A Spatially Intensive Approach to Water Quality Monitoring in the Rous River Catchment

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1.0 Executive Summary

From the 5-7th of September 1997, a spatially intensive water quality monitoring program was undertaken during baseflow conditions in the Rous River catchment to identify point and non-point source impacts on water quality and to relate spatial water quality patterns to environmental attributes. Samples were collected from 108 sites across the catchment and analysed *in-situ* for pH, dissolved oxygen, temperature and electrical conductivity. Filtered and non-filtered samples were collected and analysed for dissolved and particulate, inorganic and organic forms of phosphorus and nitrogen, chlorophyll-a, faecal coliforms and turbidity. Three point sources, the Murwillumbah Sewage Treatment Plant, a dairy shed and horse stables had the largest impact on water quality in the Rous River catchment. Immediately downstream of the dairy shed and the horse stables most water quality parameters greatly exceeded the ANZECC (1992) guidelines for the protection of aquatic ecosystems and secondary contact for humans. However, the impact was localised with an improvement in most water quality parameters further downstream due to dilution and assimilation. In contrast, nutrient loads from the Murwillumbah Sewage Treatment Plant appear to stimulate algal growth throughout most of the Rous River estuary. The poorest water quality in the Rous River catchment, due to non-point source inputs, was associated with cane land, which had elevated TN, TPN, and DON concentrations and temperatures that were significantly greater (Kruskal-Wallis, $\propto>0.05$) than other land uses. Elevated nutrient concentrations and temperatures in the cane drains stimulated algal growth, resulting in high turbidity in the water column. High NO_X concentrations were associated with bananas, most likely due to leaching of N-fertilisers, and NO_X concentrations in the pristine areas appear high because NO_X concentrations are low in other parts of the catchment (excluding horticulture areas) due to algal uptake and removal of inorganic nutrients. Catchment-wide water quality was generally good for ecosystem health (excluding cane and horticultural areas, and downstream of point sources), but poor for human health. Elevated faecal coliforms concentrations across the catchment were most likely due to direct cattle access to waterways. At the time of sampling, low flows were reflected by the dominance of instream processes which had converted most of the inorganic nutrients to organic nutrients. It is recommended that the sampling program be repeated in the wet season because inorganic nutrient concentrations are expected to increase significantly during higher flows. Management efforts in the Rous River catchment need to be firstly directed at reducing point source inputs (particularly nitrogen), secondly at reducing non-point source inputs (particularly nitrogen) from cane land and bananas and thirdly at improving the catchment water quality for human health by reducing direct cattle access to streams.

2.0 Introduction

Water quality monitoring is defined as the process of sampling, measurement and subsequent recording of various water quality characteristics (Bartram & Helmer, 1996). An important objective of water quality monitoring is to provide managers with appropriate information that aids the decision making process (Stout, 1992). The type of water quality information required by managers includes information on background quality and temporal and spatial trends in physical, chemical and biological properties of the aquatic ecosystem. Probably the most important outcome managers ask of monitoring programs is the identification of the key causes of poor water quality in a system. This then allows resources (that are often limited) to be directed towards critical problem areas.

Catchment-scale water quality monitoring programs fall into three general categories: (1) Routine, (2) Event, and (3) Spatially Intensive. Routine monitoring involves the periodic collection of samples (typically fortnightly, monthly, yearly) from a small number of fixed locations (low sample density) within the catchment (e.g. Close and Davies-Colley, 1990; Macdonald *et al.*, 1995; Mattikalli, 1996; Muscutt and Withers, 1996). This approach is ongoing and costly, and although it may identify that a region has a water quality problem it is unlikely to pinpoint the exact causes of poor water quality due to a limited number of sample locations (e.g. SPCC, 1987; EPA, 1996). Event monitoring is the flow weighted collection of samples at a limited number of sample sites, typically located at the catchment outlet. By combining the concentration data with discharge measurements, event monitoring provides managers with information on the amount of material being exported out of the catchment (Webb and Walling, 1985; Kronvang, 1992, 1996). Although good relationships between exports and catchment variables have been developed (e.g. Peierls *et al.*, 1991; Caraco, 1995) this approach however, also does not identify the exact causes of poor water quality because the instream processes and impacts occurring upstream are integrated and diluted (MacDonald & Smart, 1992).

Spatially intensive water quality monitoring involves the collection of samples from a large number of sites (i.e. high sample density) over a short period of time (i.e. stable river flow conditions). The advantage of this approach is that it provides detailed information from across the catchment that can be used to assess the influence of geology, soils, land use, instream processes and point source inputs on water quality (Grayson *et al.*, 1993). The first published spatially intensive monitoring study that could be identified used electrical conductivity (total dissolved solids) to illustrate the primary influence of geology and secondary influence of land use on spatial water quality trends (Walling & Webb, 1975). Although the spatially intensive approach was mentioned by Finlayson (1979) this approach has been rarely used since, until recently, when it has received renewed interest. For example, Grayson *et al.*, (1993) collected samples from sixty four sites across the Latrobe catchment in Victoria, Australia and used electrical conductivity and total suspended sediments to identify point and non-point input sources of solutes and sediments during base flow conditions. The spatial intensive approach has recently been applied by New South Wales (Australia) State Forests in the Towamba Valley catchment (Turner *et al.*, 1996a) and the Bago State Forest (Turner *et al.*, 1996b). Similar to Walling and Webb (1975), the Towamba Valley catchment and the Bago State Forest studies focused on turbidity and conductivity to illustrate the influence of geology and land use on spatial variations in water quality.

Water quality in the Rous River catchment northern New South Wales, Australia has been identified as being very poor for drinking, primary contact and in most parts for aquatic ecosystems health (SPCC, 1987; EPA, 1996). The Upper Tweed Estuary Management Plan (Anon, 1996), also identified the Rous River as having poor water quality. However, previous water quality studies only used a limited number of sample sites (Routine), and as such, gave little indication of the exact causes of the poor water quality. This provided an opportunity to trial a spatially intensive water quality monitoring approach to identify point and non-point input source impacts on water quality in the Rous River catchment, and to relate spatial water quality patterns to environmental attributes, such as land use, soils, geology, catchment characteristics and point sources. This study differs from previous spatially intensive studies, in that it uses a higher sample density (approximately 1 sample / 1 km of stream), examines a larger range of water quality parameters and land use in the catchment is more diverse than some of the catchments in previous studies.

3.0 Study Area

The Rous River catchment (185km^2) on the far north coast of New South Wales is a sub-catchment of the Tweed River Catchment. The Rous River catchment joins the Tweed river at Tumbulgum and extends to Bald Mountain in the west and to the Queensland/ New South Wales Border in the north. The Rous River is influenced by the tide up to Boat Harbour (Figure 1). Land use in the catchment includes cattle grazing, cane, bananas, forest and urban (Table 1). Current water uses are for the irrigation of crops, domestic and cattle water supply, recreation and a sink for the Murwillumbah Sewage Treatment Plant. The total population of the catchment is approximately 8000, varying in density from about 6 people/km^2 in the upper catchment above Chillingham to 2855 people/km^2 in the Murwillumbah urban area (CDATA91, 1993).

Table 1. Area and percentages for dominant land use in the Rous River catchment.

Land use	Area (km^2)	Percentage
Forested	76.7	41.0
Grazing	75.7	40.9
Bananas	5.3	2.8
Cane	24.9	13.5
Urban	2.4	1.3

3.1 Geology and Soils

Basement geology in the Rous River catchment consists of Silurian greywacke, slate, phyllite, and quartzite (Figure 2). This geology unit is overlain by Triassic rhyolite, rhyolitic tuff and claystone. During the Jurassic - Triassic period various mountain building and erosional processes produced valley filling sediments of sandstone, siltstone, claystone and conglomerate. Intrusion by volcanic rocks during the Tertiary resulted in the McPhersons Range which is composed of basalt with members of rhyolite, trachyte, tuff and agglomerate. Alluvial deposits have accumulated along the rivers and on the flood-plain during the Quaternary (Department of Mines, 1972).

Soils generally follow the same boundaries as the geology. The rivers and flood-plain consist of deep Quaternary alluvium and estuarine sediments. The variable topography and geology of the upper catchment has produced a variety of soil types. These include chocolate brown clays, brown earths, red, yellow and brown podsolics. The middle region of the catchment is dominated by red podsolic soils (Morand, 1996).

3.2 Climate and Topography

Elevation varies from less than 10m above sea level on the alluvial flood-plain at the mouth of the Rous River to over 900 metres above sea level on McPhersons Range near Springbrook. Rainfall also varies greatly across the catchment reflecting elevation changes. The lowest average rainfall (1675 mm) is recorded at Chillingham (elevation 35m) and the highest (3084 mm) at Springbrook (Elevation 900m). Highest rainfalls are recorded between January and March and the lowest between July and October.

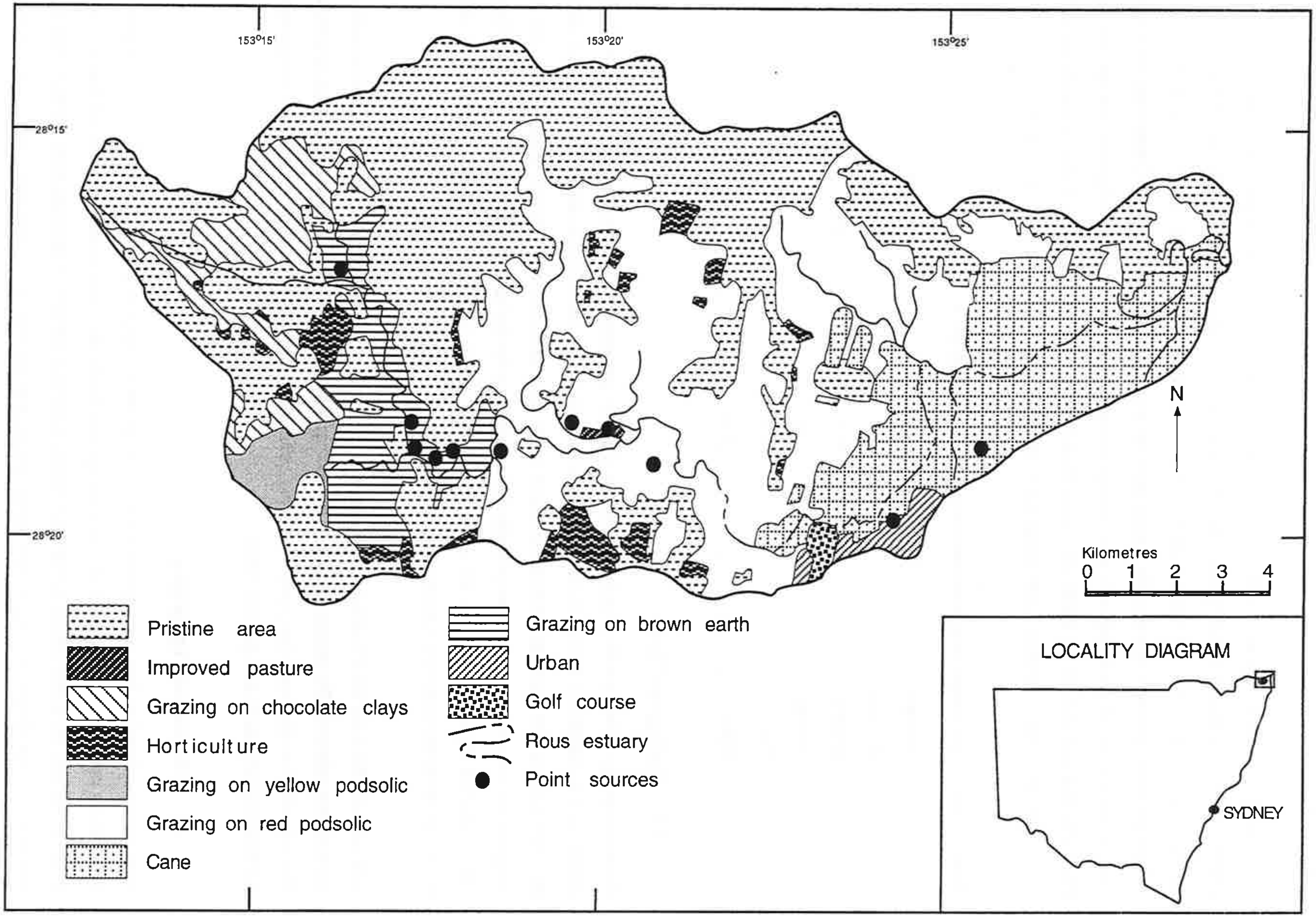

Figure 1. Location and extent of the Rous River catchment, also showing land use.

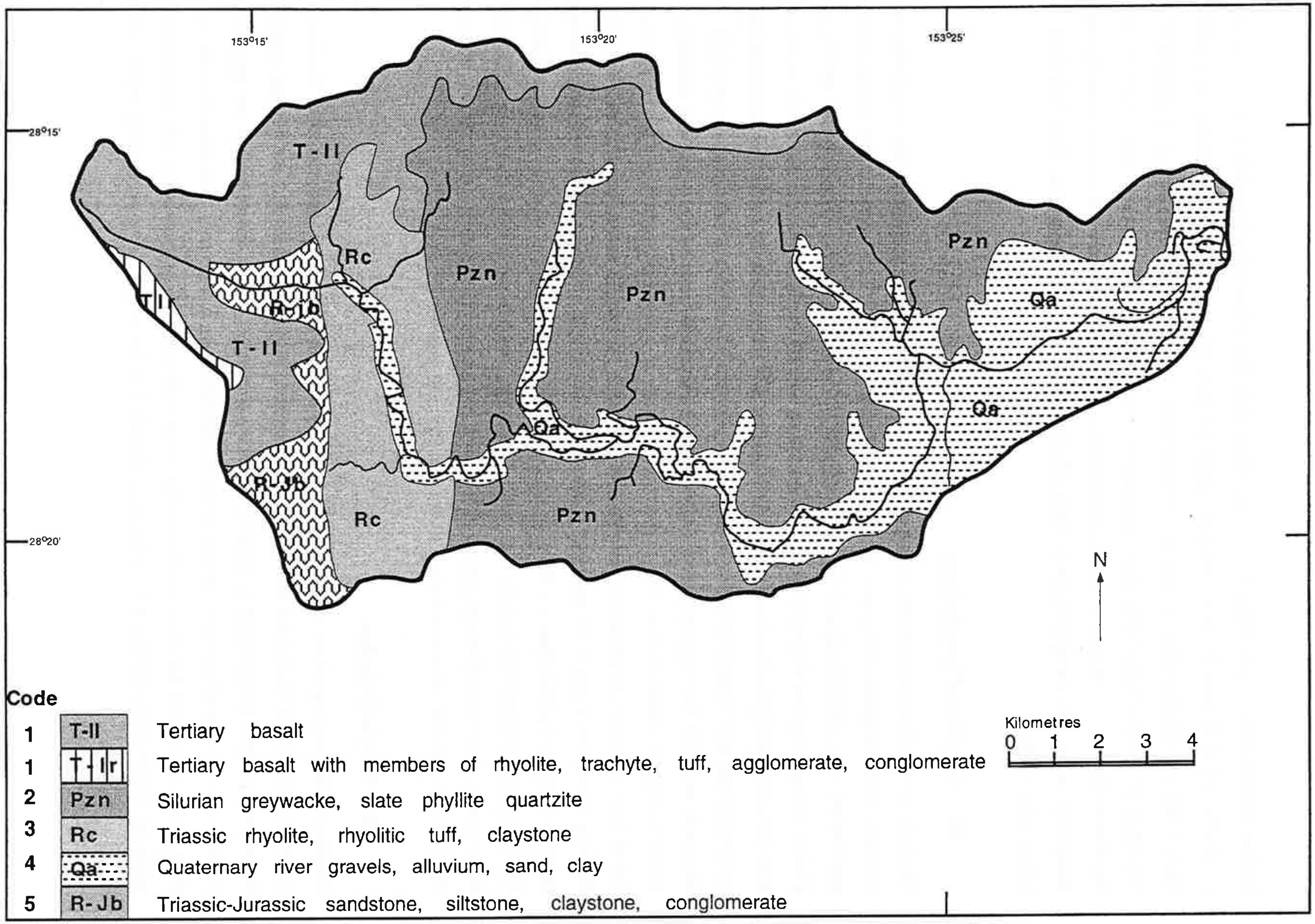

Figure 2. Geology of the Rous River catchment.

Prepared by the Centre for Coastal Management for Tweed Shire Council

4.0 Methods

Spatially intensive water quality monitoring is the collection of water quality data from a large number of sites over a short period of time. A short period of time is defined as a period of uniform flow within the catchment. Sampling was carried out during baseflow conditions to show the influence of environmental attributes such as geology, soils, point source inputs, land use, catchment characteristics and in-stream processes on spatial patterns of water quality. In terms of water quality, baseflow conditions are more likely to reflect environmental attributes in the catchment and is a critical time for instream biological processes, the ecological health of waterways and for water allocations (Biggs *et al.*, 1990; Mulholland, 1992; Grayson *et al.*, 1993).

4.1 Location of Sample Sites

The catchment was divided into ten land use categories on the basis of geology, soil type and land use using geological and soil maps, aerial photographs, topographic maps and ground truthing (Figure 1). Twelve potential point sources of pollution were identified by ground truthing and existing maps (Table 2). The location of sample sites were then chosen, where possible, to meet a number of competing criteria. These criteria were (1) roughly an equal number of sample sites within each land use category (2) upstream and downstream of potential point source inputs, (3) sample sites were evenly spaced, (4) samples sites gave longitudinal profiles of water quality along the Rous River and major tributaries and (5) the sites were easily accessible from roads and tracks. Samples within the tidally influenced section of river were collected on the high tide along the salinity gradient from seawater to freshwater at intervals of approximately two on the Practical Salinity Scale. A total of 120 sample sites were identified, from which 108 samples were collected; 12 sites had no water. Sampling represented a total of 111 kilometres of stream and each sample on average represented approximately one kilometre of stream. The Rous River is a fifth order stream based on the Strahler method of stream classification using a 1: 100, 000 scale topographic map (Gordon *et al.*, 1992). On average, samples were collected about every 620m from first order streams, about every 690m from second order streams, about every 1260m from third order streams, about every 1080 m from fourth order streams and about 1390m from fifth order streams.

4.2 Sample Collection

Sample collection was carried out over a three day period from the 5th to the 7th of September, 1997. Samples were collected by four groups. Each group was provided with a sampling kit, sample location map and a Horiba Multi-probe. Training was provided to each group to standardise sampling procedures. At each sample location, two samples were collected in one-litre sampling bottles. Samples were collected midstream, approximately 10cm below the water surface being careful not to disturb the bottom or include surface scum in the sample. The sample bottles were rinsed three times before use at each site by half filling the sample bottle with water from the sample site, replacing the lid, shaking and then discarding the water.

Table 2. Land use categories, codes and a brief description.

Code	Land use	Description	No. sites
1	Pristine areas	• Forested areas with little or no disturbance upstream	10
2	Improved pasture	•	2
3	Cane	• Sugar cane grown on deep quaternary alluvium and estuarine sediments • Geology:- River gravels and alluvium	8
4	Horticulture	• Mainly bananas on ridges and steep slopes	10
5	Grazing on red podsolic	• Soil:- red podsolic • Geology:- greywacke, phyllite, slate, quartzite	25
6	Grazing on yellow podsolic	• Soil:- yellow podsolic • Geology:- sandstone, siltstone, claystone conglomerate	7
7	Grazing on brown earths	• Soil:- brown earth and brown podsolic • Geology:- rhyolite	11
8	Grazing on chocolate clays	• Soil:- Chocolate and brown clays • Geology:- Basalt	7
9	Rous Estuary	• Salinity fixed locations	16
10	Point sources	• Sewage treatment plant (site 92,102) • Horse Stables (Site 95) • Golf course (Site 113) • Septic village (Sites 5,26,27,29,30,42,63) • Dairy sheds (Site 64)	2 1 1 7 1

4.2.1 Nutrients

Two unfiltered and two filtered 10ml samples were sub-sampled for nutrient analysis from the 1 litre sample bottle. For the two unfiltered samples a 20ml syringe was used to transfer the sample into a 10ml polypropylene vial. Before the samples were transferred, the sample bottle was shaken thoroughly to prevent suspended solids from settling. The vials and syringe were then rinsed three times before filling. The methods for the two filtered samples were the same as for the unfiltered samples except a 0.45μm cellulose acetate filter was placed on the syringe during rinsing and filling of the vials. The nutrient samples were then placed on dry ice in an esky, until returned to the laboratory where they were frozen at -20°C.

4.2.2 Chlorophyll-a

At each sample location 250 to 500 ml of water (depending on suspended sediment load) from the sample bottle was filtered (30kPa) through a GFC glass fibre filter. The filters were folded and placed into a 10ml polypropylene vial, which was wrapped in alfoil, and then placed on dry ice in an esky, until returned to the laboratory where they were frozen at -20°C.

4.2.3 Faecal Coliforms

Bacterial samples were collected in a 50 ml sterilised sample bottle. The sample was collected as for the one litre sample except the sample bottle was not rinsed. The bacterial sample was then placed on ice in an esky until returned to the laboratory where they were kept refrigerated.

4.2.4 Turbidity

The sample bottle was shaken thoroughly then 250 ml was poured into the turbidity sample bottle. Turbidity samples were kept at room temperature until analysis.

4.2.5 Physico-chemical

Physico-chemical parameters (pH, DO, temperature and salinity/conductivity) were measured in-situ using a Horiba U-10 Multi-probe. All four Multi-probes were calibrated together using the same standards and procedures. Conductivity was calibrated against 0.005, 0.05 and 0.5 M standard potassium chloride solutions. pH was calibrated with standard buffer solutions at pH 4 and pH 7. Dissolved oxygen was calibrated against a zero solution (sodium sulphide) and an air saturated beaker of water checked with a winkler titration. Temperature is factory set and can not be adjusted, but was checked against a standard mercury thermometer for consistency between Multi-probes.

4.3 Laboratory Analysis

Water quality parameters, abbreviations, analytical procedures, detection limits and analytical errors are shown in Table 3. Every tenth nutrient sample was taken in triplicate to assess analytical error. Analytical error was calculated as the average coefficient of variance of the triplicates. All dissolved nutrient analyses were completed within one week of collection, all total nutrients analyses were completed with two weeks of collection and Faecal Coliforms analyses were completed within 24 hours. Turbidity was measured within one week of collection using a transmissometer.

4.4 Water Quality Ranking

The spatial distribution of each water quality parameter is represented on a catchment map. Each parameter was allocated a ranking from good (green), to fair (yellow), to poor (orange) to very poor (red). The criteria for each rank was based on ANZECC (1992) Water Quality Guidelines for fresh and marine waters and mean background readings for pristine areas. For most parameters this provided the upper (ANZECC, 1992) and lower limit (pristine sites) for each rank. The middle ranks were then calculated at equal intervals between the upper and lower limits. For parameters that do not appear in the ANZECC (1992) Guidelines the criteria was based on natural breaks in the parameter distributions. The mean background (pristine sites) for NO_X were not used because of the high concentrations recorded, which would have ranked the whole catchment as green. A summary of the selection criteria and sources are illustrated in Table 4.

4.5 Environmental Attributes

Percentage vegetation cover above, population at and between, population density above, sub-catchment number, average slope, elevation and stream order were calculated for each sample site to determine in any environmental attributes, other than land use and geology, had a major influence on water quality (Table 5). Percentage vegetation cover above each sampling site was estimated from Figure 1. The population represented by each sample site and the population between each sample site was estimated using population information contained in CDATA91 (1993). For the site that represented the Murwillumbah Sewage Treatment Plant, the entire urban population was included for that site, because the urban population all input into the sewage treatment plant. The urban population was ignored when calculating other sites that

Table 3. Water quality parameters, abbreviations, analytical procedures, detection limits, and analytical errors.

Nutrient Form	Abbreviation	Method	Source	Detection Limit	Error
Total Phosphorus	TP	Persulphate Digestion	Valderrama, 1981	10 $\mu g\ l^{-1}$	8.7%
Total Dissolved Phosphorus	TDP	Persulphate Digestion	Valderrama, 1981	5 $\mu g\ l^{-1}$	3.5%
Total Particulate Phosphorus	TPP	TP-TDP			6.3%
Dissolved Inorganic Phosphorus	DIP	Ascorbic acid	Lachat, 1994	1 $\mu g\ l^{-1}$	2.3%
Dissolved Organic Phosphorus	DOP	TDP-DIP			5.1%
Total Nitrogen	TN	Persulphate Digestion	Valderrama, 1981	1 $\mu g\ l^{-1}$	8.7%
Total Particulate Nitrogen	TPN	TN-TDN			7.3%
Total Dissolved Nitrogen	TDN	Persulphate Digestion	Valderrama, 1981	10 $\mu g\ l^{-1}$	4.1%
Nitrite	NO_2	Sulphanilamide	Lachat, 1994	1 $\mu g\ l^{-1}$	2.8%
Nitrate	NO_3	Cadmium Reduction	Lachat, 1994	1 $\mu g\ l^{-1}$	3.6%
Oxidised Nitrogen	NO_x	($NO_2 + NO_3$)			7.3%
Ammonium	NH_4	Hypochlorite/Phenolate	Lachat, 1994	5 $\mu g\ l^{-1}$	20.1%
Chlorophyll-a	Chl-a	Acetone Extraction	Strickland & Parsons, 1972	0.1$\mu g\ l^{-1}$	***
Faecal Coliforms	FC	Membrane Filtration	Greenberg *et al.*, 1992	1 colony/ 100 ml	***

*** No triplicates taken

Table 4. Summary of criteria for selection of spatial water quality categories.

	Rank			
Parameter	**Good (Green)**	**Fair (Yellow)**	**Poor (Orange)**	**Very Poor (Red)**
Electrical Conductivity	Irrigation water (low salinity)* 280µS or less	Irrigation water (medium salinity)* >280 - 800µS	Irrigation water (high salinity)* >800 - 2300µS	Irrigation water (very high salinity)* >2300µS
Temperature	Protection of aquatic ecosystems (background ± 2°C)* 18°C or less	>18 - 20°C	>20 - 22°C	>22°C
Dissolved Oxygen (% saturation)	Protection of aquatic ecosystems* > 80% saturation	80 - >60% saturation	60 - >40% saturation	40% saturation or less
pH	Potable water* 6.5 - 8.5	Primary contact use* 5 - 6.5; 8.5 - 9	4 - 5; 9 - 10	<4 or >10
Turbidity	Mean background 5FTU or less	>5 - 15 FTU	>15 - 25FTU	>25FTU
Total Nitrogen	Mean background for pristine areas 250µg/L or less	>250 - 450µg/L	>450 - 750µg/L	Upper limit for protection of aquatic ecosystems* >750µg/L
Total Particulate Nitrogen	Mean background for pristine areas 90µg/L or less	>90 - 150µg/L	>150 - 200µg/L	>200µg/L
Dissolved Organic Nitrogen	Mean Background for pristine areas 100µg/L or less	>100 - 250µg/L	>250 - 400µg/L	>400µg/L
Ammonium	Mean background for pristine areas 10µg/L or less	>10 -20µg/L	>20 - 30µg/L	>30µg/L
Oxidised Nitrogen	Protection of aquatic ecosystems* 30µg/L or less	>30 - 50µg/L	>50 - 70µg/L	Upper limit for protection of aquatic ecosystems* >70µg/L
Total Phosphorous	Mean background for pristine areas <30µg/L	30 - <65µg/L	65 - 100µg/L	Upper limit for protection of aquatic ecosystems* >100µg/L
Total Particulate Phosphorous	Mean background for pristine areas 5µg/L or less	>5 - 25µg/L	>25 - 45µg/L	>45µg/L
Dissolved Organic Phosphorous	Mean background for pristine areas 15µg/L or less	>15 - 25µg/L	>25 - 35µg/L	>35µg/L
Dissolved Inorganic Phosphorous	Mean background for pristine areas 15µg/L or less	>15 - 30µg/L	>30 - 45µg/L	>45µg/L
Chlorophyll-a	Mean background for pristine areas 2µg/L or less	>2 - 6µg/L	>6 - 10µg/l	>10µg/L
Faecal Coliforms	Potable water* 0 colony/100ml	<Primary contact recreation* 1 - 150 colonies/100ml	Secondary contact recreation* 151 - 1000 colonies/100ml	Above Secondary contact recreation* > 1000 colonies/100ml

* ANZECC (1992) Water Quality Guidelines.

drain from the urban area, so as to avoid double counting of the urban population. For the Numinbah and Limpinwood Nature Reserve it was assumed that the population density was zero. The catchment was also divided into a number of smaller sub-catchments which were identified by the major creeks draining into the main arm of the Rous River. The small tributaries that are not part of the other sub-catchments were grouped into a separate sub-catchment. The cane drains and main arm were also grouped into separate sub-catchment categories. Average slope was estimated by dividing the change in height by the length of stream represented by the sample.

