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An Overview of Databases and Models used to Monitor and Report on Freshwater in New Zealand

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EXECUTIVE SUMMARY

We reviewed existing databases and models for monitoring and reporting freshwater quality in New Zealand. The criteria and limitations of the models were evaluated and compared with special references to the Rivers Environment Classification (REC) system.

What is the industry problem or driver for this study?

The objective was to identify whether suitable databases and/or models are available to provide a robust and consistent approach for reporting on freshwater quality in New Zealand's planted forests. Ultimately, the aim is to develop a framework for national monitoring and reporting of water quality indicators for planted forests. Knowing these indicators will improve on the forestry's industry's freedom to operate since forestry impacts on water quality can be quantified and reported against national and international reporting frameworks (such as FSC certification and Kyoto/Montreal obligations).

Of the 13 databases and 11 models reviewed, REC is currently the most suitable database/framework for monitoring and reporting on water quality in planted forests. This recommendation is based on both its uptake by a range of organisations for both national and regional reporting and it being the most likely framework to be used in the current governmental review of the national water quality monitoring network.

REC generally performs well at reporting the state and trend of water quality at the national and regional level. Its performance at the land use level is currently restricted by the number of water quality monitoring sites and the quality of the underlying water quality, macro-invertebrate and fish databases. Therefore, REC requires further testing of its ability to provide an efficient and effective framework for reporting on water quality from planted forests.

Several of the other databases and models reviewed in this report are also valuable and important and some contribute to REC and are part of the national monitoring framework. Their success ultimately depends on the long-term support of government agencies. It will be most advantageous for the forestry industry to be part of the long-term national water quality framework as this will be the most likely to be sustained and supported in regards to methodology, maintenance of databases and advanced modelling.

In addition, the new planted forest water quality sites should be located to compliment the national network (where planted forests are currently under-represented) and the industry can leverage off the national data set, maximising the return on investment in water quality monitoring. The long term benefit for the forest industry will be a more robust water quality data set which could be used for a range of educational, management and reporting purposes.

INTRODUCTION

The purpose of this project was to provide an overview of the current databases and models used in New Zealand to monitor and report on the state of freshwater in New Zealand, and to evaluate their capacity and limitations with special references to planted forestry.

Currently, robust information on the state and trend of water quality in planted forests is difficult to obtain due to:

- the limited number of planted forest sites in the national water quality monitoring network;
- the lack of consistent measuring and reporting on the state of New Zealand's freshwaters at a national level;
- the fragmented nature of existing research material, and;
- forest company water quality monitoring programmes are variable in quality and quantity.

In 2012, 991 monitoring sites were included in an analysis to investigate the number of monitoring sites required to achieve a stated level of precision and to compare the distribution of monitoring sites and rivers across the New Zealand environment [1]. The majority of monitoring sites were in the pastoral area (63%, 626 sites) followed by natural (29%, 286 sites), urban (4%, 41 sites) and exotic forest (4%, 36 sites). Overall, REC (River Environment Classification) classes with natural land cover and exotic forest tended to be under-represented and classes with pastoral and urban land cover tended to be over-represented relative to river abundance. The under-representation of certain classes can partly be explained by the fact that many sites were originally established as consent monitoring sites or to investigate human impacts.

Currently, the forest industry is hampered in its ability to accurately report on the water quality status of planted forests for a number of reasons which include limited number of monitoring sites, and the absence of an overarching monitoring design and programme [2].

This lack of monitoring and detailed knowledge of water quality in planted forests often results in conflicting, inadequate or inaccurate accounts of water quality in planted forest by the media. Press reporting tends to focus on the more negative aspects associated with harvesting or debris flows associated with extreme weather events, even though, it is recognised in the scientific literature that planted forestry provides good water quality for most of the production cycle [i.e. 3, 4].

In addition, research on water quality in planted forests is described in a wide range of publications, making it difficult to assimilate the information into a format suitable for the general public or for industry professionals. Furthermore, research projects are usually designed to address specific issues, and they are often short-term in nature making them unsuitable for long-term monitoring and reporting on trends in water quality [i.e.5, 6].

New Zealand's national water quality monitoring network comprises over 800 sites but the variability in the parameters that are measured, and field and laboratory techniques, limits New Zealand's ability to report on both the state and trend of water quality at the national scale [1, 7]. The lack of standard, reliable state of the environment reporting in New Zealand was highlighted in a review by the Parliamentary Commissioner for the Environment [8]. Reporting on water quality at the more detailed land-use level is even further restricted and planted forests are particularly disadvantaged as they are under-represented in the current national water quality monitoring network [2].

There are a number of initiatives underway to address this issue (i.e. the Ministry for the Environment (MfE) National Environmental Monitoring and Reporting (NEMaR) Project) but whether a revised national water quality monitoring network will be able to report on the state and trend of freshwater at the land-use level is yet to be determined. A co-ordinated approach by forest companies in their water quality monitoring programmes which aligns with the national network (currently under revision) will maximise the value of the financial investment involved in monitoring

The development of a standardised, long-term data set on water quality from planted forests would provide the forest industry with robust data suitable for a wide range of purposes such as responding/reporting to media, promoting multiple values of planted forests, preparing resource consents, submissions on unitary authority planning processes, contributing to national initiatives, education, meeting Forest Stewardship Council (FSC) requirements, and national and international reporting.

