuri catchment (Table 4) are rated 'Excellent' for aquatic ecosystem health indicating that the natural suspended sediment regulation ES is coping with current sediment loads.

Class Code:2.2.1.5
The Ohinemuri River is approximately 28 km in length, providing a natural fire protection ES and a potential source of water for fire-fighting. The quality of this ES will depend on the location of the fire in the catchment; narrower headwater sections of the river will have a lower capacity to provide a barrier to fire than the wider sections of the river further downstream. The effectiveness of the river in providing a fire barrier will also depend on the composition, size, severity, extent, direction and speed of the fire.

Group: Lifecycle maintenance, habitat and gene pool protection
Class Code: 2.2.2.2
The Ohinemuri River provides a mechanism for seed dispersal (aquatic and terrestrial); the seeds of indigenous plants can be transported by the river aiding downstream colonisation (but see 2.2.3.2).

Class Code: 2.2.2.3
The Ohinemuri River system is providing habitat, including nursery habitat, for a range of aquatic organisms (Jowett 2014; Shelley et al 2016; https://fishandgame.org.nz/dmsdocument/7). While Figure 15 maps important trout and indigenous fish habitat in the catchment, the fish distribution maps in Spiers (2001) indicate further suitable habitat for freshwater fish outside of these areas. However, in the Ohinemuri River system both trout and native fish habitats are constrained by natural low flows along with water quality characteristics such as water temperature (Franklin 2015; Tulagi 2018). These

habitats could be further compromised if alterations to flow regimes (i.e. increased water takes) further impacted on low flow regimes and critical water quality characteristics.

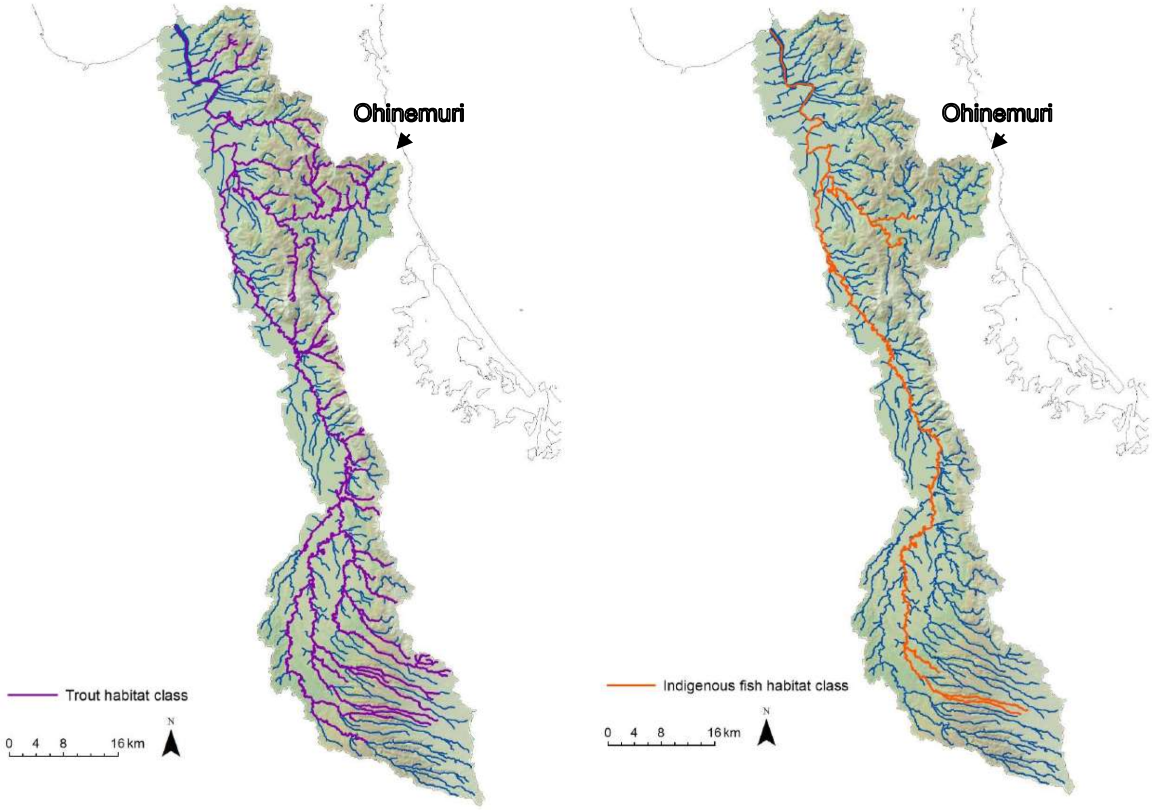

Figure 15: Important trout (left) and indigenous fish (right) habitat in the Ohinemuri catchment Extracted from Figures 4-2 and 4-3 in Franklin (2015)

Group: Pest and disease control
Class Code: 2.2.3.1 & 2.2.3.2
The Ohinemuri River is of insufficient width to provide a natural barrier to the spread of pests and diseases. However, the river and its riparian margins is providing provide habitat and a transport vector for the dispersal of unwanted or pest plant and animal species (aquatic and terrestrial) including alligator weed (*Alternanthera philoxeroides*), woolly nightshade (*Solanum mauritianum*), pampas (*Cortaderia jubata* & *C. selloana*), tutsan (*Hypericum androsaemum*), Japanese walnut (*Juglans ailantifolia*), privet (*Ligustrum spp.*), broom (*Cytisus scoparius*), gorse (*Ulex europaeus*) and others. In some riparian areas, native species are planted to assist with weed control. There are costs associated with annual surveillance programmes and pest control programmes although we were unable to identify specific costs for the Ohinemuri.

Group: Atmospheric composition and conditions
Class Code: 2.2.6.1.
The river system will be sequestering carbon and releasing carbon to the atmosphere. River & streams can release carbon to the atmosphere in the form of methane & nitrous oxide (Wilcock & Sorrell 2008). Rivers and streams also export carbon from the system in the form of dissolved and particulate organic carbon (Carey et al. 2005; Galy et al. 2015). However, no quantitative information was found for the Ohinemuri River system.