4.6 Boxplots

Boxplots were constructed to graphically illustrate the variability and distribution of water quality parameters within different land use and geology types.

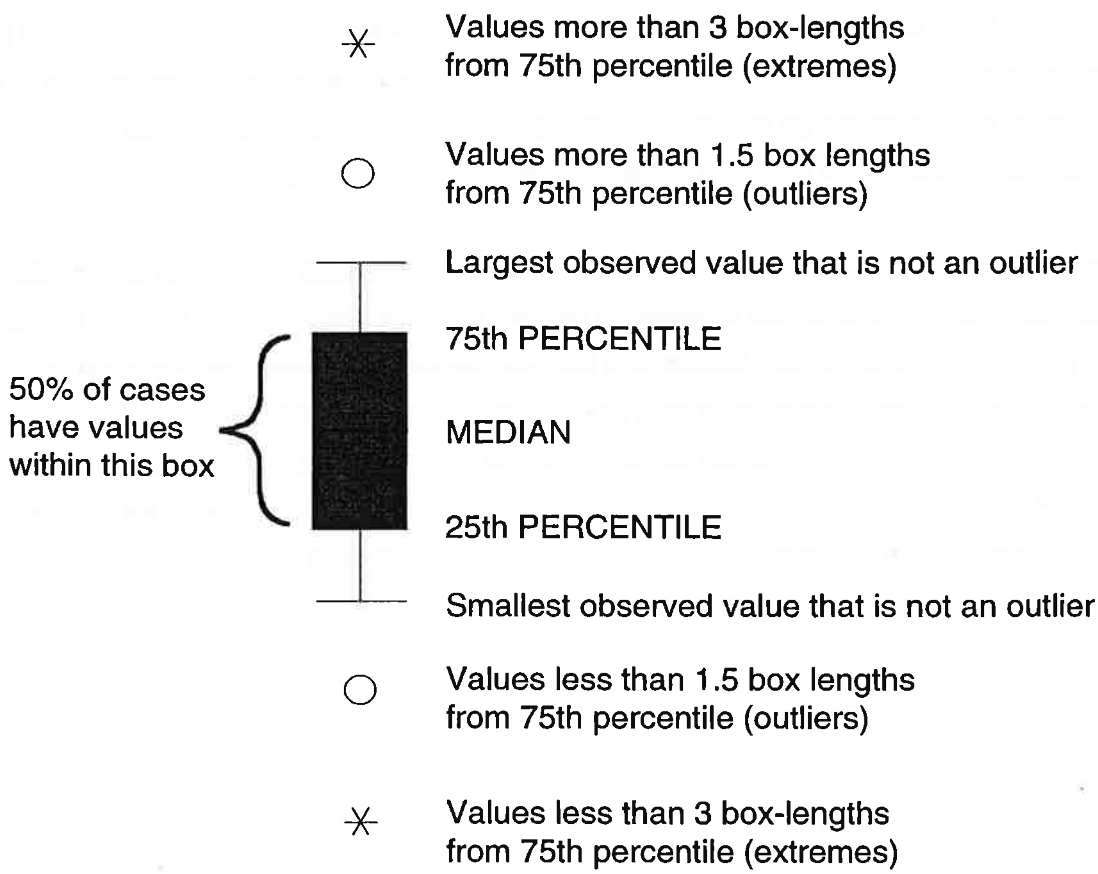

Figure 3. An annotated boxplot.

Table 5. Environmental attributes and a brief description.

Environmental attribute	Description	Median	10th percentile	90th percentile
Popden	Population density above sample site	11.0	5.4	42.8
Popbet	Population represented between sample sites	10.8	1.5	41.8
Cumpop	Cumulative population above the sample site.	33.8	1.5	7296.2
Vegcov	Percentage vegetation cover above the sample site.	48.7	0	91.4
Elevat	Elevation of the sample site (metres above sea level).	25.0	5.0	126.5
Slope	Average percentage slope represented by the sample site	1.5	0	12.9
Strmord	Stream order of the sample site.	5 stream orders		
Subcat	Subcatchment of the sample site.	13 subcatchments		
Geo	Geology	5 geology types		
Lduse	Land use	10 land use types		

4.7 Statistical Analysis

The non-parametric Kruskal-Wallis test was used to assess whether water quality parameters within different geology and land use types were significantly different (Gilbert, 1987). Results were compared at the ninety five percent confidence interval ($\propto$>0.05), two tailed with ties corrected. When geology and water quality parameters were compared the estuary results were not included because of the over-riding tidal influence. However, when comparing land use types and water quality parameters, the estuary was included as a separate land use category.

Factor analysis was undertaken to identify a small number of groups of variables (factors) that explain relationships between water quality parameters and environmental attributes at the 108 samples sites. Correlations between water quality parameters and environmental attributes were firstly analysed using a Pearsons Correlation Matrix (p <0.01; two tailed test). The factors were then extracted using principal component analysis which forms linear combinations of the water quality parameters and environmental attributes. The factor matrix was subjected to an orthogonal rotation using the varimax method to aid interpretation of the important controlling factors. The factor analysis was undertaken using SPSS 7.0 software, and further details of the statistical methods and software used can be found in Noruesis (1994).

5.0 Results

All raw results are given in Appendix 1.

5.1 Spatial Patterns in Water Quality

5.1.1 Electrical Conductivity

Seventy nine percent of the sample sites were ranked as good (70%) and fair (9%) for electrical conductivity (EC) (Figure 4). Low EC values were found across most of the catchment. The other 21% of the catchment was ranked poor (6%) and very poor (15%). High EC values were recorded in the estuary and in Jacksons Creek. The median EC value for the catchment was 120mS with a range from 70µS to 7848µS for the 10th and 90th percentiles. EC values were significantly different ($\propto$>0.05) between geology types with a higher EC for river alluvium (Figure 5), and significantly different ($\propto$>0.05) between land uses with higher EC for cane land and the estuary (Figure 6), reflecting the influence of brackish water in the lower catchment.

5.1.2 Temperature

Eighty five percent of the sample sites were ranked as good (45%) and fair (40%) for temperature (Figure 7). Low temperatures were found in the pristine areas, Crystal Creek and the upper reaches of the Rous River. The other 15% of the catchment was ranked poor (7%) and very poor (8%). High temperatures were found mainly in cane drains and streams with little or no flow. The median temperature for the catchment was 18.1^{o}C with a range from 15.5^{o}C to 20.8^{o}C for the 10th and 90th percentile. Temperatures were significantly different ($\propto$>0.05) between geology types with higher temperatures for river alluvium, and significantly different ($\propto$>0.05) between land uses with higher temperatures for cane land.

5.1.3 Dissolved Oxygen

Ninety two percent of the sample sites in the catchment were ranked as good (70%) and fair (22%) for dissolved oxygen (DO). Low concentrations of DO were found downstream of the dairy shed and horse stables (Figure 10). Other sites with low DO concentrations were sites 19, 66, 86, 90 and 91. The median DO value for the catchment was 83.3% saturation with a range from 63.5% to 102.8% saturation for the 10th and 90th percentiles. There was no significant difference ($\propto$>0.05) between geology and land use types for DO values (Figures 11 and 12).

5.1.4 pH

Ninety six percent of the sample sites were ranked as good (85%) and fair (11%) for pH. Very low pH values were found in cane drains and low pH values was also recorded in Crystal and lower Dungay Creeks (Figure 13). The median pH value for the catchment was 7.2 with a range of 6.2 to 7.8 for the 10th and 90th percentiles. pH values were significantly different ($\propto$>0.05) between geology types with lower pH values for river alluvium (Figure 14). pH values were also significantly different ($\propto$>0.05) between land use types with lower pH values for cane land (Figure 15).

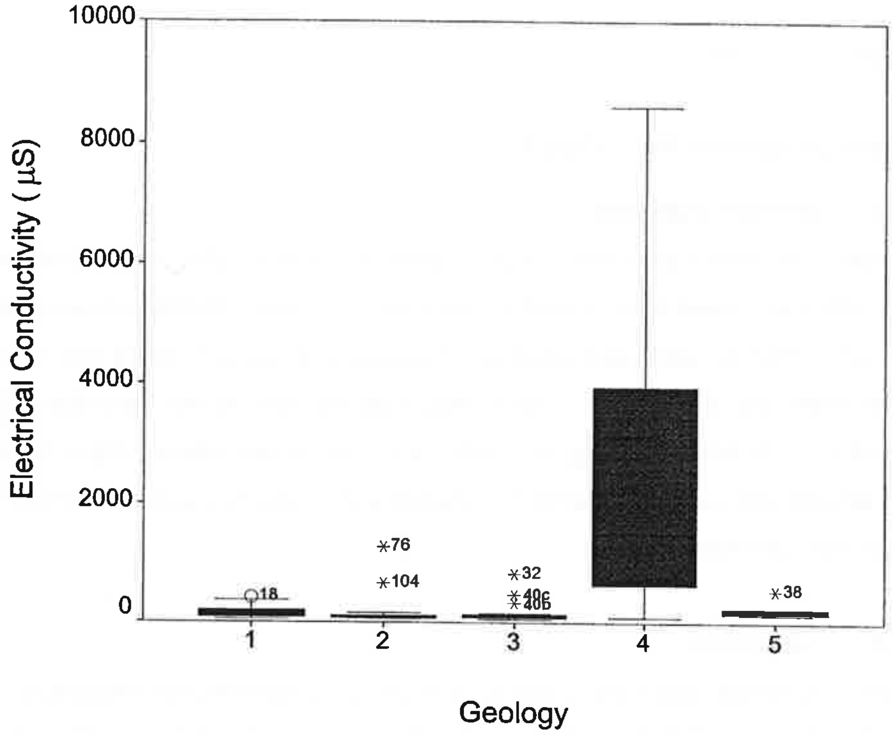

Figure 5. ***Electrical conductivity for different geology types. Geology Code: (1) Basalt, (2) Greywacke, (3) Rhyolite, (4) River Alluvium, and (5) Sandstone.***

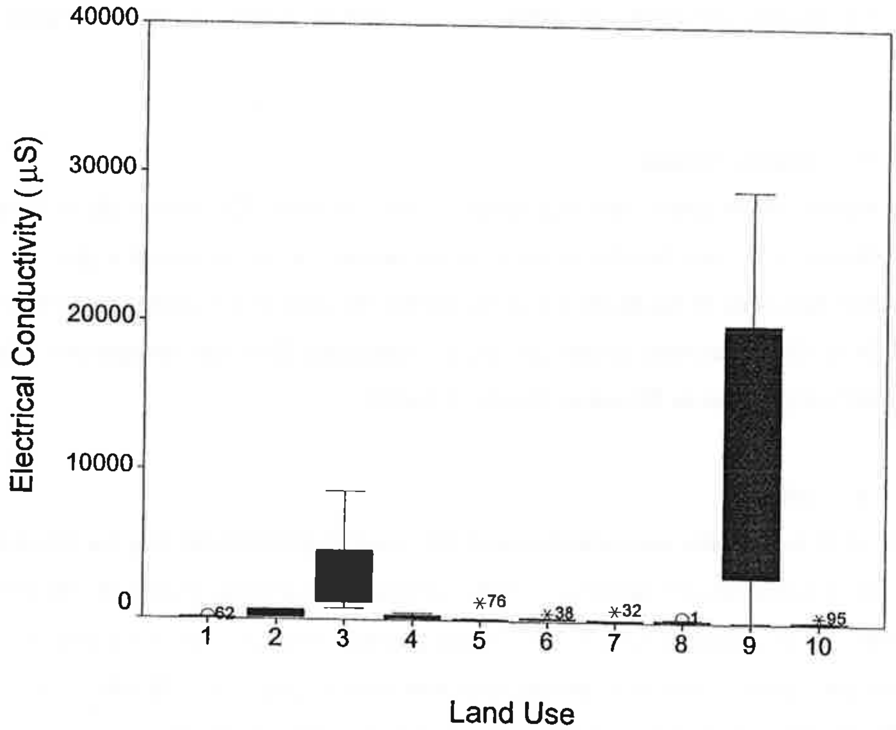

Figure 6. ***Electrical conductivity for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.***

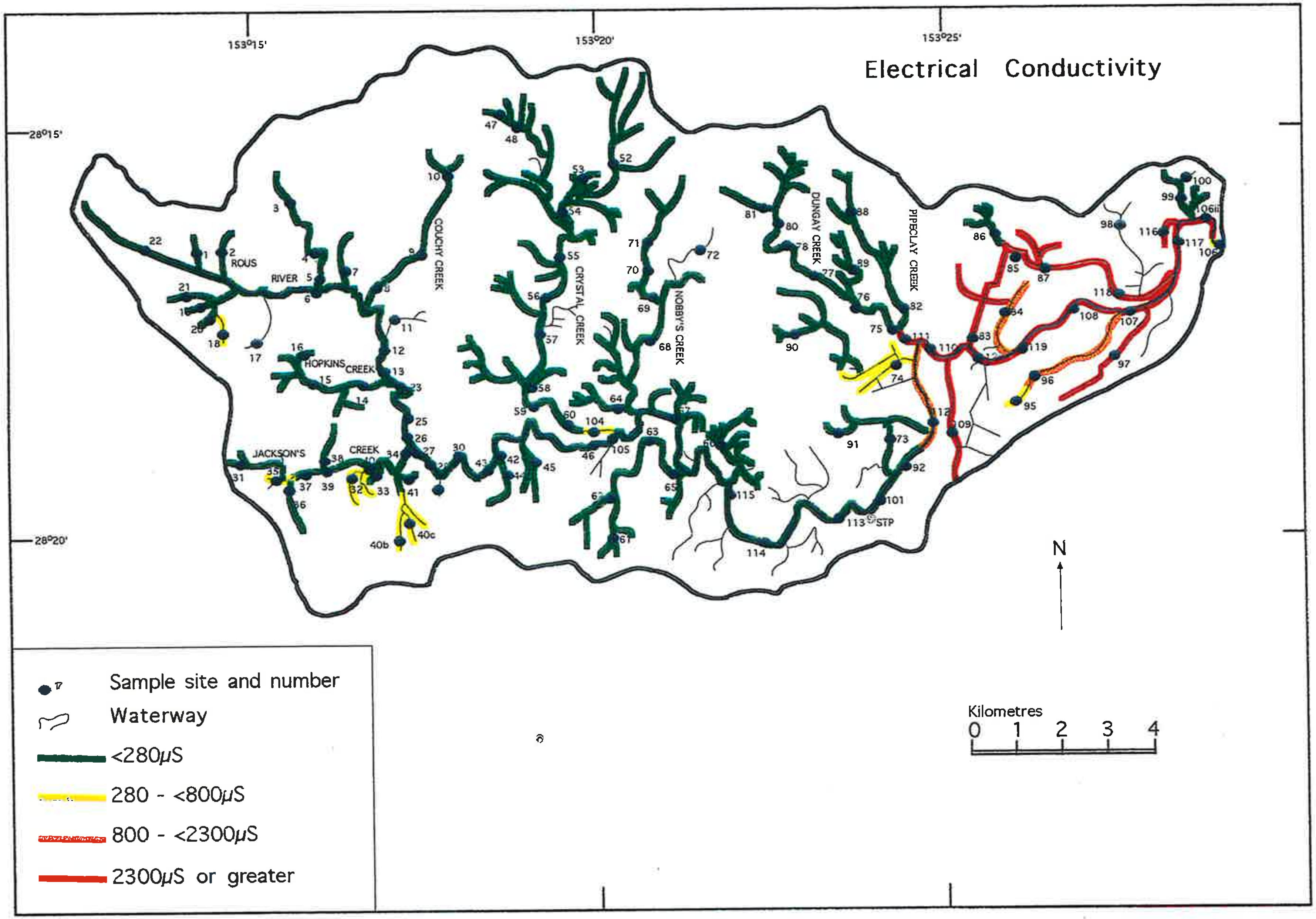

Figure 4. Spatial distribution of electrical conductivity in the Rous River catchment.

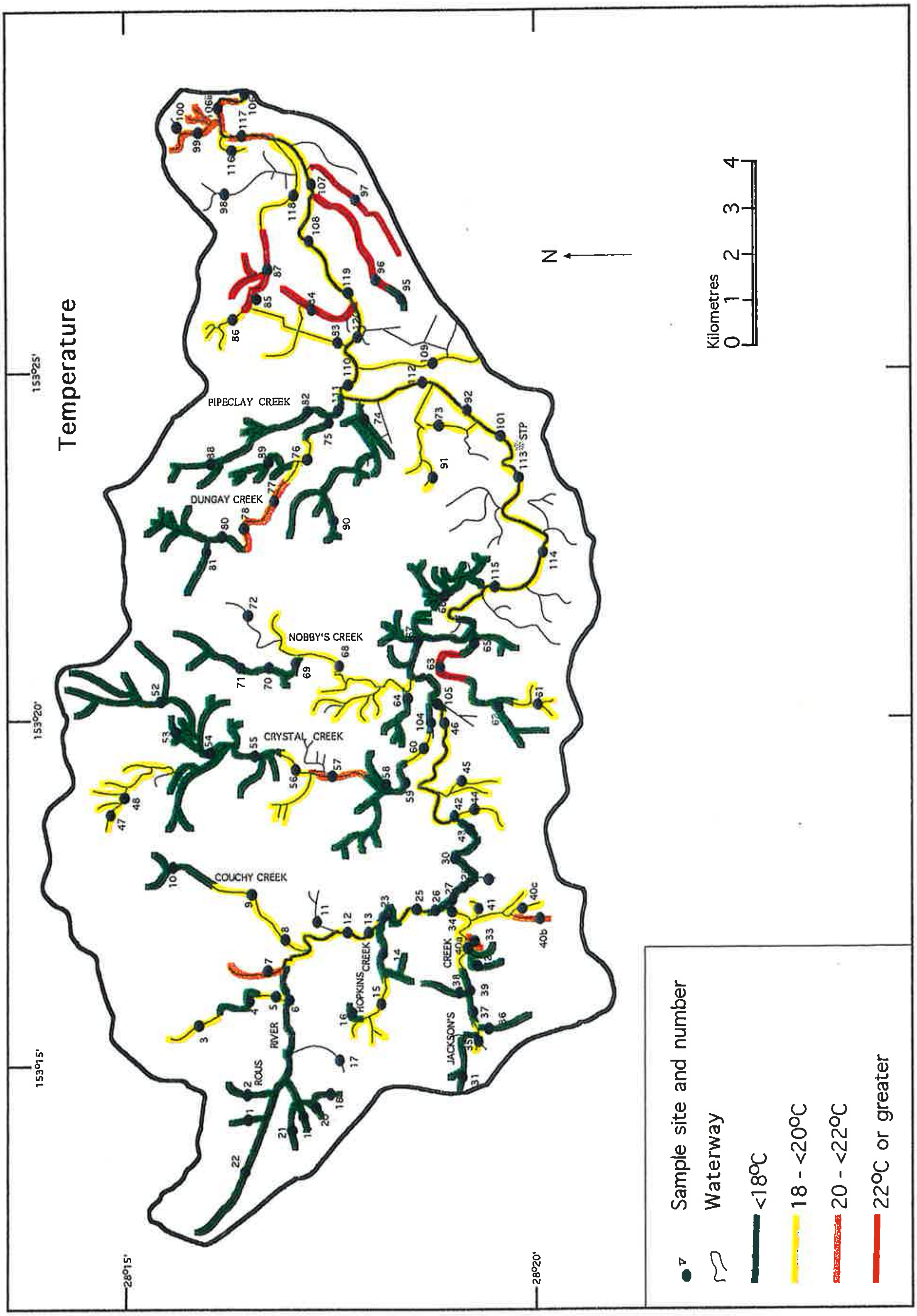

Figure 7. Spatial distribution of temperature in the Rous River catchment.

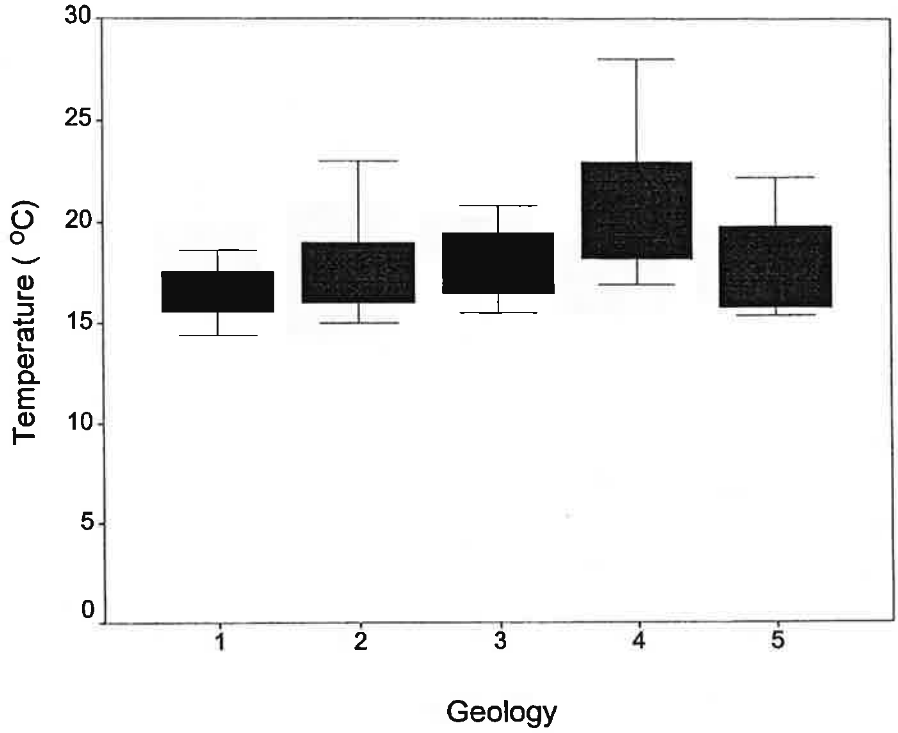

Figure 8. ***Temperature for different geology types. Geology Code: (1) Basalt, (2) Greywacke, (3) Rhyolite, (4) River Alluvium, and (5) Sandstone.***

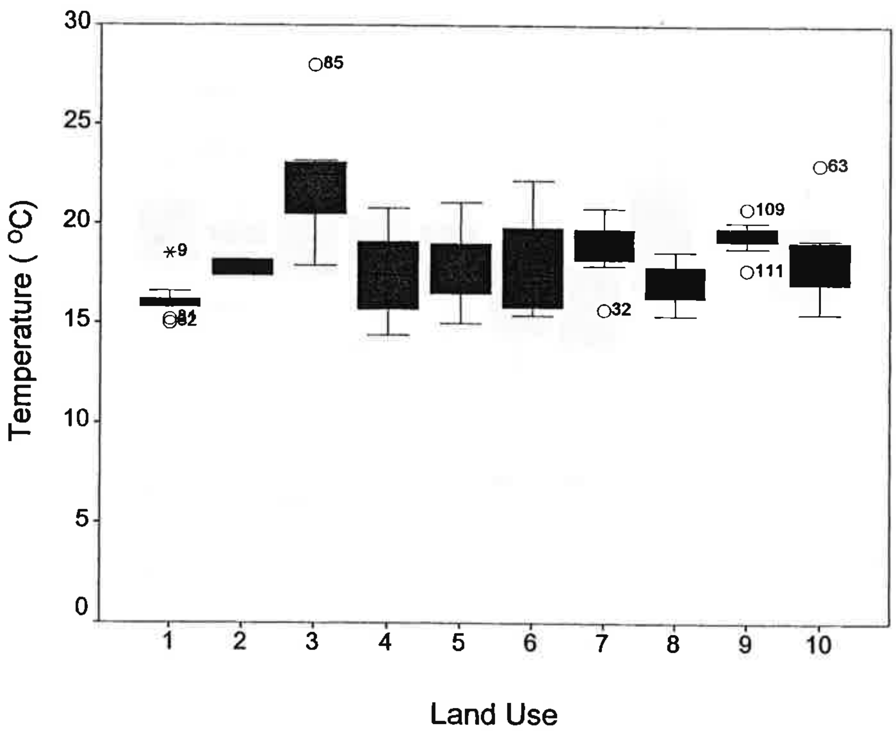

Figure 9. ***Temperature for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.***

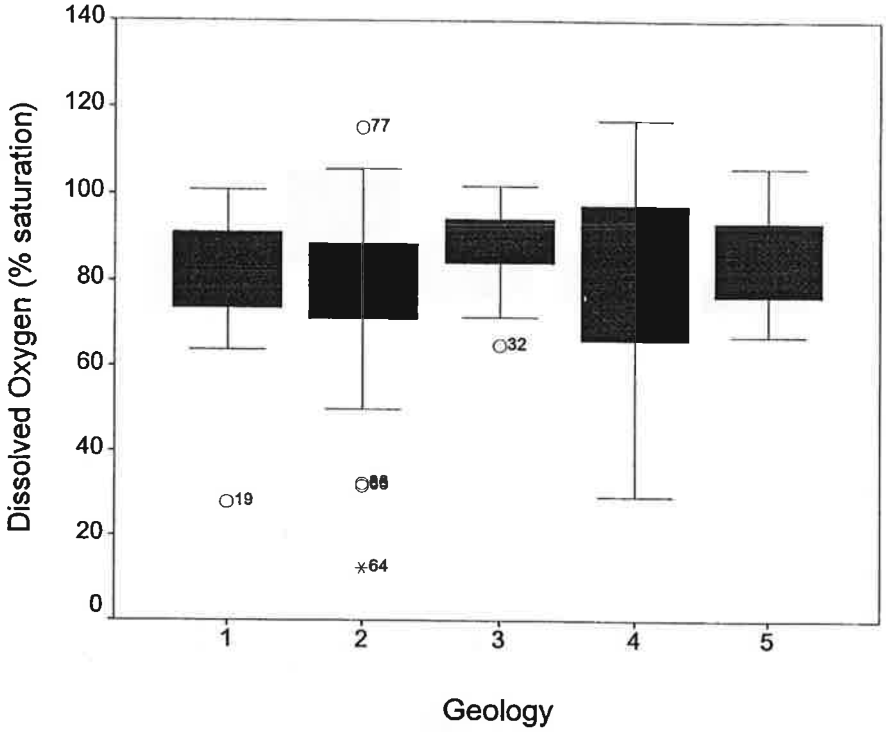

Figure 11. ***Dissolved oxygen values for different geology types. Geology Code: (1) Basalt, (2) Greywacke, (3) Rhyolite, (4) River Alluvium, and (5) Sandstone.***

