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Water Quality Monitoring and Water Quality Indicators for Plantation Forests

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Water quality data from national and regional monitoring networks are used in New Zealand's State of the Environment (SOE) reporting. A 2010 report by the Parliamentary Commissioner for the Environment has highlighted the lack of standardised, reliable and independent SOE reporting in New Zealand. The Ministry for the Environment (MfE) is reviewing the existing national and regional freshwater monitoring networks under its National Environmental Monitoring and Reporting (NEMaR) Project with the objective of producing a statistically valid and consistent national freshwater monitoring programme for New Zealand.

National and regional water quality data are also used to report on the state of water quality from plantation forests. It is important to ensure that the water quality monitoring sites and the water quality information collected on plantation forests is a fair representation of the planted forest estate in New Zealand.

The purpose of this project was to evaluate the representativeness and robustness of water quality monitoring sites in plantation forests. The evaluation included an assessment of the suitability of water quality variables currently used to measure water quality for plantation forests. We aimed to identify any shortfalls in the number and location of water quality monitoring sites and the water quality indicators used in reporting on forest plantations, and provide recommendations to promote the accuracy of reporting on water quality from plantation forests in New Zealand.

The first step was to compile a database of the location of the national and regional water quality monitoring sites used in SOE reporting, and a list of water quality variables measured at each site. Information was collected from a total of 856 national and regional water quality monitoring sites. Regional information was not available for Canterbury. Based on the Rivers Environment Classification (REC), plantation forests were the dominant land cover for 38 of these sites. This equates to 5% of the total number of water quality monitoring sites, slightly lower than the land area in plantation forests (7%). While plantation forests were the dominant land cover in these catchments, factors such as other land uses, discharges from processing facilities and restricted access at some sites limiting sampling to more accessible locations several kilometres below the boundary of the forest, reduced the number of sites accurately reflecting water quality from plantation forests to closer to 25.

Water quality monitoring sites in plantation forests averaged one site for every 48450 hectares, compared with the national average across all land covers of one site for every 27213 hectares. Plantation forests were under-represented in most regional water quality monitoring programmes, particularly those that contained most of the plantation forest estate. The exceptions were the Auckland, Nelson and Tasman regions. Additional sites were potentially available across New Zealand to capture both the spatial and temporal variation inherent in plantation forests and improve national representativeness. However, many of the suitable locations for monitoring water quality from plantation forests are often in smaller, less accessible catchments, requiring additional travel and cost to measure.

An upgrade of the land cover database used in REC is currently under way with Landcare Research and will improve the accuracy of this tool which is currently around 10 years out of date. This review has shown that while REC is a good first cut for classifying monitoring network water quality sites into a dominant land cover, complex land use patterns mean that only a percentage of all sites will be suitable for comparing water quality between different land uses.

If the forest industry wants to improve the representativeness of plantation forests in SOE reporting there is the opportunity to work alongside MfE and the district and regional councils during Phase II of the NEMaR project, to ensure that plantation forests are adequately represented in the review and that the sites and variables used to measure water quality are pertinent to plantation forestry.

This review showed that approximately 60 different water quality variables were being measured by regional monitoring networks, including 13 for nitrogen. Plantation forests differ from other land uses in that the cyclic nature of this land use can result in marked changes to some water quality variables during the forestry cycle. We identified a core set of 13 water quality variables suitable for monitoring spatial and temporal variability in plantation forest streams and for comparison between land uses. Most were being measured by councils and as part of the national water quality monitoring network. The exception was suspended sediment which wasn't measured by some councils, neither is it part of the current national monitoring programme and it has not been identified as a core variable in Phase I of the NEMaR project. Suspended sediment is an important water quality variable across all land uses, and we recommend further discussion in Phase II of the NEMaR project on the inclusion of this variable as a core indicator in New Zealand's future national water quality monitoring network.

The main recommendations in this report support the concept of a robust, standardised national water quality monitoring system for New Zealand, based on a core set of water quality variables. More specifically, as part of the national network design, it would be beneficial to undertake an exercise to determine the minimum number of sites required nationally in plantation forests to capture the spatial and temporal variability of water quality in plantation forests for statistically valid analysis.

A robust, standardised, publically available national water quality monitoring programme would be advantageous to the forest industry. Along with the direct benefits of consistent and accurate reporting on water quality from plantation forests, indirectly the information could be used for a range of other purposes including Montreal Process and FSC (Forest Stewardship Council) reporting, water quality modelling, valuing ecosystem services from forests and water footprinting of forest products.

INTRODUCTION

New Zealand strongly depends on water for its economic, environmental, cultural and social needs, and both the quality and quantity of water resources in New Zealand are coming under increasing pressure e.g.(Parliamentary Commissioner for the Environment, 2004)[1]. The New Zealand government has recognised the pressure on New Zealand's water resources as a nationally significant issue and has initiated a number of reforms under its Fresh Start for Fresh Water programme, including the recently released National Policy Statement for Freshwater Management, which outlines a national regulatory framework for the management of New Zealand's freshwater resources[2] .

The management and monitoring of freshwater is the responsibility of Regional and District Councils under the Resource Management Act 1991 (RMA). Each region maintains a network of freshwater monitoring sites. In addition the National Institute of Water and Atmospheric Research, (NIWA) maintains the National River Water Quality Network (NRWQN), a national network of 77 sites, which has been monitored for over 20 years. Information from these data sets is used for regional, national and international reporting on the status of our waterways and should provide a basis for good policy formulation. A review by the Parliamentary Commissioner for the Environment has highlighted the lack of robust, standardised, reliable and independent state of the environment reporting in New Zealand with particular emphasis on water quality[3].

Plantation forests occupy around 1.8 million hectares[4] and the water quality data collected by NIWA and regional councils provides baseline information on the water quality from plantation forests for national and international reporting. Of the 22 national environmental indicators in MfE's State of the Environment (SOE) monitoring programme, five relate to freshwater quality[5]. These indicators are used in MfE's international reporting obligations to the OECD, which periodically reviews New Zealand's environmental performance[6]. It is important then to ensure that the water quality monitoring sites and the water quality information collected on plantation forests is an accurate representation of the planted forest estate in New Zealand.

The purpose of this project was to undertake an evaluation of the current national and regional water quality monitoring sites around New Zealand to identify gaps (if any) in the representation of plantation forests in the current water quality monitoring programme. The evaluation included an assessment of the applicability of current WQ variables measured in existing water quality monitoring programmes for plantation forests, their ability to report on critical forestry water quality variables over a range of temporal and spatial scales and their suitability for comparability and transference between land-uses. Any short-comings in the location of WQ monitoring sites and relevance of WQ indicators used in reporting on forest plantations were identified and reported.

MfE is currently reviewing the existing national and regional freshwater monitoring networks as part of its National Environmental Monitoring and Reporting (NEMaR) Project, with the objective of producing a statistically valid and consistent national freshwater monitoring programme for New Zealand. Phase I of this project has been completed. NIWA have provided recommendations on methodologies for single environmental indicators, a core set of water quality variables, monitoring protocols, environmental frameworks for site selection and network design, quality assurance and laboratory analysis procedures[7]. Phase II of the project involves consultation with regional councils CRIs, universities and other governmental agencies. There is the opportunity during Phase II for the forest industry to work with MfE to ensure that plantation forests are adequately represented in the review and that the sites and variables used to measure water quality are pertinent to plantation forestry and transferable across land uses. The results and recommendations in this report will provide the forest industry with information to assist them in that process.

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).

METHODS

Scope of the Project

While it is recognised that water quality monitoring programmes have to take into account a number of factors when selecting sites (i.e. geology, stream type, select water quality issues), the focus of this study was on the representativeness of plantation forests in national and regional water quality monitoring networks.

Although regional monitoring programmes include lakes, groundwater and recreational water quality, the scope of this exercise was confined to the national river water quality monitoring programmes undertaken by NIWA and regional and district councils for State of the Environment (SOE) monitoring purposes. As the focus of this project was on variables used to monitor water quality and their applicability to plantation forests, we did not collect or attempt to analyse the actual water quality datasets. Nor did we review the field and laboratory methodologies used around New Zealand to collect and analyse water quality samples. This exercise has been undertaken by NIWA [7-9] under contract to MfE, and readers can obtain copies of these and other associated reports from the MfE website.

Data Collection and Compilation of Water Quality Site Database

The first step in the evaluation process was to compile a database of national and regional water quality monitoring sites and a list of water quality variables measured at each site. Data on the NRWQN were provided by MfE, and the regional and district councils were approached individually for data on their regional water quality monitoring programmes for SOE reporting. Data were obtained from all regional and district councils except for Canterbury which is still recovering from the February 2011 earthquake. For each site we collected:

- the site name;
- site code if available;
- a grid reference;
- whether the site was a national or regional site; and
- the region in which the site was located.

A database was compiled of physical, chemical, microbial and biological (i.e. fish, macroinvertebrates, phytoplankton) water quality variables measured at each site.

A dataset of the location of all the water quality monitoring sites was entered into GIS and ESRi ArcGis v10; data on land cover and stream statistics were used to analyse the data. The New Zealand River Environment Classification (REC) system [10] was clipped to match regional council boundaries. Regional and national water quality monitoring points were found to be non-coincident with river lines, so they were snapped to the nearest river line, which in most cases was obvious. Clarification was sought from individual councils when uncertainty arose. The REC data were then extracted for each monitoring point and compiled into a table for analysis. Land cover classes in the New Zealand Land Cover Database (LCDB) v2 were combined to produce the eight classes in Table 1. Maps were produced for each region showing the land cover classes in Table 1 and the location of the water quality monitoring points (Appendix 1). Lower orders in the stream order classification were removed in most regions to aid mapping clarity. The LCDBII layer was clipped to match regional council boundaries. For each region, the catchment area (ha) and the percentage land cover for each of the eight classes was calculated.

Table 1. The eight land cover classes used in this report based on the LCDBII land cover classes.

Class number	Class name	LCDB II class No.
1	Indigenous Forest	69
2	Plantation Forest	62 - 67
3	High Producing Grassland	40
4	Low Producing Grassland	41
5	Tussock Grassland	43,44
6	Cropland	30 - 32
7	Other	1-5, 10-15, 20-22, 45-47, 60,61,70
8	Scrub and shrub	50-57

RESULTS

Water Quality Monitoring Sites – National and Regional Overview

Information was collected from 856 water quality monitoring sites across New Zealand. Included in this total were the 77 sites from the National River Water Quality Network, the remainder from the regional councils and unitary authorities, based on data provided to us in the early part of 2011. No regional data were available for Canterbury; the 10 sites in Table 2 are part of the national water quality monitoring network. Some of these sites were co-monitored between NIWA and the regional regulatory authority and were treated as a single site for analysis. The land cover classes in Table 2 were derived from REC and based on the dominant land-use in the catchment upstream from the water quality monitoring point with two exceptions; if pasture exceeded 25% of the catchment area the land cover was classified as pasture, and if urban exceeded 15% of the catchment area, the land cover was classified as urban [10]. For the purposes of this project, urban has been included in the 'Other' class (Table 2). There were three sites in the Tasman region and two sites in the Otago region that could not be connected to the REC river network and were excluded from analyses using REC (n = 851). None of these sites were in plantation forest.

Most of the water quality monitoring sites were located in either pasture (64%) or indigenous forest (21%) catchments. Plantation forests comprised 5% of total sites (Table 2). Based on the REC definition of land cover, two North Island and three South Island regions did not sample plantation forests as part of their regional water quality monitoring programmes. In each of these regions the proportion of total land cover in plantation forest was ≤ 6%. Bay of Plenty, Nelson and Tasman regions had the highest number of plantation forest sites in their water quality monitoring programmes (Table 2).

Table 2. The number of water quality (WQ) monitoring sites in each region (national and regional sites combined) by land cover. NB national sites only for Canterbury.

	Land cover (based on REC definitions)						
Region	**Indigenous**	**Plantation**	**Pasture**	**Tussock**	**Scrub**	**Other**	**Total**
Northland	4	2	27	—	—	1	34
Auckland	2	2	17	—	1	9	31
Waikato	17	5	82	—	1	3	108
Bay of Plenty	14	8	34	—	—	0	56
Gisborne	1	1	31	—	—	3	36
Hawke's Bay	15	2	49	—	6	3	75
Taranaki	9	—	56	—	2	4	71
Manawatu-Wanganui	7	—	57	—	3	0	67
Greater Wellington	20	1	28	—	5	6	60
Nelson	11	8	5	—	1	3	28
Tasman	28	7	30	—	1	0	66
Marlborough	13	1	12	2	4	2	34
Canterbury	1	—	6	3	—	0	10
West Coast	23	—	18		—	0	41
Otago	—	—	48	10	—	4	62
Southland	12	1	50	6	—	3	72
Total	177	38	550	21	24	41	851

Table 3. Comparison of the proportion of land cover and water quality (WQ) sites in plantation forests and the density of WQ monitoring sites for each region (Canterbury excluded from analysis, insufficient data). Shaded regions are those with over 150 000 hectares in plantation forests.

Region	Plantation forest Area (ha)	% land cover	%WQ sites	Ratio WQ sites:hectares
Northland	181 928	14	9	1:90 964
Auckland	52 192	10	6	1:26 096
Waikato	341 100	14	5	1:68 220
Bay of Plenty	283 243	23	14	1:35 405
Gisborne	153 587	18	3	1:153 587
Hawke's Bay	151 239	11	3	1:75 619
Taranaki	26 906	4	0	—
Manawatu-Wanganui	138 511	6	0	—
Wellington	68 582	8	2	1:68 582
Nelson	11 549	27	29	1:1 443
Tasman	104 531	11	11	1:14 933
Marlborough	74 329	7	3	1:74 329
Canterbury	120 714	3	NA	NA
West Coast	47 303	2	0	—
Otago	125 084	4	0	—
Southland	81 003	3	1	1:81 003
Total	1961802	7		

With the exception of Nelson and Tasman regions, the proportion of the total number of water quality monitoring sites in plantation forests was less than the proportion of total land cover in plantation forests (Table 3). The five regions with over 150 000 hectares in plantation forests (shaded in grey) were all proportionally under-represented in regional water quality monitoring programmes. Of the regions with between 100 000 and 150 000 hectares in plantation forests, the water quality monitoring programmes of two regions (Manawatu-Wanganui and Otago), did not include plantation forests (Table 3). Nationally, plantation forests comprise 7% of the land area and 5% of the water quality monitoring sites.