Class Code: 2.2.6.2
Regulation of temperature and humidity, including ventilation and transpiration
The main biotic component of the Ohinemuri River system contributing to air quality will be provided by aquatic plants and algae and the riparian vegetation along the river margins. Shading provided by vegetation and processes such as evapo-transpiration, photosynthesis and air contaminant removal

will have a local influence on air quality characteristics. The cooling and shading effects would benefit people using the river and recreating along the river's edge, particularly during the warmer summer months.

Class Code: 5.1.2.1
This class covers the mediation of nuisances/environmental by abiotic structures and processes and has been covered by a range of regulating ES discussed above.

Cultural ecosystem services

Cultural ES are the non-material benefits that people derive from freshwater ecosystems. Examples include recreational fishing, picnicking, boating, kayaking, tourism, intellectual development, spiritual enrichment, reflection and creative and aesthetic experiences (UKNEA, 2011). Similar to the provision and regulating ES categories, we followed the CICES framework. In the cultural ES category, we have merged together the biotic and abiotic because they usually have a joint (non-separable) effect on ES beneficiaries.

Biotic & Abiotic

Division: Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting
Groups: Physical and experiential interactions with natural environment & natural abiotic components of the environment
Biotic - Class Code: 3.1.1.2 Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions
Abiotic - Class Code: 6.1.1.1 Natural, abiotic characteristics of nature that enable active or passive physical and experiential interactions

Recreational Fishing (trout): The Ohinemuri River, its tributary the Waitawheta River and to a lesser extent the Waitekauri River tributary, are popular rivers for fishing. The Ohinemuri has excellent access and a good population of both rainbow and brown trout and the section through the Karangahake Gorge is the most popular and productive section of the river for trout fishing. Access to much of the Ohinemuri is relatively easy as State Highway (SH) 2 follows the river for much of its length. Within the Karangahake gorge there are several good access points and parking spaces (Unwin 2016; https://fishandgame.org.nz/dmsdocument/7). In the 2014/15 National Angling Survey, angler days total 1030 for the Ohinemuri River system (Unwin 2016). Using a value of $72.40 per fishing visit (Appendix II), provides an estimated value of $74,569 per annum (Appendix III). Figure 16 shows details of the number fishing visits for the Ohinemuri River and two main tributaries. These data show that the number of angling days in the Ohinemuri River has declined from the initial survey in 1994/95.

This decline is most likely influenced by increasing water temperatures and for 7-8 months of the year this thermal barrier limits trout occupancy in the lower section of the river. Regional and national trout fishing competitions are no longer held in the Ohinemuri and the decline in trout fishing means fewer fisherman visiting and staying in the catchment (pers. comm. Fish & Game; Daniel, 2018). While this will result in a decline in income coming into the catchment we were unable to quantify the amount.

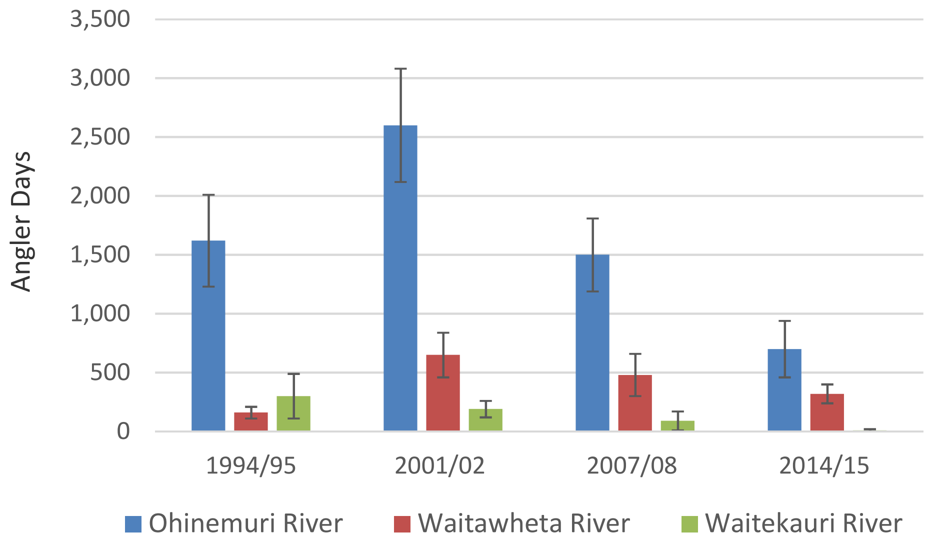

Figure 16: Angler days in the Ohinemuri River and two if its tributaries. Error bars represent standard errors (from Unwin, 2016)

Swimming: There are numerous swimming holes on both the Ohinemuri and Waitawheta Rivers, including the popular swimming spots at the Mackaytown Reserve and the Owharoa Falls[8] . The water quality monitoring site on the Ohinemuri River at Karangahake is monitored for swimmability with mixed results. No data on suitability for swimming was available on the LAWA website for this site. The WRC says that swimming is "not OK", while MfE says "it's OK, every now and then[9] . In the Ohinemuri River upstream of Waihi (SH25), the Waikato Regional Council says it's OK for swimming most of the time whereas the Ministry for the Environment says it's OK, some of the time[10].

Boating/Kayaking/Canoeing: The Ohinemuri and Waitawheta Rivers, including the Karangahake Gorge, provide opportunities for canoeing and kayaking (i.e. https://rivers.org.nz/nz/bay-of-plenty/ohinemuri/karangahake-gorge).

Picnicking: The river margins provide picturesque sites for picnics, particularly in the Karangahake Gorge (i.e. Karangahake Reserve) and at the Owharoa Falls. Kaval and Yao (2010) provided an approximation of the value of a picnicking visit of $7.34 per person. This approximated value per visit may have already changed over the past 12 years and would need to be updated. Also, the availability of data on the number of picnicking visits per year would help calculate this recreational value and allow its representation in decision making.

Walking/Biking: There are numerous walking trails in the Ohinemuri catchment, the majority of which are located between Paeroa and Waihi, particularly in the Karangahake Gorge. While many of these trails feature a historic mining component, trails also incorporate the river margin and the river scenery is also an important attraction for visitors[11]. A section of the Hauraki Rail Trail cycleway extends from Paeroa to Waihi (24km, passing through the Karangahake Gorge[12]) (Figure 17).