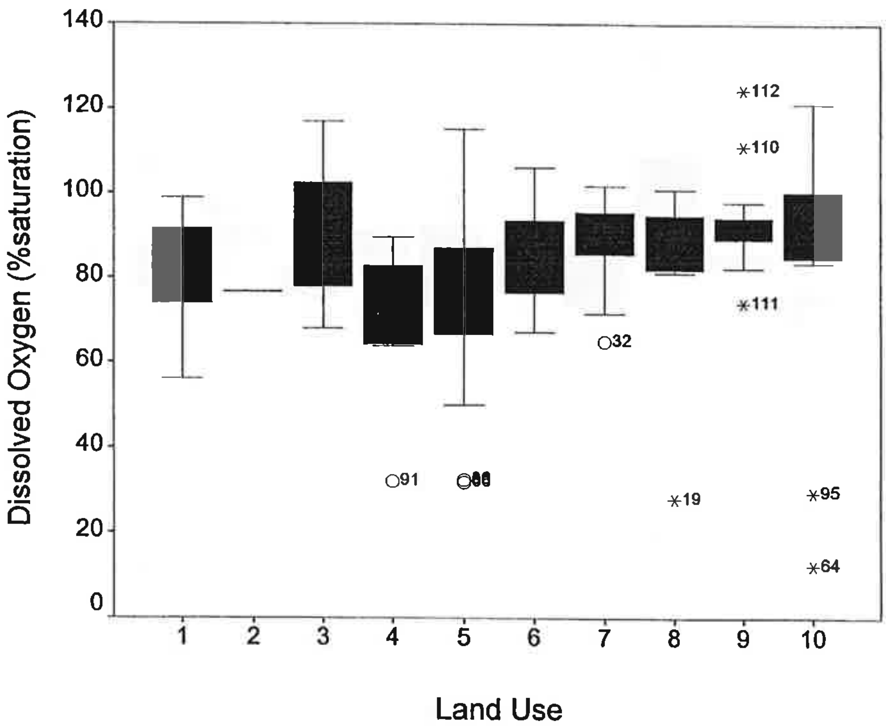

Figure 12. ***Dissolved oxygen values for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.***

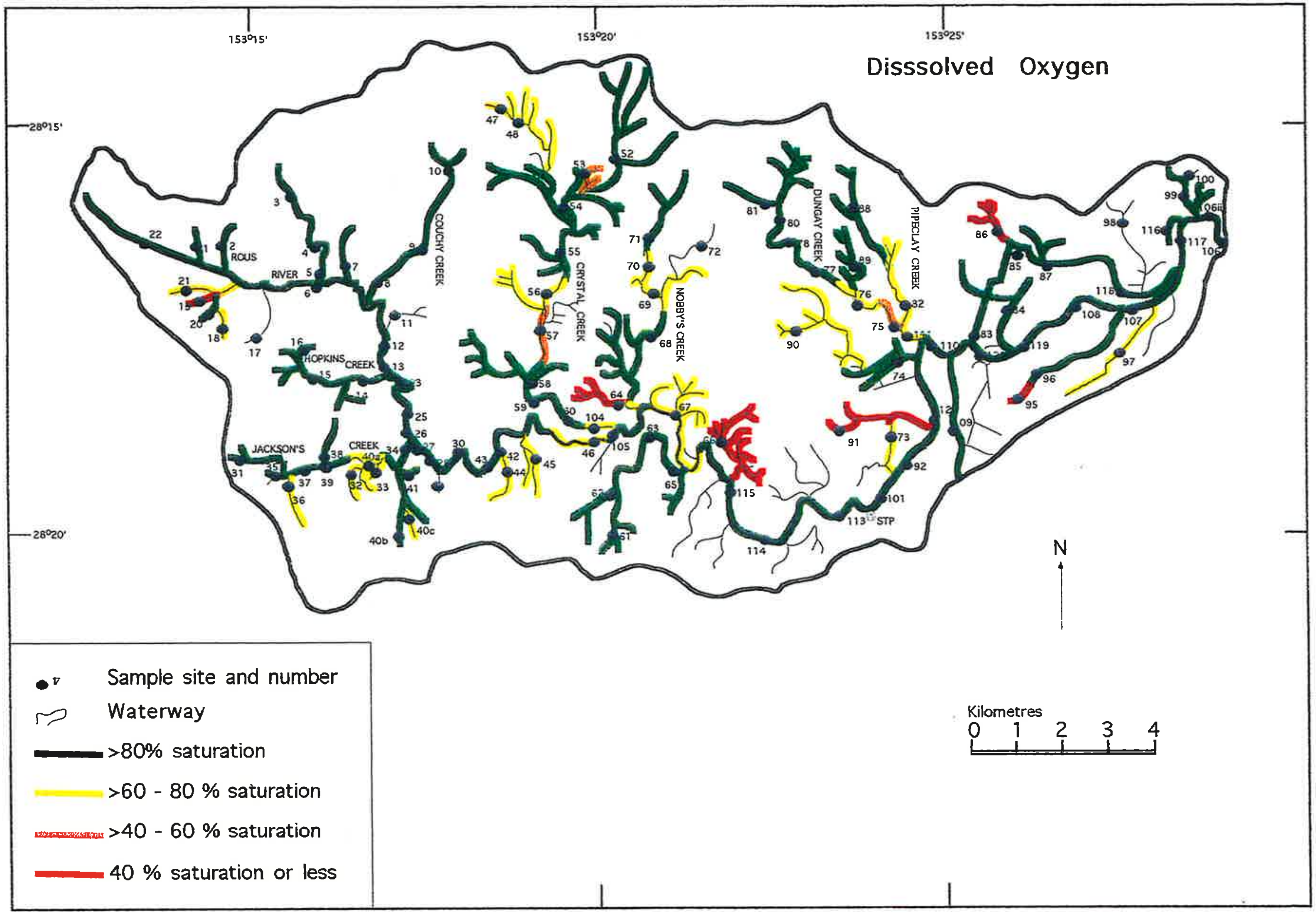

Figure 10. Spatial distribution of dissolved oxygen in the Rous River catchment.

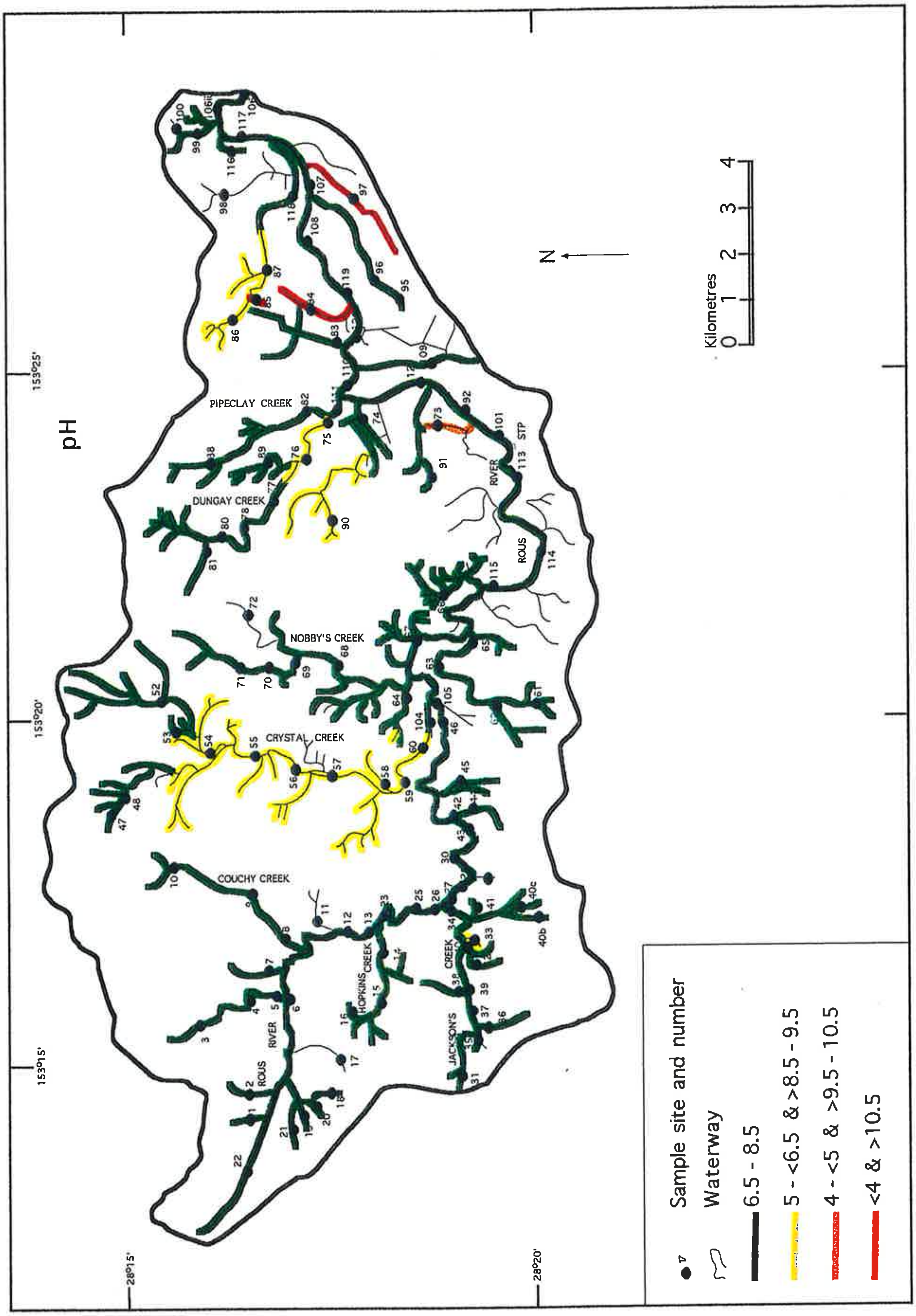

Figure 13. Spatial distribution of pH in the Rous River catchment.

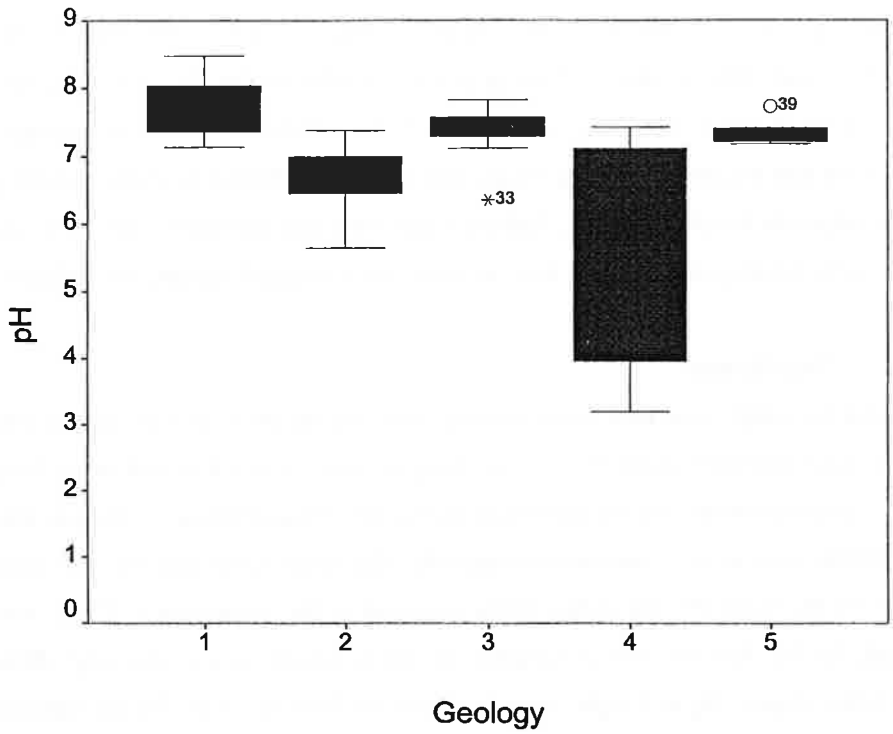

Figure 14. ***pH values for different geology types. Geology Code: (1) Basalt, (2) Greywacke, (3) Rhyolite, (4) River Alluvium, and (5) Sandstone.***

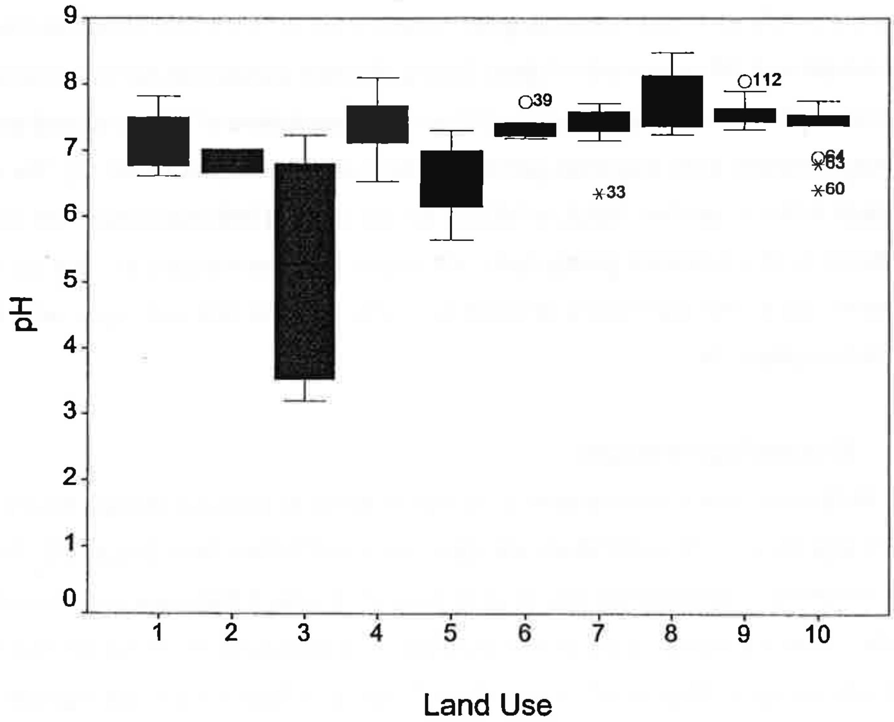

Figure 15. ***pH values for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.***

5.1.5 Turbidity

Eighty three percent of the sample sites were ranked as good (33%) and fair (50%) for turbidity. Low turbidity values were found in Crystal Creek and the upper reaches of Rous and Dungay Creek (Figure 16). Areas of high turbidity were downstream of the STP, horse stables, dairy shed and in cane drains (sites 83, 84, 85). Other sites with high turbidity include sites 16, 19, 33, 63, 86 and 91. The median turbidity value for the catchment was 8 FTU with a range from 3 FTU to 27 FTU for the 10th and 90th percentiles. Turbidity values were significantly different ($\propto$>0.05) between geology types with higher turbidity values for basalt (Figure 17). Turbidity values were also significantly different ($\propto$>0.05) between land use types with higher turbidity values for cane land and lower turbidity values for pristine areas (Figure 18).

5.1.6 Total Nitrogen

Eighty three percent of the sample sites were ranked as good (41%) and fair (42%) for total nitrogen (TN). These sites covered much of the upper catchment (upstream of site 14), Dungay Creek and near the mouth of the Rous River (Figure 19). Of the other 17% of the catchment, 9% was ranked poor and the other 8% was ranked as very poor. These poor areas were located downstream of the sewage treatment plant (sites 92, 101), horse stables (site 95), dairy shed (site 64) and in cane drains (sites 73, 83, 84, 91, 97). The median TN concentrations for the catchment was 273μg/L with a range from 173μg/L to 701μg/L for the 10th and 90th percentiles. TN concentrations were significantly different ($\propto$>0.05) between geology types (Figure 20) with higher concentrations for River Alluvium. TN concentrations were also significantly different ($\propto$>0.05) between land use types with higher TN concentrations for cane land and downstream of point sources (Figure 21).

5.1.7 Total Particulate Nitrogen

Eighty two percent of the sample sites were ranked as good (61%) and fair (21%) for total particulate nitrogen (TPN) (Figure 22). Low concentrations of TPN were found in Crystal, Couchy, Pipeclay, Dungay and Jackson's Creeks. The other 18% of the catchment was ranked poor (5%) and very poor (13%). High concentrations of TPN were found downstream of the horse stables, sewage treatment plant, dairy shed, golf course and in cane drains (sites 74, 83, 84). The median TPN concentration was 69μg/L with a range from 13μg/L to 302μg/L for the 10th and 90th percentiles. TPN concentrations were significantly different ($\propto$>0.05) between geology types with higher TPN concentrations for river alluvium (Figure 23). TPN concentrations were also significantly different ($\propto$>0.05) between land use types with higher TPN concentrations for cane land (Figure 24).

5.1.8 Dissolved Organic Nitrogen

Eighty percent of the sample sites were ranked as good (13%) and fair (67%) for dissolved organic nitrogen (DON). Low concentrations of DON were found in Crystal Creek and the upper reaches of Nobby's Creek (Figure 25). The other 20% of the catchment was ranked poor (16%) and very poor (4%). High concentrations of DON were found downstream of the horse stables, dairy shed, banana plantations (sites 18, 40b, 61) and in cane drains (sites 73, 74, 84, 97). The median DON concentration for the catchment was 163μg/L with a range from 92μg/L to 330μg/L for the 10th and 90th percentiles. DON concentrations were significantly different ($\propto$>0.05) between geology types with higher DON concentrations for river alluvium (Figure 26). DON concentrations were also significantly different ($\propto$>0.05) between land use types with higher DON concentrations for cane land (Figure 27).

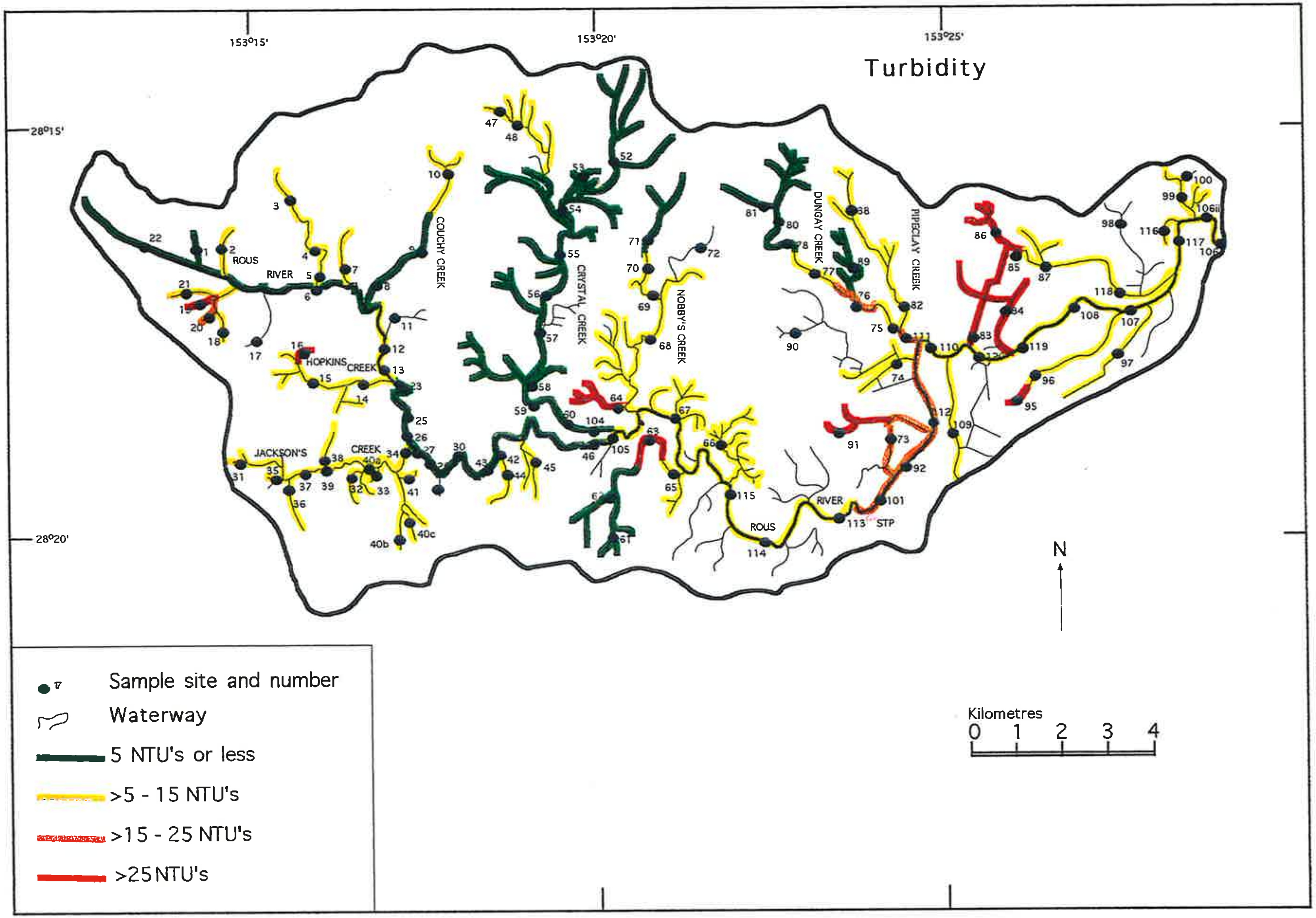

Figure 16. Spatial distribution of turbidity concentrations in the Rous River catchment.

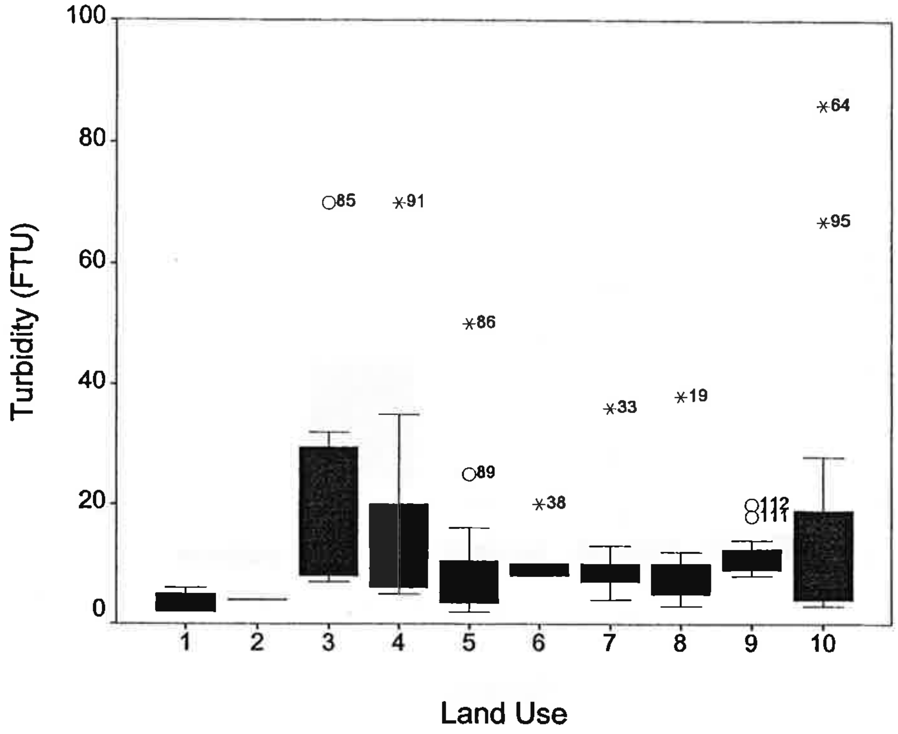

Figure 17. ***Turbidity concentrations for different geology types. Geology Code: (1) Basalt, (2) Greywacke, (3) Rhyolite, (4) River Alluvium, and (5) Sandstone.***

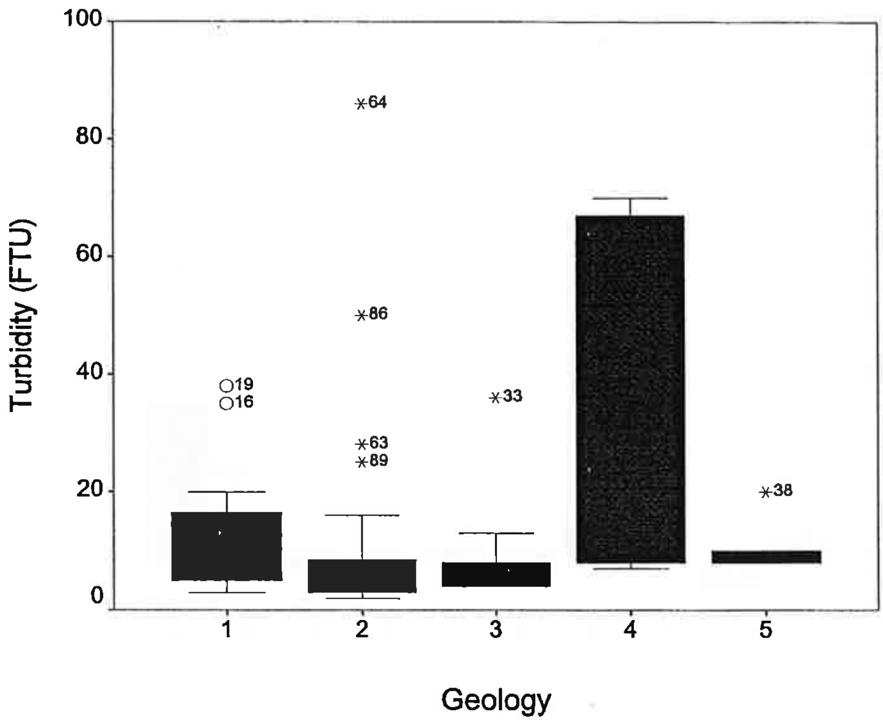

Figure 18. ***Turbidity concentrations for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.***

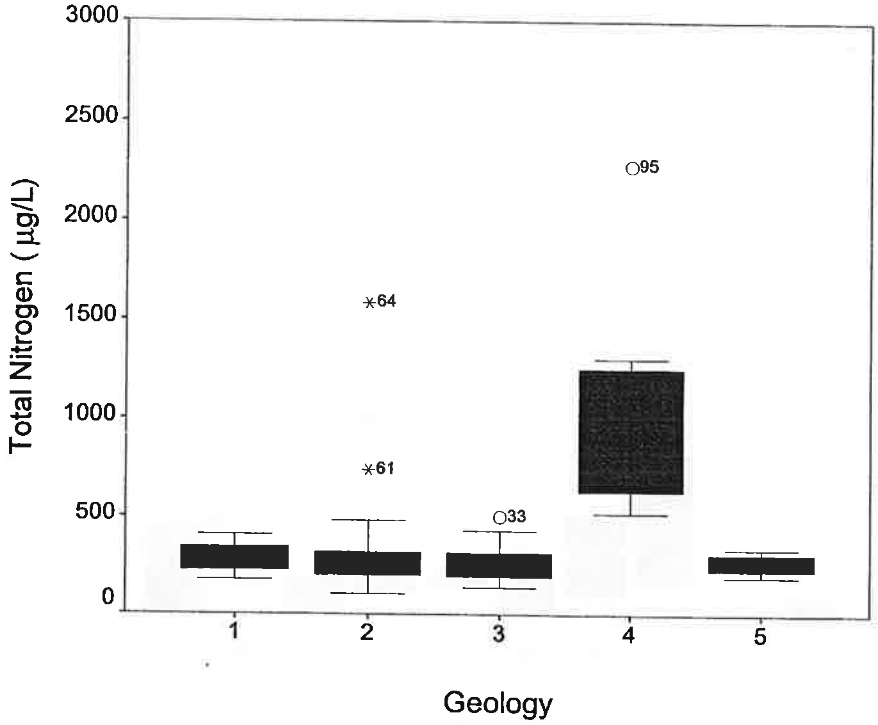

Figure 20. ***Total nitrogen concentrations for different geology types. Geology Code: (1) Basalt, (2) Greywacke, (3) Rhyolite, (4) River Alluvium, and (5) Sandstone.***