The density of water quality monitoring sites varied across regions. Nelson (which had the smallest area in plantation forests) and Tasman regions had the highest density of plantation forest water quality sites (Table 3), with approximately one water quality monitoring site for every 1 400 and 15 000 hectares respectively. Lowest densities of plantation forest water quality monitoring sites occurred in the Gisborne, Northland and Southland regions. Excluding Canterbury, there was one plantation forest water quality monitoring site for every 48 450 hectares. This compares with one water quality monitoring site for every 38 119 hectares of indigenous forest and every 15 867 hectares of pasture land. The average density across all land covers was one water quality monitoring site for every 27 213 hectares.

Table 4. Regional comparison of the current number of water quality (WQ) monitoring sites in plantation forests versus the ideal number of sites required based on the average national density of WQ monitoring sites. Shaded regions are those with over 150 00 hectares in plantation forests.

Region	Plantation forests Current number of WQ sites	No. of WQ sites based on national density*	Additional WQ sites required
Northland	2	7	5
Auckland	2	2	0
Waikato	5	13	8
Bay of Plenty	8	10	2
Gisborne	1	6	5
Hawke's Bay	2	6	4
Taranaki	0	1	1
Manawatu-Wanganui	0	5	5
Wellington	1	3	2
Nelson	8	0	-8
Tasman	7	4	-3
Marlborough	1	3	2
Canterbury	NA	NA	
West Coast	0	2	2
Otago	0	5	5
Southland	1	3	2
Total	38	68	43

*Number of sites required based on the average national density (excluding Canterbury) of one site for every 27213 hectares

Table 4 outlines the current number of water quality monitoring sites in plantation forests for each region. It then lists the number of sites needed based on the average density of water quality monitoring sites across New Zealand. The final column identifies the shortfall in the number of water quality monitoring sites needed to meet this number. Most of the shortfalls occurred in the regions with the largest areas of plantation forests (shaded in grey). Conversely, plantation forest sites were more than adequately represented in the Nelson and Tasman regions. Plantation forests were under-represented in regional water quality monitoring programmes across most of New Zealand.

Plantation Forest Water Quality Monitoring Sites

This section of the report looks in more detail at the 38 water quality monitoring sites identified by REC as having plantation forest as the dominant land cover (Figure 1).

Table 5. Number of plantation water quality monitoring site characteristics based on REC data.

Climate	**Warm extremely wet**	**Warm wet**	**Cool wet**	
No. of sites	2	7	29	
Source of flow	Hill	Low elevation	Lake	
No. of sites	14	19	5	
Geology	Hard sedimentary	Soft sedimentary	Volcanic acidic	
No. of sites	12	11	15	
Network position	Low order (1&2)	Middle order (3&4)	High order (≥ 5)	
No. of sites	6	17	15	
Valley landform	High gradient	Medium gradient	Low gradient	
No. of sites	4	4	30	
Catchment area (ha)	<1000	1000-<10 000	10 000-<100 000	>100 000
No. of sites	8	17	11	3

The majority of plantation forest water quality monitoring sites were located in cool wet climates (Table 5). The two 'warm extremely wet' sites were in the Gisborne and Hawke's Bay regions. For most sites, the source of river flow originated in either hill or low elevation areas. The five lake sources were sites located along the main stem of the Tarawera River in the Bay of Plenty region which originates from Lake Tarawera. The hard sedimentary sites were mainly in the Nelson region and the volcanic sites were mainly in the Waikato and Bay of Plenty regions. Most of the soft sedimentary sites were located in the Auckland and Tasman regions. Only a few sites were located in low order (small) streams (Table 5), with most sites in middle or high order river systems. All the Bay of Plenty sites and three of the Tasman region sites were on high order river systems. The tendency for most sites to be on larger streams or rivers reflects the SOE water quality monitoring networks which tend to monitor water quality at the larger catchment scale, and is also why most sites are low gradient (Table 5). Most of the catchments upstream of plantation water quality monitoring sites were between 1000-100 000 ha in size. This compares with a national average of 51 000 hectares.

Appendix 1 contains maps of each of the 16 regions showing the land cover and location of the national and regional water quality monitoring sites. The plantation water quality monitoring sites in a selection of regions, mainly those containing most of the plantation forest estate, were examined in more detail.

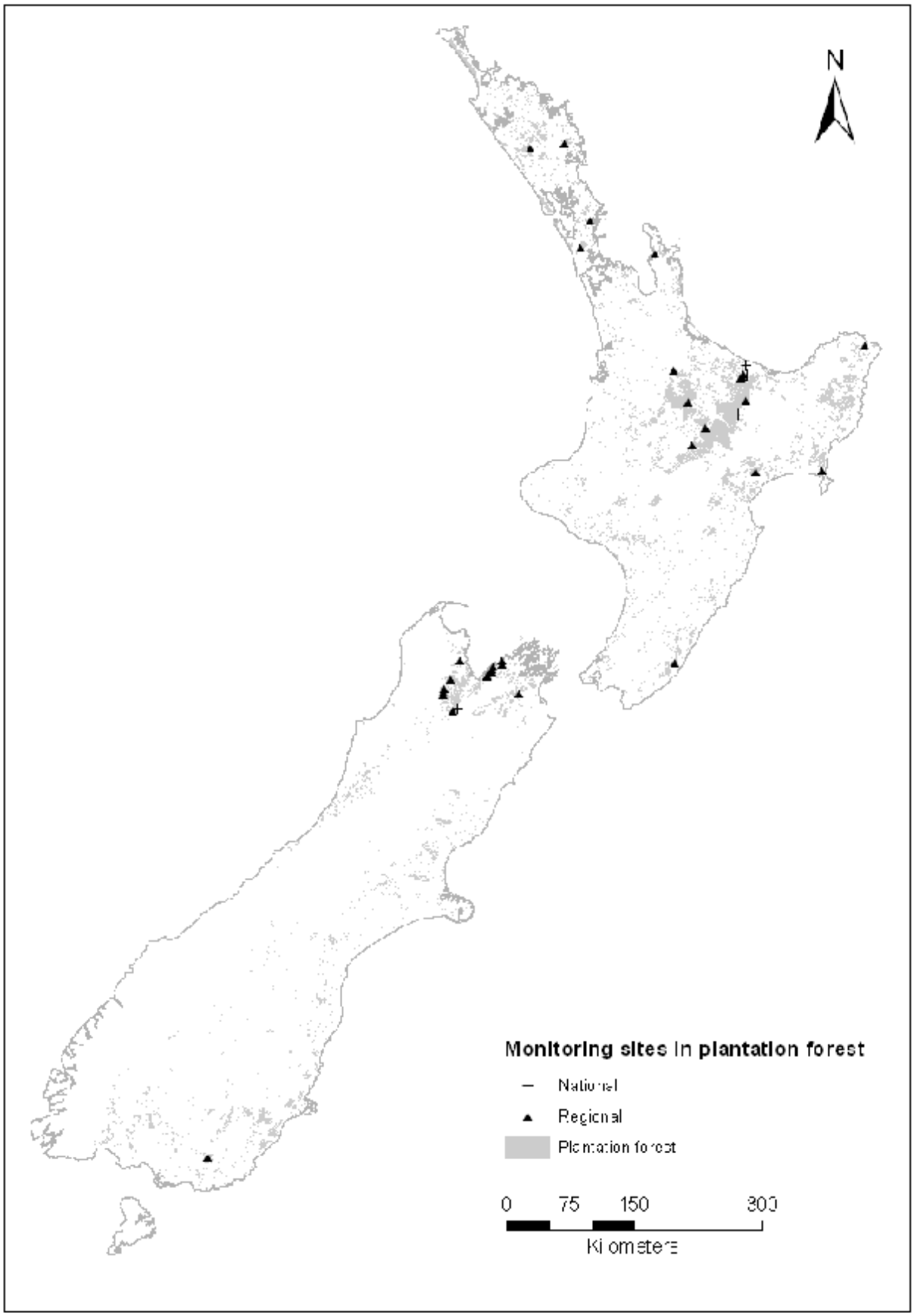

Figure 1. Distribution of water quality monitoring sites in New Zealand where plantation forests are the dominant land cover.

Northland Region

Northland currently has two water quality sites in plantation forests (Appendix 1, Figure A). While seven sites would be desirable based on the average national density of water quality monitoring sites (Table 4), large areas of the plantation estate in Northland are on coastal dune country (Appendix 1, Figure A) where streams are either absent or of low order. Taking this into account, one additional site in plantation forests may be a more appropriate goal to aim for. One possible site is the Patutahi River (Appendix 1, Figure A). This site is on a different geology (conglomerate of sandstone, siltstone etc.) than the two current sites, one on volcanic geology the other on hard sedimentary (predominantly greywacke and argillite)[11] and would improve representativeness across the geologies in Northland.

Auckland Region

Under REC definitions of land cover there are currently two plantation sites in the Auckland region (Appendix 1, Figure B). According to REC the predominant land use at a site in the Hunua Range south of Auckland is pasture (Appendix 1, Figure B). However, the land cover database used in REC is approximately 10 years old and Google Earth (2010 photo) shows this catchment is entirely in plantation forest. The underlying geology of this site is mainly greywacke and argillite[11]. This geology differs from the other two sites (both in mainly limestone & calcareous siltstone with brown clay soils). All three sites appear to be entirely in plantation forest. Based on this information, plantation forests are well represented in the Auckland region.

Waikato Region

The Waikato Region contains the largest proportion of the plantation forest estate in New Zealand (17%). There were five plantation forest water quality monitoring sites, according to REC definition, in the Waikato Region (Appendix 1, Figure C). All sites are in volcanic geology[11], typical of the geology underlying most of the plantation forests in this region. Streams at two sites exit the plantation forest and travel through high producing grass land, one site for six kilometres, the other for three kilometres before reaching the road where the monitoring is undertaken. Two monitoring sites, one on the Coromandel and the other on the eastern shores of Lake Taupo have a large component of plantation forests in their catchments, but the dominant land cover is indigenous forest. As the indigenous forest occurs in the headwaters of these two catchments, these sites may be being monitored as plantation sites by the regional council.

A large portion of the plantation estate in the Waikato Region is not monitored for water quality (Appendix 1, Figure C). Any additional sites in this area would improve the representation of plantation forests in the water quality monitoring network of this region.

Bay of Plenty Region

Fourteen percent of the national plantation forest estate is located in the Bay of Plenty region. Most of the forest estate is on volcanic geology[11]. A small portion of the forests is scattered throughout the eastern Bay of Plenty with underlying sedimentary geology. Most of the plantation forests are in the Rangitaiki River catchment and to a lesser extent, the Tarawera River catchment (Appendix 1, Figure D).

There are eight plantation forest water quality monitoring sites in the Bay of Plenty region (Appendix 1, Figure D). Of those sites, five are located on the Tarawera River, four regional and one national. The four regional sites are located above, at and at two sites below the Tasman mill at Kawerau. Only the site above the Tasman mill and possibly the site at the mill if it is above the discharge point, are likely to represent plantation forest water quality. Although plantation forest is the dominant land cover at the remaining three sites, discharge from the Tasman mill will be influencing water quality. The last site on the Tarawera River is a national monitoring site about seven kilometres upstream from where the river enters the ocean (Appendix 1, Figure D). Although classified as a plantation forest site, along with the discharge from the Tasman mill at Kawerau, the

Tarawera River runs through approximately 20 kilometres of high producing grass land upstream of this water quality monitoring point. Therefore out of the five plantation forest water quality sites on this river system, it is possible that only one site may be truly representing water quality from plantation forests.

Three plantation forest water quality monitoring sites are located in the Rangitaiki River (Appendix 1, Figure D). The national site in the upper part of the Rangitaiki River is primarily in plantation forests. The regional site further down stream is located at the outlet of Lake Aniwhenua. Although plantation forest is still the dominant land cover at this site, at this point on the river system the Rangitaiki has run through the Galatea Valley, an area of high producing grassland. The site furthest downstream on the Rangitaiki is another national monitoring site located approximately 13 kilometres downstream of the Matahina Dam where the river flows through predominantly high producing grassland. It is possible that of the three sites on the Rangitaiki River, only one may be adequately representing water quality from plantation forests.

A large portion of the plantation forest estate in the Bay of Plenty is not monitored for water quality (Appendix 1, Figure D) and there are a number of streams draining this area that could provide potential additional water quality monitoring sites. However many of them are further upstream from where the regional monitoring sites are currently located and would require additional travel. Although only a small proportion of the regional forest estate is in the eastern Bay of Plenty, these forests are on environmentally sensitive topography, and an additional site to capture the water quality from plantation forests in this area would be beneficial. While REC identifies eight sites in the Bay of Plenty region where plantation forest was the dominant land cover, the actual number of sites measuring water quality of plantation forests may be as low as two.

Gisborne Region

Eight percent of New Zealand's plantation forests are in the Gisborne region. This region has one plantation forest site (Appendix 1, Figure E); the underlying geology is predominantly sandstone and siltstone[11]. There is another possible site classified as pasture under REC that may be monitored as a plantation forest site as a large portion of the lower catchment is in this land cover. Some other possible locations for plantation forest water quality sites are in Appendix 1, Figure E. Additional sites would improve the representation of plantation forests in general as well as capturing the range of different sedimentary geologies underlying the plantation forests in this region. However, most of the plantation forests in the Gisborne region are in remote locations and would require additional travel and expense to improve representativeness.

Hawke's Bay Region

Similar to the Gisborne region, Hawke's Bay has around 8% of New Zealand's plantation forest estate. Under the REC land cover classification there were two plantation forest water quality monitoring sites in this region (Appendix 1, Figure F). Most of the inland areas of plantation forest are remote, and potential sites are either unsuitable or inaccessible. Possible additional sites are shown in Appendix 1, Figure F and extend the range of geologies currently included in the existing monitoring programme for plantation forests.