[8] http://www.waihi.org.nz/about-us/karangahake/;
https://www.stuff.co.nz/travel/destinations/nz/75251412/
[9] https://www.waikatoregion.govt.nz/environment/natural-resources/water/rivers/our-other-rivers/water-quality-monitoring-map/ohinemuri-river-at-karangahake-niwa-site/
[10] https://www.waikatoregion.govt.nz/Environment/Natural-resources/Water/Rivers/Our-other-rivers/Water-quality-monitoring-map/Ohinemuri-River-upstream-of-Waihi/
[11] https://www.thecoromandel.com/activities/must-do/karangahake-gorge/activities/
[12] https://haurakirailtrail.co.nz/choose-your-ride/paeroa-to-waihi

Figure 17: Hauraki Rail Trail cycleway in the Karangahake Gorge.

According to Kaval (2006), approximately 62,781 New Zealanders walked on the Karangahake walkway. According to Matthews (2009), an indicative NZ walking value per year of walking along a scenic river in the Waikato region (includes use, option use and non-use values) is about NZ$27.95 (in 2019 NZ$) (Appendix II). Multiplying the two figures above result to a conservative public walkway value of approximately NZ$1.754 million per year (Appendix III). The value for international visitors would likely be higher. As we did not have the walking value of overseas people, we did not include this value in the calculation. However, as visitor numbers in the region increase (Destination Coromandel, 2018), there is pressure on existing infrastructure at Karangahake to cope with the demand. The Hauraki District Council has a low-ratepayer-base from which to provide funding and the Council has had success in securing Central Government Funding for infrastructure upgrades (Destination Coromandel, 2018; https://www.hauraki-dc.govt.nz/news-page/2018/october/18/karangahake-reserve-toilets/).

More than 30 cycling visits in the Karangahake Gorge was reported in Ryan et al. (2013). Dhakal et al. (2012) estimated the value of a mountain biking visit in Whakarewarewa forest to be about $57 (in 2019NZ$). There is potential to calculate the aggregate value of mountain biking/cycling visits if the number of visitations per year was available.

Groups: Intellectual and representative interactions with natural environment & abiotic components of the natural environment

Biotic - Class Code: 3.1.2.1 Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge

Abiotic - Class Code: 6.1.2.1. Natural, abiotic characteristics of nature that enable intellectual interactions

The four water monitoring points in the Ohinemuri catchment (Figure 2) are key points of scientific interest. The water quality and ecological data collected from these sites is of regional and national importance and has been used in numerous reports and scientific studies (Appendix V). Although not a conclusive list, we found approximately 70 publications relating to research on the surface waters of the Ohinemuri River system.

Class Code: 3.1.2.2. Characteristics of living systems that enable education and training

The Ohinemuri River system provides a source of educational and training opportunities. The Department of Conservation has developed a teaching resource kit for the Karangahake Gorge[13]. The Waitawheta Camp provides a range of outdoor educational opportunities and activities for school groups including swimming and canoeing in the Waitawheta River (https://www.waitawhetacamp.co.nz/).

The Ohinemuri and its tributaries also provide sites for conservation and restoration projects. HELP undertake restoration activities in the catchment, including riparian restoration projects in the Waitete and Mangatoetoe streams and the Ohinemuri River, in collaboration with mining companies, farmers, WRC, HDC, local schools, DOC and others. This restoration work is improving aesthetics along river and stream margins, and assisting with weed control, nutrient and sediment run-off and water quality improvement in the catchment (pers. comm, HELP Waihi[14]). Mike O'Donnell, a Paeroa sculptor and potter, known as 'The Waterman', has worked with community school groups in restoring local waterways, including his local stream, the Tarariki, and the Ohinemuri. He is an inspirational and educational speaker about water at forums around New Zealand.

Educational opportunities on the culture and history of the area, particularly the mining history, are provided by museums such as the Waihi Arts Centre and Museum, archaeological and historic sites of interest, and walkways (https://www.thecoromandel.com/towns/waihi/activities/culture-and-heritage/).

Class Code: 3.1.2.3 Characteristics of living systems that are resonant in terms of culture or heritage
The Ohinemuri river system has a rich cultural and historic heritage. The Ohinemuri Regional History Journals (1964-2012) provide a wealth of historic information on the Ohinemuri[15] . The mining history is nationally significant in terms of NZ mining heritage[16] . There are museums and several trails and walkways showcasing the areas heritage and mining history (Figure 18) which has strong linkages with the Ohinemuri River system[17] . The Ohinemuri (Masonry) Dam on the Ohinemuri River, near the confluence with Waitete Stream has a heritage status of National or Outstanding Regional Significance; the Woodstock Battery at the confluence of Waitawheta and Ohinemuri Rivers has a Category 2 heritage status as a Registered Historic Place; National or Outstanding Regional Significance and the Karangahake Gorge Historic Area has a heritage status of National or Outstanding Regional Significance. In addition, there are several other sites pertaining to the Ohinemuri River system that have Regional or Sub-Regional Significance or Local or Neighbourhood Significance (Hauraki District Council, 2014).

[13] https://www.doc.govt.nz/Documents/getting-involved/students-and-teachers/field-trips-by-region/bop/karangahake-historic-walkway/03-karangahake-kit-page14-22.pdf
[14] http://www.waihihabitat.co.nz/
[15] http://www.ohinemuri.org.nz/journals
[16] http://www.doc.govt.nz/Documents/parks-and-recreation/tracks-and-walks/waikato/karangahake-gorge-brochure.pdf
[17] https://www.thecoromandel.com/towns/waihi/activities/culture-and-heritage/

Figure 18: Mining remnants on the Hauraki Rail Trail cycleway

The Ohinemuri is of cultural significance to Māori[18] ; the word “Ohinemuri” meaning the ‘the maiden/girl who was left behind’. The Ohinemuri Waahi Tapu Area on the Ohinemuri River is of cultural significance to Māori (Hauraki District Council, 2014). In a separate research project, the WRC is undertaking an assessment of Māori cultural freshwater ES across the region (Hopkins, Kelepamu and Olubode-Awosola, 2019) and hopefully the Ohinemuri catchment will be covered shortly.