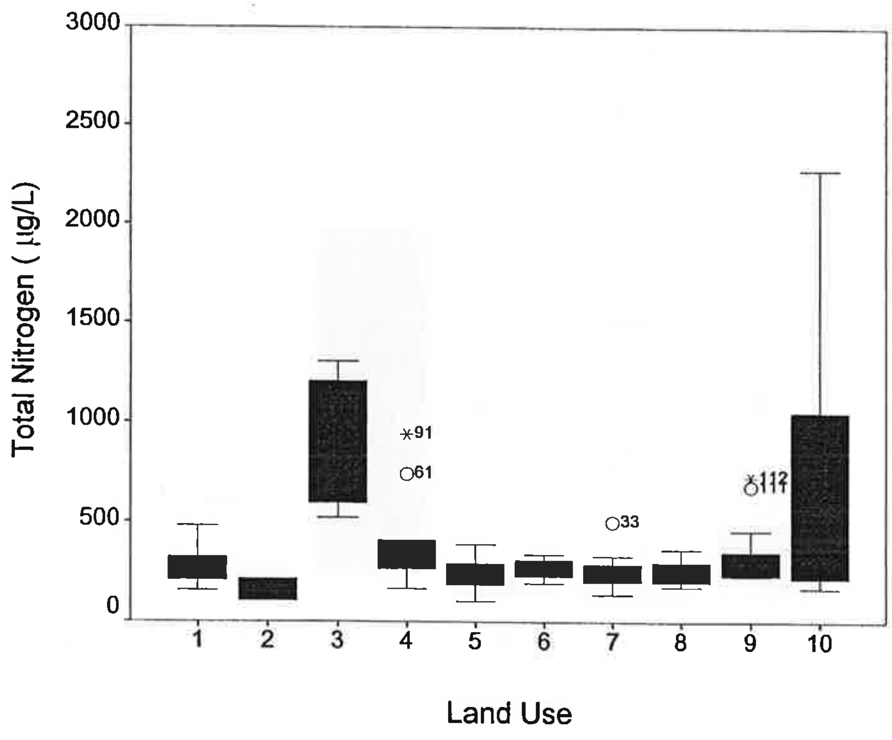

Figure 21. ***Total nitrogen concentrations for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.***

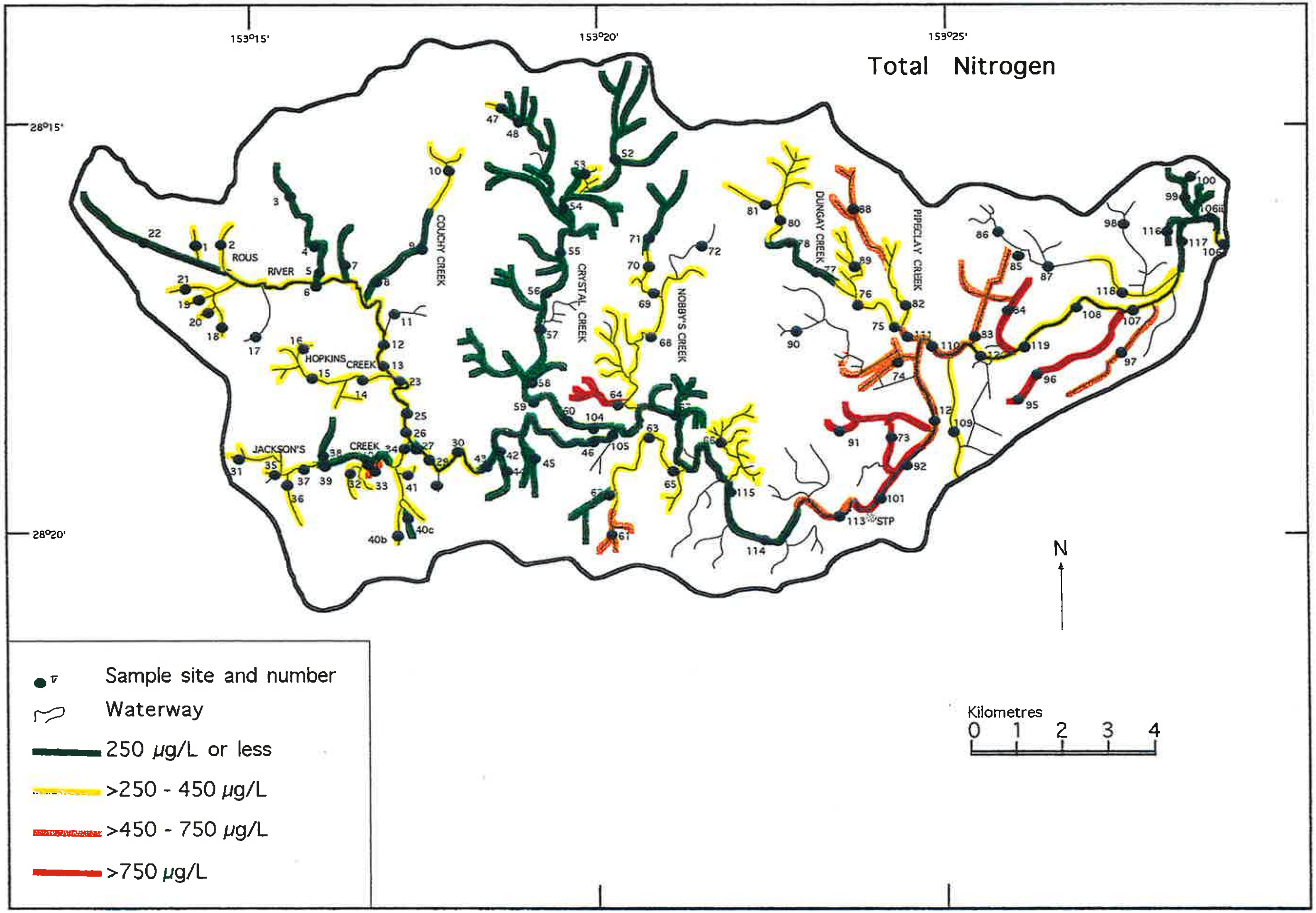

Figure 19. Spatial distribution of total nitrogen concentrations in the Rous River catchment.

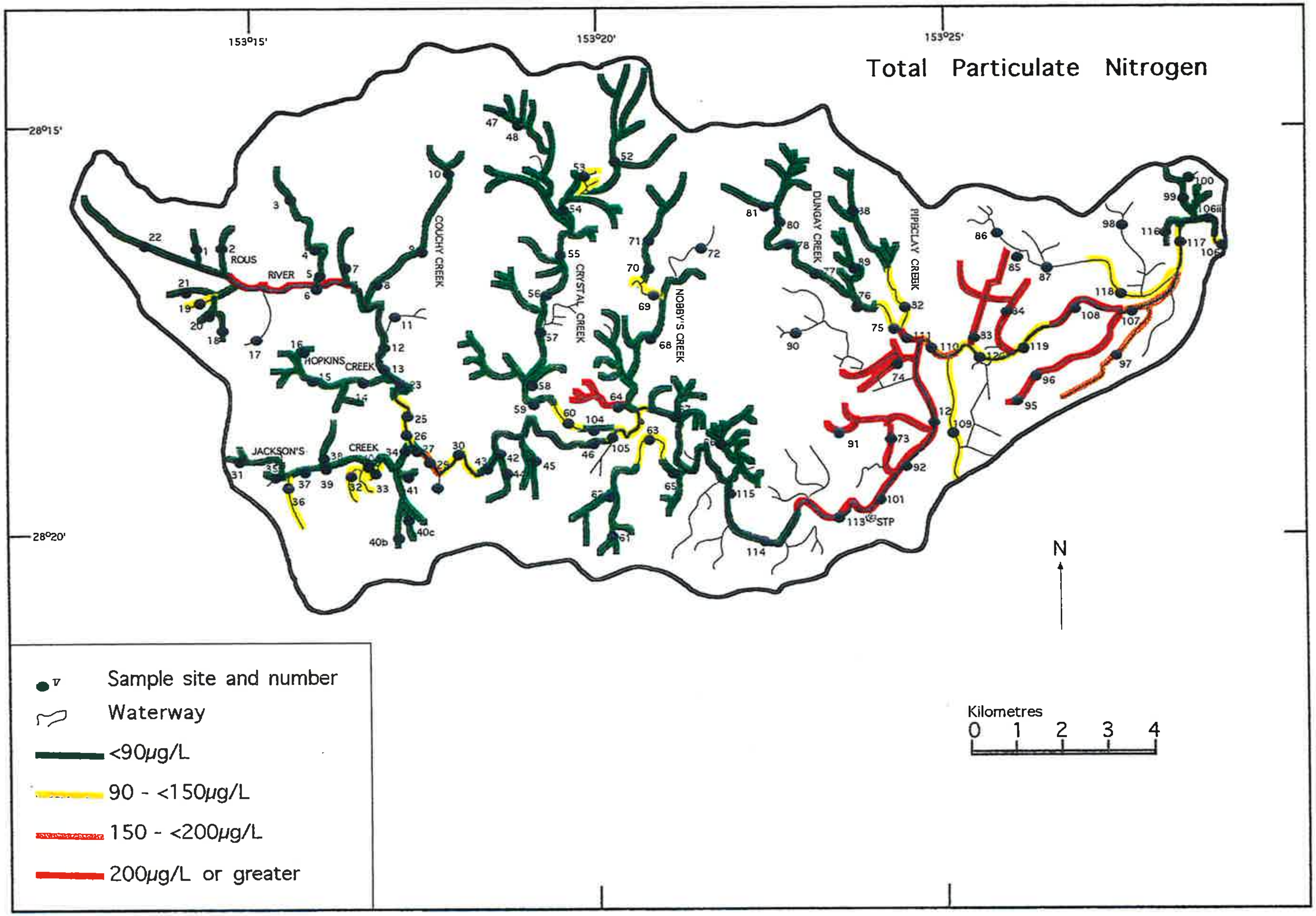

Figure 22. Spatial distribution of total particulate nitrogen concentrations in the Rous River catchment.

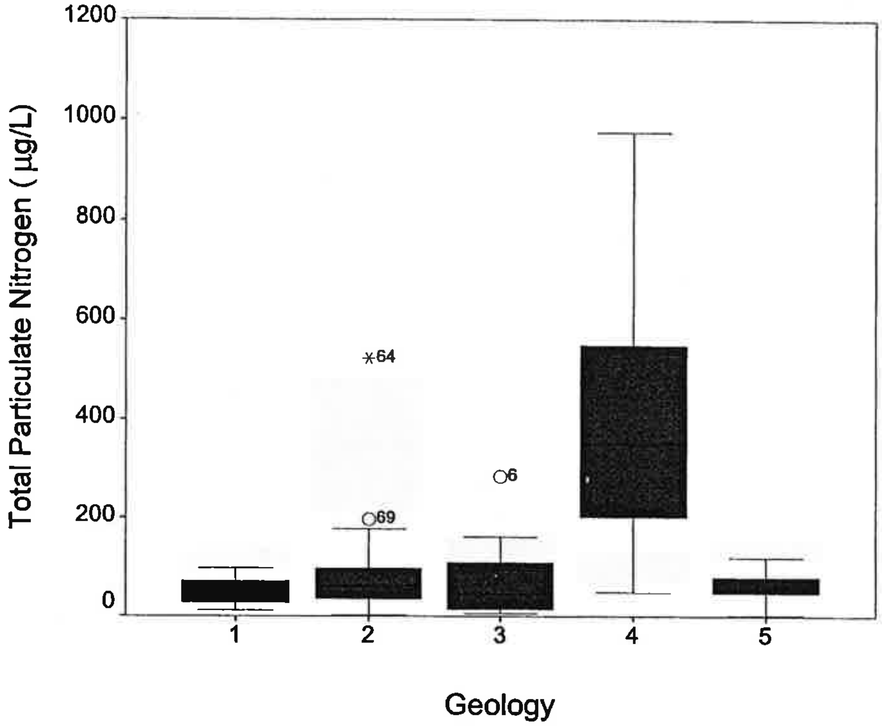

Figure 23. Total particulate nitrogen concentrations for different geology types. Geology Code: (1) Basalt, (2) Greywacke, (3) Rhyolite, (4) River Alluvium, and (5) Sandstone.

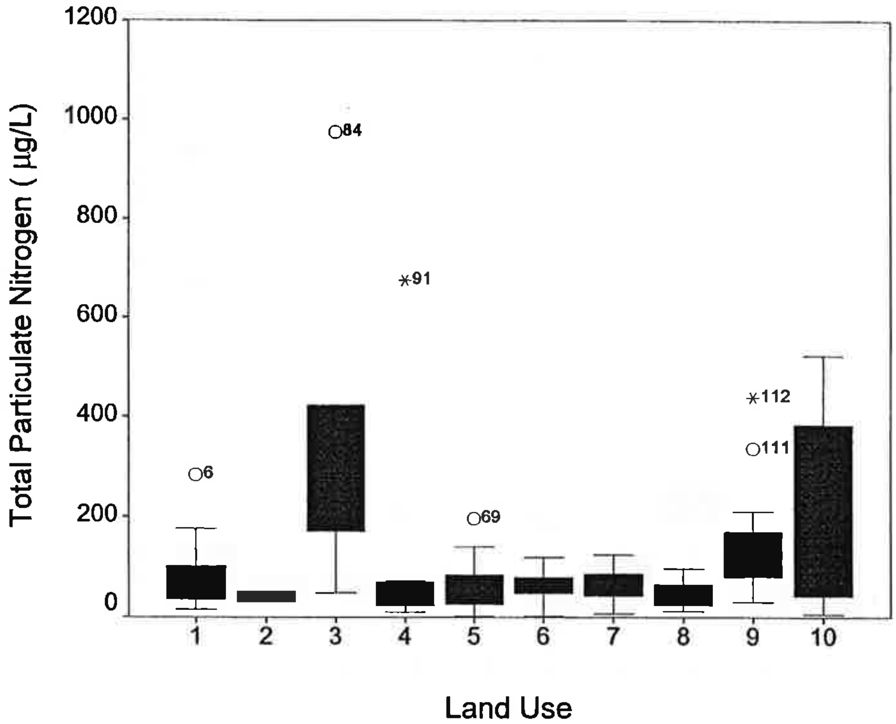

Figure 24. Total particulate nitrogen concentrations for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.

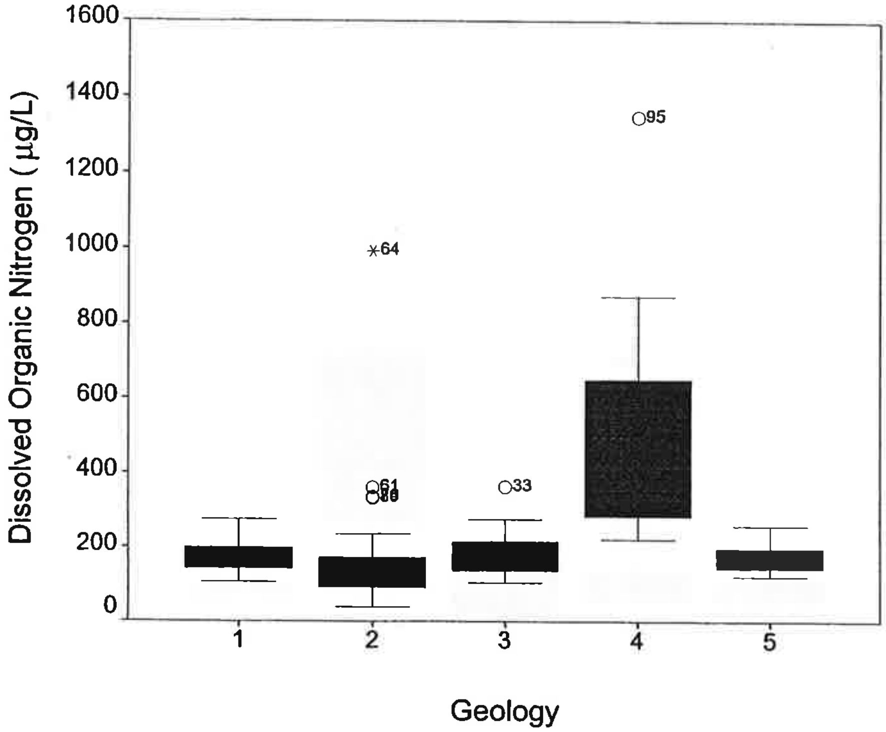

Figure 26. ***Dissolved organic nitrogen concentrations for different geology types. Geology Code: (1) Basalt, (2) Greywacke, (3) Rhyolite, (4) River Alluvium, and (5) Sandstone.***

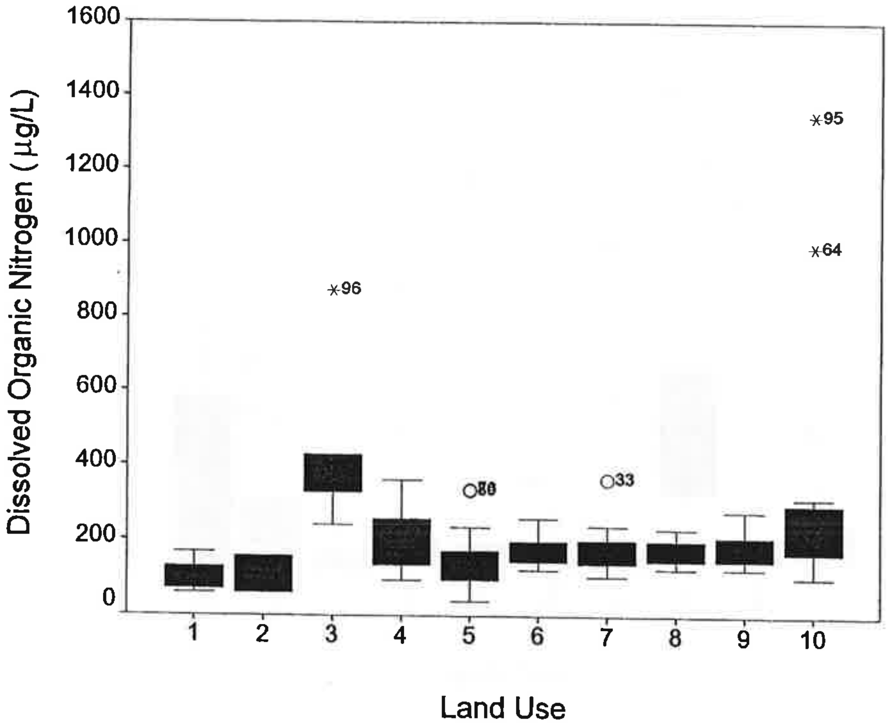

Figure 27. ***Dissolved organic nitrogen concentrations for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.***

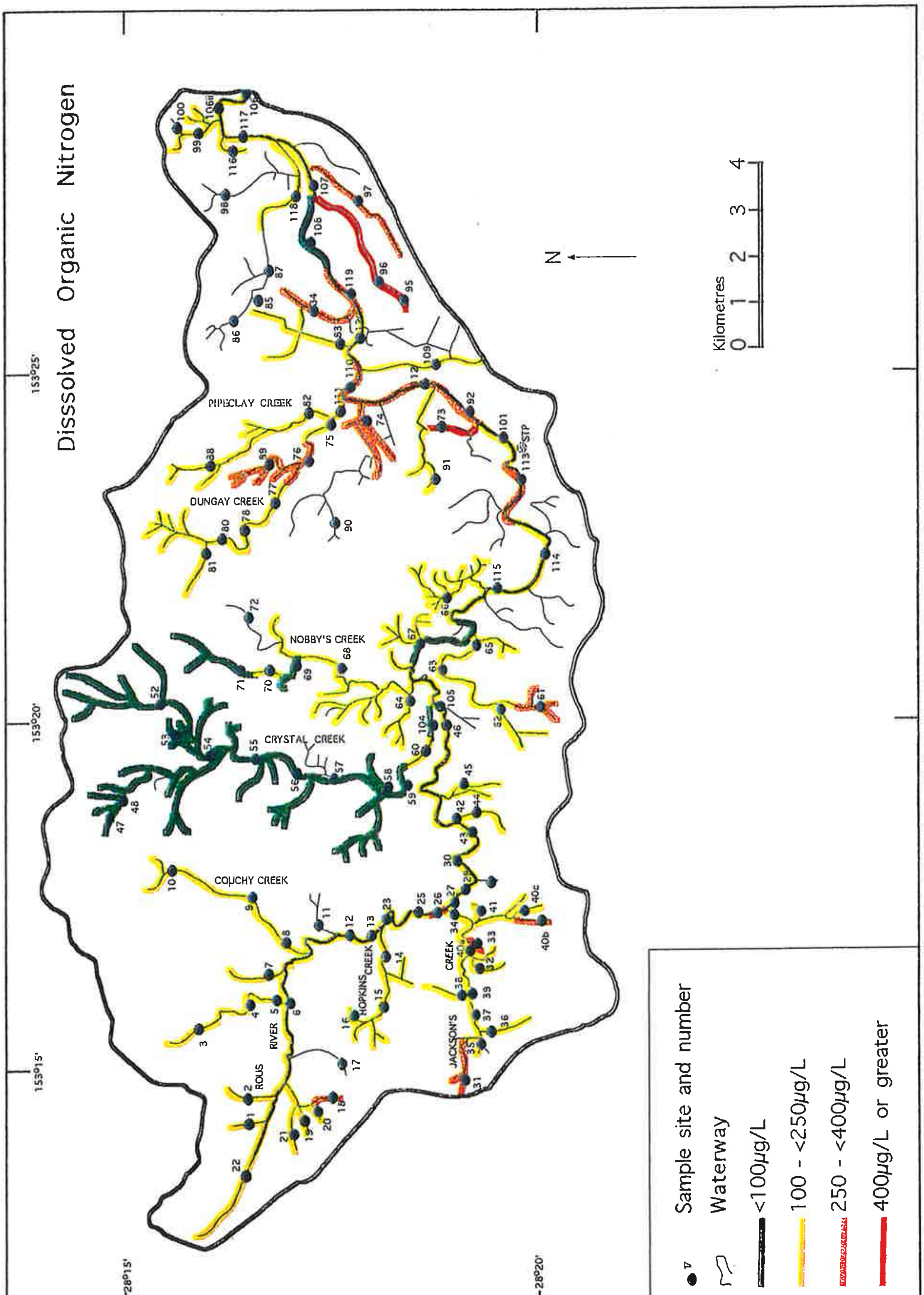

Figure 25. Spatial distribution of dissolved organic nitrogen concentrations in the Rous River catchment.

5.1.9 Ammonium

Eighty nine percent of the sample sites were ranked good (72%) and fair (17%) for ammonium (NH_4) concentrations. Low NH_4 concentrations were recorded in Crystal, Couchy, Numinbah and the upper Dungay Creek. Low concentrations were also recorded in the estuary except near the sewage treatment plant (Figure 28). The rest of the catchment was ranked as 2% poor and 9% very poor. High NH_4 concentrations were recorded downstream of the dairy shed, horse stables, banana plantations (Site 61), in cane drains (sites 73, 85) and in the middle region of Nobby's Creek. The median concentration for the catchment was 6µg/L with a range of 2µg/L to 28µg/L for the 10th and 90th percentiles. There was no significant difference ($\propto$>0.05) between geology types for NH_4 concentrations (Figure 29). There was however, a significant difference ($\propto$>0.05) between land use type for NH_4 concentrations with higher NH_4 concentrations for cane (Figure 30), but this is probably an artefact of the two very high NH_4 concentrations at sites 73 and 85 (573 and 2622 µg/L, respectively).

5.1.10 NO_X

Seventeen percent of the sample sites were ranked very poor (14%) and poor (3%) for NO_x. High concentrations of NO_x were recorded in pristine areas in the upper reaches of Crystal, Couchy, Dungay and Pipeclay Creek (Figure 31). High concentrations were also recorded in the lower Dungay Creek, downstream of the STP and banana plantations (sites 61, 40c, 16, 21 and 90). The rest of the catchment was ranked good (81%) except for 2% that was ranked fair. The median NO_x concentration for the catchment was 9µg/L with a range from 2µg/L to 92µg/L for the 10th and 90th percentiles. There was no significant difference ($\propto$>0.05) between geology types for NO_x concentrations (Figure 32). However, there was a significant difference ($\propto$>0.05) between land use types for NO_x concentrations with higher NO_x concentrations for horticulture and pristine areas (Figure 33).

5.1.11 Total Phosphorus

Eighty eight percent of sample sites were ranked as good (58%) and fair (30%) for total phosphorus (TP). Low concentrations of TP were found in Crystal, Hopkins and Jacksons Creeks and the upper reaches of Dungay Creek (Figure 34). The other 12% of the catchment was ranked poor (6%) and very poor (6%). High concentrations of TP were found downstream of the sewage treatment, horse stables, golf course and in the upper reaches of the Rous River. The median TP concentration for the catchment was 35µg/L with a range from 24µg/L to 83µg/L for the 10th and 90th percentiles. TP concentrations were significantly different ($\propto$>0.05) between geology types with higher TP concentrations for Basalt (Figure 35). TP concentrations were also significantly different ($\propto$>0.05) between land use types with higher TP concentration for grazing on chocolate clays (Figure 36).