Purpose of this report

The purpose of this project is to provide an overview of the main current databases and models used in New Zealand to monitor and report on the state of freshwater in NZ, and to evaluate their capacity and limitations. The overview for the databases includes a short general description, the institutions responsible, availability and web links. The overview for the models includes, among others, a short general description, the water parameters measured, their pros and cons, and web links.

We provide an interim recommendation for the suitability of these databases and models to use as a suitable framework for national monitoring and reporting of water quality indicators for planted forests. A final recommendation will depend on the latest developments in the National Objectives Framework Reference Group.

This project contributes to the Environmental and Social research programme Objective 2: IO2 – Validating indicators of site quality and contributes to both Tasks 2.2.1 (Environmental quality indicators) and 2.2.2. (Forest management impacts). This work is a component of the Water Story Work Plan No. FFR- ESWP-003 (V2) and is closely aligned to other work on developing water quality indicators for planted forests and reviewing the representativeness of planted forests in the current national water quality monitoring network [2].

METHODS

Scope of the Project

The aim of this project is to provide an overview of existing databases and models in regards to freshwater monitoring in New Zealand. Initially, a web based search was used to identify the range of programmes, models and datasets currently used to monitor and report on water quality in New Zealand's freshwater environments.

The majority of information was found to be assembled in the following websites:
Data for freshwater modelling:
https://teamwork.niwa.co.nz/display/IFM/Data+for+Freshwater+Modelling.
Compilation of models:
https://teamwork.niwa.co.nz/display/IFM/Compilation+of+models+and+their+attributes

Some databases, such as REC (River Environment Classification) and FWENZ (Freshwater Environment New Zealand), are not pure data sets as such but rather data frameworks and sit somewhat between datasets and models. However, as they are not models per se they are included in the databases section.

The interactive website http://ifm.niwa.co.nz/launch.html provided a tool to see how datasets and models were being used in different combination.

Water quality is defined by the physical, chemical and biological aspects of water. Indicators commonly used to report on these three aspects of water quality include:

- Physical – i.e., water temperature, water clarity, suspended sediment, dissolved oxygen;
- Chemical – i.e., pH, total nitrogen, nitrate, ammonia, total phosphorus, dissolved reactive phosphorus
- Biological – i.e., Macroinvertebrate Community Index (MCI), % Ephemeroptera (mayflies), Trichoptera (caddisflies), Plecoptera (stoneflies) (%EPT), periphyton, E.coli (as an indicator of microbial contamination).

The review does not cover water quantity although it is acknowledged that water quality and water quantity are closely interlinked.

RESULTS

A number of key databases are used to model and report on water quality in New Zealand, e.g., the National River Water Quality Network (NRWQN), the River Environment Classification (REC), the Freshwater Ecosystems of New Zealand (FENZ), the Freshwater Biodata Information System (FBIS) and the New Zealand Freshwater Fish Database (NBFFD). In addition, land and climate databases are available to be included in modelling, e.g. the Land Cover Database 3, Land Environments of New Zealand (LENZ), and National Climate Database (CliFlo). Most of these datasets can be accessed easily and without costs (see web links below & Appendices).

A number of key models are used to report on water quality in New Zealand, e.g. Catchment Land Use for Environmental Sustainability (CLUES), the Spatial Regional Regression on Watershed Attributes (SPARROW), Waikato Integrated Scenario Explorer (WISE), and the Integrated Dynamic Environmental Analysis System (IDEAS).

A summary overview of the 13 key databases and 11 models in relation to freshwater monitoring, land use and climate is in the Appendices. A large proportion of the information for the Appendices was extracted from the three websites below.

This NIWA website provides an extensive list of available datasets for freshwater modelling in New Zealand: https://teamwork.niwa.co.nz/display/IFM/Data+for+Freshwater+Modelling

This NIWA website provides an extensive list of available models (including freshwater modelling) and their attributes:
https://teamwork.niwa.co.nz/display/IFM/Compilation+of+models+and+their+attributes

The interactive NIWA website http://ifm.niwa.co.nz/launch.html provides a tool to see how datasets and models are linked and can be used.

Databases

Selected databases are summarised in Appendix 1 and below is a more detailed description and assessment of t databases which are likely to be of relevance to forestry and their water quality monitoring.

NRWQN

National Rivers Water Quality Network and Regional Water Quality Data Sets

The Regional Council and NIWA's National Rivers Water Quality Network (NRWQN) water quality datasets currently measure an array of physical, chemical and biological (including microbial) water quality variables [2, 7]. However, the lack of a nationally robust, standardised system for measuring and reporting on water quality in New Zealand limits the ability to report on our freshwaters for State of the Environment purposes [8]. A range of projects, including the Ministry of the Environment (MfE) National Environmental Monitoring and Reporting (NEMaR) project, are currently underway to improve the existing national and regional freshwater monitoring networks, with the objective of producing a statistically valid and consistent national freshwater monitoring programme for New Zealand. While the regional and national water quality datasets are currently used for reporting and modelling purposes, the proposed work to improve the national water quality monitoring network will improve the performance of any model to be used.