Manawatu-Wanganui Region

Under REC land cover classification; there were no water quality sites in plantation forests in the Manawatu-Wanganui region. The three suggested areas in Appendix 1, Figure H cover three different geologies; volcanic, marine sandstone/siltstone based geology and a gravel/sand/silt based geology[11]. The streams in the coastal plantation forests are unsuitable for sampling as most of the upper catchments are in high producing grassland (Appendix 1, Figure H).

Remaining North Island Regions

The two remaining North Island regions, Taranaki and Wellington have comparatively small areas of plantation forests (<100 000 ha). Taranaki Region has no water quality monitoring sites in plantation forests. However, one site on the Tangahoe River at the downstream end of an area of plantation forest (Appendix 1, Figure G), may be monitored by the council as a plantation forest site, but as the catchment is over 25% pasture, REC classifies it as a pasture site. The Wellington Region has one plantation forest water quality monitoring site. Appendix 1, Figure I shows this site and some potential areas for additional water quality monitoring sites in plantation forests.

Nelson Region

Nelson currently has eight water quality monitoring sites in catchments where plantation forest is the dominant land cover (REC) (Appendix 1, Figure J). All these catchments are predominantly in hard sedimentary geologies, mainly a limestone/fine sandstone and siltstone composition with some smaller areas of volcanics[11]. The headwaters of one site extend into an ultramafic zone. However, closer examination shows that at two sites located on the main stem of the Wakapuaka River and one site on the main stem of the Whangamoa River (Appendix 1, Figure J), the rivers run through several kilometres of high producing grass land before reaching the monitoring sites. These sites may not truly reflect water quality from plantation forests, and if this is the case the number of plantation forest water quality monitoring sites in the Nelson Region could be closer to five. Even so Nelson has a more balanced suite of water quality monitoring sites in plantation forests (Table 4).

Tasman Region

There are seven plantation forest water quality monitoring sites in the Tasman Region. The lower plantation forest site on the Motueka River has a large section of high producing grassland immediately upstream (Appendix 1, Figure K) Two other plantation forest sites also have sections of high producing grassland above their sampling points. Out of the seven sites, four are in predominantly plantation forest. All sites are in soft sedimentary geology, comprising mainly gravels in the valley bottom and a mix of conglomerates, sandstones and siltstone on the hill slopes[11]. Plantation forests are well represented in the Tasman Region.

Otago Region

Otago currently has no plantation forest water quality monitoring sites under REC land cover classification (Appendix 1, Figure O). Plantation forests in this region cover a range of geologies; mainly schist-derived geologies along with sedimentary geologies comprised mainly of greywacke and argillite[11]. The selection of possible plantation forest monitoring sites on the Otago regional map (Appendix 1, Figure O), covers the range of geologies underpinning the forests in this region.

Remaining South Island Regions

The remaining South Island regions, excluding Canterbury (Appendix 1, Figure M), have small areas of plantation forest (<100 000 ha). Marlborough region currently has one site in plantation forest (Appendix 1, Figure L) although most of the valley through which the river flows is in high producing grassland. Three other possible plantation sites are marked on the regional map. There are no plantation forest water quality monitoring sites in the West Coast region. Plantation forests in this region are fragmented, and two possible sites are marked on the regional map (Appendix 1, Figure N). Southland region has one plantation forest water quality monitoring site under REC classification. Another four possible sites are marked on the regional map (Appendix 1, Figure P).

Water Quality Variables

Sixty-three different water quality variables were being measured in the national and regional water quality monitoring programmes at the time of this study. This included 13 variables of nitrogen (N), and 19 water quality variables covering a range of heavy metals, major ions and other factors such alkalinity & hardness. A summary of the key water quality variables measured by each region is in Table 6.

Table 6. The key water quality variables measured in national and regional water quality monitoring programmes (excluding Canterbury), compared with the recommended key variables for plantation forests.

WQ variable	National	Regional (n=15)	Key for forestry
Dissolved oxygen	●	15	●
pH	●	13	
Conductivity	●	15	
Water temperature	●	15	●
Visual clarity	●	11	●
Turbidity	●	15	
Suspended sediment		12	●
Coloured dissolved organic matter	●	3	
Total nitrogen (N)	●	10	●
Nitrate NO_3/oxidised nitrogen	●	10	●
Ammonia/ammonium (NH_3/NH_4)	●	15	●
Total phosphorus (P)	●	11	●
Dissolved reactive-P (DP)	●	15	●
E coli	●	13	●
Periphyton	●	8	●
Chlorophyll *a*	●	4	
Aquatic invertebrates	●	10	●
Fish		2	●

Some regions had separate water quality monitoring programmes outside of their SOE water quality programme which focus on bio-monitoring and monitoring of sites for recreational use (i.e. bathing). Some of the sites in these programmes intersected with the SOE sites. As a result, not all water quality variables recorded for each region were consistently measured at each site at each sampling date. In particular the biological variables were often measured at a reduced frequency at SOE sites because they were measured elsewhere, at sites more suitable for bio-monitoring.

Most of the physico-chemical variables measured under the national water quality monitoring programme (NRWQN) were also measured by most of the regional councils (Table 6). Colour and chlorophyll *a*, although measured nationally were only measured by a few regional or unitary authorities. About half the regions measured periphyton at their SOE sites but could have been measuring this variable in other water quality programmes.

The last column in Table 6 identifies thirteen key water quality variables (indicators) for plantation forests; nine physico-chemical variables, one bacterial indicator and three biological indicators. This list includes water quality variables most pertinent to forestry activities along with additional

variables important for between land-use comparison and national and international reporting requirements. With the exception of fish, most of these variables are already measured by the majority of regional councils, and all except suspended sediment are measured in the national water quality monitoring programme.

Low dissolved oxygen levels and elevated water temperatures can adversely impact on aquatic organisms affecting ecosystem functioning and metabolic processes. These two variables are closely correlated, although factors other than temperature (i.e. microbial and primary production), also influence dissolved oxygen levels[12]. Plantation forest streams usually provide cool, highly oxygenated waters for most of the forest rotation. However, these two variables can reach levels which are stressful for more sensitive aquatic organisms during harvesting, particularly when operational practices remove streamside vegetation. While effects may be short-lived, in some instances streams can take longer than a year to recover to pre-harvest levels[13, 14].

One of the more important indicators for plantation forests is suspended sediment. While sediment loads from plantation forests are likely to be lower than in agricultural streams over a rotation length[15], post-harvest sediment pulses can leave a legacy that can remain in streams, particularly small headwater streams, for several years after harvest[16, 17]. Sediment provides binding sites for a wide range of contaminants and nutrients[12], and in particular for forestry, particulate forms of P bind to sediment and provide an additional pathway of phosphorus export from stream systems. While in suspension, sediment affects optical properties of water, reduces light penetration and ecosystem primary production, is detrimental to filter feeders, can damage gills, and affects aquatic invertebrate and fish behaviour[12]. As it settles, sediment can adversely impact on benthic habitat and downstream receiving environments. Sediment is an issue across all land uses.

Visual clarity measures the transparency of water and affects the aesthetic and recreational values of waterways. Water clarity is measured in New Zealand's river systems using a back disc[18]. Water clarity in plantation forest streams is usually high, similar to that in indigenous forest streams[19], although one study recorded lower water clarity in mid-rotation plantation forests streams than in both pasture and indigenous streams[20]. As water clarity is closely associated with suspended sediment, effects on river ecosystems are similar to those for suspended sediment[12].

The nutrients N and P and their more soluble forms (Table 6) are toxic to aquatic life at high concentrations, and together are major nutrients associated with the eutrophication of water bodies and associated increases in nuisance plant growth such as periphyton[12]. N and P levels from plantation forests are generally low throughout most of the forest rotation[21]. Elevated levels can occur after harvest, with nitrate the main driver of increased concentrations of N, but these increases are generally short-lived[14, 22] and usually at lower concentrations than in other land uses such as agriculture[23, 24]. Therefore these two variables provide important indicators for land use comparison.

Escherichia coli (*E.coli*) is widely used in New Zealand as an indicator of faecal contamination, which can affect quality of streams for contact recreation and potentially downstream shellfish resources. Generally, *E.coli* contamination is not a problem in plantation forest streams, with few sites exceeding guideline levels[19, 25] but it remains an important national indicator of water quality and an important indicator for plantation forests in land use comparisons.

Periphyton occupy a fundamental role in food chains and ecosystem functioning and are used to monitor nutrient enrichment[12, 26]. High levels of shade and low nutrient concentrations limit periphyton growth in mature pine plantation streams. However post-harvest fluxes in periphyton can occur in association with increased light levels following riparian vegetation removal, elevated stream temperature and increases in nutrient levels[17, 27, 28].

Aquatic invertebrates are widely used in New Zealand and overseas as a biological indicator of freshwater environments as they are found throughout most freshwater habitats, and protocols for sampling, analysis and reporting are well established [12, 29]. They are often used as an indicator of sediment toxicity and general water pollution. Aquatic invertebrates are the most common

biological indicator used in studies of plantation forest streams in New Zealand, with invertebrate communities in mature forests showing similar attributes to those in indigenous forest streams, but often undergoing marked shifts in community composition in the harvest and immediate post-harvest phase of the forestry cycle. [13, 14, 17, 20, 30, 31]

Freshwater fish have been suggested as a tentative biological indicator for plantation forests (Table 6). Fish are used less frequently than aquatic invertebrates as a biological indicator in plantation forests, but where they have been assessed they have captured shifts in community composition at different stages of the forestry cycle[32-34]. While fish occupy an important position at the top of the food chain, the high diadromy (fish that migrate between the freshwater and the sea as part of their life cycle) among indigenous fish species, and associated decline in richness and abundance with increasing altitude and distance inland[35] is problematic for robust monitoring. However, protocols have been developed for sampling fish communities[36], although this issue is still under debate [7]. Given the value of our freshwater fishes, we support the recommendation in the Davies-Colley et al. 2010[7] report to hold a workshop on river bio-monitoring which would include this indicator for further discussion.

DISCUSSION

Plantation Forest Water Quality Monitoring Sites

Based on the information collected in this review, plantation forests are under-represented in New Zealand's national water quality monitoring network. In particular, the two largest areas of plantation forest, Kaingaroa and Kinleith, located in the Bay of Plenty and Waikato regions, contained few water quality monitoring points. The rivers environment classification (REC) identified 38 potential water quality sites where plantation forests were the dominant land cover, although the true number may be closer to 25. While REC provided an initial identification of sites in plantation forests, follow-up with other resources identified water quality monitoring sites potentially compromised by other land uses or processing facilities. These resources also provided a more up-to date land cover. LCDBII which is used by REC is approximately 10 years old, so some catchments in younger plantation forests were not identified in REC, or they contained larger or smaller areas of plantation forest than identified by REC. The current upgrading of the land cover database by Landcare will improve the performance of REC in this area.

The density of water quality monitoring sites in plantation forests was lower than both indigenous forests and pasture land. An estimated 70 sites are needed to align the number of sites in plantation forests with that of the average density of water quality monitoring sites across all land covers in New Zealand. While that number is based on the current number of water quality sites identified in this review and will obviously change if the total number of sites increases or declines, it does highlight the fact that plantation forests are proportionally under-represented, and there is quite a wide margin between the actual number of sites and the possible number required to improve representation.

We recommend designing a properly structured national network to determine the minimum number of sites required nationally in plantation forests to capture the spatial and temporal variability of water quality in plantation forests for statistically valid analysis.

We acknowledge that the design of a national water quality monitoring network will involve the evaluation of a wide range of criteria, not just land use, based on potential environmental frameworks such as REC, FENZ (Freshwater Ecosystems of New Zealand) and WONI (Water of National Importance)[7]. Cost and ease of access are also major considerations. National water quality monitoring programmes also tend to target larger catchments. Plantation forests are at a disadvantage in this respect as they are often fragmented, located in the headwaters of catchments, require additional travel, are often not easily accessible and lack proximity to flow recorders. However, if New Zealand is serious about a dependable monitoring programme then additional costs seem unavoidable if plantation forests are to be accurately represented in the national monitoring network.

A compromise for the forestry industry may be to accept a lower number of sites to offset the additional cost and travel involved but ensure that site locations are almost entirely (if not entirely) in plantation forests. Forest companies could assist with access to facilitate this process. Another possibility is that regional councils may have plantation forest sites in other water quality programmes which could be incorporated into their SOE network. Site numbers would still need to be sufficient for national statistical analysis. Plantation forests differ from other land uses in that the cyclic nature of this land use can result in marked changes to some water quality variables during the forestry cycle. This review indicates that sufficient sites are potentially available to capture both the spatial and temporal variation inherent in plantation forests. Robust, high quality data would also enhance the accuracy of models to predict water quality in unmonitored plantation forest streams.

Plantation Forest Water Quality Variables

Most of the important water quality variables from plantation forests are currently monitored by most regional councils and the National Rivers Water Quality Network (NRWQN). These variables have been indentified as 'core' variables in the report recently completed by NIWA for MfE [7]. The exception is suspended sediment which isn't monitored in the NRWQN and is rated as a 'supporting' variable in the recent NIWA report.

Sediment is a generic and significant issue across all land uses including forestry, particularly during the harvest phase of the forestry cycle. It impacts on both the immediate and downstream receiving environments. Initiatives to improve land management practices such as SLUI (Sustainable Land Use Initiative) often have reduced erosion and sedimentation into waterways as one of their outcomes. It will not be possible to evaluate the effectiveness of these types of initiatives if suspended sediment is missing from the national water quality programme. As most sediment (and nutrient) export occurs during high flow events, a water quality programme that samples across a range of flows will more accurately capture the full range of data on these variables. Suspended sediment is an expensive indicator to measure[7], but given the importance of this variable, we recommend further discussion on suspended sediment in Phase II of MfE's NEMaR project.

Ability to Report

Water quality indicators for plantation forests and water quality indicators in general do not sit in isolation. Water quality is closely linked with water flow in the interpretation of water quality data and calculation of sediment and nutrient loads (Figure 2). In conjunction with bio-monitoring and physical habitat assessments, these variables provide a holistic assessment on the state of New Zealand's freshwaters (Figure 2). Water quality indicators are linked to indicators in other environmental domains such as land and ocean (Figure 2), contributing to a core set of indicators used by MfE for national and international reporting[5, 6] to provide an integrated picture of New Zealand's environmental performance.