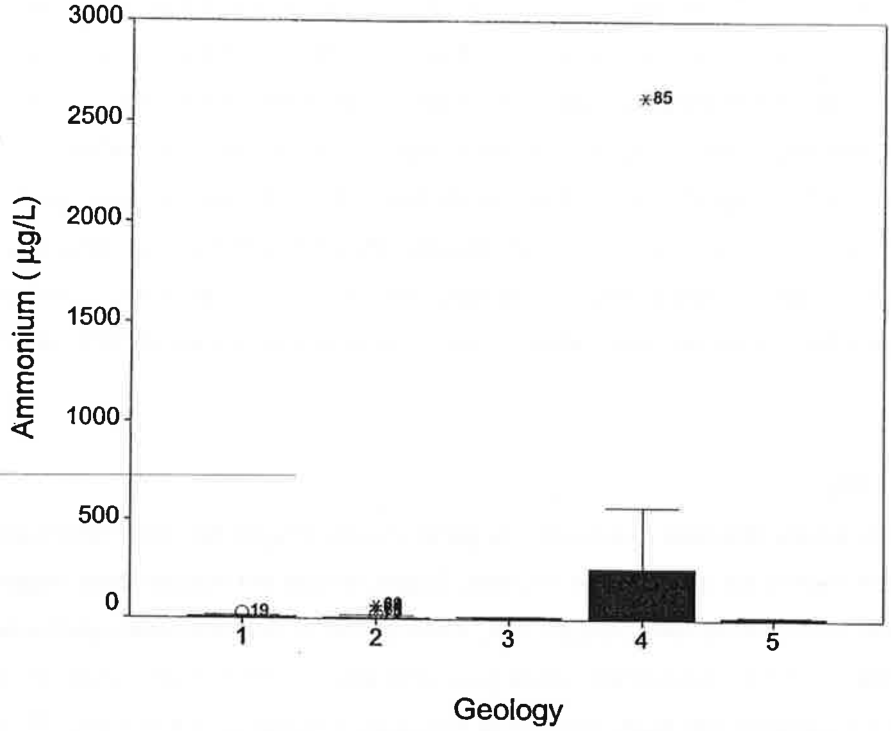

Figure 29. **Ammonium concentrations for different geology types. Geology Code: (1) Basalt, (2) Greywacke, (3) Rhyolite, (4) River Alluvium, and (5) Sandstone.**

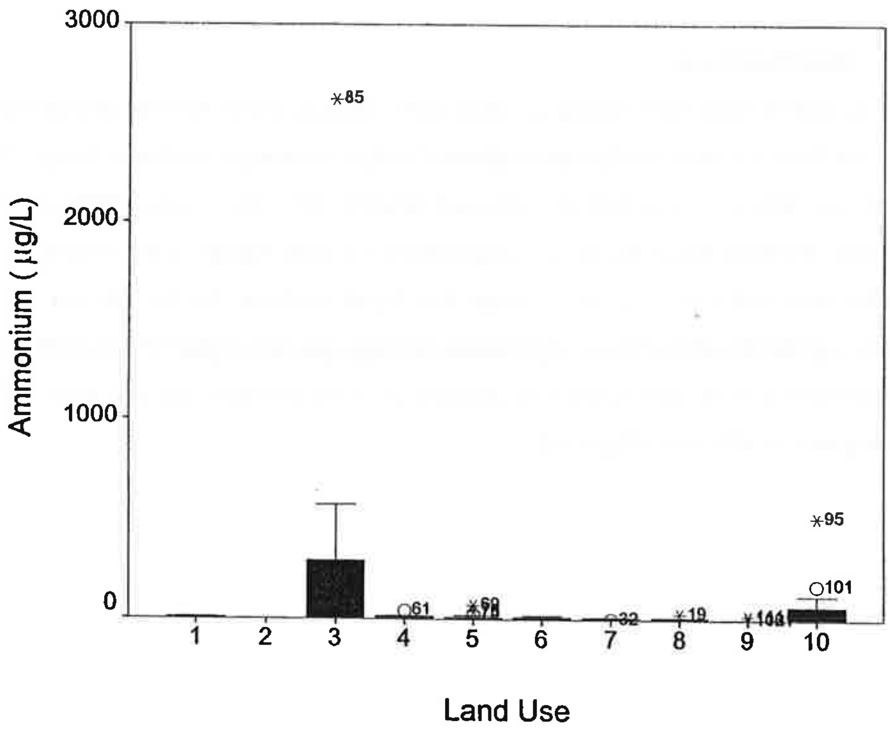

Figure 30. **Ammonium concentrations for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.**

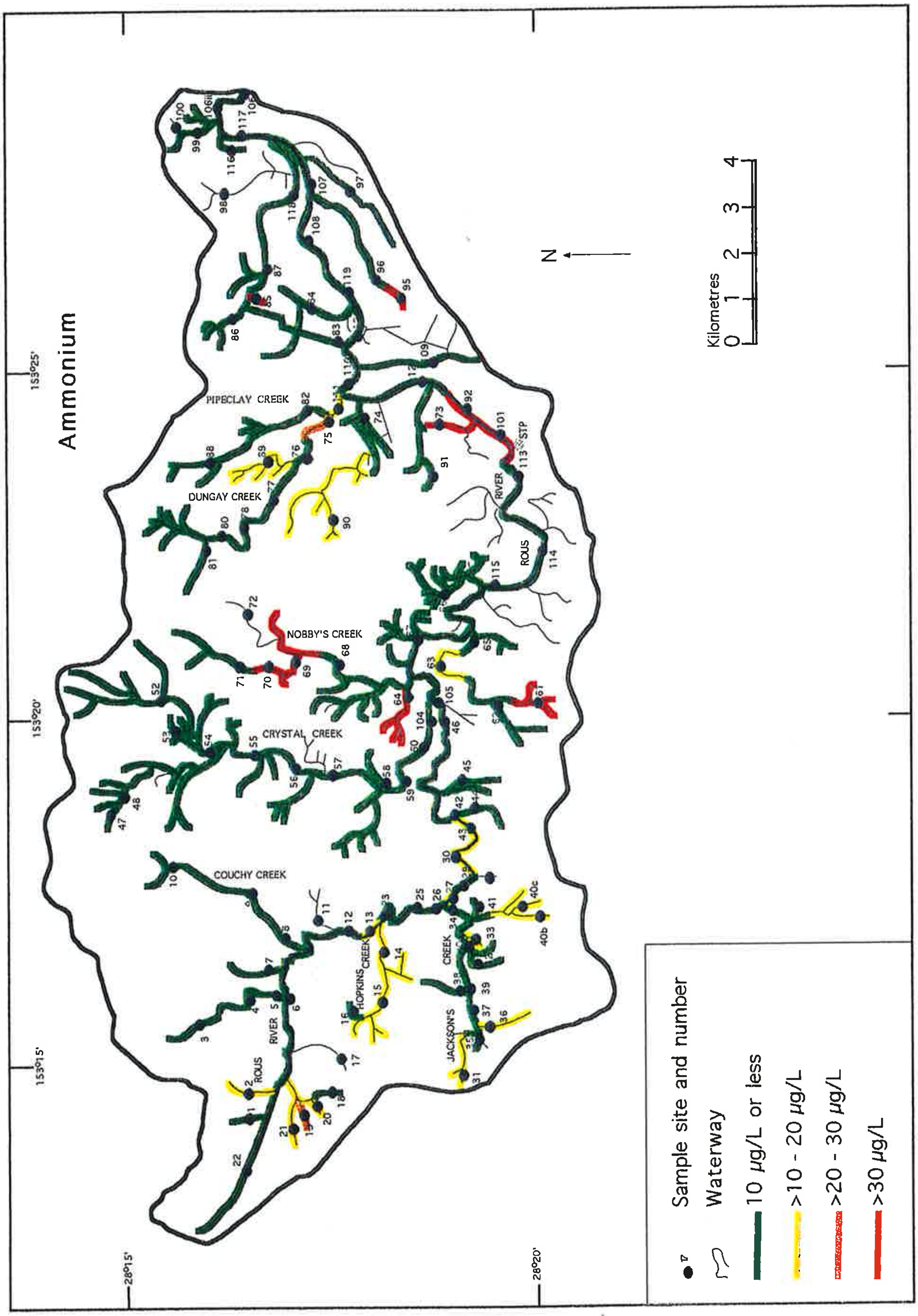

Figure 28. Spatial distribution of ammonium concentrations in the Rous River catchment.

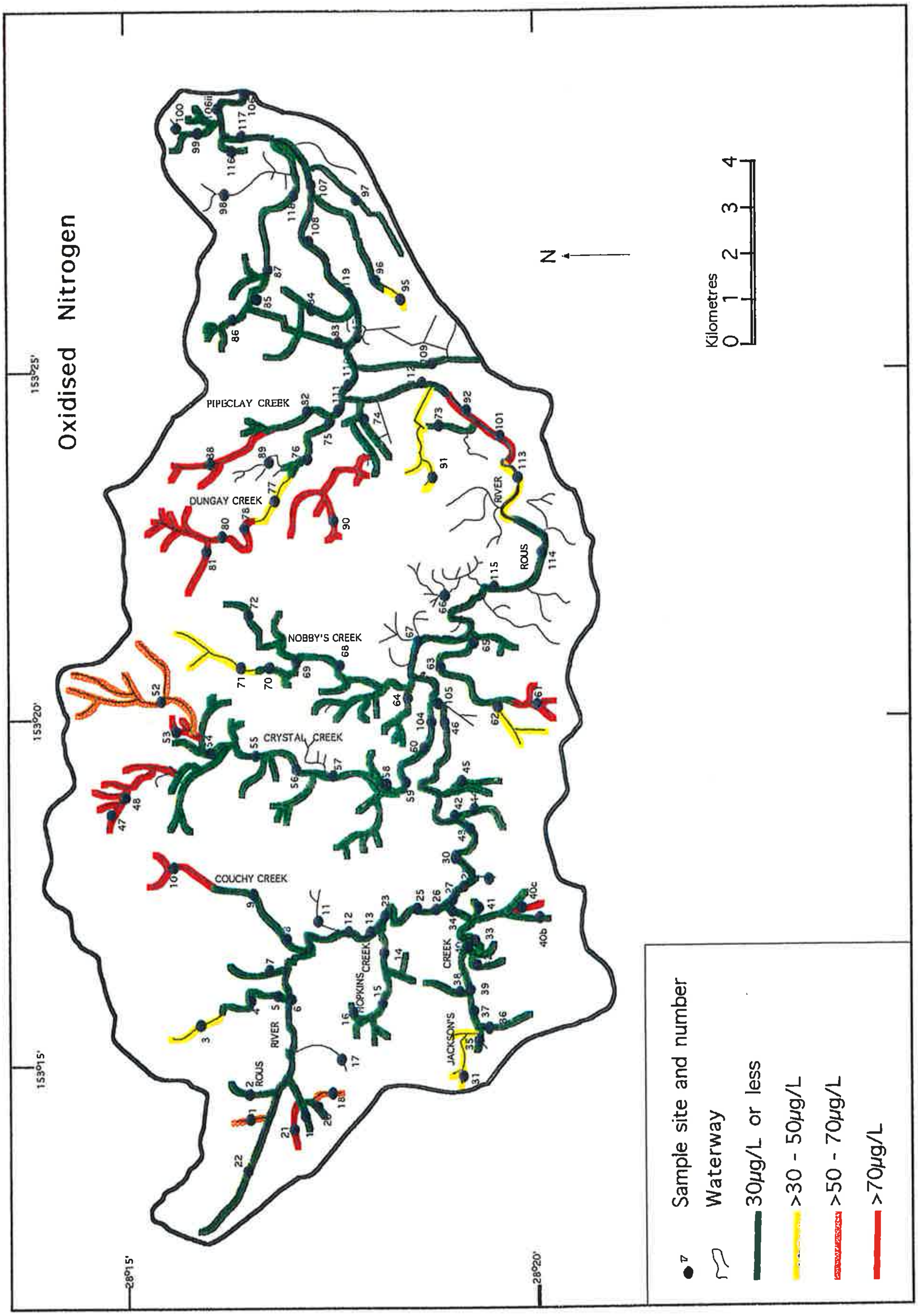

Figure 31. Spatial distribution of oxidised nitrogen in the Rous River catchment.

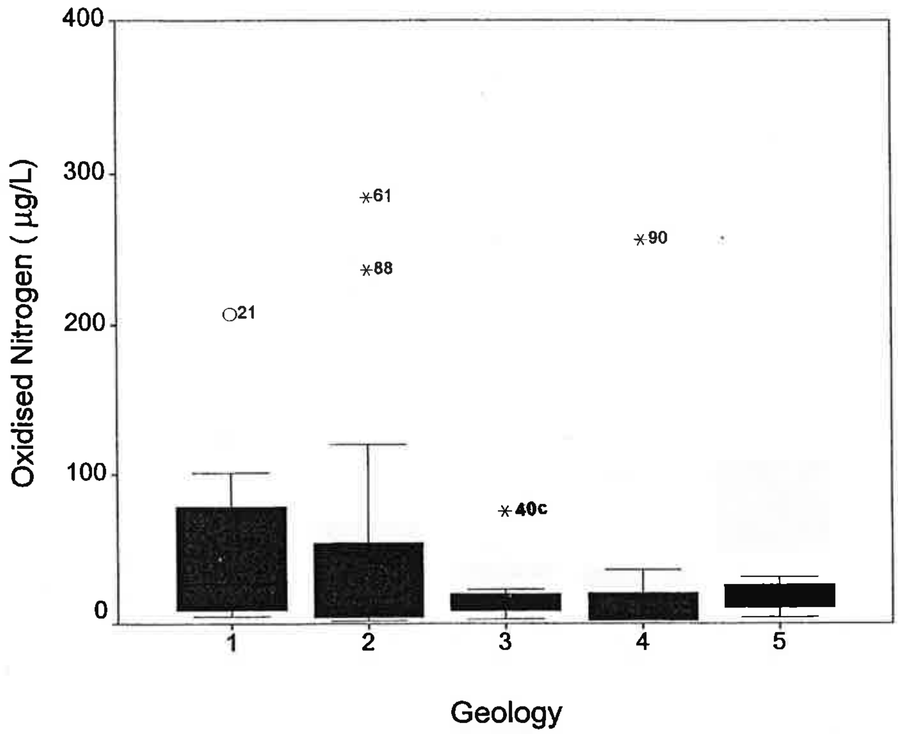

Figure 32. ***Oxidised nitrogen concentrations for different geology types. Geology Code: (1) Basalt, (2) Greywacke, (3) Rhyolite, (4) River Alluvium, and (5) Sandstone.***

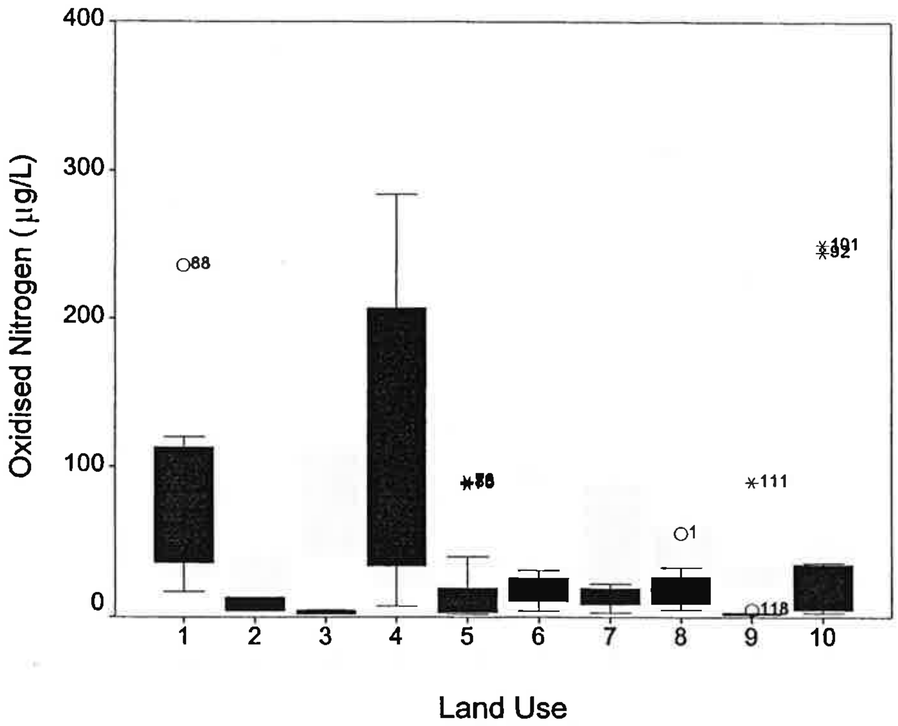

Figure 33. ***Oxidised nitrogen concentrations for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.***

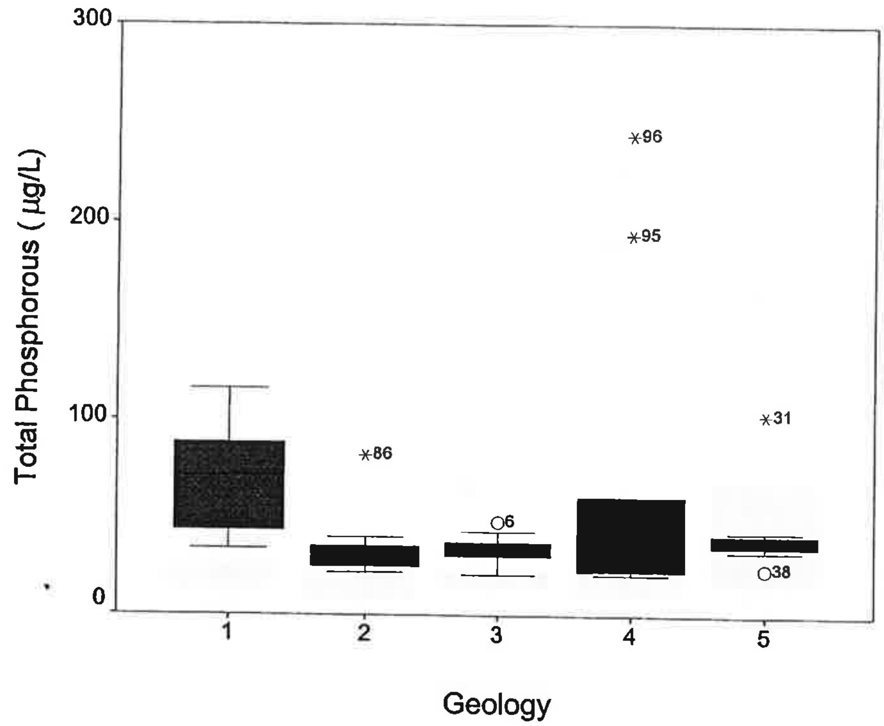

Figure 35. ***Total phosphorus concentrations for different geology types. Geology Code: (1) Basalt, (2) Greywacke, (3) Rhyolite, (4) River Alluvium, and (5) Sandstone.***

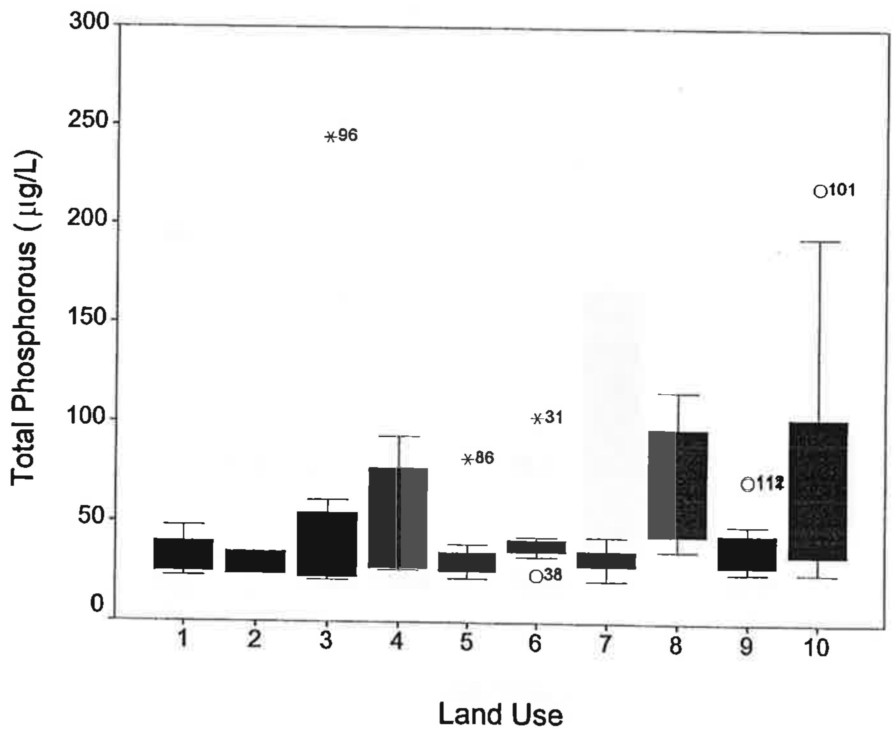

Figure 36. ***Total phosphorus concentrations for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.***

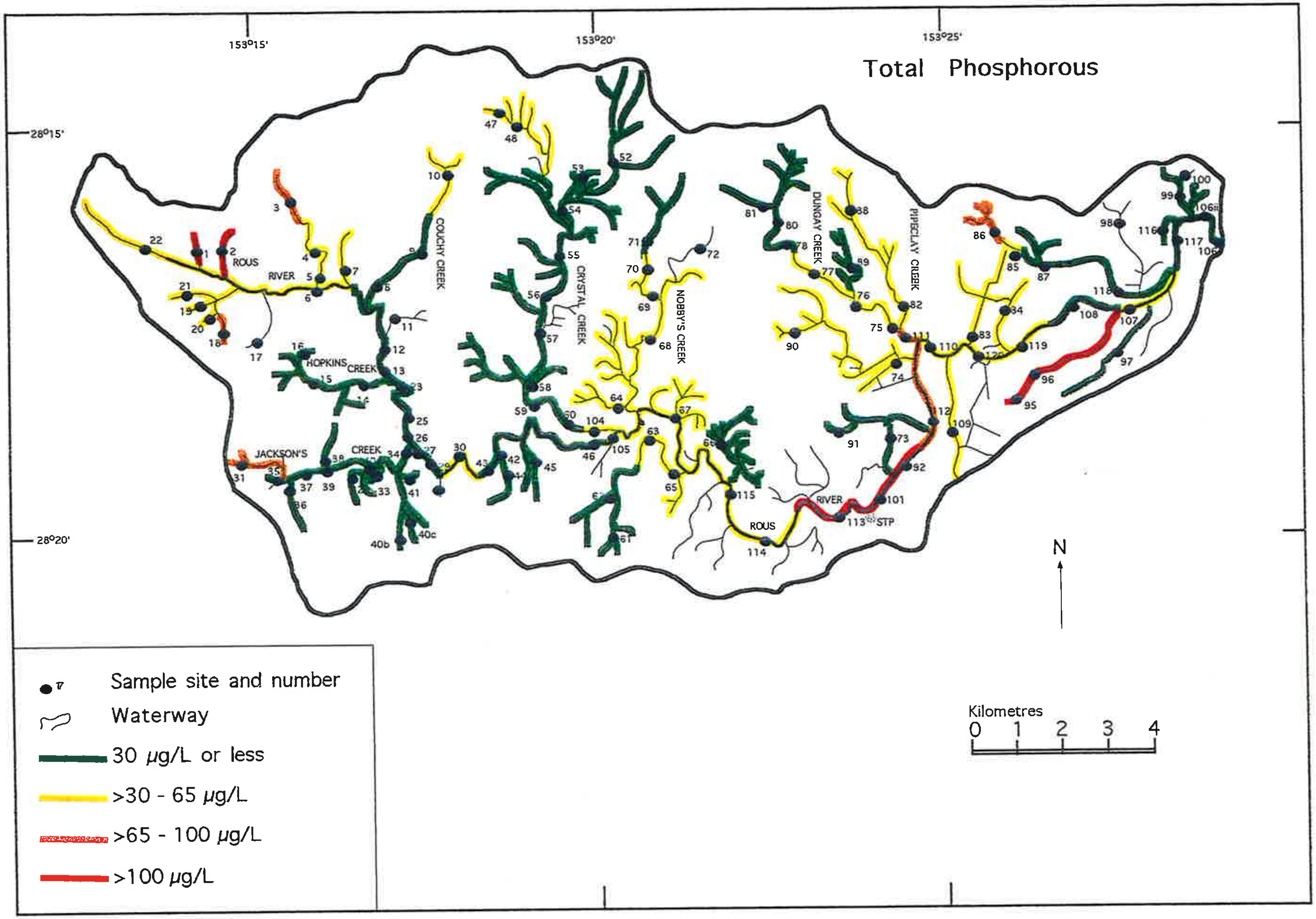

Figure 34. Spatial distribution of total phosphorus concentrations in the Rous River catchment.

5.1.12 Total Particulate Phosphorus

Eighty three percent of the sample sites were ranked as good (8%) and fair (75%) for total particulate phosphorus (TPP) (Figure 37). Low concentrations of TPP were found in Crystal and Couchy Creeks. The other 17% of the catchment was ranked poor (9%) and very poor (8%). High concentrations of TPP were found downstream of the horse stables, sewage treatment plant, golf course and banana plantations (sites 20,16, 21) and in cane drains (sites 74, 83). The median TPP concentration for the catchment was 10µg/L with a range from 5µg/L to 38µg/L for the 10th and 90th percentiles. TPP concentrations were significantly different (∝>0.05) between geology types with higher TPP concentrations for basalt (Figure 38). There was no significantly difference (∝>0.05) between land use types for TPP (Figure 39).

5.1.13 Dissolved Organic Phosphorus

Ninety five percent of the sample sites were ranked as good (64%) and fair (31%) for dissolved organic phosphorus (DOP) (Figure 40). These sites covered much of the upper catchment with low concentrations of DOP found in Crystal, Dungay, Pipeclay and Nobby's Creeks. The other 5% of the catchment was ranked poor (1%) and very poor (4%). High concentrations of DOP were found downstream of the horse stables, sewage treatment plant and the upper reaches of Jacksons Creek. The median DOP concentration for the catchment was 13µg/L with a range of 7µg/L to 20µg/L for the 10th and 90th percentiles. There was no significant difference (∝>0.05) between DOP concentrations and geology and land use types (Figures 41 and 42).

5.1.14 Dissolved Inorganic Phosphorus

Seventy one percent of the sample sites were ranked as good (58%) and fair (13%) for dissolved inorganic phosphorus (DIP). Areas that rated very poorly (5%) were the upper reaches of the main arm and downstream of the golf course, STP and the horse stables (Figure 43). The median DIP concentration for the catchment was 9µg/L with a range from 6µg/L to 26µg/L for the 10th and 90th percentiles. DIP concentrations were significantly different (µ>0.05) between geology types with higher DIP concentrations for Basalt (Figure 44). DIP concentrations were also significantly different (µ>0.05) between land use types with higher DIP concentrations for grazing on chocolate clays (Figure 45).

5.1.15 Chlorophyll-a

Ninety percent of the sample sites were ranked as good (46%) and fair (44%) for chlorophyll-a (Chl-a). Low concentrations of Chl-a were found in Crystal Creek and the upper reaches of the catchment past Chillingham (above site 26) (Figure 46). The other 10% of the catchment was ranked poor (4%) and very poor (6%). High concentrations of Chl-a were found downstream of the dairy shed, sewage treatment plant and in cane drains (sites 74, 84). The median Chl-a concentration for the catchment was 1.5µg/L with a range of 0.5µg/L to 6.5µg/L for the 10th and 90th percentiles. Chl-a concentrations were significantly different (∝>0.05) between geology types with a higher Chl-a for river alluvium (Figure 47). Chl-a concentrations were also significantly different (∝>0.05) between land uses with higher Chl-a concentrations for cane land (Figure 48).