REC

River Environment Classification

REC is a GIS-based spatial framework for river management which uses a hierarchy of six controlling factors to classify river environments in New Zealand in descending order of climate, source of flow, geology and land cover which operate at the landscape/catchment scale, followed by network position and valley landform that operate at the local scale [9], Figure 1. Each factor is subdivided into a number of classes. Under this system the possible number of class combinations increases cumulatively with each level, often to an unmanageable level. This is often addressed by collapsing some of the classes such as Geology into two classes of 'soft rock' and 'hard rock' and Land cover classes such as native forest and scrub into one class.

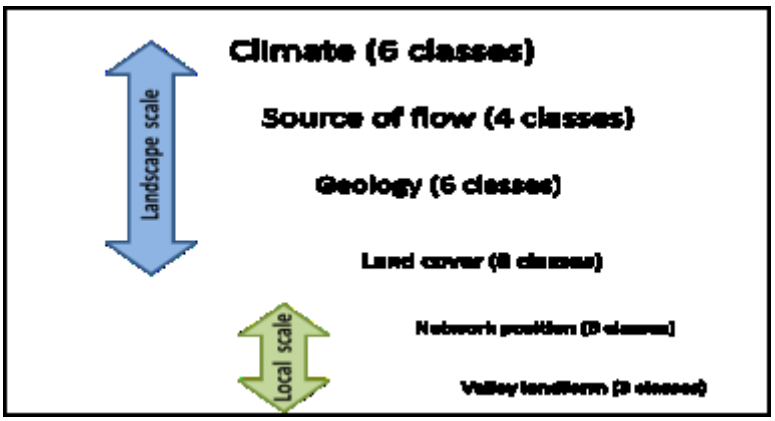

Figure 1. REC hierarchical classification levels based on controlling factors [9].

River networks in REC are composed of a series of adjoining sections (classification units). At any given point (node) in the network, the class to which that section of river is assigned is usually determined by the dominant class in the upstream catchment. However, as some factors can have a disproportionate effect on the river environment some rules are applied to cater for this e.g. because of high nutrient loadings associated with pasture, if 25% or more of the catchment is in pastoral land then the land cover for that section is classified as pasture.

REC classifies river environments over a wide range of spatial scales for the whole of New Zealand. It is used widely used by a range of organisations and agencies in the classification and management of New Zealand's river systems, policy development and monitoring and reporting on water quality. REC has been used to report on the state and trend of water quality at both the national and regional level [10, 11] for a range of physio-chemical, microbial (i.e. *E. coli*) and other biological (i.e. MCI [Macro-invertebrate Community Index], periphyton cover) indicators of water quality.

REC performs well in classifying rivers by their hydrological and water quality characteristics [12]. However, its ability to report on the state and trend of New Zealand's water quality is currently limited by the underlying datasets provided by the National Rivers Water Quality Network (NRWQN) and Regional Councils [7]. The range of water quality parameters and methods used by different agencies throughout New Zealand constrains the ability of New Zealand to report on the state of its water quality, and reporting on water quality in planted forests is further limited by the low number of monitoring sites in this land use in the national network [2, 7].

The REC framework uses the New Zealand Land Resources Inventory (LRI) for the geology layer. The Land Cover Database (LCDB) provides the land cover layer and a recent update of this database will improve the performance of REC in discriminating water quality characteristics of different land uses.

REC can be used to highlight the most appropriate management tools and approaches to reduce pressures for each river type. Information from the classification is used to develop policy, assess the environment, and report on the quality of river water. More information and a user guide are available from MfE http://www.mfe.govt.nz/environmental-reporting/about/tools-guidelines/classifications/freshwater/.

FENZ

Freshwater Ecosystems of New Zealand (= Freshwater Environment NZ (FWENZ))

FWENZ is a multivariate classification of New Zealand's rivers initiated by the Department of Conservation (DoC). Generalised Dissimilarity Modelling (GDM) was used to produce a hierarchical classification using distribution data for freshwater fish and macro-invertebrates. The classification system can be used over a range of spatial scales to determine biological variation in New Zealand's river systems [12, 13]. It is based on REC and provides a spatial framework for freshwater biodiversity management for all river networks in New Zealand. FWENZ uses 14 input variables covering a range of spatial scales to predict the distribution and composition of aquatic communities.

A comparative test with REC showed that REC generally performed better than FWENZ for physico-chemical data but FWENZ generally performed better than REC for biological characteristics of rivers [12]. Recommendations arising from the National Environmental and Reporting project (NEMaR) process include the use of both REC and FWENZ in assessing environmental classes for the national water quality monitoring network [14].

FBIS

Freshwater Biodata Information System & NZFFD – New Zealand Freshwater Fish Database

FBIS is a New Zealand centralised database maintained by NIWA containing fish, algae, aquatic plant and invertebrate data from freshwater environments, based on voluntary contributions from a range of organisations throughout New Zealand, such as NIWA, fish and game councils, DoC, regional councils, environment consultants, universities and interested individuals (http://www.niwa.co.nz/our-services/online-services/freshwater-fish-databas).