For forestry in particular, a nationally robust and standardised water quality database would improve monitoring and reporting on water quality from plantation forests. It would improve New Zealand's ability to compare environmental performance between different land uses (Figure 2) and consequently provide for better structured land management policies. It also provides a potential resource to fulfil New Zealand's commitment and ability to report on Indicator 4.3.b of the Montreal Process; 'Area and percent of water bodies, or stream length, in forest areas with significant change in physical, chemical or biological properties from reference conditions'[37]. New Zealand's ability to report on this indicator based on the quality of information currently available is rated 'low' and its progress against this indicator is rated 'neutral'[37]. Most forest companies in New Zealand are FSC (Forest Stewardship Council) certified. FSC requirements include the identification, assessment and monitoring of waterways. However, most of this monitoring is *ad hoc* and company based, providing little aggregated value. A robust national water quality dataset could provide baseline data for forest companies if this information were publicly available. The efficiencies of forest companies' own water quality monitoring programmes could then be improved by leveraging off and extending the national dataset. Public access to national water quality data is also advocated in the 2010 Parliamentary Commission for the Environment report on measuring and reporting on the health of our environment[3].

This information could be used for a suite of other purposes including water quality modelling, valuing ecosystem services from forests, water footprinting, legislative requirements and evaluating the effectiveness of changes in freshwater policies and standards in improving freshwater quality (Figure 2).

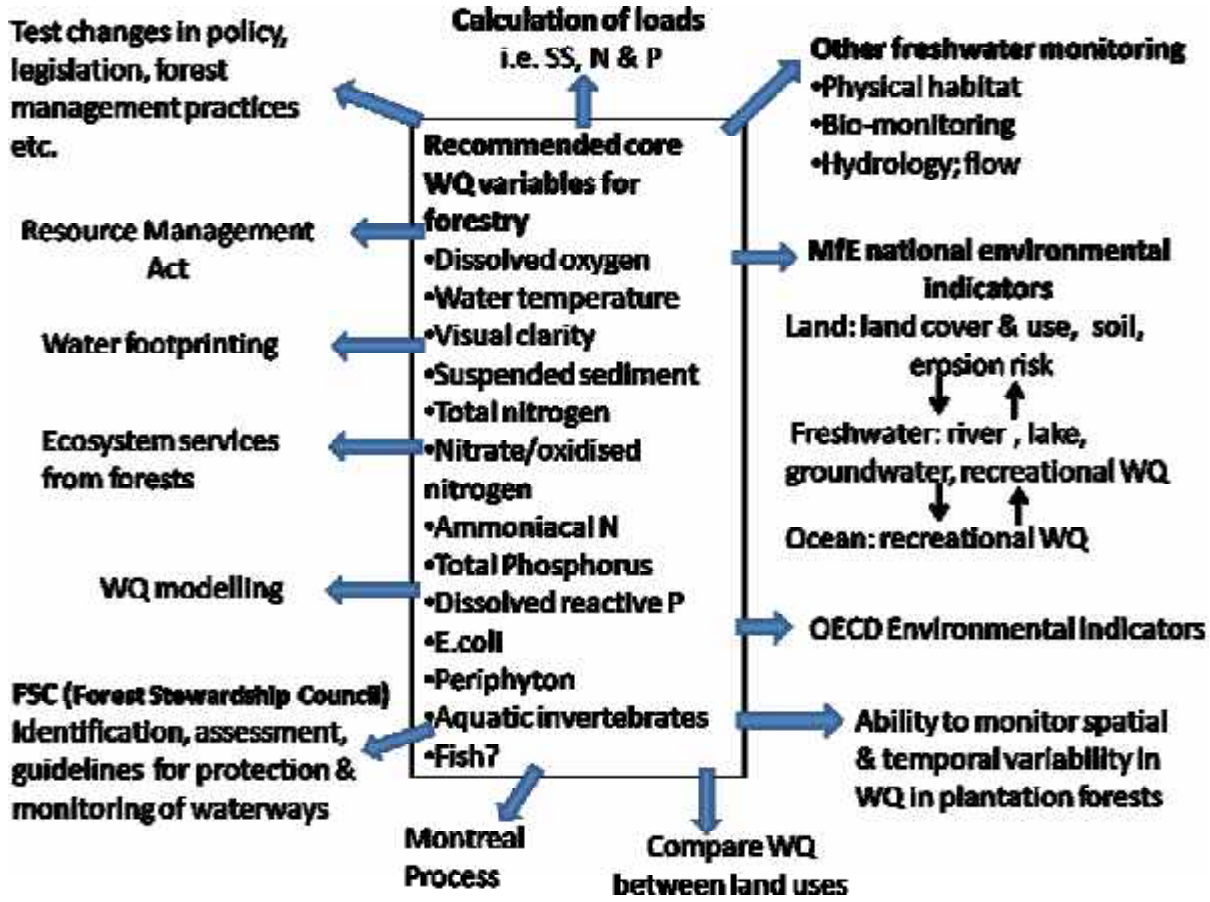

Figure 2. Linkages between recommended core variables (indicators) for plantation forests and other key reporting requirements.

CONCLUSION & RECOMMENDATIONS

- Based on the current number of water quality sites identified in this report, plantation forestry as a land cover is under-represented in New Zealand's national SOE water quality monitoring programmes, particularly in regions containing most of the plantation forest estate. MfE is currently reviewing the national water quality monitoring network. The forest industry should align itself with this process to include and improve the representativeness of plantation forests.

- Forest companies can work alongside regional and district councils to grant access for establishment of long term monitoring sites in plantation forests which aren't compromised by other land uses or activities.

- Plantation forests are inherently located in smaller catchments and have a cyclic component unique to this land use. This needs to be catered for in a national water quality monitoring network. A number of sites representing the geo-spatial and temporal variation in plantation forests across New Zealand and of sufficient number to allow statistically valid analysis, would improve national reporting on this land use.

- Water quality monitoring is time consuming and expensive; central government assistance would benefit some smaller councils with these costs.

- It was evident in this review that only a portion of all water quality sites in a national water quality monitoring network will be suitable for analysing and comparing water quality between land uses. While REC can classify all sites by dominant land cover, further investigation is needed to identify the subset of sites that accurately reflect water quality from a particular land use. The ability of REC to classify accurately the dominant land cover will be strengthened with an upgraded land cover database.

- A wide range of water quality variables is currently monitored by regional and district councils. Refinement of these variables, particularly N, would assist in standardising water quality reporting at the national and international level. A standard SOE reporting format that includes land use comparison would also facilitate this process, and contribute to the formulation of public policy.

- This review has identified 13 water quality variables considered core for plantation forestry to meet reporting requirements. Most are included in existing national and regional water quality monitoring networks. We recommend discussion around the inclusion of suspended sediment as a core variable as it is a key issue across all land uses, is needed for yield calculations and provides a linkage to indicators in other environmental domains. Associated with this is the need for sampling regimes to sample water quality across a range of flows, as most sediment and nutrient export occurs during high flow events. Refinement of national protocols for fish monitoring would assist in the inclusion of this indicator in bio-monitoring. We would like to see further discussion on these points in Phase II of MfE's NEMaR Project.

- We concur with the Parliamentary Commission Report on the need for publically available water quality data.

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APPENDIX 1 – Regional maps showing land cover and location of water quality monitoring sites

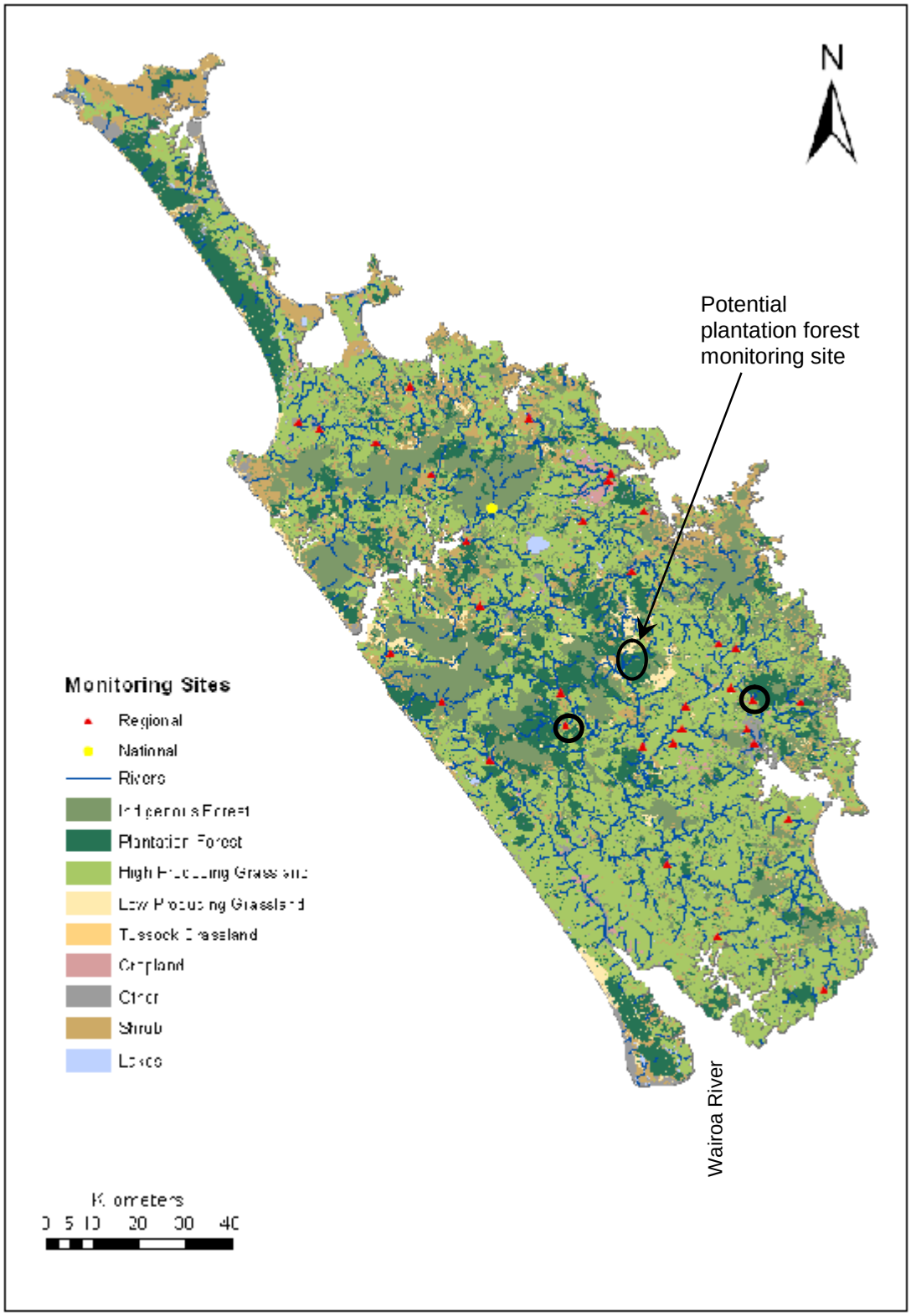

Figure A. Northland region showing the distribution of national and regional water quality monitoring sites across the different land covers (LCDBII). The two plantation sites identified by REC land cover classification are circled in black.

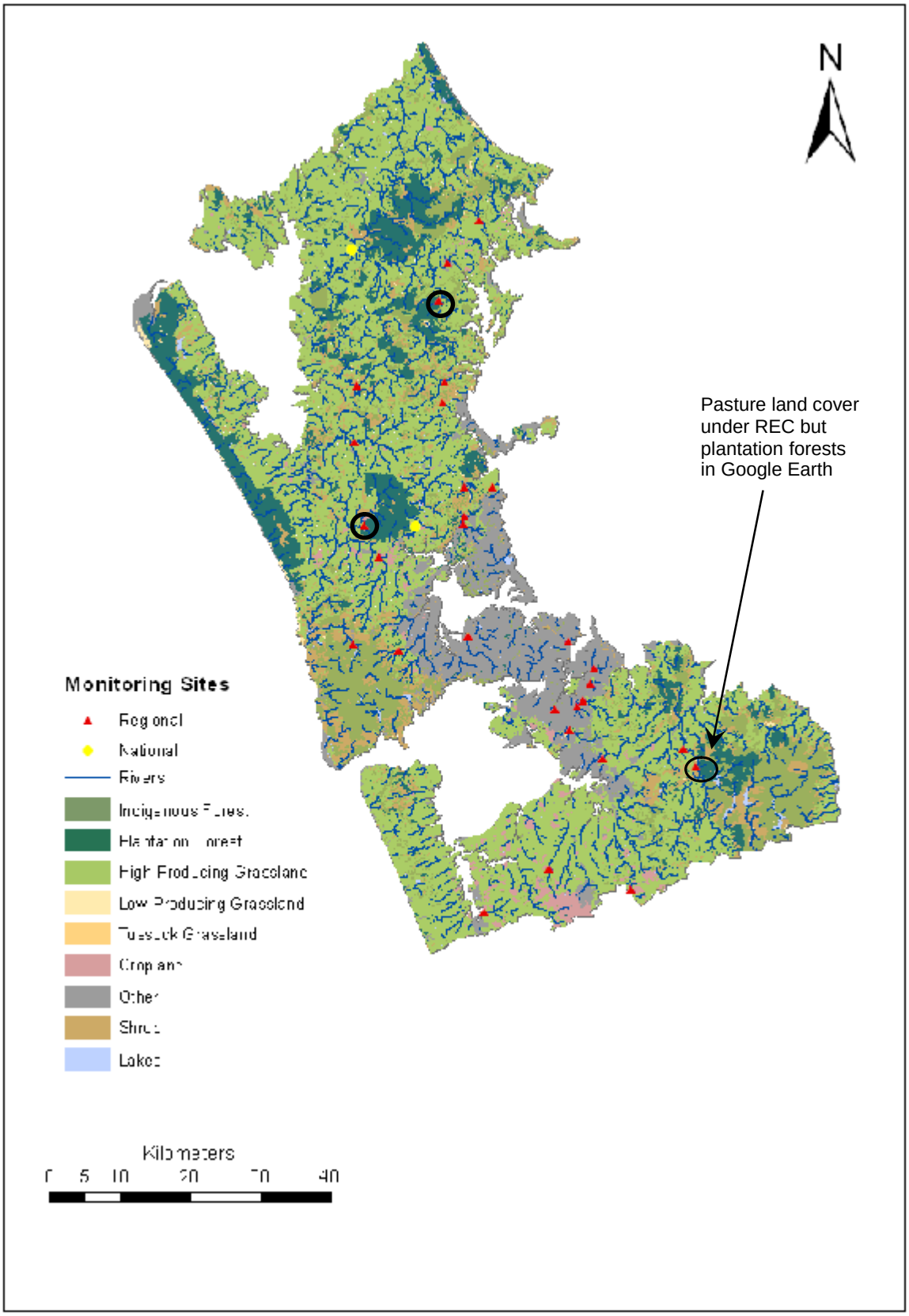

Figure B. Auckland region showing the distribution of national and regional water quality monitoring sites across the different land covers (LCDBII). The two plantation sites identified by REC land cover classification are circled in black.