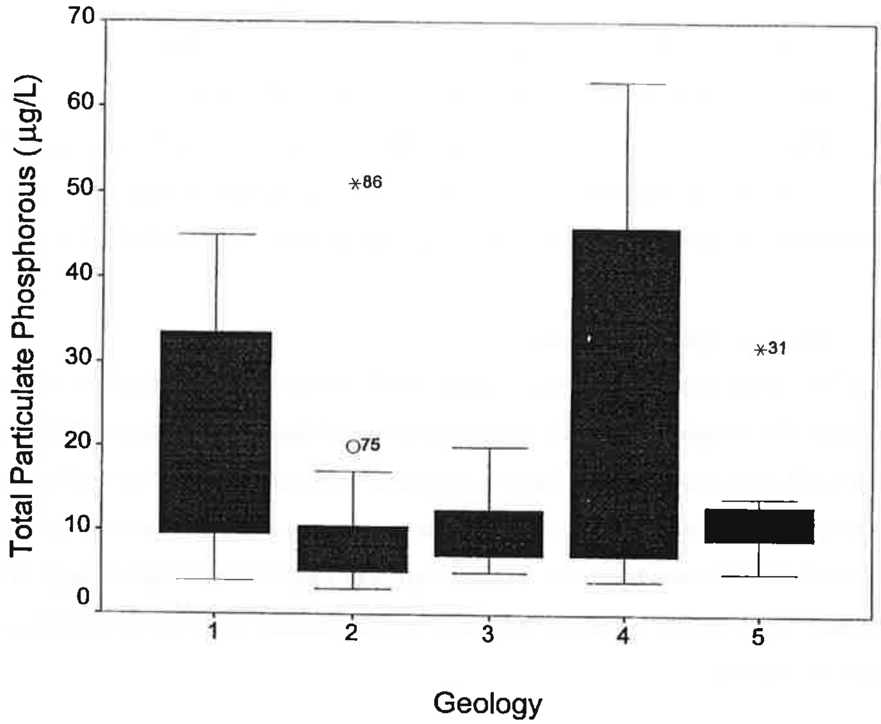

Figure 38. ***Total particulate phosphorus concentrations for different geology types. Geology Code: (1) Basalt, (2) Greywacke, (3) Rhyolite, (4) River Alluvium, and (5) Sandstone.***

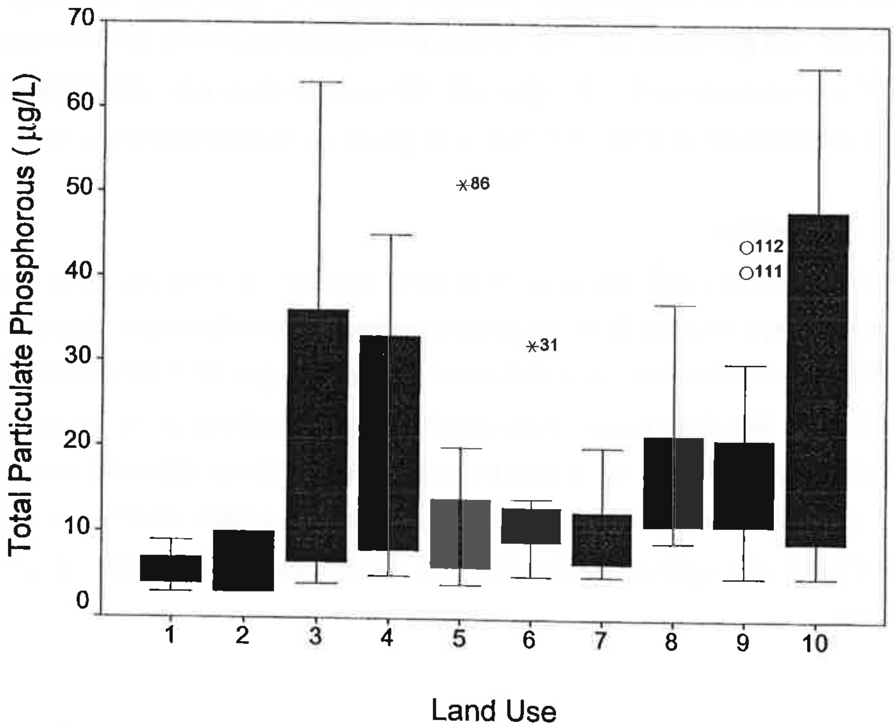

Figure 39. ***Total particulate phosphorus concentrations for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.***

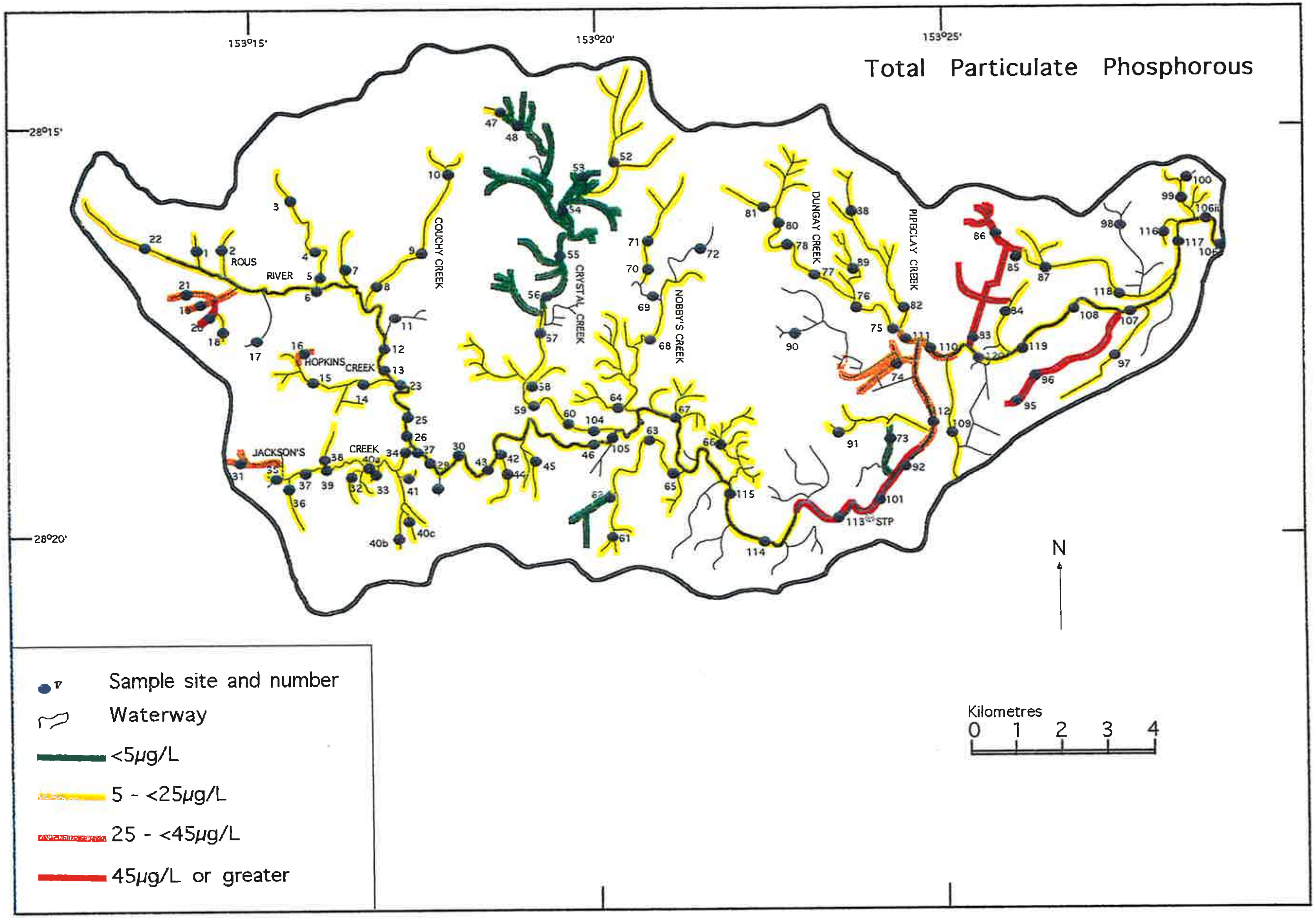

Figure 37. Spatial distribution of total particulate phosphorus concentrations in the Rous River catchment.

Prepared by the Centre for Coastal Management for Tweed Shire Council

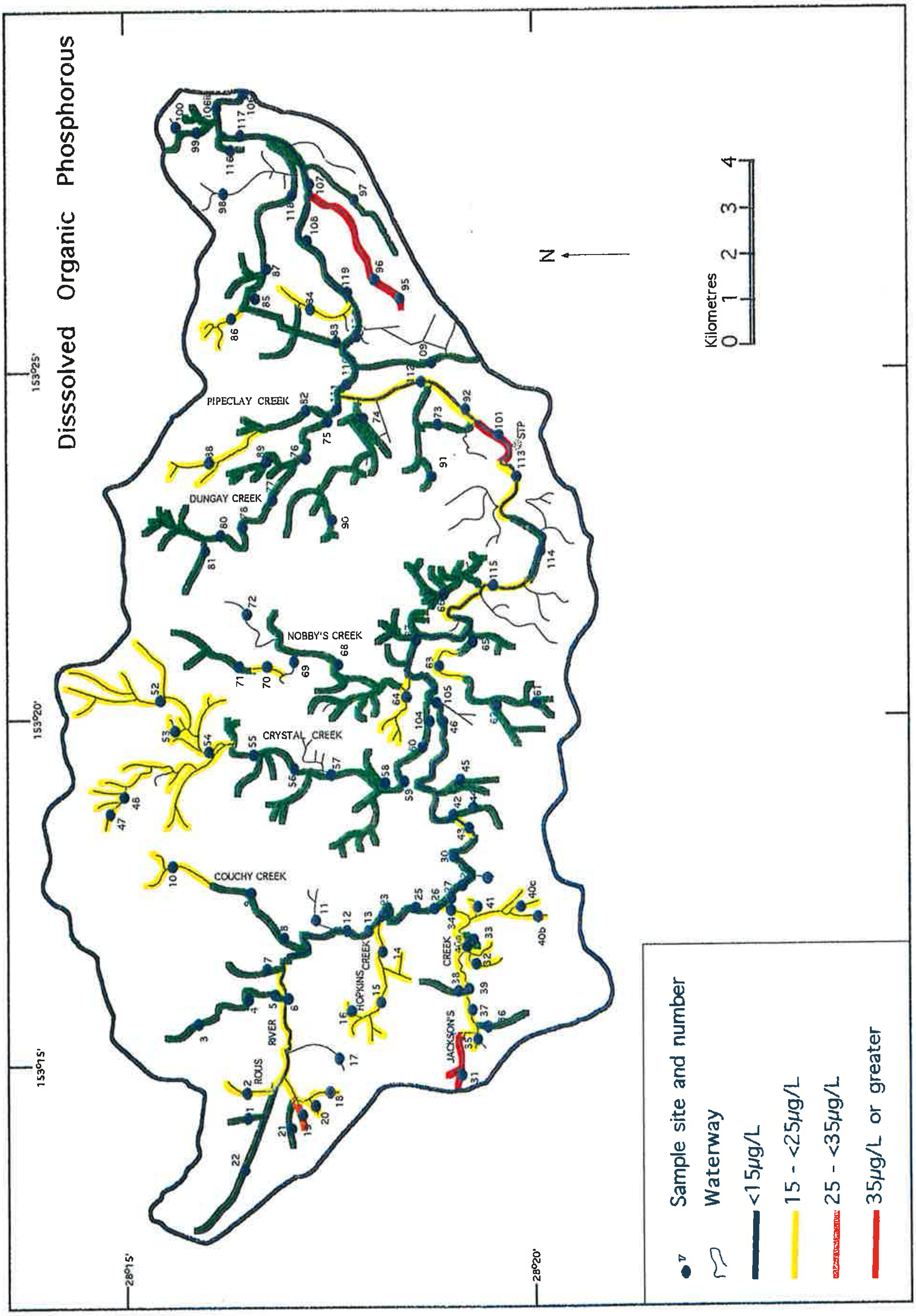

Figure 40. Spatial distribution of dissolved organic phosphorus concentrations in the Rous River catchment.

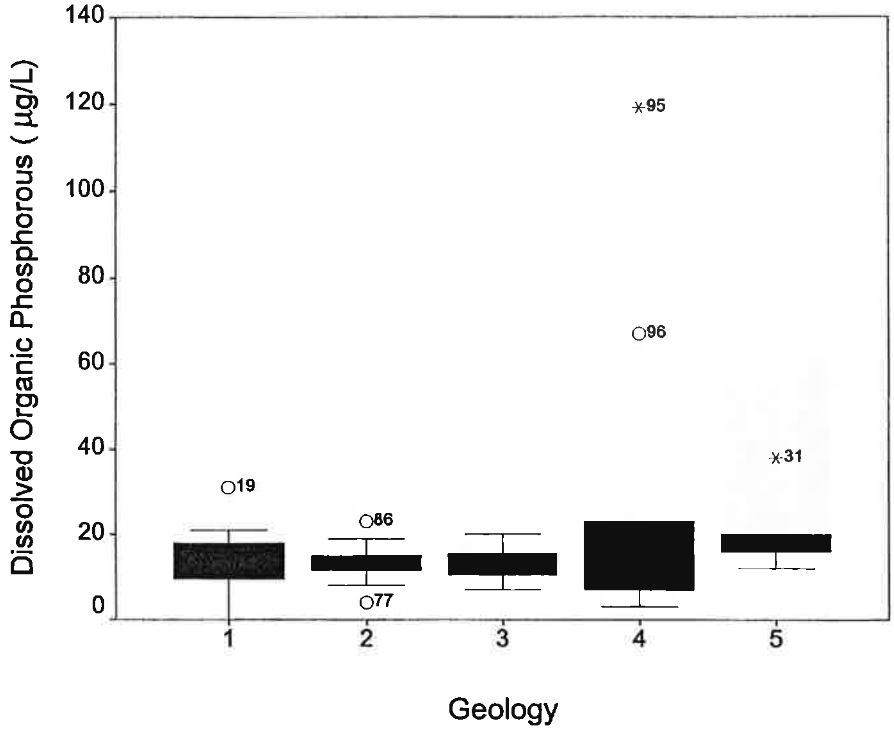

Figure 41. ***Dissolved organic phosphorus concentrations for different geology types. Geology Code: (1) Basalt, (2) Greywacke, (3) Rhyolite, (4) River Alluvium, and (5) Sandstone.***

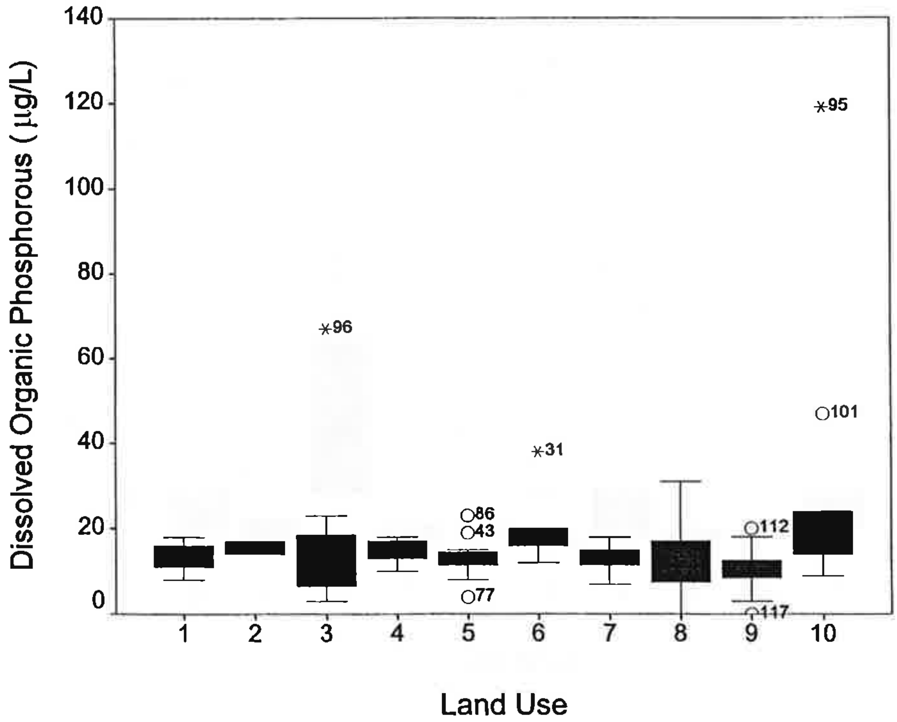

Figure 42. ***Dissolved organic phosphorus concentrations for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.***

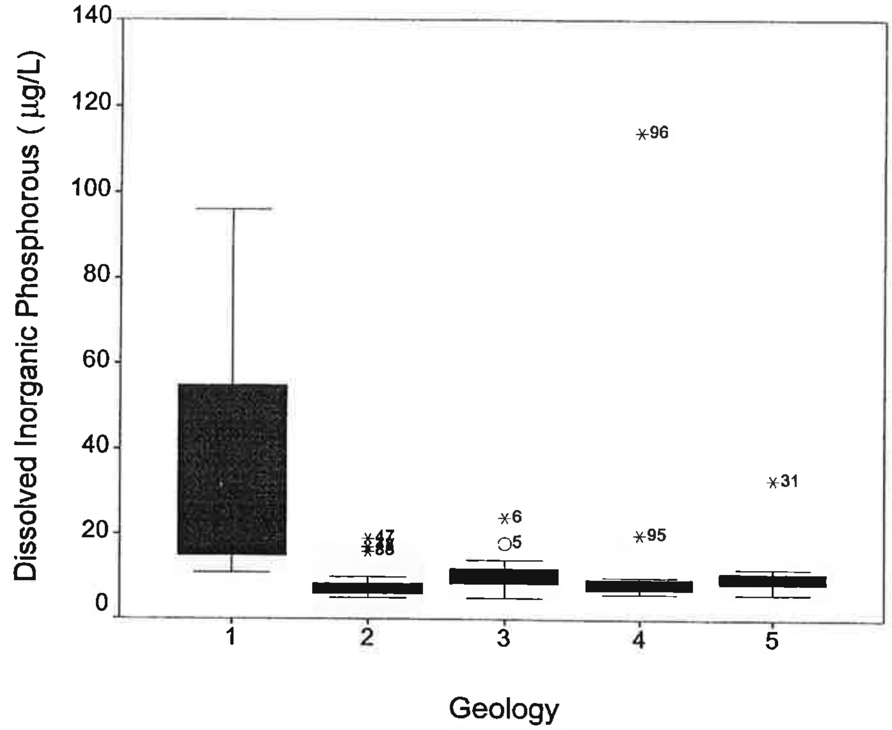

Figure 44. ***Dissolved inorganic phosphorus concentrations for different geology types. Geology Code: (1) Basalt, (2) Greywacke, (3) Rhyolite, (4) River Alluvium, and (5) Sandstone.***

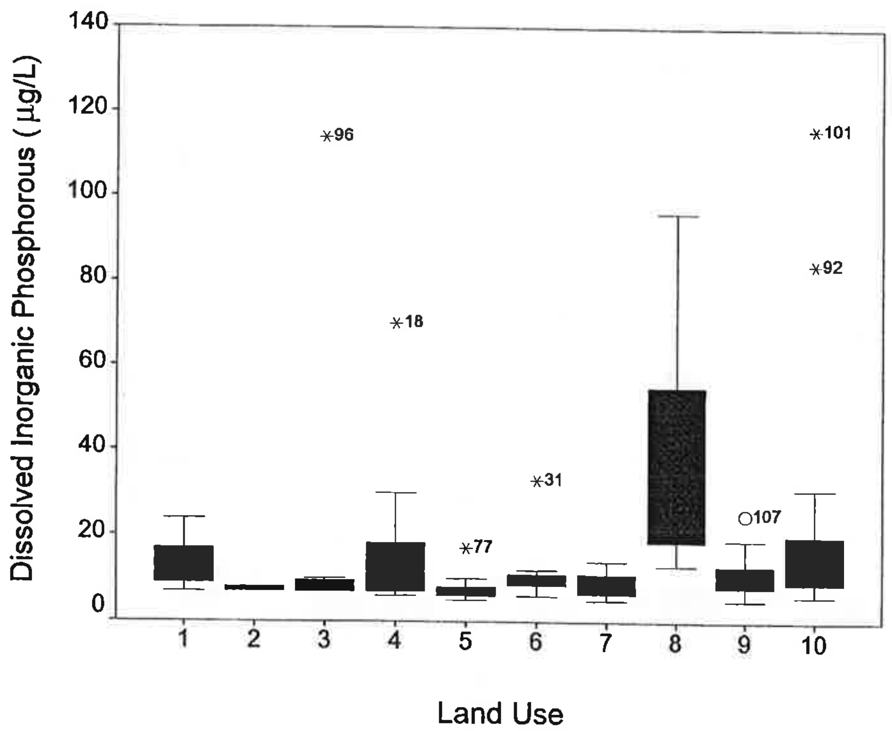

Figure 45. ***Dissolved inorganic phosphorus concentrations for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.***

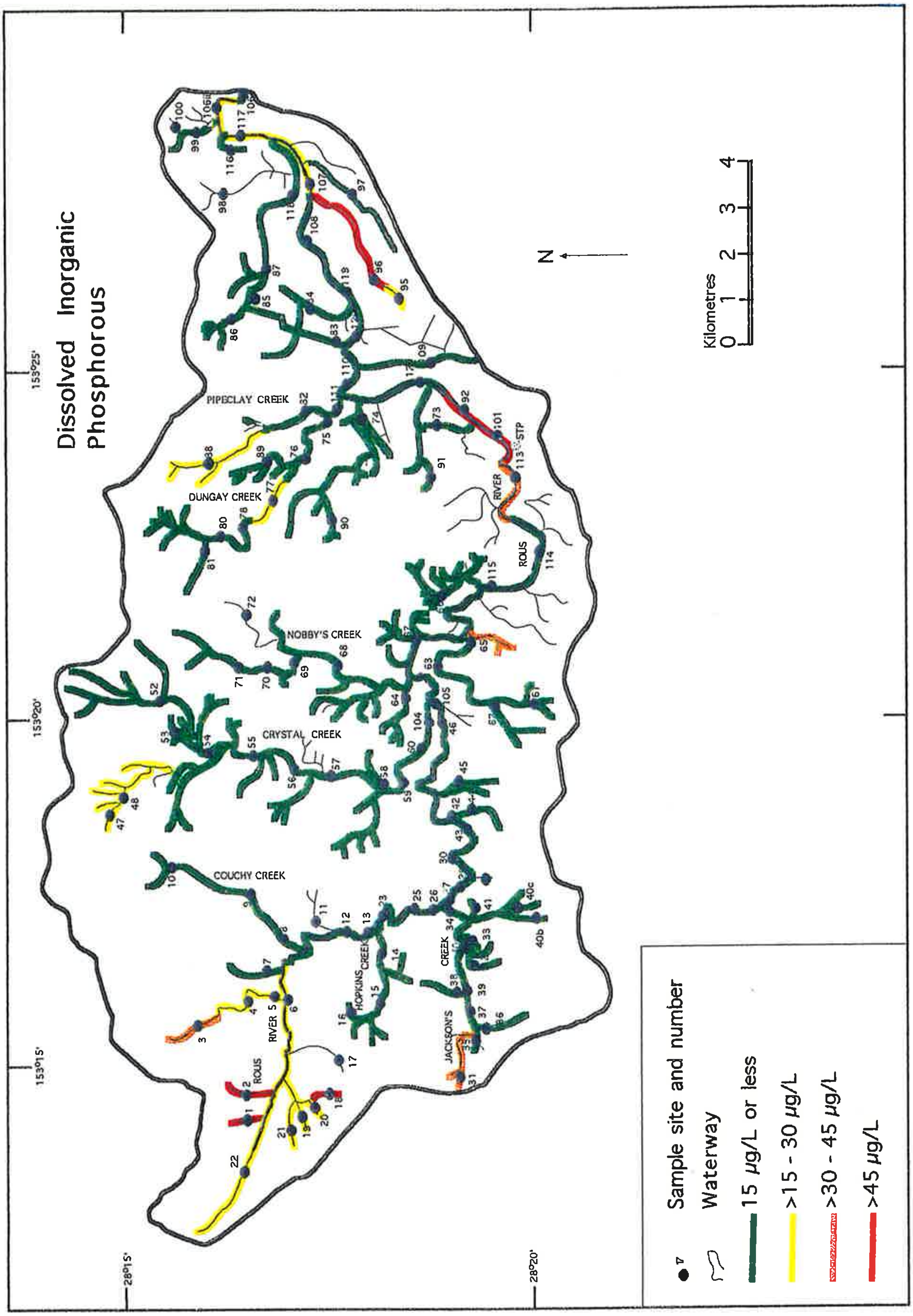

Figure 43. Spatial distribution of dissolved inorganic phosphorus concentrations in the Rous River catchment.

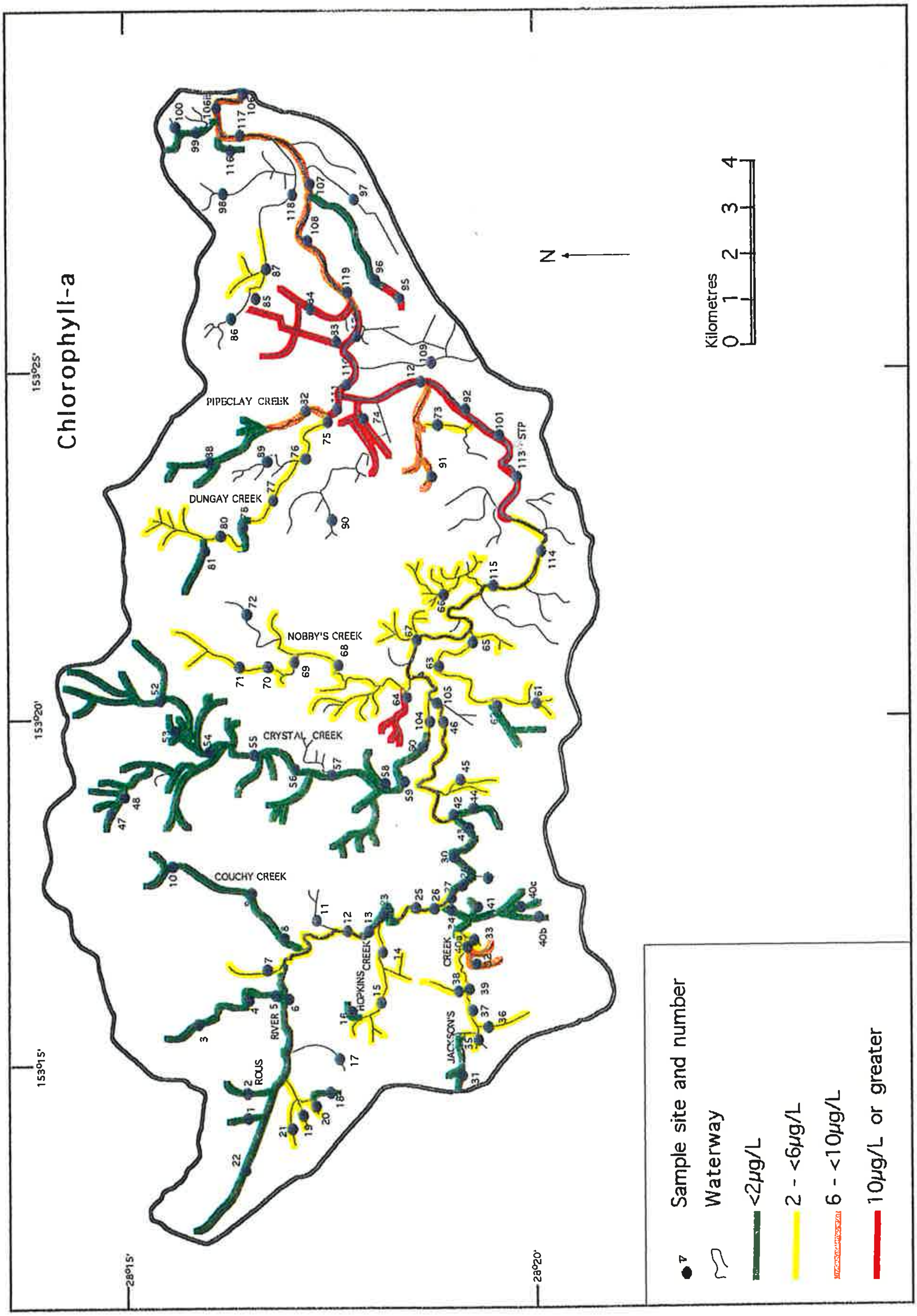

Figure 46. Spatial distribution of chlorophyll-a concentrations in the Rous River catchment.