Class Code: 3.1.2.4 Characteristics of living systems that enable aesthetic experiences
The Ohinemuri River and its main tributaries, such as the Waitewheta River, along with the Owharoa Falls[19] are regarded as having high scenic and aesthetic values. The Karangahake Gorge (see cover photo) has particularly high aesthetic values and is voted as one of the 101 Must Do's for Kiwis[20] . The Coromandel Range and Moehau Range have been identified as outstanding natural features and landscapes of regional significance and this landscape includes the Karangahake Gorge (Buckland, 2010). The Karangahake Gorge and surrounds provide inspiration for photographers and artists with an arts community based in Waikino[21] .

Groups: Spiritual, symbolic and other interactions with natural environment & abiotic components of the natural environment
Biotic - Class Code: 3.2.1.1. Elements of living systems that have symbolic meaning
Biotic - Class Code: 3.2.1.2 Elements of living systems that have sacred or religious meaning
Abiotic - Class Code: 6.2.1.1. Natural, abiotic characteristics of nature that enable spiritual, symbolic and other interactions

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[18] http://www.ohinemuri.org.nz/journals/39-journal-13-may-1970/675-the-legend-of-ohinemuriculture
[19] http://waterfalls.co.nz/waterfalls-by-region/87-new-zealand-waterfalls/north-island/waikato/108-owharoa-falls
[20] https://www.thecoromandel.com/activities/must-do/karangahake-gorge/activities/listing/karangahake-gorge
[21] https://www.newzealand.com/int/article/experiencing-new-zealand-nature-history-and-culture-through-art-in-waikino/

This freshwater ES is closely linked to Class Code 3.1.2.3. The Ohinemuri River is of spiritual and symbolic value to Māori, artists and visitors and contributes to the identity of communities living in the catchment. One Māori sacred site, the Ohinemuri Waahi Tapu Area on the Ohinemuri River is listed in the schedule of historic heritage inventory – areas of significance to Māori (Hauraki District Council, 2014). The Karangahake Gorge is the most iconic feature in the river system and is listed as an iconic heritage site on the DOC website (https://www.doc.govt.nz/parks-and-recreation/places-to-go/icon-heritage-sites/).

Class Code: 3.2.1.3 Elements of living systems used for entertainment or representation
There are numerous on-line video clips on the Ohinemuri River, particularly the Karangahake Gorge. The film 'Water Whisperers' explores the work of ten different communities as they seek to heal damaged New Zealand rivers, lakes, coastlines and oceans, and protect them for future generations, including the Ohinemuri River. The Karangahake Gorge features in tourism promotional videos[22] The book 'True Tales of Waikino and Waitekauri' (Stubbs et al., 2016) provides a collation of stories from people living in the area, including the floods.

Group: Other biotic characteristics that have a non-use value
Biotic - Class Code: 3.2.2.1 Characteristics or features of living systems that have an existence value
Biotic - Class Code 3.2.2.2 Characteristics or features of living systems that have an option or bequest value
Abiotic - Class Code 6.2.2.1 Natural, abiotic characteristics or features of nature that have either an existence, option or bequest value
The Ohinemuri River system has an existence value. In particular, the iconic status of the Karangahake Gorge indicates that this landscape has value beyond those who live in and visit the area. The importance of protecting the natural assets in the Ohinemuri River system, such as landscape values, water quality, water supply, freshwater ecosystems and freshwater species for future generations, forms an integral component of regional and district policy and plans (Hauraki District Plan, 2014; Waikato Regional Council, 2016) New Zealand's indigenous freshwater fauna also have existence, option or bequest values. As an example, in the Ohinemuri River system, there are three native freshwater fish with conservation status of At Risk – Declining (*Anguilla dieffenbachii* – longfin eel, *Cheimarrichthys fosteri* – torrentfish, *Galaxias maculatus* – inanga, *Neochanna diversus* – black mudfish) and one Nationally vulnerable species (*Galaxias postvectis* – shortjaw kōkopu) (Freshwater fish database https://nzffdms.niwa.co.nz/; Dunn et al., 2017).

[22] https://visuals.newzealand.com/asset/205765

Conclusions and recommendations

This study has identified and estimated a wide range of provisioning, regulating and cultural freshwater ES in the Ohinemuri catchment. Freshwater ES are providing valuable flows of services that benefit the local communities and the economy while also contributing to environmental conservation. Freshwater ES such as the provision of a good water supply for domestic, agricultural and industrial use, along with tourism and recreational activities associated with the river, are critical to the on-going well-being and economic prosperity of the catchment. However, the study also identified pressures on current freshwater ES mainly in relation to low flows and water quality characteristics such as high nitrogen and water temperatures that are impacting on water supply treatment costs, indigenous fish habitat and a declining recreational trout fishery. Any land-use or terrestrial management activities that mediate these pressures can only further improve the high-value freshwater ES present in this catchment. The information from this catchment level assessment contributes to and builds on the work undertaken in Phases 1 and 2 of this long-term research programme and provides additional information to populate the WRC's map of freshwater ES in the region. The outcomes and information from this project will also assist the WRC with its role and responsibilities under the Ministry for the Environment's (MfE) Action for healthy waterways programme, including the National Policy Statement for Freshwater Management and the MfE essential freshwater modelling project.

Our recommendations for possible future work are outlined below:

- That the results of the Māori cultural freshwater ES that is being undertaken separately are synthesised with this report to provide a more comprehensive assessment of the freshwater ES in the Ohinemuri catchment.
- The catchment could be used as a study site to assess the effects of implementing government and regional policies such as the One Billion Trees Programme on freshwater ES.
- Areas in the catchment that have the highest erosion and nitrogen rates could also consider options such as increasing river setbacks and riparian plantings. New permanent plantings of native trees and shrubs, also enhance the provision of habitats for indigenous biodiversity which is valued by New Zealanders (Kaval and Yao 2010; Yao et al. 2019b). Using spatial economic (e.g. FIF, InVEST) combined with economic valuation tools (choice experiments, replacement costs, travel cost), the spatial non-market value of the change in the provision of freshwater ES, given various land-use change or new freshwater management scenarios, can be robustly estimated and/or spatially described to enable their representation in decision making and policy analysis.
- The valuation of avoided erosion was outside the scope of this project. The spatial calculation of this value requires the identification of potential afforestation areas which can include the marginal pasture areas on steep terrain and bare land areas near waterways. The type of afforestation regime (e.g. permanent planting, timber production) should also be specified to enable the spatial economic modelling of afforestation scenarios in FIF (Yao et al. 2019a). These data will allow the calculation of the value of avoided erosion while accounting for the major events across a 28-year rotation of exotic forest production (e.g. radiata pine) wherein sedimentation rates are high during the time of establishing the production forest (years 1 to 3), extremely low at mid-rotation (years 8 to 29) and high during the harvest (year 30) and immediate post-harvest period. In the case of slow growing native forests planted permanently for the provision of non-market ecosystem service benefits (e.g. mānuka, totara), sedimentation remains extremely low even after mid-rotation as no-harvesting takes place.
- The quantification of water yield has been done on an annual basis due to limited time and data. Decision making processes and policy discussions would need information on the impacts of seasonal flows, especially during the high rainfall winter months and the dry summer period. There is potential to expand this modelling to account for seasonality flows (high and low flows) using the application of the InVEST Seasonal Water Yield model. This model computes spatial indices for quantifying the relative contribution of land spatial units to the generation of both baseflow and quick flow across the catchment (Sharp et al 2018). This is important modelling work because the Ohinemuri catchment is prone to flood events. Further, with climate change and potential drought episodes of increasing severity across New Zealand, an expected outcome would be greater periods of low water flows.

- Extending this surface freshwater ES assessment to include all ES services in the catchment (i.e. terrestrial and other freshwater resources such as lakes, wetlands and groundwater), would allow a trade-off analysis using an ES approach for catchment management.
- Quantified value of freshwater ES can be used to support the development of various environmental accounts of StatsNZ. These New Zealand environmental accounts, which follow the United Nations System of Environmental Economic Accounting system, support both national and international reporting of the state and trends of freshwater values. These accounts can also help inform policy and investment decisions as well as research programmes that support policies related to land and water.
- The observation that water use is mostly less than the amount of water consented should be explored to understand any implications for the WRC’s role of exploring potentials and identifying trade-off in its resource management and plan review process under the Resource Management Act.

Acknowledgements

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Note: this list covers the refences in this report and the accompanying spreadsheet.

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Appendix I: The CICES (V5.1) classes used in the Ohinemuri catchment freshwater ecosystem services assessment

Freshwater ES evaluation code: 1 = high level of certainty that the ES is not present in the catchment; 2 = ES may be present but no information found; 3 = ES highly certain to be present but no information found; 4 = ES present and qualitative information located; 5 = ES present, quantitative information located; 6 = ES present, quantitative & economic data available

Section	Division	Group	Class	Code	Class type	Simple descriptor	Evaluation Code
Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy	Plants cultivated by in- situ aquaculture grown for nutritional purposes	1.1.2.1	*Plants, algae by amount, type*	*Plants that are cultivated in fresh or salt water that we eat*	1
			Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials)	1.1.2.2	*Plants, algae by amount, type*	*Plants that are cultivated in fresh or salt water that we can use as a material*	1
			Plants cultivated by in- situ aquaculture grown as an energy source	1.1.2.3	*Plants, algae by amount, type*	*Plants that are cultivated in fresh or salt water that we can use as an energy source*	1
		Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture for nutritional purposes	1.1.4.1	*Animals by amount, type*	*Animals that are cultivated in fresh or salt water that we eat.*	1
			Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials)	1.1.4.2	*Animals by amount, type*	*Animals that are cultivated in fresh or salt water that we can use as a material.*	1
			Animals reared by in-situ aquaculture as an energy source	1.1.4.3	*Animals by amount, type*	*Animals that are cultivated in fresh or salt water that we can use as a source of energy.*	1

		Wild plants (aquatic) for nutrition, materials or energy	Wild plants (aquatic, including fungi, algae) used for nutrition	1.1.5.1	*Plants, algae by amount, type*	*Food from wild plants*	4
			Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)	1.1.5.2	*Plants, algae by amount, type*	*Materials from wild plants*	4
			Wild plants (aquatic, including fungi, algae) used as a source of energy	1.1.5.3	*Material by type/source*	*Materials from wild plants, fungi and algae used for energy*	2
		Wild animals (aquatic) for nutrition, materials or energy	Wild animals (aquatic) used for nutritional purposes	1.1.6.1	*Animals by amount, type*	*Food from wild animals*	4 (whitebait, trout); 6 (eel)
			Fibres and other materials from wild animals for direct use or processing (excluding genetic materials)	1.1.6.2	*Material by type/source*	*Materials from wild animals*	2
			Wild animals (aquatic) used as a source of energy	1.1.6.3	*By amount, type, source*	*Material from wild animals that can be used as a source of energy*	2
	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population	1.2.1.1	*By species or varieties*	*Seed collection*	2
			Higher and lower plants (whole organisms) used to breed new strains or varieties	1.2.1.2	*By species or varieties*	*Plants. fungi or algae that we can use for breeding*	2
			Individual genes extracted from higher and lower plants for the design and construction of new biological entities	1.2.1.3	*Material by type*	*Genetic material from wild plants. fungi or algae that we can use*	2
		Genetic material from animals	Animal material collected for the purposes of maintaining or establishing a population	1.2.2.1	*By species or varieties*	*Animals used for replenishing stock*	2
			Wild animals (whole organisms) used to breed new strains or varieties	1.2.2.2	*By species or varieties*	*Wild animals that we can use for breeding*	2