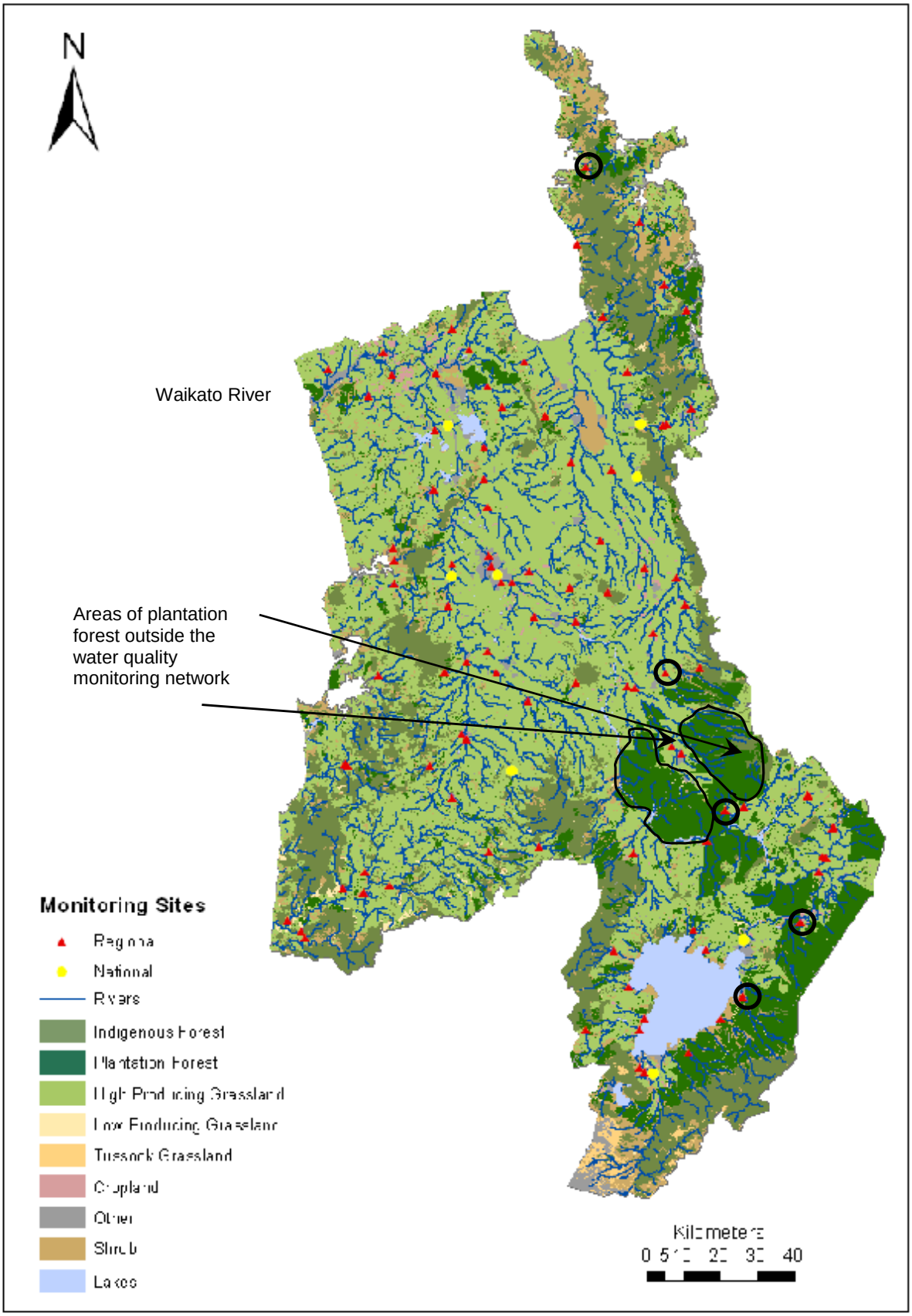

Figure C. Waikato region showing the distribution of national and regional water quality monitoring sites across the different land covers (LCDBII). The five plantation sites identified by REC land cover classification are circled in black.

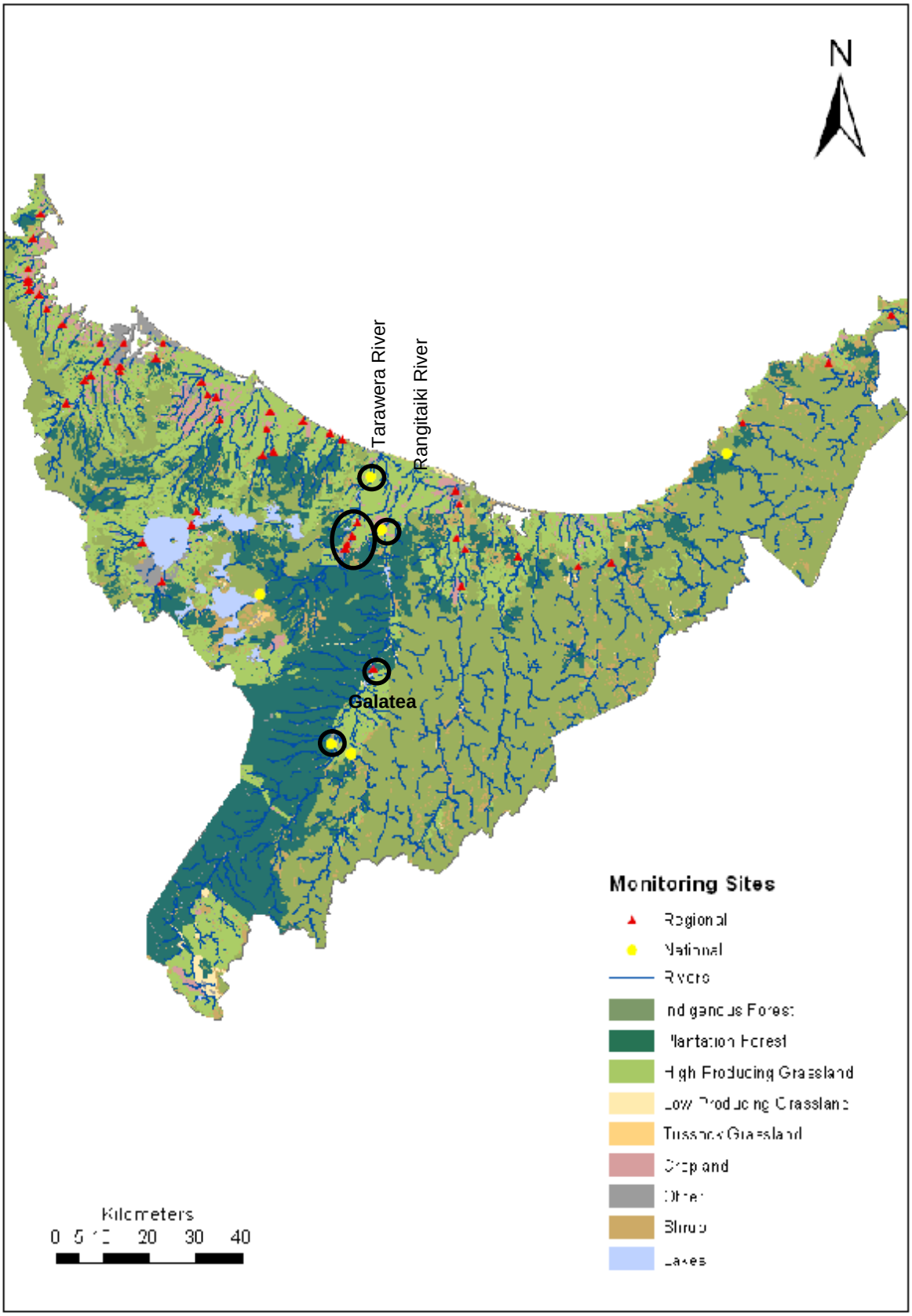

Figure D. Bay of Plenty region showing the distribution of national and regional water quality monitoring sites across the different land covers (LCDBII). The eight plantation sites identified by REC land cover classification are circled in black.

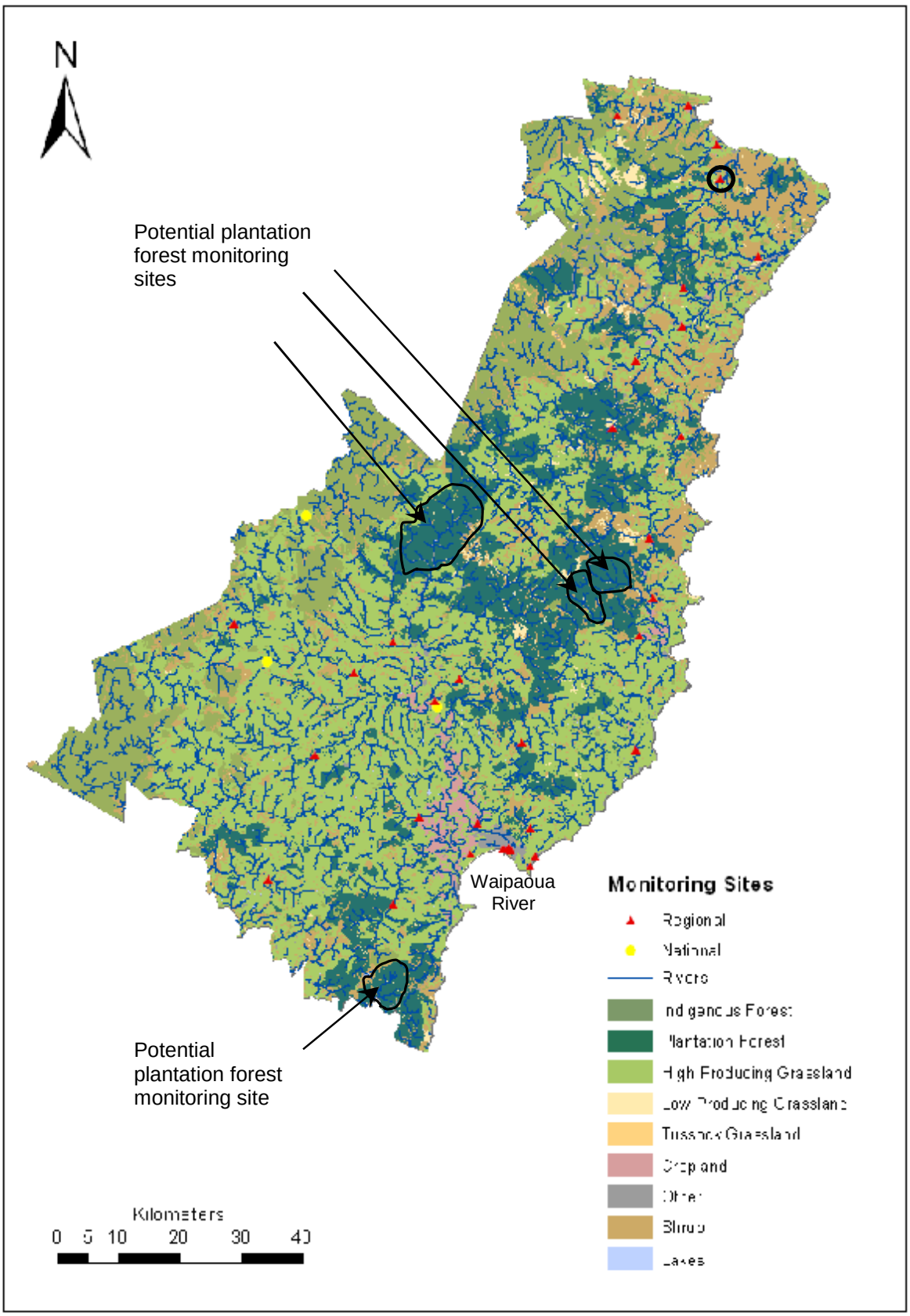

Figure E. Gisborne region showing the distribution of national and regional water quality monitoring sites across the different land covers (LCDBII). The single plantation site identified by REC land cover classification is circled in black.