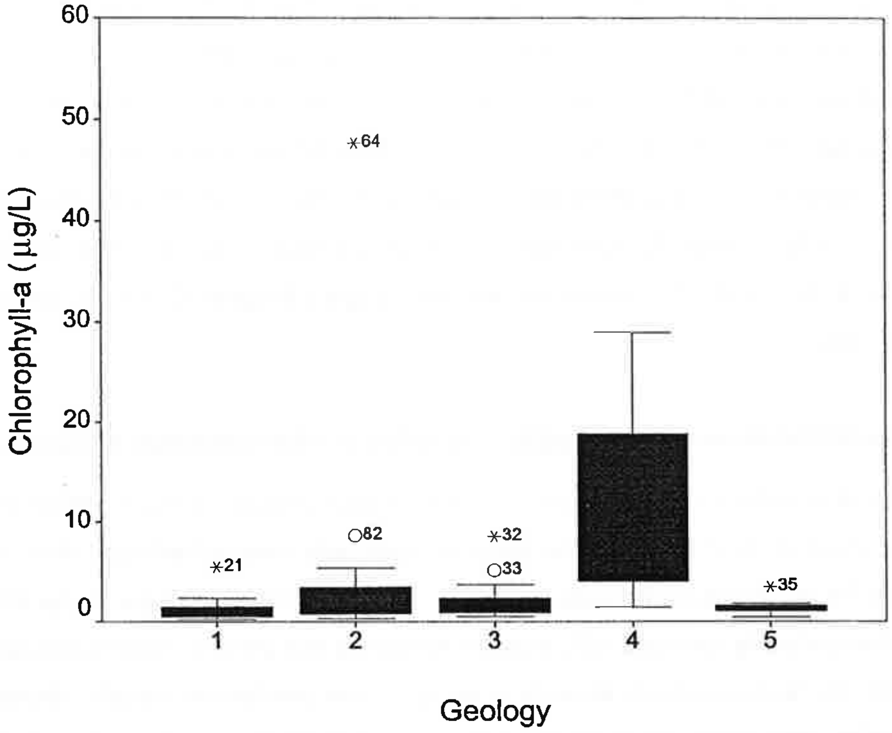

Figure 47. Chlorophyll-a concentrations for different geology types. Geology Code: (1) Basalt, (2) Greywacke, (3) Rhyolite, (4) River Alluvium, and (5) Sandstone.

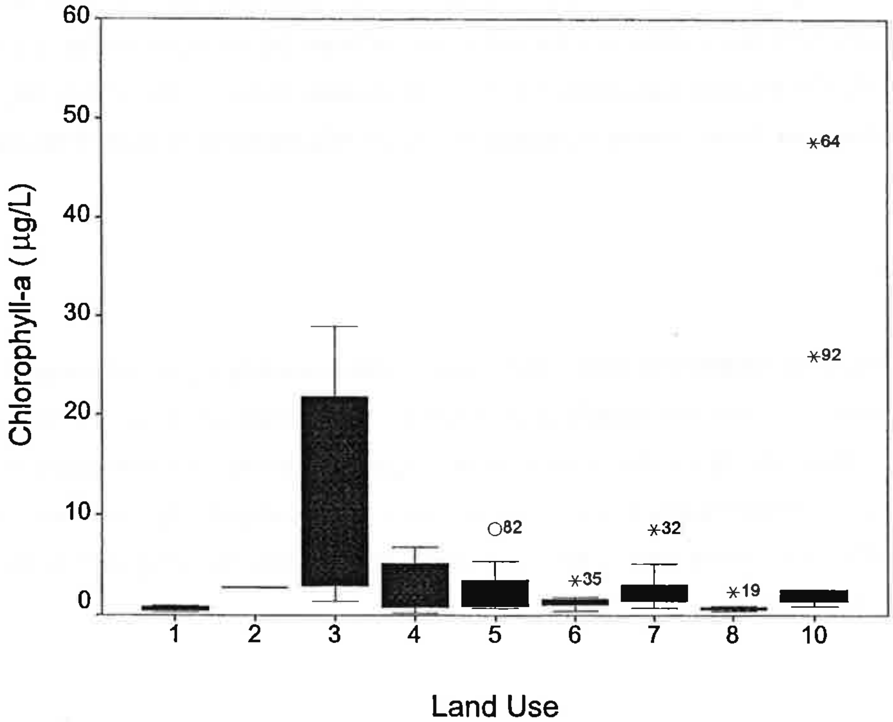

Figure 48. Chlorophyll-a concentrations for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.

5.1.16 Faecal Coliforms

Seventy six percent of the sites were ranked as good (11%) and fair (65%) for faecal coliforms (FC). Low FC concentrations were found in pristine areas and the upper reaches of Crystal Creek (Figure 49). Of the other 24% of the catchment, 19% was ranked poor and 5% very poor. High FC concentrations were found downstream of the sewage treatment, horse stables, dairy shed and at sites 40b, 90 and 99. The median FC concentration for the catchment was 40 colonies/100ml with a range from 0 colonies/100ml to 400 colonies/100ml for the 10th and 90th percentiles. There was no significant difference ($\propto>0.05$) between FC concentrations and geology types (Figure 50). However, there was a significant difference ($\propto>0.05$) between FC concentrations and land use type with higher FC concentrations downstream of point sources (Figure 51).

5.2 Relationships between Water Quality Parameters and Environmental Attributes

The correlation matrix of all water quality parameters and environmental attributes shows a number of significant ($P<0.01$) relationships (Table 6). All of the phosphorus forms are significantly correlated with each other, and TP and DOP are correlated with TN. No phosphorus forms are correlated with any environmental attributes. Except NO_X, all of the nitrogen forms are also significantly correlated. NO_X shows no relationship with any other water quality parameters or environmental attributes. All the nitrogen forms, except NO_X, are significantly correlated with turbidity, chlorophyll-a, and faecal coliforms. Turbidity, chlorophyll-a and faecal coliforms are also significantly correlated with each other. EC is significantly correlated with population density and cumulative population. Elevation is significantly correlated with slope, stream order and sub-catchment number and population density is significantly correlated with cumulative population.

Factor analysis identified 4 groups of variables (factors) that account for 73.3% of the variance in the data set (Figure 52). Factor 1 contained turbidity, faecal coliforms, chlorophyll-a, TPN, DON and DO and explained 29.6 % of the variance. Factor 2 contained DIP, TPP and DOP and explained 17.7% of the variance. Factor 3 contained EC, NH_4 and pH and explained 15.2% of the variance. Factor 4 contained population density and NO_X and explained 10.8% of the variance.

6.0 Discussion

Water quality is typically highly variable, both spatially and temporally, due to a variety of point and non-point inputs and a myriad of instream physical, chemical and biological processes that control its composition. As such, routine monitoring programs with a low sampling density are often unable to identify the factors that control the water quality of a system. In contrast, the spatially intensive water quality monitoring approach with a high sampling density and statistical analysis used in this study has identified a number of patterns which give insight into the factors controlling water quality in the Rous catchment during baseflow conditions.

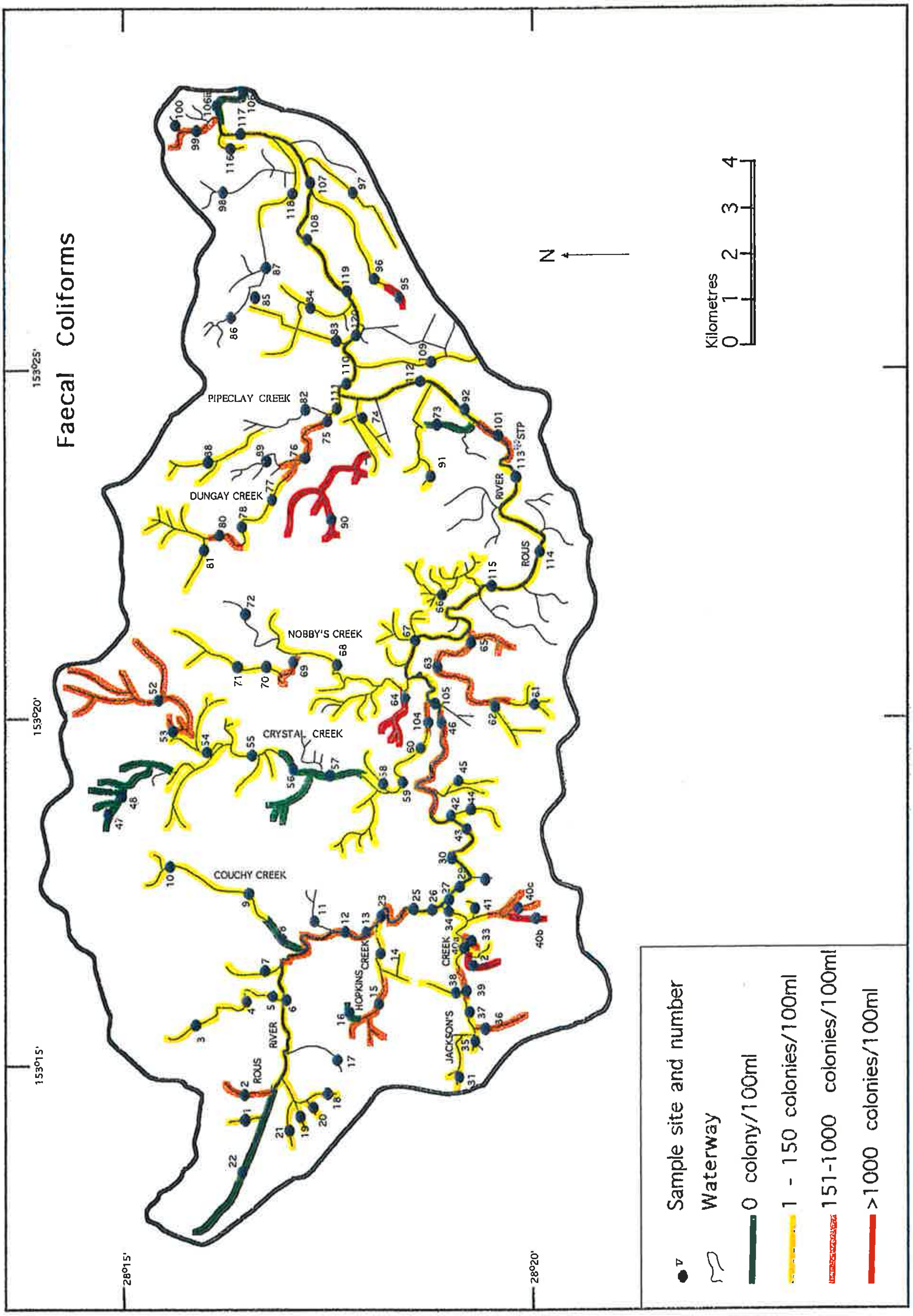

Figure 49. Spatial distribution of faecal coliform concentrations in the Rous River catchment.

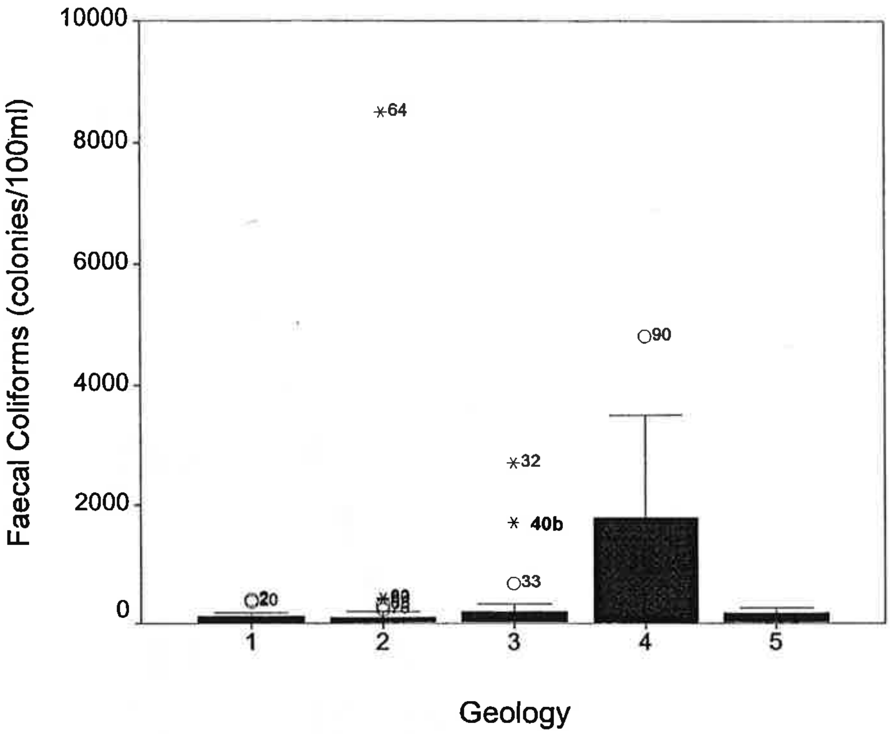

Figure 50. ***Faecal coliform concentrations for different geology types. Geology Code: (1) Basalt, (2) Greywacke, (3) Rhyolite, (4) River Alluvium, and (5) Sandstone.***

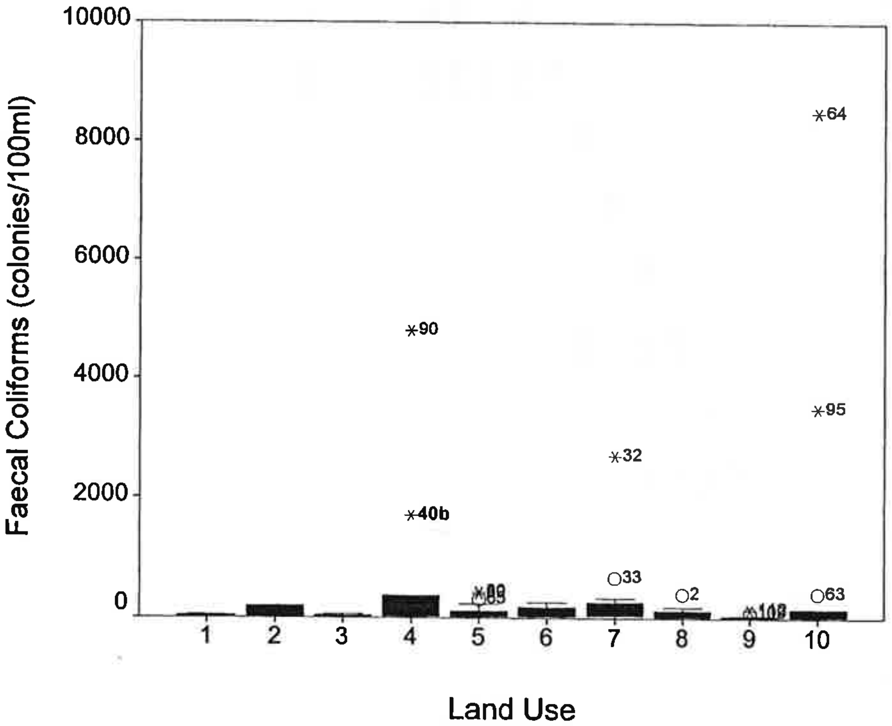

Figure 51. ***Faecal coliform concentrations for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.***

Table 6. Pearson correlation coefficients for water quality parameters and environmental attributes. Only correlations > r = 0.5 and significant at the 0.01 level are shown.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1 Popden	1.000																									
2 Popbet		1.000																								
3 Cumpop	0.943		1.000																							
4 Vegcov				1.000																						
5 Elevat					1.000																					
6 Slope					0.665	1.000																				
7 Strmno					-0.536		1.000																			
8 Subcat					-0.733		0.535	1.000																		
9 Geo									1.000																	
10 Lduse							0.525			1.000																
11 TP											1.000															
12 DOP											0.728	1.000														
13 DIP											0.844		1.000													
14 TPP											0.834	0.548	0.534	1.000												
15 TN											0.604	0.670		0.560	1.000											
16 TPN															0.747	1.000										
17 NOx																	1.000									
18 NH4															0.642			1.000								
19 DON											0.546	0.707			0.872				1.000							
20 DO																				1.000						
21 EC	0.567		0.624																		1.000					
22 Temp																						1.000				
23 pH															0.711	0.628			0.663				1.000			
24 Turbidity															0.725	0.645			0.617					1.000		
25 CHL															0.553				0.647					0.642	1.000	
26 FC																								0.677	0.727	1.000

6.1 Influence of Geology on Water Quality

There is some conjecture in the literature on the influence of geology on phosphorus exports and water column concentrations (Young *et al.*, 1996). For example, Mulholland (1992) found that the weathering of parent dolomite was the dominant source of inorganic phosphorus to streams in the West Fork catchment, USA. Rocks of volcanic origin leach significant amounts of phosphorus (Timperley, 1983) and phosphorus exports from catchments of volcanic origin can be 15 times higher than loads exported from catchments of plutonic origin (Dillon and Kirchner; 1975). Close and Davies-Colley (1990) used the percentage of volcanic rocks in a catchment to discriminate between groups with differing phosphorus concentrations. In contrast, in a National Eutrophication Survey, Omernik (1977) found no significant influence of geology type on phosphorus concentrations or loads. However, the failure of Omernik's (1977) work to demonstrate the influence of geology on water quality was probably due to an artefact common in many water quality monitoring programs, a low sampling density. The high sampling density in this study clearly demonstrated the influence of geology on water quality in the Rous River catchment during baseflow conditions, by the significantly higher concentrations of TP and DIP (Kruskal-Wallis, $\propto$>0.05) in areas underlain by basalt. Volcanic rocks, particularly basalts, in northern NSW have high concentrations of phosphorus (Duggan and Mason, 1978) which would be leached into adjacent streams during the normal process of weathering.

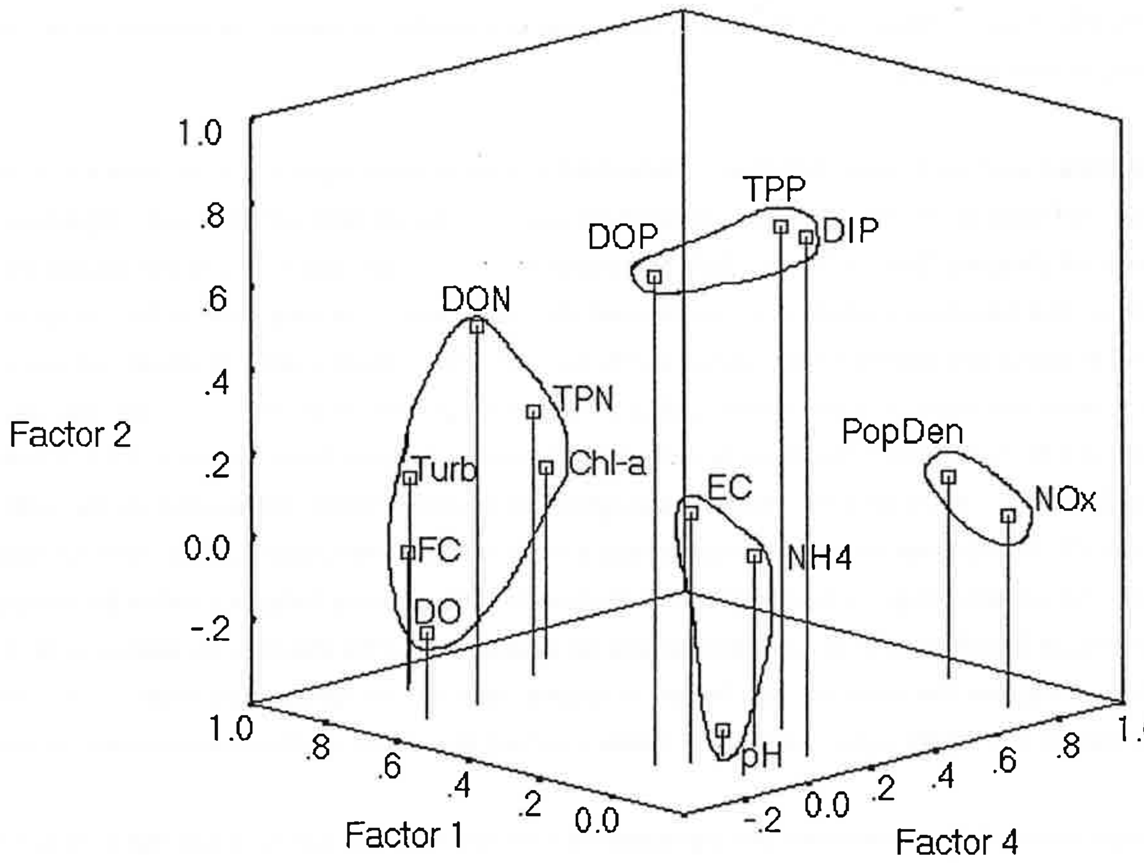

Figure 52. ***Three-dimensional factor analysis plot, after orthogonal rotation, of the water quality parameters and environmental attributes using the factor loadings as co-ordinates. The factor analysis identified 4 groups of variables that account for 73.3% of the variance. Factor 1 contains turbidity, faecal coliforms, chlorophyll-a, TPN, DON and DO, Factor 2 contains DIP, TPP and DOP, Factor 3 contains EC, NH_4 and pH and Factor 4 contains population density and NO_x.***

Although areas of the Rous River catchment underlain by basalt have naturally elevated concentrations of TP and DIP, this appears to have little effect on the overall water quality of these areas. Other indicators of poor water quality such as dissolved oxygen values, pH, nitrogen concentrations, faecal coliforms and chlorophyll-a concentrations are generally good in the basalt areas. The influence of geology only on TP and DIP concentrations and not water quality as a whole, is further illustrated by the factor analysis (Figure 52) which show phosphorus is not associated with any other water quality parameters or environmental attributes.

It is often difficult to separate spatial variations in water quality from geology and land use because the two are usually interdependent (Walling & Webb, 1975); geology usually determines the type of land use. This is illustrated by the river alluvium land use category which showed elevated TN, TPN, NH_4, TPP, Chlorophyll-a and FC concentrations, elevated temperatures and depressed pHs. The poor water quality, more likely reflects the land use (cane) that covers most of the river alluvium.

6.2 Influence of Land Use (non-point sources) on Water Quality

The influence of non-point sources on water quality relates to different land management practices such as type and percentage vegetation cover (including riparian zones), drainage and fertiliser application rates. Three land use categories in the Rous River catchment (cane, horticulture, and pristine) were identified as having some influence on water quality during baseflow conditions.

The poorest water quality in the Rous River catchment due to non-point source impacts was associated with cane land, which had elevated TN, TPN, DON, and Chlorophyll-a concentrations, elevated turbidities and temperatures, and depressed pH values. Elevated TN, TPN, DON, NH_4 concentrations were most likely associated with leaching of excess fertilisers that have been applied to cane land (Rayment *et al.*, 1996). Many of the sample sites in the cane drains were rated as poor or very poor for nitrogen and exceed the ANZECC (1992) guidelines upper limit for protection of aquatic ecosystems. Leached nutrients are usually in soluble inorganic forms (Rayment *et al.*, 1996), suggesting they have been trapped in the poorly flushed cane drains for some time and converted to organic forms. This is consistent with the high algal biomass (i.e. chlorophyll-a concentrations) and high organic nitrogen: inorganic nitrogen ratios recorded in the cane drains (53). The significant correlation between nitrogen concentrations and chlorophyll-a (Table 6; Figure 52) across the catchment suggests nitrogen is most likely the nutrient stimulating and controlling biological growth in the canes drains. Low median DIN:DIP ratios in the cane drains (Figure 54) suggests some of the sites have the potential to be nitrogen limited during base flow conditions. High turbidity in the cane drains and the significant correlation (Table 6) between chlorophyll-a and turbidity suggests much of the turbidity is probably derived from algal biomass in the water column.

Temperatures in the cane drains were also significantly higher than the other land uses, most likely due to the their lack of riparian vegetation and slow flushing. The cane drains had median temperatures more than $2^{o}C$ higher than the pristine areas, which exceeds the ANZECC (1992) guidelines for protection of aquatic ecosystems. Elevated temperatures would also help stimulate algal growth in the presence of high nutrient concentrations. The significantly lower pH values in cane

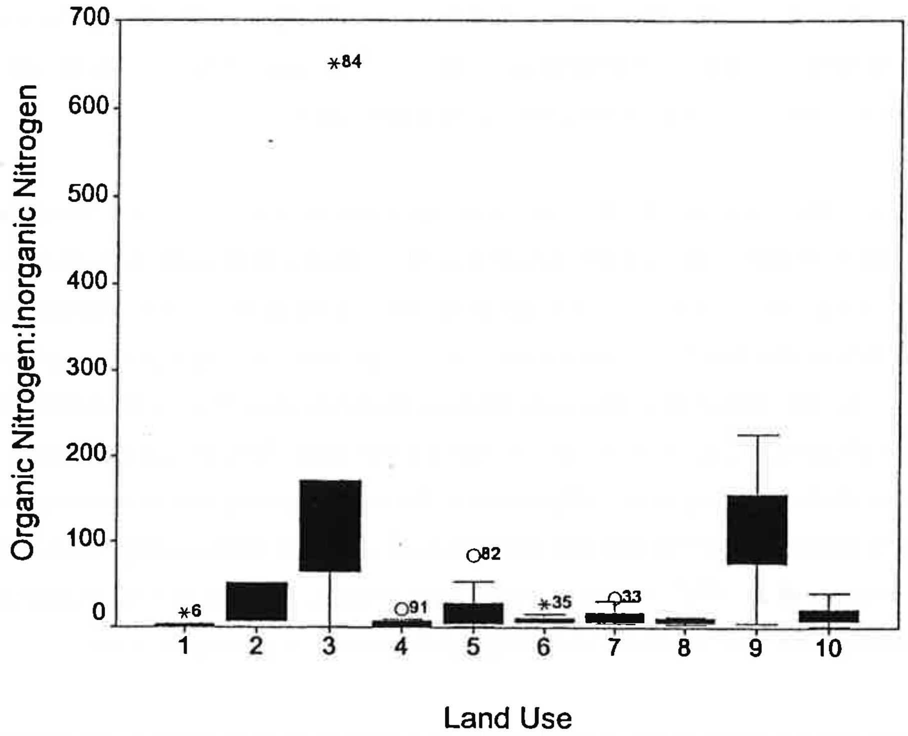

Figure 53. ***Organic nitrogen: inorganic nitrogen ratios for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.***

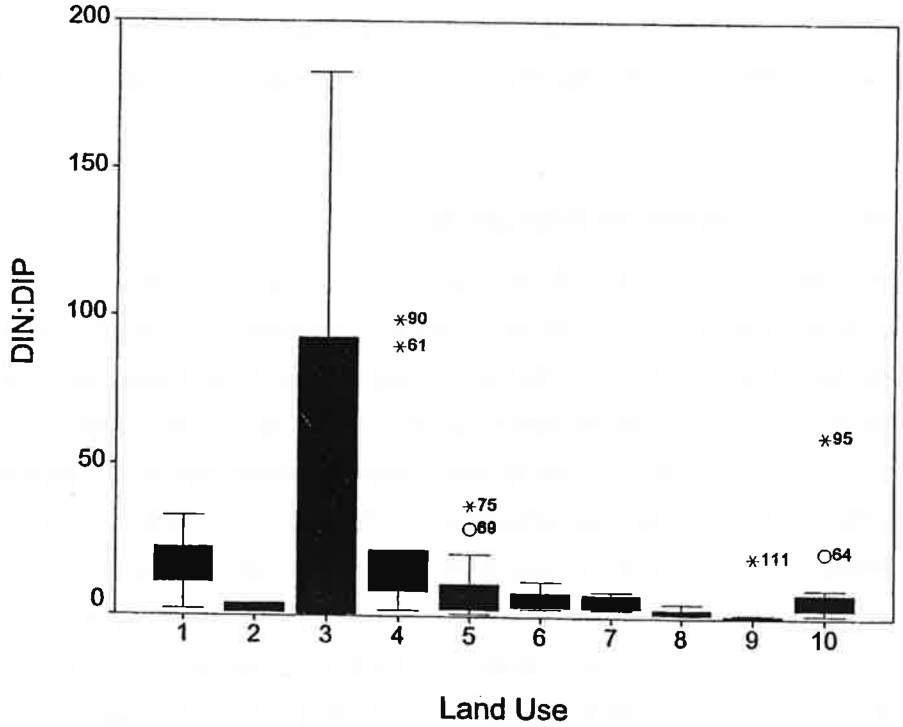

Figure 54. ***DIN:DIP ratios for different land uses. Land Use Code: (1) Pristine areas, (2) Improved pastures, (3) Cane, (4) Horticulture, (5) Grazing on red podsolic, (6) Grazing on yellow podsolic, (7) Grazing on brown earths, (8) Grazing on chocolate earths, (9) Rous estuary, and (10) Downstream of point sources.***

drains were most likely a result of flushing of acid from exposed acid sulphate soils. Draining of low lying coastal swamps for sugarcane production has exposed potential acid sulphate soils, oxidising pyrite which produces sulphuric acid (Ferguson and Eyre, 1996). The impact of acid sulphate soils is enhanced by floodgates at the end of the cane drains. These drains protect the low lying cane land from inundation during flooding of the main Rous River channel and help remove localised surface water, but also prevent tidal mixing and flushing of acid waters.