		Genetic material from organisms	Individual genes extracted from organisms for the design and construction of new biological entities	1.2.2.3	*Material by type*	*The genetic information that is stored in wild animals that we can use*	2
	Other types of provisioning service from biotic sources	Other	Wild plants (aquatic, including fungi, algae) used for medicinal/pharmaceutical/health purposes	1.3.1.1	*Material by type/source*	*Wild plants that we can use for health benefits*	2
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Surface water for drinking	4.2.1.1	*By amount, type, source*	*Drinking water from sources at the ground surface*	6
	Water	Surface water used for nutrition, materials or energy	Surface water used as a material (non-drinking purposes)	4.2.1.2	*By amount & source*	*Surface water that we can use for things other than drinking*	6
	Water	Surface water used for nutrition, materials or energy	Freshwater surface water used as an energy source	4.2.1.3	*By amount, type, source*	*Hydropower*	1
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Bio-remediation by micro-organisms, algae, plants, and animals	2.1.1.1	*By type of living system or by waste or subsistence type*	*Decomposing wastes*	3
			Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	2.1.1.2	*By type of living system, or by water or substance type*	*Filtering wastes*	3
		Mediation of nuisances of anthropogenic origin	Smell reduction	2.1.2.1	*By type of living system*	*Reducing smells*	3
			Noise attenuation	2.1.2.2	*By type of living system*	*Reducing noise*	3
			Visual screening	2.1.2.3	*By type of living system*	*Screening unsightly things*	5
	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Control of erosion rates	2.2.1.1	*By reduction in risk, area protected*	*Controlling or preventing soil loss*	3 (river system); 5 (land-use)

			Buffering and attenuation of mass movement	2.2.1.2	*By reduction in risk, area protected*	*Stopping landslides and avalanches harming people*	3
			Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	2.2.1.3	*By depth/volumes*	*Regulating the flows of water in our environment*	3
			Fire protection	2.2.1.5	*By reduction in risk, area protected*	*Protecting people from fire*	5
		Lifecycle maintenance, habitat and gene pool protection	Seed dispersal	2.2.2.2	*By amount and dispersal agent*	*Spreading the seeds of wild plants*	3
			Maintaining nursery populations and habitats (Including gene pool protection)	2.2.2.3	*By amount and source*	*Providing habitats for wild plants and animals that can be useful to us*	4
		Pest and disease control	Pest control (including invasive species)	2.2.3.1	*By reduction in incidence, risk, area protected by type of living system*	*Controlling pests and invasive species*	5
			Disease control	2.2.3.2	*By reduction in incidence, risk, area protected by type of living system*	*Controlling disease*	5
		Water conditions	Regulation of the chemical condition of freshwaters by living processes	2.2.5.1	*By type of living system*	*Controlling the chemical quality of freshwater*	5
		Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans	*2.2.6.1*	*By contribution of type of living system to amount, concentration or climatic parameter*	*Regulating our global climate*	3
			Regulation of temperature and humidity, including ventilation and transpiration	2.2.6.2	*By contribution of type of living system to amount, concentration or climatic parameter*	*Regulating the physical quality of air for people*	3

Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Dilution by freshwater and marine ecosystems	5.1.1.1	*Amount by type*	*Diluting wastes*	3
			Mediation by other chemical or physical means (e.g. via Filtration, sequestration, storage or accumulation)	5.1.1.3	*Amount by type*	*Natural processing of wastes*	4
	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Mediation of nuisances by abiotic structures or processes	5.1.2.1	*Amount by type*	*Natural protection*	3
	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Mass flows	5.2.1.1	*Amount by type*	*Physical barriers to landslides*	3
		Regulation of baseline flows and extreme events	Liquid flows	5.2.1.2	*Amount by type*	*Physical barriers to flows*	3
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	3.1.1.2	*By type of living system or environmental setting*	*Watching plants and animals where they live; using nature to destress*	4, 5 & 6
		Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	3.1.2.1	*By type of living system or environmental setting*	*Researching nature*	5
		Intellectual and representative interactions with natural environment	Characteristics of living systems that enable education and training	3.1.2.2	*By type of living system or environmental setting*	*Studying nature*	4

		Intellectual and representative interactions with natural environment	Characteristics of living systems that are resonant in terms of culture or heritage	3.1.2.3	*By type of living system or environmental setting*	*The things in nature that help people identify with the history or culture of where they live or come from*	4 & 5
		Intellectual and representative interactions with natural environment	Characteristics of living systems that enable aesthetic experiences	3.1.2.4	*By type of living system or environmental setting*	*The beauty of nature*	4
	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have symbolic meaning	3.2.1.1	*By type of living system or environmental setting*	*Using nature to as a national or local emblem*	4 & 5
		Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have sacred or religious meaning	3.2.1.2	*By type of living system or environmental setting*	*The things in nature that have spiritual importance for people*	4
		Spiritual, symbolic and other interactions with natural environment	Elements of living systems used for entertainment or representation	3.2.1.3	*By type of living system or environmental setting*	*The things in nature used to make films or to write books*	4 & 5
		Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an existence value	3.2.2.1	*By type of living system or environmental setting*	*The things in nature that we think should be conserved*	4
		Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an option or bequest value	3.2.2.2	*By type of living system or environmental setting*	*The things in nature that we want future*	4

						generations to enjoy or use	
Cultural (Abiotic)	Direct, in-situ and outdoor interactions with natural physical systems that depend on presence in the environmental setting	Physical and experiential interactions with natural abiotic components of the environment	Natural, abiotic characteristics of nature that enable active or passive physical and experiential interactions	6.1.1.1	*Amount by type*	*Things in the physical environment that we can experience actively or passively*	4
		Intellectual and representative interactions with abiotic components of the natural environment	Natural, abiotic characteristics of nature that enable intellectual interactions	6.1.2.1	*Amount by type*	*Things in the physical environment that we can study or think about*	4 & 5
	Indirect, remote, often indoor interactions with physical systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with the abiotic components of the natural environment	Natural, abiotic characteristics of nature that enable spiritual, symbolic and other interactions	6.2.1.1	*Amount by type*	*Things in the physical environment that are important as symbols*	4 & 5
		Other abiotic characteristics that have a non-use value	Natural, abiotic characteristics or features of nature that have either an existence, option or bequest value	6.2.2.1	*Amount by type*	*Things in the physical environment that we think are important to others and future generations*	4 & 5

Appendix II: Price assumptions/estimates used in the Ohinemuri freshwater ES assessment

Item	Unit	Price/unit (2015 NZ$)	Price/unit (Sep 2017 NZ$)	Price/unit (Jun 2019 NZ$)	Reference/Comment
Drinking water	m3	1.7	1.75	1.80	WDCIC (Waikato District Council Infrastructure Committee) 2015 Meeting held in Ngaruwahia on 12 May 2015; Proposed consumption charge per m3 for 2015/2016
Cost of farm irrigation water	m3	0.12	0.13	0.15	Denne et al. 2011; Doak et al. 2004
Eel	kg	21	21.56	22.64	2015 Ngati Porou Eel model
Fishing visit	visit	69	70.84	72.40	$70.84 (in 2017 NZ$) derived from McBeth (1997). This is very similar to Kerr (1996) with $65.58 per fishing visit in the South Island. https://www.commtrade.co.nz/
Walkway access to streams NZ$24/person/year	person per year	26.64	27.42	27.95	Matthews (2009) Valuation of enviro improvements to Hamilton streams