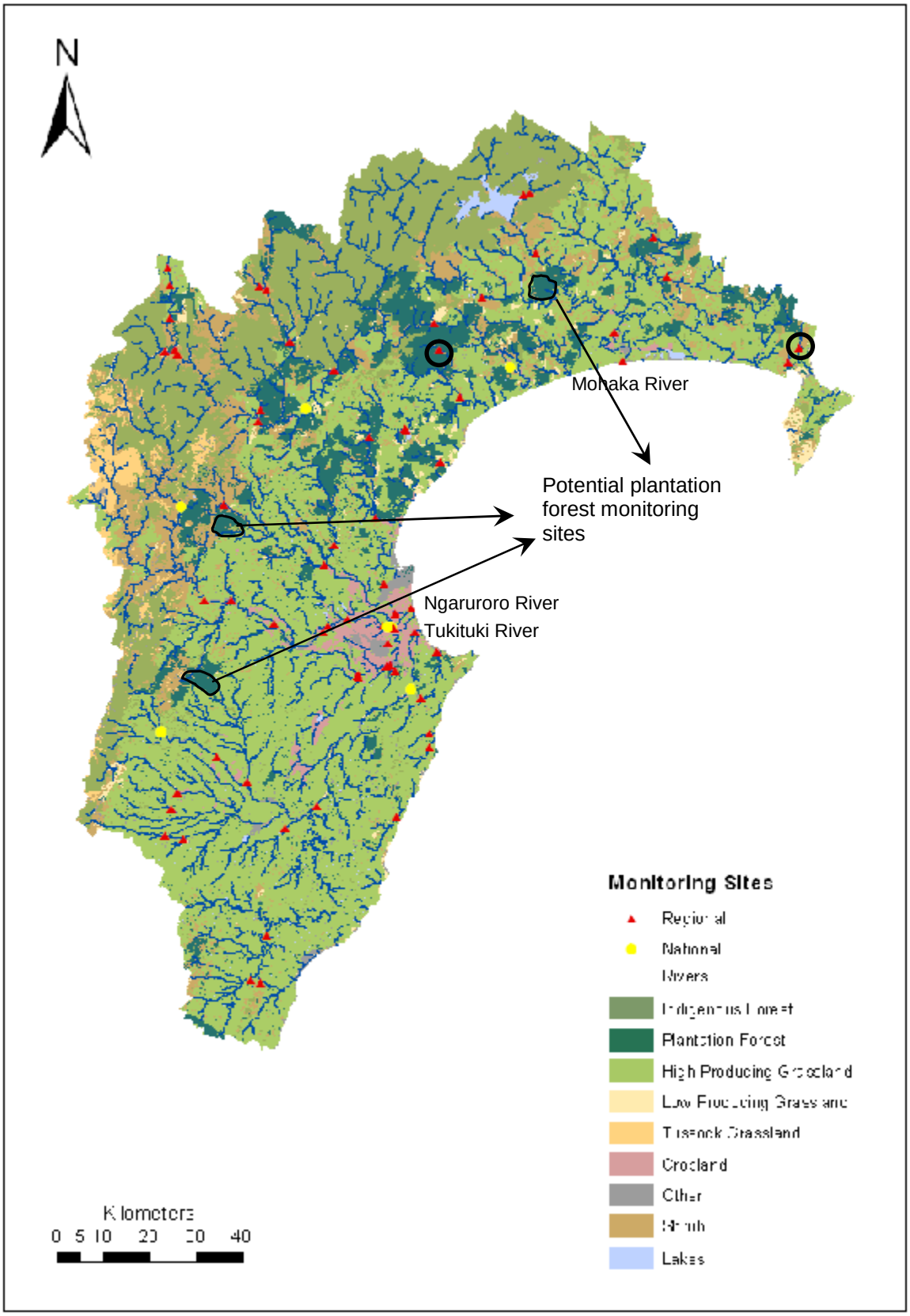

Figure F. Hawke's Bay region showing the distribution of national and regional water quality monitoring sites across the different land covers (LCDBII). The two plantation sites identified by REC land cover classification are circled in black.

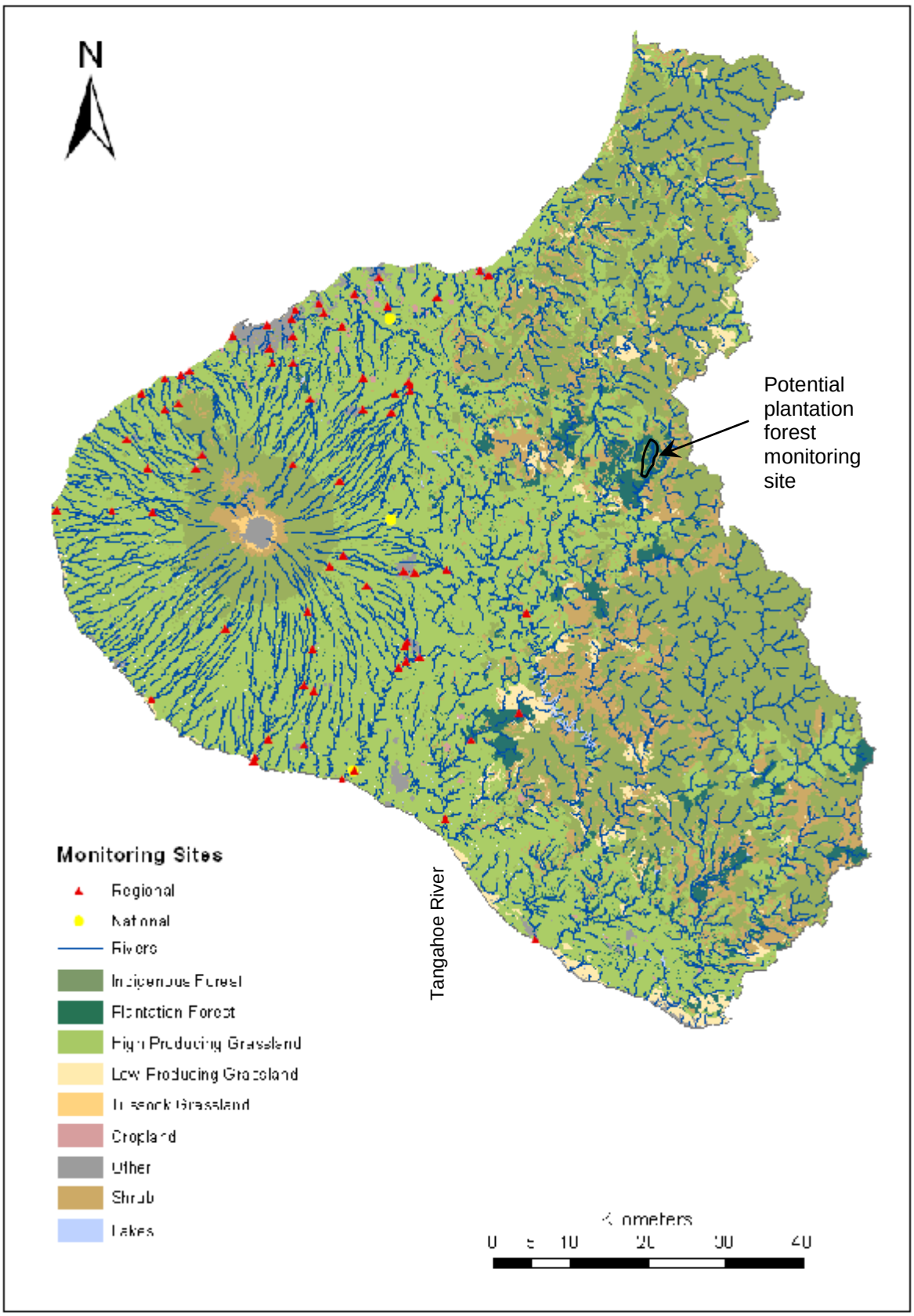

Figure G. Taranaki region showing the distribution of national and regional water quality monitoring sites across the different land covers (LCDBII). There are no plantation sites as identified by REC land cover classification.

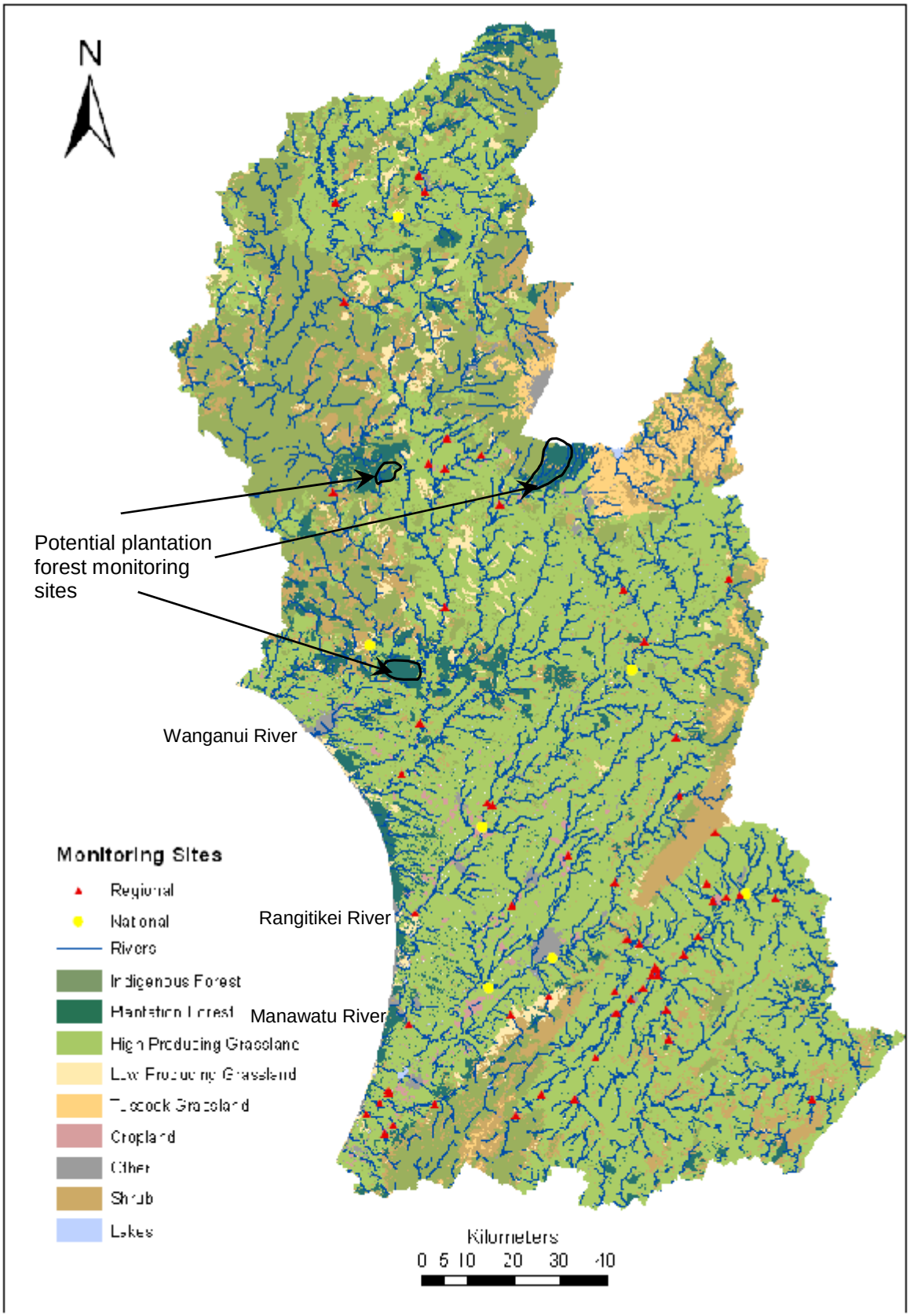

Figure H. Manawatu-Wanganui region showing the distribution of national and regional water quality monitoring sites across the different land covers (LCDBII). There are no plantation sites as identified by REC land cover classification.

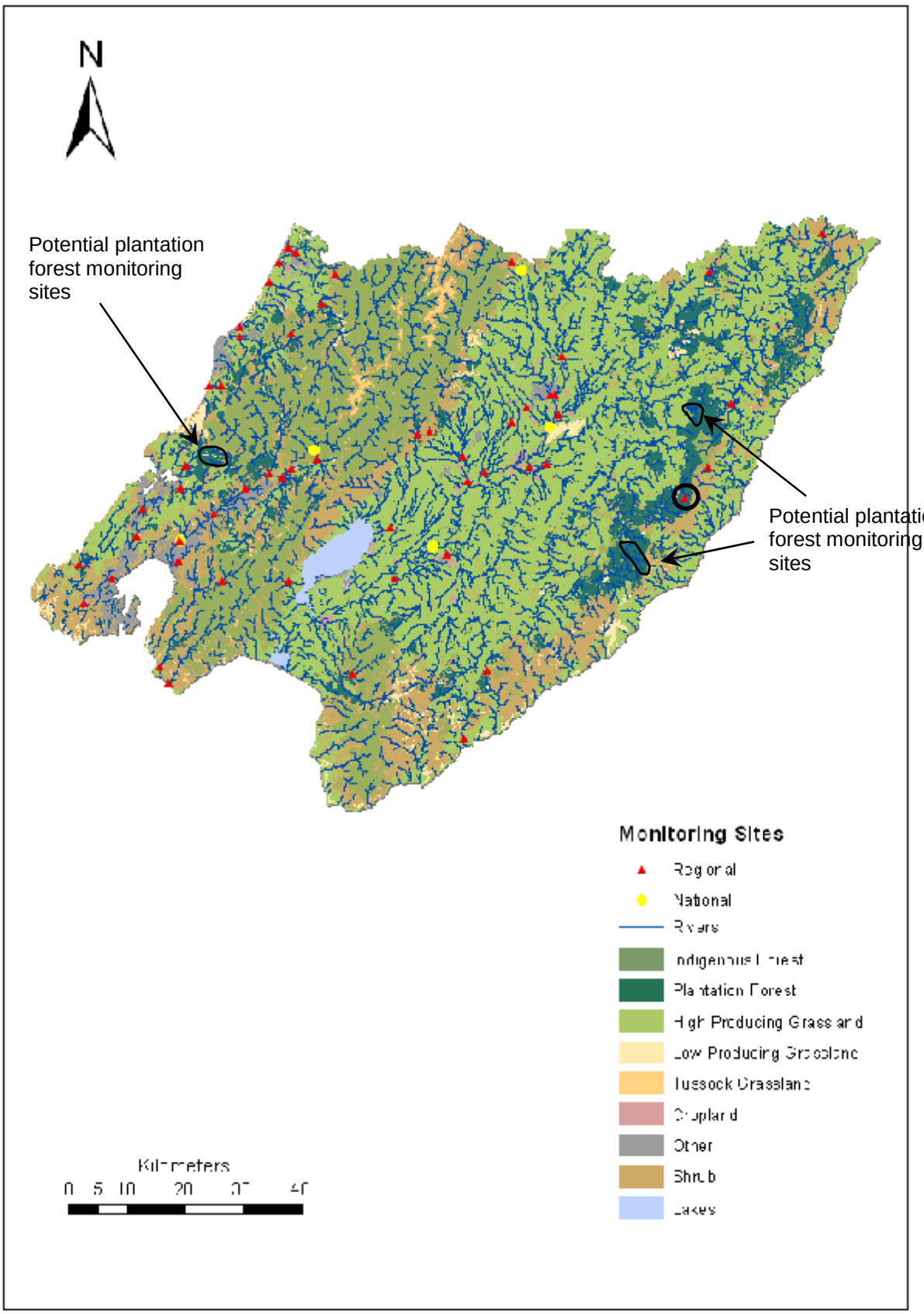

Figure I. Wellington region showing the distribution of national and regional water quality monitoring sites across the different land covers (LCDBII). The single plantation site identified by REC land cover classification is circled in black.