NBFFD (http://www.niwa.co.nz/freshwater-and-estuaries/nzffd) tends to be biased to the smaller rivers and streams that are accessible, particularly for electric fishing which is the main method used to monitor fish. There are limited long-term datasets in the fish database but fish are being considered in the revision of the national water quality network and could potentially provide long-term datasets for modelling and reporting in the future.

Aquatic invertebrates have been used as a biological monitoring tool for many years with long term data sets available for modelling [15] (see also the section on FWENZ) and reporting [16] and will continue to be developed under the proposed revised national water quality monitoring network.

NZLRI or LRI

New Zealand Land Resource Inventory

The New Zealand Land Resource Inventory (NZLRI) is an assessment of New Zealand's physical land resources, undertaken in the 1970's, provided as a series of worksheets with accompanying explanatory text (http://www.landcareresearch.co.nz/databases/nzlri.asp). The worksheets include information on rock, soil, slope, erosion and vegetation and land use capability assessments. It is available as a GIS layer and in spite of the age of the original dataset, is frequently used as a land information layer in the development of frameworks and models for reporting on water quality in New Zealand (http://ifm.niwa.co.nz/launch.html). The vegetation layer is currently being reviewed by Landcare Research.

LCDB

New Zealand Land Cover Database 3

The New Zealand Land Cover Database (LCDB) provides a digital map of the land surface of New Zealand based on satellite imagery (http://lris.scinfo.org.nz/layer/304-lcdb-v30-land-cover-database-version-3/#). The latest version (LCDB3 v3) contains 33 classes designed to be compatible with earlier LCDB versions. The polygon features contain a code and boundary representing the land cover type at each of three periods; summer 1996/97, summer 2001/02, and summer 2008/09. As a GIS layer, it can be combined with other layers to monitor, report on and model water quality in New Zealand (http://ifm.niwa.co.nz/launch.html). As land use can have a significant influence on water quality, regular updates of this layer will assist in maintaining accuracy when reporting on New Zealand's freshwaters.

Models

The full list of models and their pros and cons is summarised in Appendix 2.

CLUES

Catchment Land Use for Environmental Sustainability

CLUES (Catchment Land Use for Environmental Sustainability) is a catchment-scale model for modelling and predicting the effects of land-use on water quality and socio-economic factors[17]. The main water quality parameters include TN, TP, sediment and *E. coli*. CLUES is a GIS based model, where land-use layers and data sets relevant to the catchment under investigation can be imported into the system. CLUES has been used to assess a number of catchments around New Zealand although the focus has been primarily on agricultural catchments (https://teamwork.niwa.co.nz/pages/viewpage.action?pageId=3899633). The model has been used to identify contaminant sources and their relative contribution to catchment loads, assess the effects of changes in land use and farming practices including land use intensification and mitigation practices using a range of tools. Variability and uncertainty of the underlying databases and some underlying assumptions, e.g. inappropriate simplification of leaching models, in the model can affect the accuracy of the predictions of the model.

SPARROW

Spatial Regional Regression on Watershed Attributes

SPARROW is used to model in-stream loads of total nitrogen (TN) and total phosphorus (TP) at the national scale to predict annual average nutrient loads [18]. The model calculates predicted nutrient loads for a range of source types within each sub-catchment, the load is accumulated and then attenuated down through the river system to predict loads delivered to the coastline. Known nutrient loads at monitoring points within the catchment are used to set the model. SPARROW is highly effective at predicting TN with a less accurate prediction of TP. Data from the national water quality monitoring stations were used to calibrate the model and as the catchments in this network were >10 km^2 the model accuracy will be less in smaller sized catchments [18]. When using this model it is also important to check that the point source locations and loads information is up-to-date and accurate.

WISE

Waikato Integrated Scenario Explorer

WISE is a spatially explicit integrated spatial decision support system. WISE includes hydrology and water quality modules that link to land use and climate.

IDEAS

Integrated Dynamic Environmental Analysis System

IDEAS is a scenario modelling tool which loosely couples biophysical, economic and agent-based models. IDEAS runs multiple biophysical models simultaneously and summarises output as a mean value of 'environmental intensity' for each land.

RF

Random Forest Models

Random Forest (RF) is a regression based model developed by Breiman [19] and Cutler [20]. It operates by creating a multitude of decision trees hence its name. Some of the features of the RF model include its ability to run efficiently on large datasets, handle thousands of input variables, effectively manage missing data points, balance error in unbalanced data sets, and estimate which variables are important in the classification. A RF model can be composed of many decision support trees. This model was used in New Zealand to model water quality at the national scale using REC as the underlying framework and regional and national water quality datasets to provide the water quality data [21]. Eleven variables were used in the model which was able to explain >60% of variance for eight of the 11 water quality variables tested. Suspended sediment had the poorest fit to the model at 40% of the variance explained and total nitrogen the best fit at 78%. Overall the model performed well in predicting water quality in New Zealand's river systems, even when underlying data sets such as those for suspended solids, were sparse. The authors note that uncertainties around predictions will increase the further the location point is from a water quality sampling point.