Appendix III: Freshwater ES in the Ohinemuri catchment where quantitative/economic information was identified

Section	Code	Ecosystem Service Indicator	Quantification unit		Information on the underlying model and data used to map the ecosystem service			Mapped year or period	Self-assessment of the mapping and modelling study				Comments
					Input data source	Quantific a-tion method	Spatial details		Study objective met	Well-being value			
			Quantity (e.g. kg)	Time (e.g. year)			Scale			Economic ($'000)	Health (+)	Social/ cultural/ spiritual	
Provisioning (Biotic)	1.1.6.1	Eel harvested in the wild for commercial purposes (ton/year)	35	year	N/A	N/A	N/A	N/A	N/A	791	unknown	unknown	There is longfin and shortfin eel commercial fishing in the Ohinemuri catchment valued at $791,497.
Provisioning (Abiotic)	4.2.1.1	Surface water extraction - drinking (m3/year)	1,681,119	year	average measures with missing data	used an indexing approach to extrapolate missing values	local	Years 2000 to 2016 for both sites (Waitawheta and Walmsey). Both sites have missing data.	3 (simple extrapolation undertaken using indices)	3,026	+	N/A	There are three current resource consents for surface water takes for domestic and municipal water supply in the Ohinemuri catchment that provide drinking water to the Waihi and Paeroa townships. Water supplies from the Ohinemuri and Waitewheta Streams are being treated to remove the smell and unpalatable taste from the water.
	4.2.1.2	Surface water extraction - non-drinking (m3/year)	58,345	year	average measures with missing data	used an indexing approach to extrapolate missing values	local	Varying across seven non-drinking water extraction sites (one had one month, while others had multiple years of data)	4 (extrapolation undertaken with strong assumptions made)	8.75	N/A	N/A	There are 10 current resource consents for surface water takes for non-drinking water purposes in the Ohinemuri catchment, primarily dairy and horticultural use.

Regulation & Mainte-nance (Biotic)	2.1.2.3	Visual screening of anthropogenic structures provided by living material (km)	28	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	There is approximately 28 km of vegetated riparian margin along most of the length of the Ohinemuri River, supplemented by indigenous restoration plantings, particularly along the mid-section of the river. Additional riparian restoration work is occurring along the Waitete and the Mangatoetoe Streams (pers comm., HELP Waihi) Riparian vegetation will be providing a visual screen along sections of the Ohinemuri River system.
	2.2.3.1	Barrier to pests & invasive species (km)	28	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	28 kms of river. The Ohinemuri River may provide a barrier to the spread of unwanted plant and animal pests, particularly along the wider sections of the river system. However, the river and its riparian margins may also provide a transport vector for the dispersal of unwanted or pest plant and animal species (aquatic and terrestrial).
	2.2.3.2	Barrier to the dispersal of disease (km)	28	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	28 kms of river. The Ohinemuri River is unable to provide an effective barrier to the spread of pests & diseases (pers. comm. WRC). Both the river system and its riparian margins provide a transport vector for the dispersal of a range of aquatic and terrestrial pests (pers. Comm., WRC & HELP Waihi).
Cultural (Biotic)	3.1.1.2 a	Recreational activities; number of angler days (number/year)	1,030	year	National Angling Survey		global, national, regional, local	2016	1	75	+	+	For the 2014/15 National Angling Survey, angler days totalled 700 (± 240 (SE)) in the Ohinemuri River, 320 days (± 80) in the Waitawheta River and 10 days (±10) in the Waitekauri River (Unwin 2016). Physical activities involving interaction with the waters and riparian areas of the Ohinemuri River system include recreational fishing, swimming, kayaking, picnicking, walking and biking. However, the number of angling days in the Ohinemuri have declined from the initial survey in

													1994/95 (1620 angler days ± 390) to the latest survey in 2014/15 (700 angler days ± 240) (Unwin 2016).
	3.1.1.2 b	Recreational activities; number of walking visits (number/year)	62,781	year	Approximations	Approximation	global, national, regional, local	2006	1	1,755	+	+	According to Kaval (2006) approximately 62,781 New Zealanders walked on the Karangahake walkway. According to Matthews (2009), an indicative NZ walking value per year of walking along a scenic river in the Waikato region (includes use, option use and non-use values) is about NZ$27.95 (in 2019NZ$). By multiplying the two figures above results to a conservative public walkway value of approximately NZ$1.754 million per year. The value for international visitors would likely be higher. As we did not have the walking value of overseas people, we did not include this value in the calculation.
	3.1.2.1	Sites of special scientific interest(number)	4	N/A	Local, regional, national	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4 key research sites: Ohinemuri River @ SH25 Br (water quality, ecology), Ohinemuri River @ Queens Head (water quality, flow), Ohinemuri River @ Karangahake (water quality, flow), Waitekauri River @ U/S Ohinemuri confluence (water quality); no. of publications. The four water monitoring points in the Ohinemuri catchment are key points of scientific interest. The water quality and ecological data collected from these sites is of regional and national importance and has been used in numerous reports and scientific studies.

													Although not a conclusive list, we found approximately 70 publications relating to research on the surface waters of the Ohinemuri River system.
	3.2.1.3	Number of nature films produced (number)	2	N/A	media	N/A	global, national, regional, local	N/A	N/A	N/A	+	+	There are numerous on-line video clips on the Karangahake Gorge and the river has featured in a film 'Water Whisperers' and a book 'True Tales of Waikino and Waitekauri' (Stubbs et al. 2016).