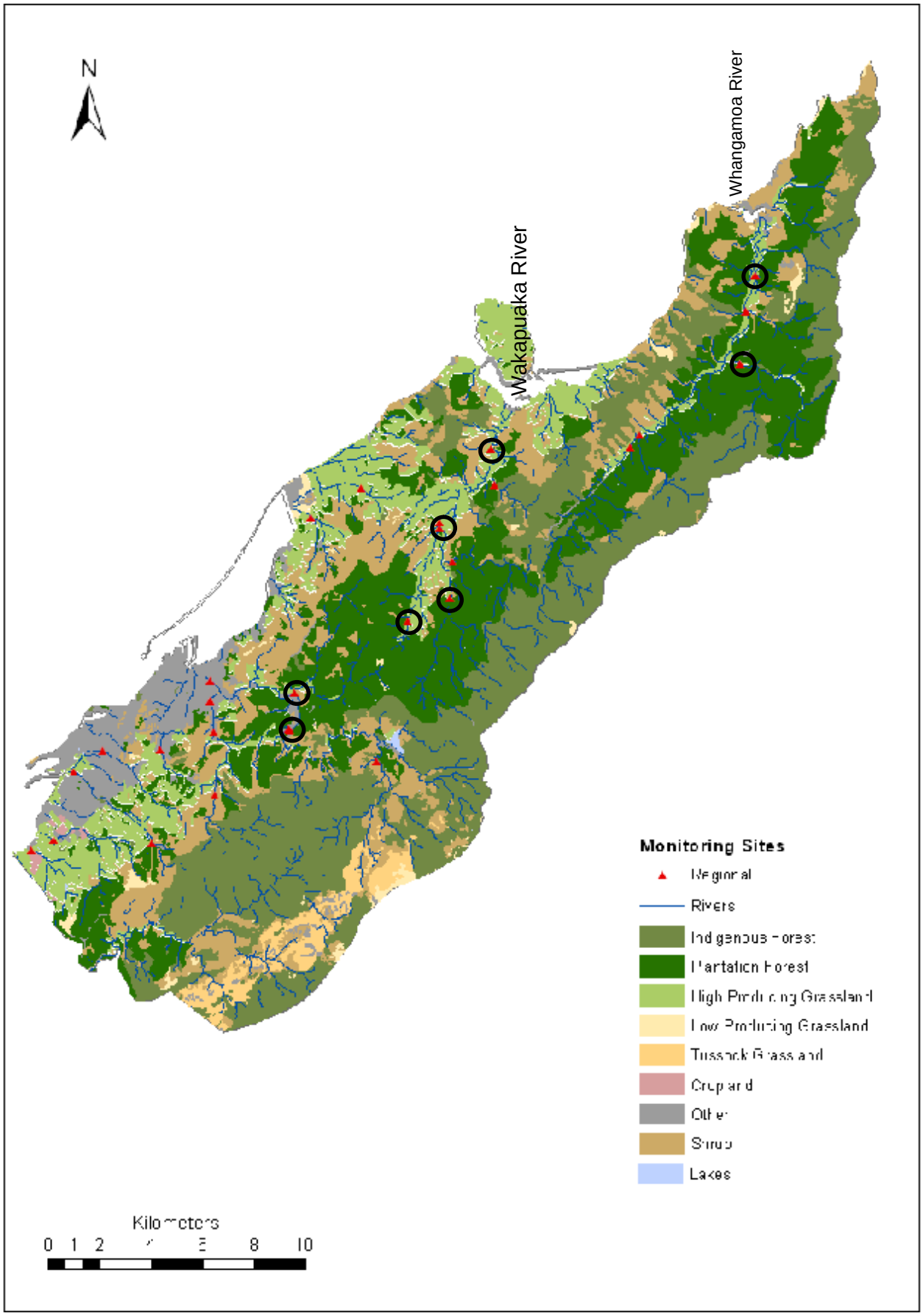

Figure J. Nelson region showing the distribution of national and regional water quality monitoring sites across the different land covers (LCDBII). There are eight plantation sites identified by REC land cover classification.

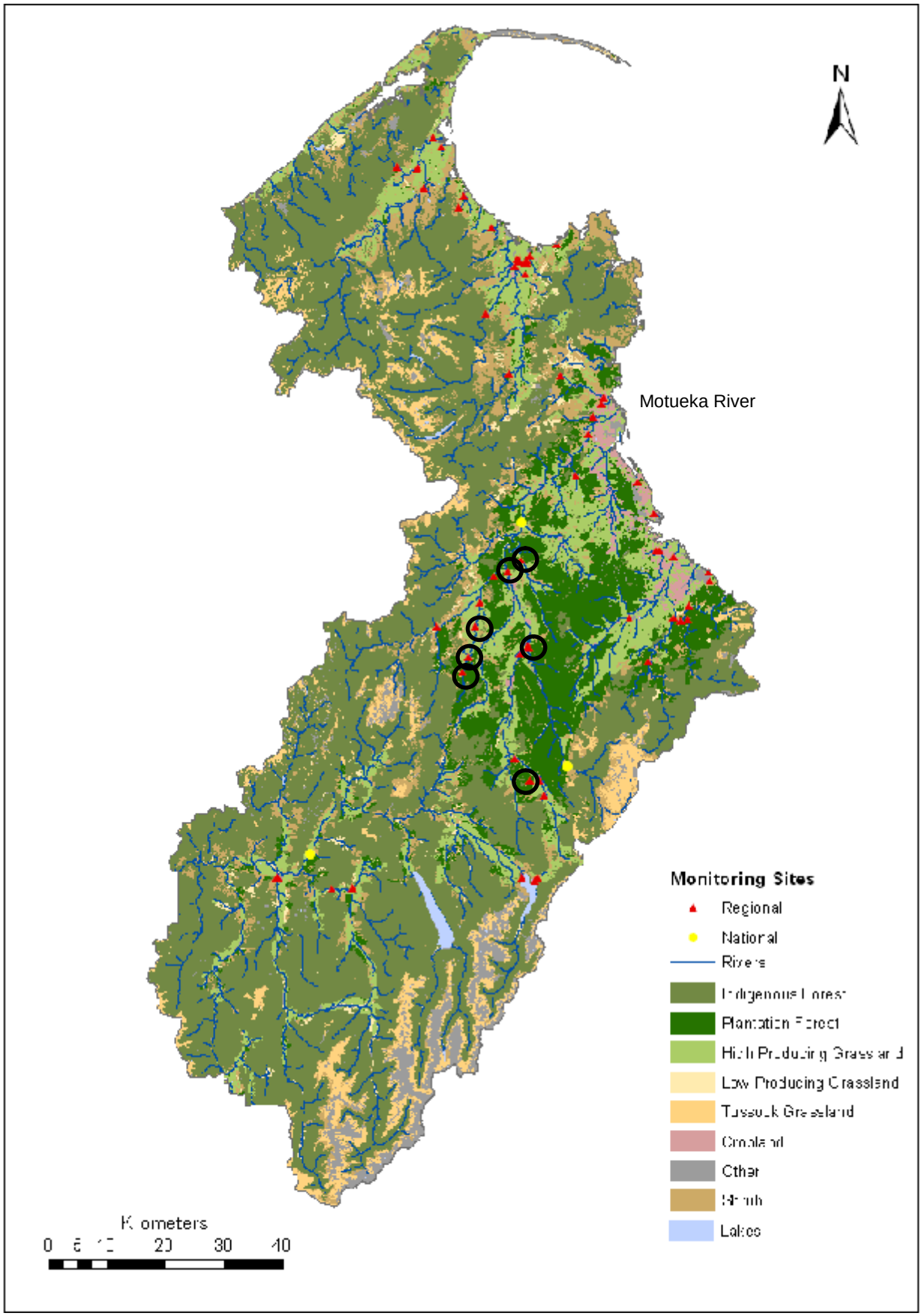

Figure K. Tasman region showing the distribution of national and regional water quality monitoring sites across the different land covers (LCDBII). There are seven plantation sites identified by REC land cover classification.

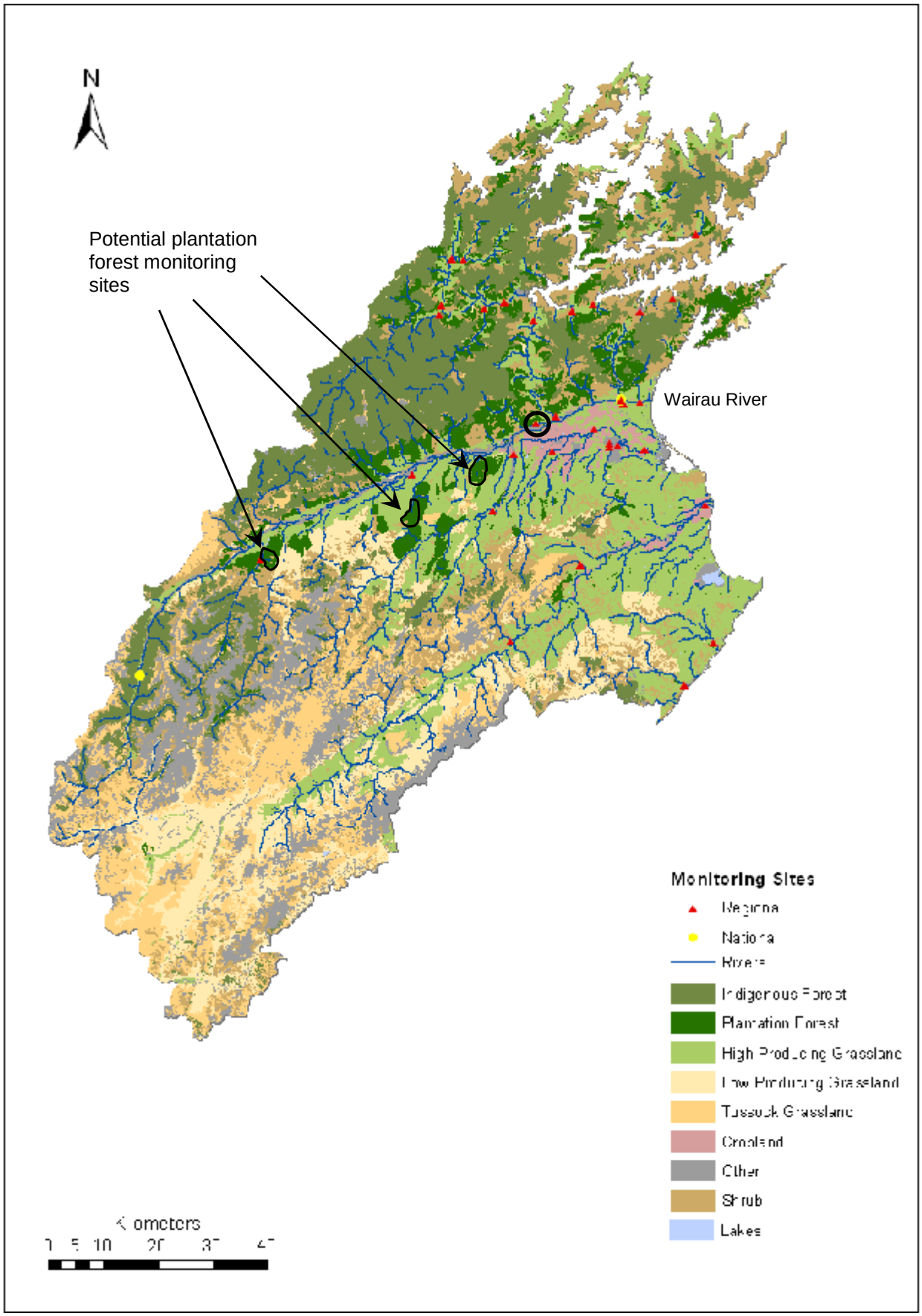

Figure L. Marlborough region showing the distribution of national and regional water quality monitoring sites across the different land covers (LCDBII). The single plantation site identified by REC land cover classification is circled in black.