RIVPACS

River Invertebrate Prediction and Classification System

River Invertebrate Prediction and Classification System (RIVPACS) assesses the ecological quality of river sites using macro-invertebrate sampling [22]. It is a predictive model which uses the statistical relationship between macroinvertebrates and a range of environmental variables at high quality reference sites to predict macroinvertebrate fauna that would be present at other sites in the absence of any impacts or stressors. The predicted fauna is compared with the actual fauna at the site (Observed/Expected; O/E) to derive an index of ecological integrity or quality. This model requires a set of reference sites with no, or low human impacts. The empirical and descriptive nature of the RIVPACS model makes it suitable for estimating and monitoring the ecological quality of sites, rather than a dynamic model which predicts in the impacts of environmental change. Although originally developed in Great Britain, RIVACPS is widely used around the world and is the main model used in Australia to monitor the ecological integrity of their river systems [23][20].

RIVPACS has been tested in New Zealand using both macroinvertebrates and fish in the Manawatu-Wanganui region [15, 24]. The authors considered the RIVPACS approach preferable to using a single indicator (such as MCI (Macroinvertebrate Community Indicator) for aquatic invertebrates), which assigns subjective scores to species, as the model uses a combination of environmental variables and macroinvertebrate assemblages to predict environmental quality. The authors were able to identify a range of suitable reference sites in the Manawatu-Wanganui region subject to minimal human disturbance and representative of a range of river types. Although the predictive capacity of RIVPACS provided a reliable assessment of biological conditions for both aquatic invertebrates and fish, the O/E index was less effective in detecting land use impacts.

CREAMS

CREAMS is an agricultural field scale mechanistic model initially developed in the USA to model spatial runoff of water, sediment and nutrients from a catchment [25]. Modifications have been made to the original American version to suit New Zealand conditions. The model focuses primarily on agricultural catchments. Good underlying catchment information and an understanding of the key sensitivities within the catchment are important in maximising the performance of this model. While CREAMS is a poor predictor of sediment loss on an event scale it is a good predictor of sediment loss over longer time scales and similar predictive patterns were evident for the components of N and P bound to sediment. Predictions were improved for the soluble component of N and P. CREAMS was also simulated reductions in sediment and nutrient following the installation of a vegetated buffer strip.

CONCLUSIONS AND RECOMMENDATIONS

The management of water resources in New Zealand's planted forests require an integrated approach that should include both monitoring and modelling.

Of the databases reviewed, the regional and national water quality datasets are currently the main databases being used to feed into various models. The REC framework is widely applied in the national and regional monitoring and reporting of water quality in New Zealand. A number of reforms are underway in New Zealand to improve the monitoring and reporting of water quality in New Zealand and indications are that REC (and possibly FENZ) will continue to be the programme of choice. Once the national revision and standardisation of the national water quality monitoring network has been completed, it would be advantageous to the industry to leverage off the existing regional and national datasets on water quality from planted forests.

Modelling can help in a variety of management decisions, meeting regulatory requirements and protection strategies across broad regions. However, most water quality models in New Zealand rely on data collected from agricultural areas. A high quality monitoring network associated with New Zealand planted forests will provide direct observations over time of water-quality properties and characteristics. These observations can then be used to create or improve models that will accurately account for the influence of planted forests on water quality.

Models

Integrated models (so called "super models") that use data from other models as inputs or completely amalgamate other models are the direction that water quality modelling is heading (see examples, http://ifm.niwa.co.nz/launch.html). Super models will provide the best results in regards to accounting for forestry's contribution to water quality. Currently, most models have been developed to account for agricultural effects on water quality, and the effects of forestry on water quality is poorly accounted for in all models.

However, there are several models that can be used for water monitoring in forest, in particular, CLUES (Catchment Land Use for Environmental Sustainability), SPARROW (Spatial Regional Regression on Watershed attributes), WISE (Waikato Integrated Scenario Explorer) and IDEAS (Integrated Dynamic Environmental Analysis System).

CLUES stands out because,

- It is specifically designed to estimate water quality in New Zealand.
- Is the water quality model of choice for MPI. Therefore, this model is well supported in terms of funding for continued development.
- While this model is set up to model water quality in agricultural land it does have the ability to model water quality of forestry.
- This super model incorporates data from other widely used and supported models (SPARROW, OVERSEER (model for farm-scale nutrient budgeting and loss estimation), SPASMO (physically-based dynamic generic plant growth and nutrient leaching model) and the Soil Vulnerability Model (defines zones of similar vulnerability profile for nutrient and microbial contamination to waterways). Meaning as above these models have continued support and should continue to be refined and updated.
- Available as a Free ESRI ArcMap GIS add on and therefore relatively easy to learn and use for someone with some GIS skills.

WISE and IDEAS offer much more in terms of outputs (land use optimisation, economic, biodiversity, etc.). However, they are not water quality models but more decision support tools. Their outputs can include water quality but actually use CLUES and SPARROW to calculate the water quality.