Appendix IV Current discharge consents in the catchment

	Authorisation ID	Holder	Activity Description	Primary Purpose
No.*	**Discharge - stormwater**			
14	AUTH104870.01.01	Midway Storage Limited	Discharge up to 340 litres per second of stormwater onto land and/or into the Ohinemuri River	Manufacturing/ Processing - timber
15	AUTH105633.01.01	Hauraki District Council - Paeroa Office	Divert & discharge urban stormwater runoff & assoc contaminants to Criterion catchment, main drain stream, Opukeko Stream, Ohinemuri & Waihou Rivers & land, & use discharge structures within the Paeroa Urban Area	Sewage disposal - domestic
16a	AUTH105634.01.01	Hauraki District Council - Paeroa Office	Divert & discharge urban s/water runoff & assc contaminants at multiple locations to Gilmour Lake, Eastern, Mangatoetoe, Waitete Streams & Ohinemuri River & land, & use disch structures within the Waihi, Karangahake & Mackaytown urban areas	Sewage disposal – domestic (Mackaytown)
16b	AUTH105634.01.01	Hauraki District Council - Paeroa Office	Divert & discharge urban s/water runoff & assc contaminants at multiple locations to Gilmour Lake, Eastern, Mangatoetoe, Waitete Streams & Ohinemuri River & land, & use disch structures within the Waihi, Karangahake & Mackaytown urban areas	Sewage disposal – domestic (Karangahake)
16c	AUTH105634.01.01	Hauraki District Council - Paeroa Office	Divert & discharge urban s/water runoff & assc contaminants at multiple locations to Gilmour Lake, Eastern, Mangatoetoe, Waitete Streams & Ohinemuri River & land, & use disch structures within the Waihi, Karangahake & Mackaytown urban areas	Sewage disposal – domestic (Waikino)
16d	AUTH105634.01.01	Hauraki District Council - Paeroa Office	Divert & discharge urban s/water runoff & assc contaminants at multiple locations to Gilmour Lake, Eastern, Mangatoetoe, Waitete Streams & Ohinemuri River & land, & use disch structures within the Waihi, Karangahake & Mackaytown urban areas	Sewage disposal – domestic (Waihi)
17	AUTH118430.01.01	Online Contractors (2016) Limited	Discharge up to 0.096 cubic metres per second of treated stormwater into the Waitete Stream from a residential subdivision	Accomodation
18	AUTH118984.01.01	Hauraki District Council - Paeroa Office	Discharge stormwater from the Paeroa landfill (during and after closure) into the Paeroa Main Drain and Central Drain and into and onto land	Waste treatment/ disposal
19	AUTH119658.01.01	Coeur Gold NZ Ltd & Coeur Gold NZ II, LLC	Discharge stormwater from the rehabilitated open pit and western diversion drain of the Golden Cross Mine into the Waitekauri River	Mining - gold/precious metals
20	AUTH124678.01.01	H.G. Leach & Company Limited	Discharge treated stormwater to unnamed tributaries of the Kiekie Stream in association with quarrying activities	Mining - rock/aggregate
21	AUTH137420.02.01	Builtsmart Limited	To discharge stormwater to water in association with a subdivision development at 7-23 Thames Road, Paeroa	Subdivision development
22	AUTH137891.01.01	Feng Man Lian Property Development Ltd.	To divert and discharge stormwater to a modified tributary of the Ohinemuri River from a residential subdivision, Thames Road, Paeroa.	Subdivision development
	Discharge - other			

23	AUTH103087.01.02	Coeur Gold NZ Ltd. & Coeur Gold NZ II, LLC	Discharge water from the Golden Cross & Empire workings at the Golden Cross Mine site	Mining - gold/precious metals
24	AUTH107327.01.01	Hauraki District Council - Paeroa Office	Discharge contaminants mainly in the form of leachate and sediment to water being an unnamed tributary of Eastern Stream in association with the closure of the Waihi Refuse tip closure	Waste treatment/ disposal
25	AUTH110199.01.01	JK Property Limited	Discharge up to 1,300 cubic metres per day of dry weather flow treated meat processing wastewater into the Ohinemuri River	Manufacturing/ processing - meat
26	AUTH118545.01.01	Edwards Transport Limited (Ceased Trading)	Discharge up to 5 cubic metres per day of truck wash water to the Mangatoetoe Stream	Transport services - road
27	AUTH132558.01.01	Hauraki District Council - Paeroa Office	To discharge backwash water to the Ohinemuri River from the Paeroa Water Treatment Plant	Water supply - municipal/ community
28	AUTHW2326.01.03	Coeur Gold NZ Ltd. & Coeur Gold NZ II, LLC	Discharge waste water from project site into river	Mining - gold/precious metals
29	AUTH971297.01.03	Oceana Gold (NZ) Ltd. - Waihi Operations	Discharge natural water (farm run-off & intercepted groundwater)	Mining - other
30	AUTH971301.01.03	Oceana Gold (NZ) Ltd. - Waihi Operations	Discharge natural water diverted around surplus soil stockpiles	Mining - other
31	AUTH971308.01.03	Oceana Gold (NZ) Ltd. - Waihi Operations	Discharge natural water diverted around eastern side of storage 1A	Mining - other
32	AUTH971310.01.03	Oceana Gold (NZ) Ltd. - Waihi Operations	Discharge diverted natural water around storage 2 & part of 1A	Mining - other
33	AUTH971311.01.08	Oceana Gold (NZ) Ltd. - Waihi Operations	Discharge all water from silt ponds within area D	Mining - other
34	AUTH971312.01.07	Oceana Gold (NZ) Ltd. - Waihi Operations	Discharge all water from collection ponds within area D	Mining - other
35	AUTH971315.01.03	Oceana Gold (NZ) Ltd. - Waihi Operations	Discharge all water from collection ponds for treatment plant	Mining - other
36	AUTH971317.01.02	Oceana Gold (NZ) Ltd. - Waihi Operations	Discharge natural water diverted to south on western side of plant	Mining - other
37	AUTH971318.01.10	Oceana Gold (NZ) Ltd. - Waihi Operations	To discharge treated water from the Water Treatment Plant into the Ohinemuri River via two discharge points	Mining - gold/precious metals
38	AUTH971323.01.06	Oceana Gold (NZ) Ltd. - Waihi Operations	Discharge water from tailings ponds area D following rehabilitation	Mining - other

*These numbers refer to the locations of the consents in the catchment - see Figure 4

Appendix V: Scientific Papers/Reports pertaining to the Ohinemuri catchment

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