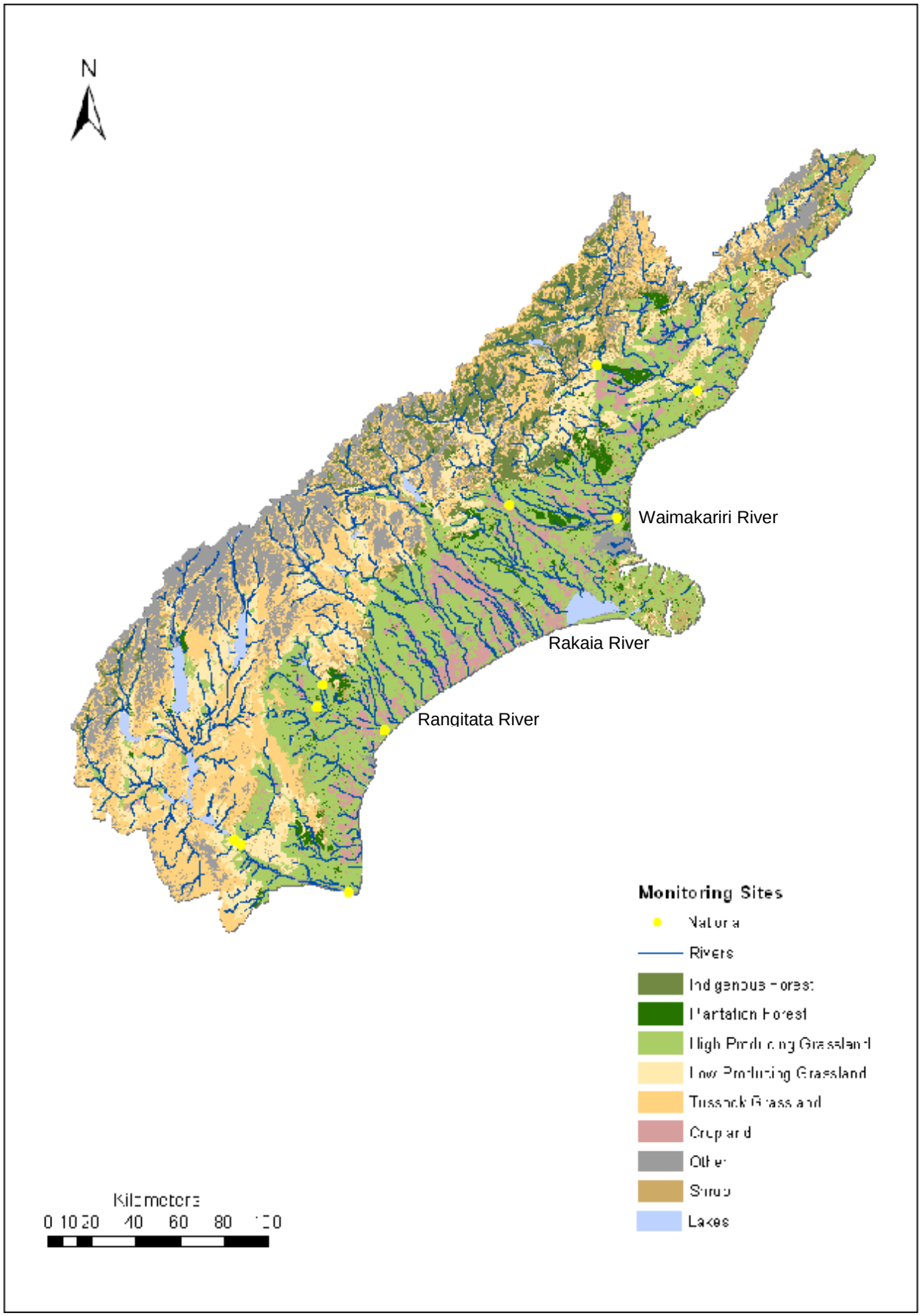

Figure M. Canterbury region showing the distribution of national monitoring sites *only* across the different land covers (LCDBII).

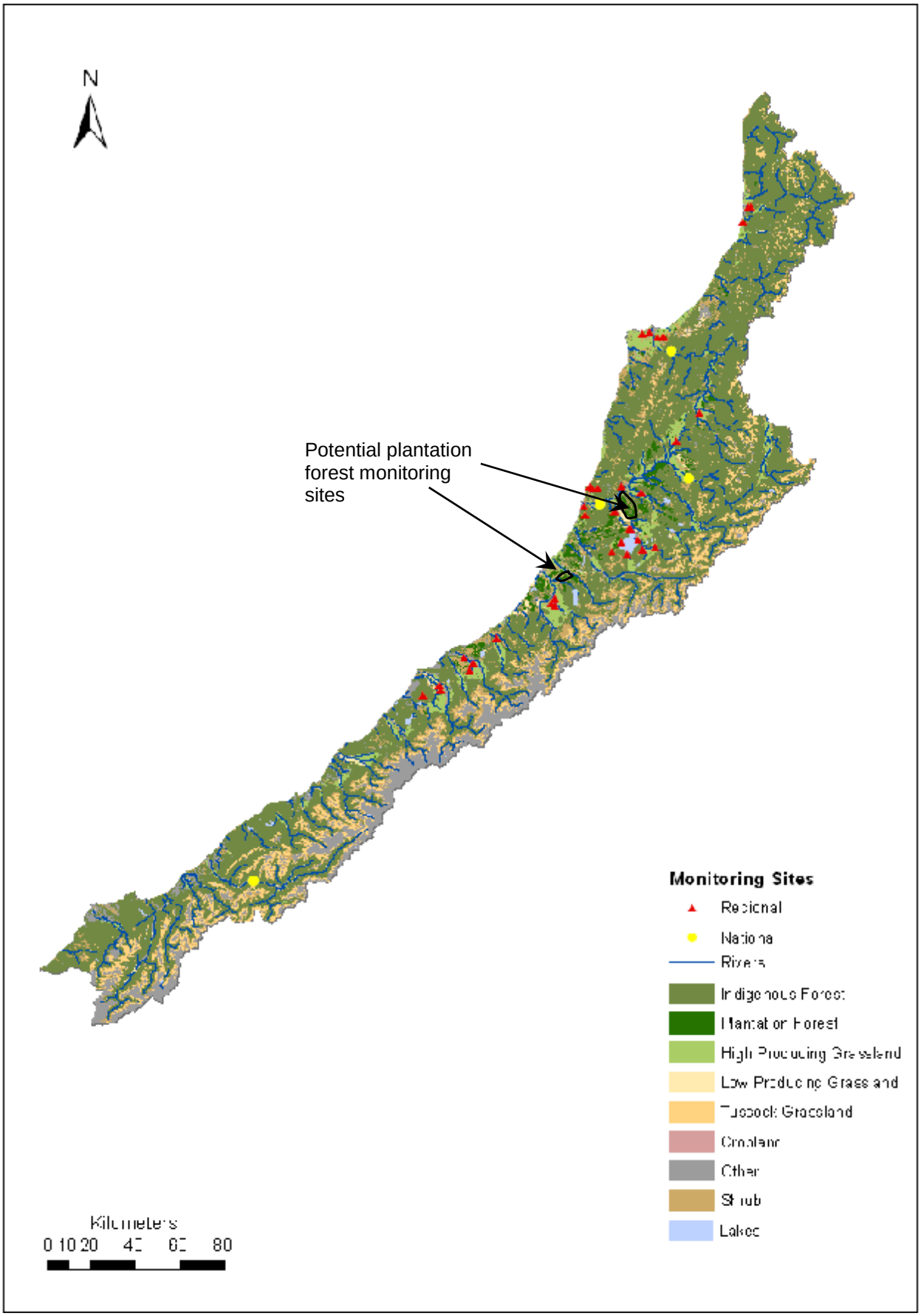

Figure N. Westland region showing the distribution of national and regional water quality monitoring sites across the different land covers (LCDBII). No plantation sites were identified by REC land cover classification.

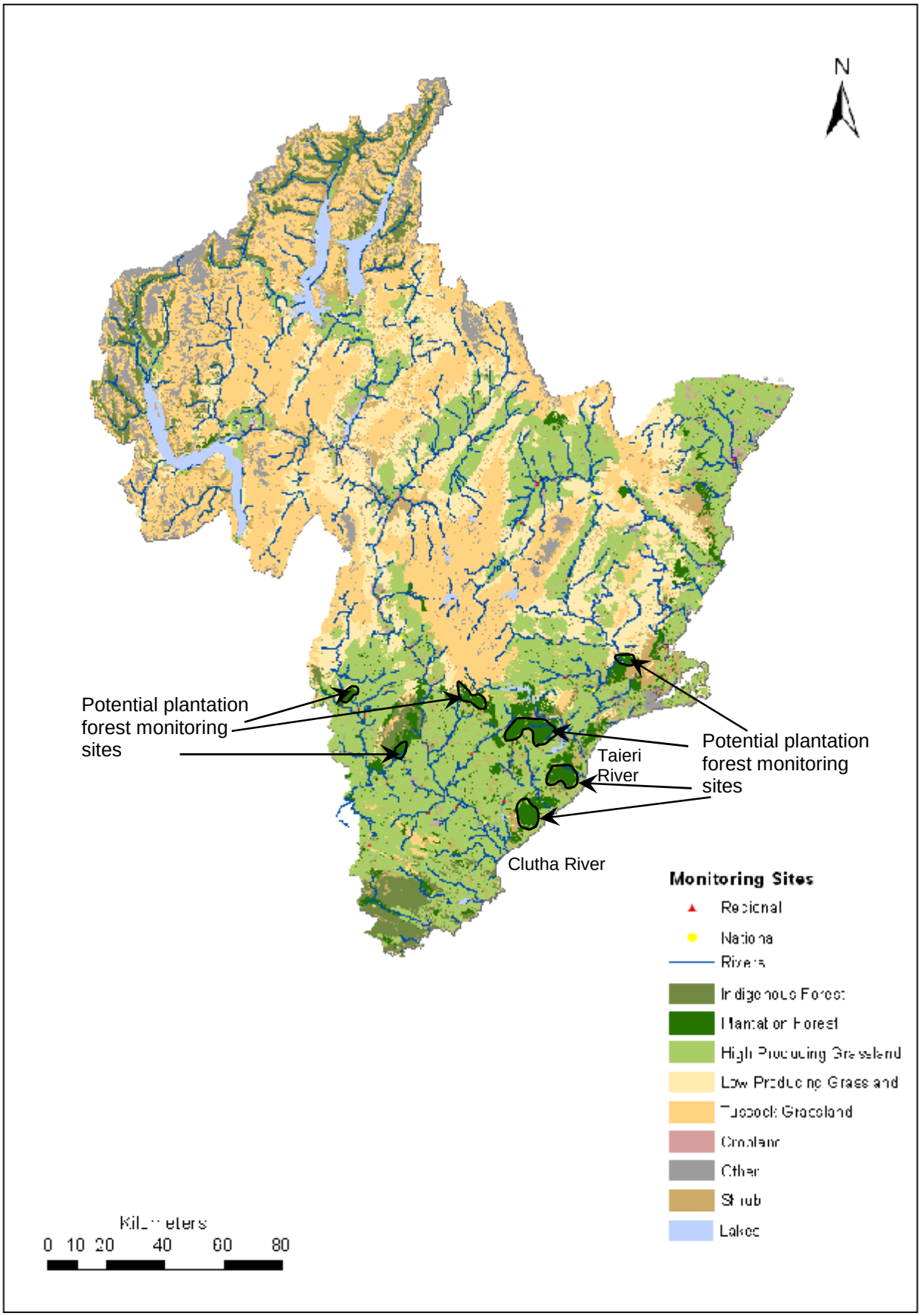

Figure O. Otago region showing the distribution of national and regional water quality monitoring sites across the different land covers (LCDBII). There are no plantation sites identified by REC land cover classification.

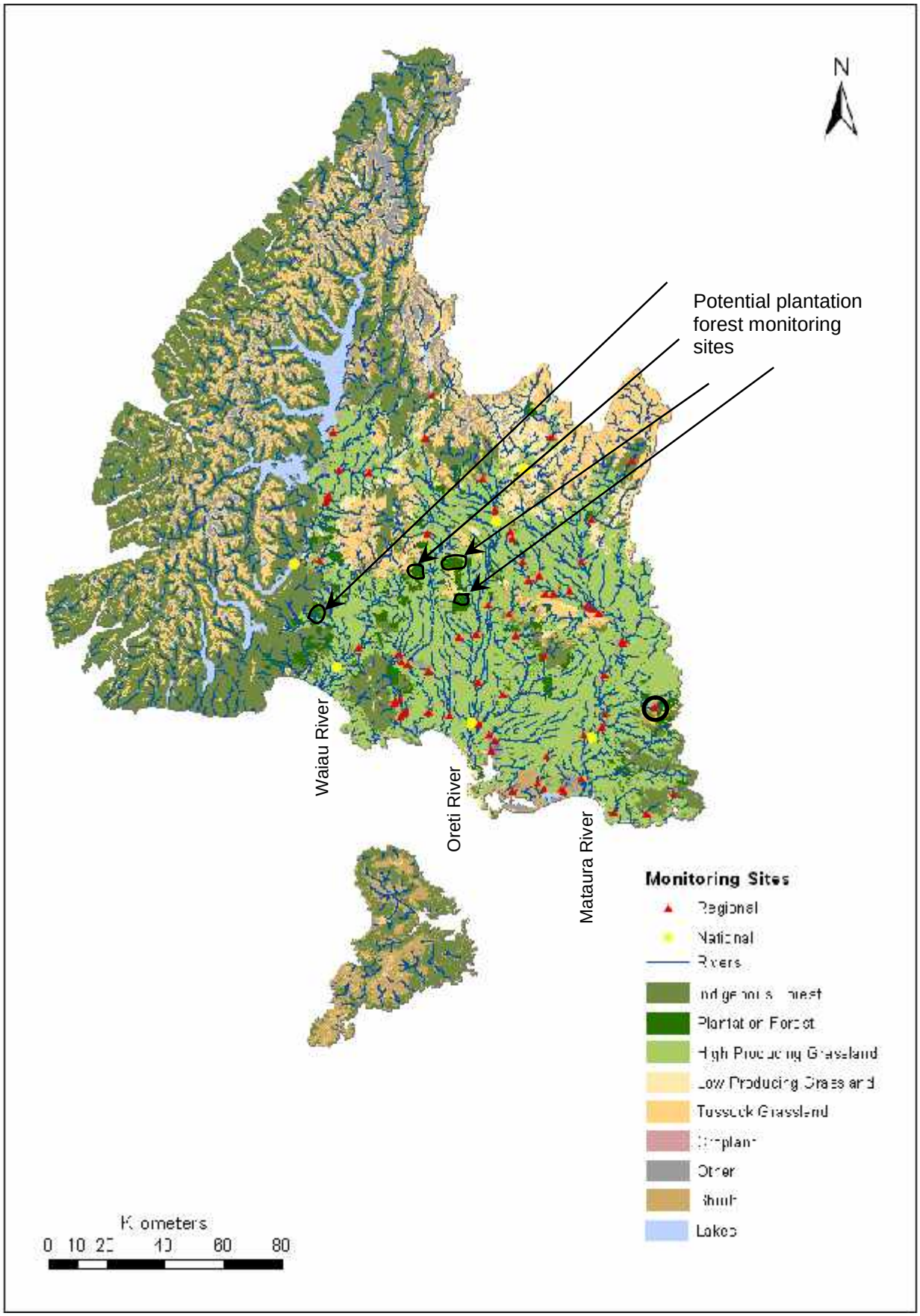

Figure P. Southland region showing the distribution of national and regional water quality monitoring sites across the different land covers (LCDBII). The single plantation site identified by REC land cover classification is circled in black.