The above mentioned models are likely to be refined over time or replaced with new and better ones. The precision and strength of any future models will ultimately rely on the underpinning quality and quantity of the monitoring sites across forestry land.

Recommendations for the forestry industry are:

- For the industry to wait until the revision and standardisation of water quality assessments has been completed before revising the industry water quality monitoring network.

- Any developments should be closely aligned with the national water quality network to leverage of the existing water quality data currently in the national system. At the moment the 13 water quality indicators recommended in Baillie & Heaphy (2011)[2] for planted forestry are very similar to the proposed national list of indicators.

- Once the revised national water quality monitoring network is complete, a gap analysis will identify the most appropriate location of any additional sites to enhance the representativeness of planted forests.

- The gap analysis should also include some of the key underlying databases. Additional sampling may be required to fill in any spatial gaps in these datasets to improve reporting and modelling of water quality in planted forests.

Some preliminary indications, on how many extra sites might be required can be found in Larned and Unwin 2012[1] which included current 991 monitoring sites in their study. In this report, sites were assigned to FENZ (Freshwater Environments of New Zealand) classes at the 20 group level and to REC (River Environment Classification) classes at the climate, source of flow and landcover level. They found that the distribution of monitoring sites across FENZ and REC classes was very uneven. For example, in regards to monitoring sites for Exotic Forests in REC climate classes - there are currently sites in the in the cool dry (1), cool wet (25), warm wet (9), and warm, extremely wet (1) category, but none in the cool, extremely wet or warm dry category. In regards to monitoring sites for Exotic Forests in REC climate/source of flow classes - there are some sites in the in the cool dry/lowland (1), cool wet/hill (13), cool wet/lowland (10), cool wet/lake (1), warm wet/lowland (8), warm wet/lake (1), and warm, extremely wet/lowland (1) category, but none in the mountain category.

The distribution of monitoring sites among REC climate classes relative to the distribution of river lengths revealed that following classes are under-represented for exotic forests: warm wet (-3), cold dry (-5), cool extremely wet (-2), and warm dry (-2). However, over-representation of monitoring sites among REC climate classes in exotic forests relative to the distribution of river lengths was found for the cool wet (1) category; the warm extremely wet category was appropriately presented. The distribution of monitoring sites among REC climate/source of flow classes relative to the distribution of river lengths revealed that following classes are under-represented for exotic forests: cool wet/hill (-6), warm wet/lowland (-3), cold dry/lowland (-3), cold dry/hill (-2), warm dry/lowland (-2), cool extremely wet/hill (-1), cool extremely wet/lowland (-1). Over-representation in exotic forests was found for the cool wet/lowland (5), cool wet/Lake (2) and warm wet/lake (1) category; the warm extremely wet category was appropriately presented.

A more detailed gap analysis is required to determine the exact number and geographical distribution of monitoring sites required to allow detailed reporting of water quality in planted forests. In addition, Larned and Unwin (2012)[1] make several recommendations, such as the inclusion of environmental and logistical criteria, to improve the FENZ and REC reporting system and to allow for more precise reporting options.

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APPENDICES

Appendix 1: Overview of Select Databases likely to be relevant to Water Quality Monitoring in New Zealand's Plantation Forests

Data Name	Description	Institution responsible	Availability	Data source link
River Environment Classification (REC)	Organises information about the physical characteristics of New Zealand's rivers. Individual river sections are mapped according to physical factors such as climate, source of flow for the river water, topography, geology, and catchment land cover e.g., forest, pasture or urban.	NIWA	Free	http://koordinates.com/ (search for REC)
Freshwater Ecosystems of NZ (FENZ)	A large set of spatial data layers and supporting information on New Zealand's rivers, lakes and wetlands	Department of Conservation	Free	http://www.doc.govt.nz/conservation/land-and-freshwater/freshwater/freshwater-ecosystems-of-new-zealand/
Regional water quality databases	Datasets comprising physical, chemical and biological aspects of water quality. The number and range of water quality variables measured, sampling frequency, field and laboratory methods and length of monitoring records varies between regions	Regional and District Councils	Usually free on request	
National River Water Quality Network (NRWQN)	Monthly Data (commencing Jan 1989) comprising physical measurements, chemical and bacteriological analyses, and periphyton observations from 77 National River Water Quality Network (NRWQN) sites for the purpose of environmental assessments and monitoring of long term trends	NIWA	Under agreement	https://wqis.niwa.co.nz/wqis/index.do

Data Name	Description	Institution responsible	Availability	Data source link
Freshwater Biodata Information System (FBIS)	this archive contains fish, algae, aquatic plant and invertebrate data and metadata gathered from New Zealand's freshwater streams, rivers and lakes	NIWA	Free	https://fbis.niwa.co.nz/fbis/index.do
New Zealand Freshwater Fish Database (NZFFD)	The New Zealand Freshwater Fish Database (NZFFD) records the occurrence of fish in fresh waters of New Zealand, including major offshore islands. Data stored include the site location, the species present, their abundance and size, as well as information such as the fishing method used and a physical description of the site.	NIWA	Free	http://www.niwa.co.nz/our-services/online-services/freshwater-fish-database
Land Resource Inventory (LRI, NZLRI)	A spatial database containing similar information to that in the NZLRI worksheets. There are about 100,000 polygons (map units) within the NZLRI, each of which describes a parcel of land in terms of five characteristics or attributes (rock, soil, slope, erosion, vegetation).	Landcare Research	Free	http://lris.scinfo.org.nz/#
Land Cover Database 3	This database is a thematic classification of land cover and land use classes. The polygon features contain a code and boundary representing the land cover type at each of three periods; summer 1996/97, summer 2001/02, and summer 2008/09	Landcare Research	Free	http://lris.scinfo.org.nz/layer/304-lcdb-v30-land-cover-database-version-3/#
Land Environments of New Zealand (LENZ)	A classification of fifteen climate, landform, and soil variables chosen for their relevance to biological distributions.	Landcare Research	Free	http://koordinates.com/

Data Name	Description	Institution responsible	Availability	Data source link
Land Use and Carbon Analysis System (LUCAS)	LUCAS consists of a number of regional ESRI shape files which map four key land use classes i.e. Natural forest, Pre-1990 Planted Forest, Post-1989 Forest, and Grassland with woody biomass.	MfE	Free	http://www.mfe.govt.nz/issues/climate/lucas/data/index.html
National Climate Database (CliFlo)	Holds data from about 6500 climate stations which have been operating for various periods since the earliest observations were made in the year 1850. CliFlo returns raw data and statistical summaries. Raw data include ten minute, hourly and daily frequencies. Statistical data include about eighty different types of monthly and annual statistics and six types of thirty−year normals.	NIWA	Free	http://cliflo.niwa.co.nz/
Climate Change	National and regional climate change scenarios and guidance material.	NIWA	Dependent on data	http://www.niwa.co.nz/our-science/climate/information-and-resources/clivar/scenarios#regional
Geological Map of New Zealand (QMAP)	Hub for download of georeferenced images (SID files) of paper geological maps of NZ	GNS	Free	http://www.gns.cri.nz/Home/Our-Science/Energy-Resources/Geological-Mapping/Geological-Maps
Fundamental Soils Layers FSL	The Fundamental Soils Layers are part of the LRI and consist of GIS layers with a range of soil data	Landcare Research	Free	http://lris.scinfo.org.nz/#/layer/79-fsl-new-zealand-soil-classification/

Appendix 2: Summary of Water Quality Models

Model Name	Description	Institution responsible	Availability	Water Quality parameters	Geographical Resolution	Temporal Resolution	Pros	Cons	Link
Catchment Land Use for Environmental Sustainability (CLUES)	Catchment model developed to address implications of land use scenarios on stream water quality and some socio-economic indicators	NIWA	Free	Nitrogen Phosphorus Microbes Sediment	Medium or large catchment/aquifer/river network/lake/estuary or coastal embayment Regional or National	-	1) Reflect "real" land-use types. 2) Actively maintained and developed 3) Supported by NZ government 4) easy to learn basic GIS application 5) some training provided	1) Inappropriate simplification of leaching models 2) Documented limitations in predicting N and P 3) Areas with strong surface - ground water interactions are poorly modelled	http://www.mpi.govt.nz/environment-natural-resources/water/clues
SPARROW (Spatial Regional Regression on Watershed Attributes)	Catchment-scale model based on mass accounting and empirical parameter estimation	United States Geological Survey (USGS)	Free	Nitrogen Phosphorus Microbes Sediment Generic	Medium or large catchment/aquifer/river network/lake/estuary or coastal embayment Regional or National	None (steady state)	1) Continuing active development (in US) 2) Tested and shown to be appropriate for NZ	1) U.S. focused 2) Requires specialised knowledge 3) Documented limitations in predicting N and P	http://water.usgs.gov/nawqa/sparrow/
WISE (Waikato Integrated Scenario Explorer)	WISE is a spatially-explicit integrated spatial decision support system; WISE includes Hydrology and Water Quality modules that link to land use and climate.	Waikato Regional Council	Available on request from Waikato regional council.	Nitrogen Phosphorous	Field/hillslope/reach Farm or small catchment/aquifer/river network/lake/estuary Medium or large catchment/aquifer/river network/lake/estuary or coastal embayment Regional or national	Annual	1) Ability to explore "What if " scenarios 2) Strong surrport from Waikato Regional Council (at least until 2019) and RIKS (Research Institute or Knowledge Systems	1) Requires a commercial licence for GEONAMICA 2) Not specifically a water quality model 3) Use other models within the framework and therefore inherits the problems associated with each models	http://www.creatingfutures.org.nz/wise/what-is-wise/

Model Name	Description	Institution responsible	Availability	Water Quality parameters	Geographical Resolution	Temporal Resolution	Pros	Cons	Link
IDEAS (Integrated Dynamic Environmental Analysis System)	Scenario modelling tool which loosely couples biophysical, economic and agent-based models. IDEAS runs multiple biophysical models simultaneously and summarises output as a mean value of "environmental intensity' for each land use.	Landcare Research	In -house only	Nitrogen Phosphorus Microbes Sediment Generic	Catchment scale		1) easy to use and learn 2) Incorporates data from other standalone models 3) Integrates biophysical and socio-economic data	1) Based on theoretical test 2) Model has not been validated in the real world 3) By using data from other models incudes all weakness associated with those models	http://icm.landcareresearch.co.nz/knowledgebase/publications/public/hydrosoc_dymond.pdf
BNZ (Basin New Zealand)	Catchment-scale water quality model for sediment and nutrients	NIWA	In -house only	Nitrogen Phosphorus Sediment		Daily	1) uses GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) and well document and widely used USAGS model	1) Requires specialist modellers 2) assumes homogenous land use 3) developed for agricultural pesticide management	http://www.ars.usda.gov/Research/docs.htm?docid=9797
C-CALM	Catchment Contaminant Annual Loads Model	NIWA	on request from NIWA	Sediment (Total, dissolved and particulate), Zinc and Copper	National	Annual	1) Accounts for all land use types 2) Indicates the effectiveness of various mitigation methods	1) Designed as an urban design support system. 2) Doesn't account for N and P concentrations	http://www.niwa.co.nz/sites/default/files/dipcon_wq_models.pdf
SWAT (Soil and Water Assessment Tool)	Catchment model to quantify the impact of land management practices on flow and water quality	USDA Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas, USA	Free	Nitrogen Phosphorus Microbes Sediment	Medium or large catchment/aquifer/river network/lake/estuary or coastal embayment	Years - Decades	1) Comprehensive documentation of theory and application. 2) GIS interface and visualisation capabilities. 3) Active development by USDA and other research organisations.	1) Fairly complex and time consuming to learn. 2) Some default data tuned to USA conditions. 3) No Formal support. 4) Documented limitations in predicting N and P.	http://swatmodel.tamu.edu/

Model Name	Description	Institution responsible	Availability	Water Quality parameters	Geographical Resolution	Temporal Resolution	Pros	Cons	Link
ROTAN (Rotorua and Taupo Nitrogen Model)	Catchment-scale model for predicting nitrate entering lakes, including groundwater lags. Built within ArcGIS	NIWA	In -house only	Nitrogen	Medium or large catchment/aquifer/river network/lake/estuary or coastal embayment	Daily	1) Accounts for forestry 2) Tested under NZ conditions 3) Considered robust	1) Only predicts Nitrogen loads 2) Only calibrated for the lake Rotorua 3) No current funding for further development	http://www.boprc.govt.nz/media/127774/rotan_model_scenarios_february_2011_-_niwa.pdf
Random Forest Model	Random Forests (RF) is a regression based model. The model operates by creating a multitude of decision trees hence its name.	developed by Leo Breiman and Adele Cutler, Berkley University	Random Forests(tm) is a trademark of Leo Breiman and Adele Cutler and is licensed exclusively to Salford Systems	various			Overall the model performed well in predicting water quality in New Zealand's river systems, even when underlying data sets such as those for suspended solids, were sparse.	Uncertainties around predictions will increase the further the location point is from a water quality sampling point	http://www.stat.berkeley.edu/~breiman/RandomForests/cc_home.htm
RIVPACS (River Invertebrate Prediction and Classification System	Assesses the ecological quality of river sites using macroinvertebrate sampling. It is a predictive model which uses the statistical relationship between macroinvertebrates and a range of environmental variables at high quality reference sites to predict macroinvertebrate fauna that would be present at other sites in the absence of any impacts or stressors.	Centre for Ecology & Hydrology, United Kingdom. RIVPACS has since been adopted by other countries		Macro-invertebrates	The RIVPACS III+ software is now freely available as a new product called RICT (River Invertebrate Classification Tool), which is available through the Scottish Environment Protection Agency. Equivalent software packages have been developed in other countries (e.g. Australia)		RIVPACS has been tested in New Zealand using both macroinvertebrates and fish in the Manawatu-Wanganui region. The authors considered the RIVPACS approach preferable to using a single indicator (such as MCI for aquatic invertebrates).	The empirical and descriptive nature of the RIVPACS model is suitable for estimating and monitoring the ecological quality of sites, rather than a dynamic model which predicts in the impacts of environmental change. The O/E index was less effective in detecting land use impacts. The model requires suitable reference sites.	Clarke et al. 2003

Model Name	Description	Institution responsible	Availability	Water Quality parameters	Geographical Resolution	Temporal Resolution	Pros	Cons	Link
CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems)	CREAMS is a field scale mechanistic model to model spatial runoff of water, sediment and nutrients from a catchment. The model focuses primarily on agricultural catchments. Good underlying catchment information and an understanding of the key sensitivities within the catchment are important in maximising the performance of this model.	The CREAMS model was developed by a multidisciplinary team of research scientists from the USDA Agricultural Research Service.	To the best of our knowledge this model is not under copyright				Is a good predictor of sediment loss over longer time scales and similar predictive patterns were evident for the components of N and P bound to sediment.	A poor predictor of sediment loss on at an event scale	Cooper et al. 1992