The horticultural areas (mainly bananas) had significantly higher concentrations of NO_X. A number of studies worldwide has discussed links between the application of N-fertilisers on agricultural areas and increases in nitrate concentrations in adjacent waterways (Singh and Sekhon, 1979; Edwards *et al.*, 1990; Addiscott *et al.*, 1991). Banana plantations are particularly prone to high nutrient export rates because they are typically planted on steep slopes and generally have poor erosion management and high fertiliser application rates. The NSW Agriculture Department recommended up to 220kg/ ha nitrogen and 50kg/ha phosphorus be applied to banana plantations in the 1960's. Because application rates may have been five times higher than needed (Vimpany *et al.*, 1995) there was often rapid loss of nutrients by erosion and leaching. The current approach is to fertilise according to yield and nutrient removal in the crop, however many growers still use the old application rates (Vimpany *et al.*, 1995). A study of management practices, in particular, fertiliser application rates for banana plantations in the Rous River catchment warrants further investigation (e.g. a farmer survey).

The highest median concentrations of NO_x in the Rous River catchment were recorded in the pristine sub-tropical rainforest areas. This contrasts with many forest areas where biogeochemical processes in the upper soil horizons typically retain much of the phosphorus and nitrogen (Qualls *et al.*, 1991). NO_X concentrations in the pristine areas appear high, because NO_X concentrations in other parts of the catchment are low, due algal uptake and removal. Consistent with this are the very low chlorophyll-a concentrations and low organic nitrogen: inorganic nitrogen ratios in the pristine areas (i.e. little uptake of NO_X compared to other parts of the catchment). Further, on a world average, the Rous River catchment has low NO_X concentrations in its waterways for its population density (Figure 55), reflecting the conversion of inorganic nitrogen to organic nitrogen.

6.3 Influence of Point Sources on Water Quality

Three point sources were identified as having a significant impact on water quality, the Murwillumbah Sewage Treatment Plant, a dairy shed and a horse stables. The septic villages around Chillingham appeared to have no significant impact on water quality. Discharge from concentrated livestock facilities (ie. dairy shed and horse stables) can contain pollutants equivalent to that of untreated domestic waste and nutrient exports can be two to three times higher than from regular agricultural land (Beaulac & Reckhow, 1989). This was illustrated immediately downstream of the dairy shed and horse stables where most water quality parameters greatly exceed the ANZECC (1992) guidelines for the protection of aquatic ecosystems and secondary contact for humans. For example, FC concentrations were very high downstream of the dairy shed (8500 colonies/100ml) and the horse stables (3500 colonies/100ml). However, the impact was localised with an improvement in most water quality parameters further downstream due to dilution and assimilation. In contrast, nutrient loads from the Murwillumbah Sewage Treatment Plant appear to be stimulating algal growth throughout most of the Rous River estuary (Figure 46).

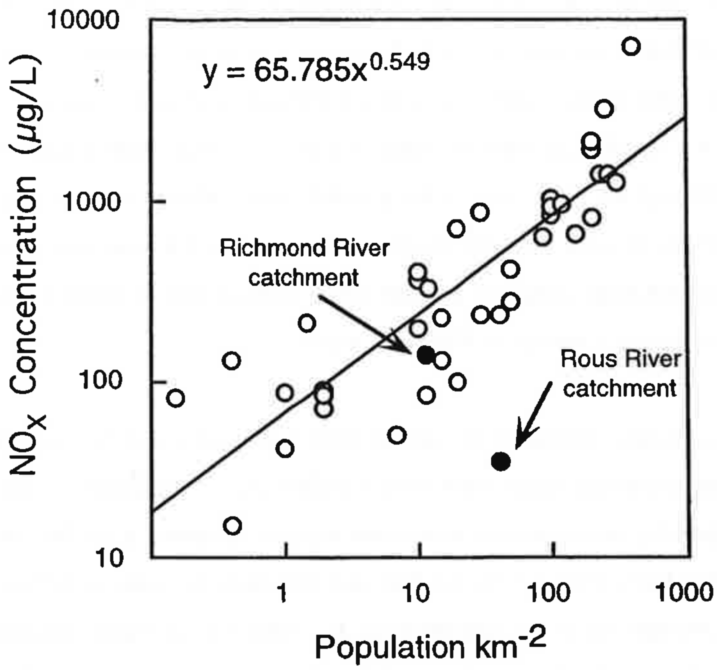

Figure 55. ***The average NO_X concentration in 41 rivers of the world as a function of the catchment population density. Also showing the average NO_X concentration in the Rous River catchment as a function of the catchment population density. Data from Cole et al., 1993, except Richmond River which is from Lester McKee, pers. comm., 1997).***

6.4 Catchment-wide Water Quality Patterns

Although land use and point sources clearly exert some influence on water quality, there are also some catchment-wide patterns. The correlation matrix and factor analysis (Table 6; Figure 52) show a good correlation between organic nitrogen concentrations and chlorophyll-a, suggesting that it is the supply of nitrogen that is stimulating and maintaining algal growth in waterways across the catchment. The high natural concentrations of phosphorus (Figures 35 and 44) and the lack of association between phosphorus forms and other water quality parameters (Figure 55), suggests its supply is not critical for stimulating algal growth. Consistent with this are the generally low DIN:DIP ratios across the catchment (Figure 54) which indicate the potential for N-limitation. Algal biomass in the water column appears to be the principal cause of turbidity across the catchment during baseflow conditions, as illustrated by the good correlation between chlorophyll-a concentrations and turbidity (Table 6; Figure 52). The negative correlation between DO and chlorophyll-a concentrations, suggests that oxygen is consumed by decaying algal-derived organic material. Because of the high natural phosphorus concentrations and the potential for N-limitation, management efforts should be directed towards limiting nitrogen loading on to the catchment.

In general, grazing appears to have a lesser impact on water quality across the Rous River catchment, than other land uses such as horticulture and cane. Most water quality parameters in the grazing areas are below the ANZECC (1992) guidelines for the protection of aquatic ecosystems. However, about 89% of the waterways in the catchment are not suitable for use as potable water, and about 24% are not suitable for primary contact (Figure 49). Faecal coliforms are also correlated with organic nitrogen concentrations suggesting a similar source. In grazing areas where there are no point sources and no (little) fertiliser applied, cattle are the most likely source of nitrogen input to the waterways. Further, number of septics were targeted during the sampling program, but gave no indication of contributing nutrients or faecal coliforms to the adjacent waterways. Although the exact cause of the elevated faecal coliform concentrations across the catchment is not known, it is most likely due to cattle that have direct access to most of the waterways in the Rous River catchment. A recent study in the Richmond River catchment, although limited, demonstrated an increase in faecal coliform concentrations where cattle have direct access to waterways (Edmonds, 1997).

Population density was the only environmental attribute, other than geology and land use, that could be related to water quality in the Rous River catchment. Factor 4 of the factor analysis showed that population density and NO_X concentrations are closely related (Figure 52). Associated with an increase in population density in the Rous River catchment are increases in the sewage and urban loads discharged to the river, and most likely increases in fertiliser application rates and cattle stocking rates as the average size of the farm decreases (i.e. hobby farms). Nitrate concentrations and exports in rivers around the world are also closely related to the population density in their catchments (Peierls *et al.*, 1991; Cole *et al.*, 1993). However, on a world average, the Rous River catchment has low NO_X concentrations in its waterways for its population density (Figure 55). This may reflect the low intensity of farming in the catchment, but most likely is an artefact of only one sampling during baseflow conditions when inorganic nutrient concentrations appear to be low due to assimilation into organic forms. As such, it is recommended that the sampling program be replicated during the wet season.

6.5 Limitations of the Spatially Intensive Methodology

The spatially intensive water quality approach used in this study identified the influence of geology, land use and points sources on water quality in the Rous catchment. However, the sampling was temporally limited to one occasion which has a number of implications. Sampling was undertaken during baseflow conditions because this hydraulic regime represents 10 to 11 months of the year, and in terms of water quality it is more likely to reflect environmental attributes in the catchment and is a critical time for instream biological processes, the ecological health of waterways and for water allocations (Biggs *et al.*, 1990; Mulholland, 1992; Grayson *et al.*, 1993). But once off sampling assumes that the baseflow water quality during the sampling period is representative of baseflow conditions throughout the year, and ignores seasonal variations. This could be overcome by sampling several times in the one year (summer, winter, spring, autumn) to test how robust water quality patterns that have emerged, are to seasonal variations. Although, this will erode the main advantage of this sampling methodology, its once off rapid assessment of water quality.

Because sampling was undertaken during baseflow conditions, water quality patterns are heavily influenced by point-source and groundwater inputs. Factors such as diffuse runoff and bank and channel erosion are not considered because they are typically associated with high flow events. The high organic nitrogen: inorganic nitrogen ratios (Figure 53) suggests many of the sites may have been dominated by instream biological processes that convert inorganic nutrients to organic forms. It would be expected that the supply of inorganic nutrients would increase as discharge increases. Point-source and groundwater inputs would also be diluted during higher flows. Although the spatially intensive methodology could be applied during higher flows, it becomes increasingly difficult to meet the essential criteria of a constant hydrological regime across the catchment.

7.0 Recommendations

- The spatially intensive water quality program should be replicated during different seasons to test how robust the water quality patterns that have emerged during this study are to seasonal variations. This is particularly important as the supply of inorganic nutrients, which are most likely to stimulate algal growth, is expected to increase in the Rous River catchment during higher flows. The spatially intensive monitoring program should be supplemented with a small number of sample sites located at sub-catchment outlets, that are sampled on a flow-weighted basis. This will allow the estimation of exports out of each sub-catchment, which would be another useful indicator of the impact each sub-catchment is having on water quality in the Rous River catchment as a whole.

- Management efforts should be firstly directed towards controlling point source inputs (particularly nitrogen) from the Murwillumbah Sewage Treatment Plant, the dairy shed and the horse stables.

- Management efforts should secondly be directed towards controlling non-point source inputs (particularly nitrogen) from cane land and bananas.

- Management efforts should thirdly be directed towards limiting cattle access to waterways by fencing and planting riparian vegetation. Priority areas should be identified by examining the spatial distribution maps, and identifying the areas (other than cane, bananas and point sources) with the poorest water quality (e.g. Jacksons Creek).

- The development of a CMSS (Catchment Management Support System) Model for the Rous River catchment would compliment the spatially intensive monitoring, and would be useful as a decision making tool to aid the development of catchment management plans.

8.0 Conclusions

Despite a few potential limitations, the spatially intensive water quality monitoring methodology outlined in this report is a rapid, robust approach that should allow environmental managers to identify point and non-point source impacts on water quality. Three land use categories (cane, horticulture, and pristine) and several point sources (Murwillumbah Sewage Treatment Plant, a dairy shed and a horse stables) in the Rous River catchment were identified as having the largest impact on water quality during baseflow conditions. Management efforts in the Rous River Catchment need to be firstly directed at reducing point source inputs (particularly nitrogen), secondly at reducing non-point source inputs (particularly nitrogen) from cane land and bananas and thirdly at improving the catchment water quality for human health by reducing direct cattle access to streams.

9.0 Acknowledgements

We would like to thank Lester McKee and Peter Davies for the nutrient and chlorophyll-a analysis. We would also like to thank Lester McKee and Jane Lofthouse for assistance with the collection of samples and Jane Lofthouse for organising the community volunteers. Finally thanks to all the community volunteers who assisted with sample collection.

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Appendix 1

Rous River Catchment Water Quality Data

Sample	Area	cumul pop	pop betwe	veg cover	sub catch	Stream No	Slope (%)	Elevatn	Land use	Geol	Turbidity (FTU)	NOx	DIP	NH4	TDN	TDP	TPN	TPP	DON	DOP	pH	EC	Temp	DO %SAT	FC	Chl-a	TN	TP
1	0.59	0.9	0.9	68.5	1	1	14.7	190	8	1	5	56	96	6	293	96	71	20	231	0	8.3	374	15.7	89.59	30	0.75	364	116
2	0.38	1.4	1.4	29.4	1	2	20	200	8	1	12	20	67	12	209	88	60	23	177	21	8	122	16.9	88.79	400	0.60	269	111
3	2.07	8.4	8.4	28.4	1	2	8.9	140	8	1	8	33	43	8	188	50	12	16	147	7	7.9	98	18.6	100.93	40	0.74	200	66
4	3.68	18.0	9.6	30.7	1	3	2	90	8	1	5	12	21	5	142	34	59	10	125	13	7.4	80	17.3	81.10	70	0.57	201	44
5	4.13	20.7	2.7	30.8	1	3	2.1	65	10	3	6	14	18	2	162	33	6	8	146	15	7.5	79	18.3	91.29	20	1.01	168	41
6	12.10	57.5	43.7	71.0	1	3	1.3	65	1	3	5	17	24	8	144	39	284	9	119	15	7.5	119	15.8	91.59	50	0.88	428	48
7	3.74	20.2	20.2	69.5	2	3	4.2	60	7	3	8	21	10	9	172	23	7	12	142	13	7.4	65	20.1	90.35	60	2.27	179	35
8	9.89	59.9	10.9	100.0	2	3	5	55	7	3	4	15	9	9	129	21	9	5	105	12	7.6	56	19.5	101.80	0	0.74	138	26
9	8.17	49.0	25.0	100.0	2	3	2.1	80	1	3	4	23	12	9	142	20	16	7	110	8	7.8	54	18.5	98.91	20	0.90	158	27
10	4.01	24.0	24.0	100.0		2	10.6	125	1	1	6	98	14	7	242	30	34	4	138	16	7.8	55	15.8	92.70	10	0.31	277	34
11																												
12	33.38	179.4	21.1	71.9	13	4	0.5	50	7	3	8	10	14	11	162	23	59	20	141	9	7.6	81	19	88.93	190	3.70	221	43
13	33.69	181.5	2.1	71.8	13	4	0.7	45	7	3	7	9	14	8	133	21	54	10	116	7	7.7	82	18.3	82.36	190	1.38	187	31
14	3.39	20.6	10.6	46.9	3	3	1.8	60	7	3	12	17	8	13	233	24	42	16	203	16	7.7	136	17.9	93.39	150	2.40	275	40
15	1.64	10.0	9.6	62.2	3	3	3.3	85	7	3	8	22	9	13	172	24	46	7	137	15	7.6	142	18.4	89.66	325	1.94	218	31
16	0.06	0.0	0.4	0.0	3	1	0.15	180	4	1	35	101	11	5	212	29	54	33	106	18	8.1	109	14.4	82.12	0	0.94	266	62
17																												
18	0.19	1.2	1.2	81.5	1	1	35.5	180	4	1	6	59	70	4	337	88	71	5	274	18	7.9	422	14.7	74.18	20	0.22	408	93
19	0.33	2.0	2.0	69.7	1	1	12.86	185	8	1	38	5	16	29	230	47	97	37	196	31	7.2	262	15.4	27.90	10	2.33	327	84
20	0.19	1.2	1.2	83.9	1	1	23.33	160	4	1	20	7	18	18	199	35	73	45	173	17	7.7	89	16.6	73.05	365	2.00	272	80
21	0.54	3.3	3.3	77.4	1	1	25.5	180	4	1	13	207	30	12	375	43	24	34	156	13	7.1	161	15.7	63.82	20	5.46	399	77
22	2.24	3.8	3.8	85.7	1	2	11.43	180	8	1	5	8	26	5	159	34	18	9	146	8	8.5	133	17.8	99.93	0	0.42	177	43
23	37.88	206.9	4.8	69.6	13	4	0.91	40	8	1	3	10	13	10	221	24	31	12	201	11	7.3	87	17.9	82.74	180	0.93	252	36
24																												
25	38.69	211.8	4.9	69.1	13	4	0.36	35	7	3	4	8	12	7	214	25	116	10	199	13	7.4	89	19.4	95.95	30	1.88	330	35
26	38.39	216.0	4.2	68.7	13	4	0.56	34	10	3	4	6	11	8	288	20	124	14	274	9	7.5	101	15.8	84.73	90	2.56	412	34
27	52.78	339.6	2.0	57.2	13	5	0.57	32	10	3	4	10	11	12	189	21	13	11	167	10	7.5	99	15.7	87.07	20	1.63	202	32
28																												
29	52.96	340.7	1.1	57.3	13	5	0.5	28	10	3	4	9	10	10	186	23	161	15	167	13	7.6	101	15.5	83.49	110	1.38	347	38
30	53.95	350.9	10.2	56.9	13	5	0.33	25	10	3	5	6	10	14	247	30	42	6	227	20	7.5	104	17.1	89.16	60	0.88	289	36
31	0.06	0.4	0.4	0.0	4	1	12	115	6	5	10	31	33	14	303	71	34	32	258	38	7.4	161	17.9	90.54	120	1.00	337	103
32	2.93	33.5	33.5	74.6	4	3	1.82	55	7	3	13	21	6	2	184	24	101	13	161	18	7.4	819	15.7	64.92	2700	8.54	285	37
33	1.06	12.1	12.1	15.0	4	1	10	45	7	3	36	3	5	11	377	16	124	5	363	11	6.4	88	20.8	71.50	670	5.10	501	21
34	13.05	121.6	24.9	38.3	4	4	0.29	40	7	3	7	4	7	5	247	21	43	9	238	14	7.2	139	18.1	96.31	20	1.44	290	30
35	0.24	2.7	2.7	0.0	4	1	11	75	6	5	8	4	8	6	209	27	78	12	199	19	7.2	157	19.8	83.68	20	3.48	287	39
36	0.57	6.5	6.5	83.8	4	2	3.57	75	6	5	9	9	12	11	216	24	119	9	196	12	7.4	240	15.8	67.08	230	1.79	335	33
37	2.49	21.1	11.5	28.1	4	3	9.09	65	6	5	10	29	9	10	191	29	80	14	152	20	7.4	132	15.4	106.12	30	1.13	271	43
38	0.24	1.5	1.5	0.0	4	1	6.47	60	6	5	20	12	6	20	154	19	75	5	122	13	7.2	540	22.2	96.43	20	1.45	229	24
39	4.56	34.0	11.4	14.0	4	3	2.29	57	6	5	8	22	9	2	192	29	2	9	168	20	7.7			87.16	255	0.44	194	38
40a	8.08	73.5	6.0	36.6	4	3	1	45	6	5	8	23	10	6	165	29	61	11	136	19	7.2	179	16.3	69.02	90	1.18	226	40
40b	0.27	3.1	3.1	17.9	4	1	20	100	4	3	7	19	9	15	290	26	11	8	256	17	7.1	333	20.8	89.60	1700	0.79	301	34

Sample	Area	cumul pop	pop betwe	veg cover	sub catch	Stream No	Slope (%)	Elevatn	Land use	Geol	Turbidity (FTU)	NOx	DIP	NH4	TDN	TDP	TPN	TPP	DON	DOP	pH	EC	Temp	DO %SAT	FC	Chl-a	TN	TP
40c	0.57	6.5	6.5	86.5	4	2	13.75	75	4	3	11	75	9	14	224	26	17	8	135	17	7.2	471	18	79.95	210	0.51	241	34
41	0.13	1.5	1.5	83.3	4	1	6.67	45	7	3	8	9	6	8	186	21	71	6	169	15	7.2	157	20	95.01	80	0.75	257	27
42	55.10	362.4	3.4	57.0	13	5	0.66	15	10	2	5	5	9	0	200	28	9	11	195	19	7.4	112.2	18	84.81	20	2.29	209	39
43	54.78	359.0	8.1	57.1	13	5	0.66	17	5	2	4	8	10	20	197	29	40	10	169	19	6.8	108	16.6	78.18	30	0.90	237	39
44	1.92	22.0	22.0	37.7	10	3	1.25	25	5	2	6	3	6	6	114	19	15	5	105	13	6.6	135	19	64.35	10	0.96	129	24
45	1.36	15.6	15.6	8.9	10	2	2.22	25	5	2	6	4	6	2	166	20	21	9	160	14	6.5	144.2	15.2	79.67	20	3.63	187	29
46	61.23	426.1	26.1	53.4	13	5	0.14	12	2	2	4	4	8	0	161	25	52	10	157	17	6.7	119.1	18.2	76.68	195	2.77	213	35
47	0.38	2.3	2.3	100.0	5	1	11.43	140	1	2	4	113	19	3	178	35	78	5	62	16	6.9	79.3	16	73.95	0	0.62	256	40
48	1.86	15.9	13.6	100.0	5	2	10	110	1	2	2	120	17	2	213	35	36	4	91	18	6.8	81.8	15.8	70.11	0	0.58	249	39
49																												
50																												
51																												
52	2.28	25.1	25.1	100.0	5	2	3.75	85	1	2	2	68	9	3	141	24	61	5	70	15	6.8	67.8	16.6	82.79	0	0.46	202	29
53	1.94	21.4	21.4	100.0	5	2	4.62	65	1	2	2	78	7	0	138	22	177	3	60	15	6.6	64.1	16.2	56.16	0	0.29	315	25
54	7.88	86.8	40.3	89.2	5	3	1.54	55	5	2	2	3	6	0	80	21	53	4	77	15	6.2	64.8	19	86.45	30	0.70	133	25
55	14.36	141.1	38.4	80.2	5	4	0.74	45	5	2	2	2	5	0	101	19	8	4	99	14	6.1	63.9	18.8	105.74	60	0.84	109	23
56	17.05	160.0	18.9	78.6	5	4	0.8	35	5	2	2	17	7	1	57	20	129	4	39	13	6.1	65.1	16.7	66.62	0	0.90	186	24
57	18.96	174.4	14.4	73.0	5	4	0.63	30	5	2	2	6	6	1	60	19	140	6	53	13	6.1	94	16.7	50.27	0	1.81	200	25
58	0.37	4.2	4.2	12.5	5	4	0.38	25	5	2	3	6	6	0	63	19	62	7	57	13	6.2	70.7	17	74.80	50	0.77	125	26
59	24.85	214.8	36.2	66.8	5	4	0.59	20	5	2	3	5	6	0	97	21	8	6	92	15	6.4	72.4	16.7	82.35	100	0.89	105	27
60	25.15	217.6	2.8	66.4	5	4	0.5	5	10	2	3	5	6	7	114	20	103	5	102	14	6.4	74	19.1	100.34	40		217	25
61	0.62	7.1	7.1	32.5	8	2	3.33	60	4	2	5	284	8	41	685	18	54	8	360	10	7.3	143	19.1	82.73	20	2.77	739	26
62	0.99	11.3	11.3	38.4	8	2	4.35	40	1	2	3	36	8	4	162	19	47	4	122	11	7.2	133	15	81.31	20	0.49	209	23
63	3.21	36.8	18.4	32.4	8	3	1.39	15	10	2	28	3	9	12	198	28	141	11	183	19	6.8	120	23	96.75	415	2.44	339	39
64	0.85	9.4	9.4	43.8	6	1	1.25	10	10	2	86	5	7	64	1062	23	523	9	993	16	6.9	160	17	12.41	8500	47.61	1585	32
65	3.78	46.3	9.5	27.5	8	3	31.25	10	5	2	6	14	8	6	192	19	67	16	172	11	7	100	16	81.04	305	2.75	259	35
66	2.21	24.4	24.4	21.5	10	3	0.43	10	5	2	11		7	6	241	15	71	7	235	8	7.3	90	15	31.73	40	5.07	312	22
67	109.66	987.8	64.9	49.8	13	5	0.135	5	5	2	7	29	7	10	172	20	76	14	133	13	7	100	16	74.96	60	2.62	248	34
68	15.87	175.0	60.9	18.0	6	4	0.77	25	4	2	11	19	6	6	196	19	70	17	171	13	7.1	80	18	89.78	20	5.39	266	36
69	9.59	105.7	85.0	6.4	6	4	1.67	25	5	2		10	6	69	149		197		70		7	80	16	71.92	200	3.26	346	
70	1.88	20.7	6.7	32.4	6	4	1.25	40	5	2	7	19	8	41	244	23	30	9	184	15	7.2	80	15	76.35	60	2.48	274	32
71	1.27	14.0	14.0	48.3	6	2	2.94	50	4	2	5	34	7	3	131	18	35	8	94	11	6.9	80	20	87.98	20	5.16	166	26
72																												
73	0.06	0.7	0.7	0.0	10	1	0	<10	3	4	8	5	7	573	1006	21	49	4	428	14	4.1	2770	22.9	67.99	0	5.12	1055	25
74	0.21	2.3	2.3	55.5	10	1	0	<10	3	4	13	4	7	5	361	16	233	26	352	9	7.2	798	17.9	80.78	20	28.95	594	42
75	9.46	105.0	15.9	55.2	7	4	0	<10	5	2	10	88	7	28	247	17	103	20	131	10	5.7	87	17.2	49.87	110	4.88	350	37
76	8.52	99.1	10.1	61.3	7	4	0	<10	5	2	16	4	7	5	344	18	44	8	335	11	6	1270	19.4	73.89	230	3.51	388	26
77	7.21	79.5	13.0	72.4	7	4	0.42	15	5	2	5	40	17	7	168	21	41	15	121	4	6.7	73	21.1	115.19	40	3.45	209	36
78	6.03	66.5	6.2	86.6	7	4	0.56	20	5	2	4	90	10	3	221	22	2	5	128	12	6.9	70	19	92.70	40	0.75	223	27
79																												
80	5.47	60.3	30.2	93.6	7	4	1.25	25	5	2	4	89	7	7	268	18	68	9	172	11	6.8	70	16.5	87.02	430	2.55	336	27

Sample	Area	cumul pop	pop betwe	veg cover	sub catch	Stream No	Slope (%)	Elevatn	Land use	Geol	Turbidity (FTU)	NOx	DIP	NH4	TDN	TDP	TPN	TPP	DON	DOP	pH	EC	Temp	DO %SAT	FC	Chl-a	TN	TP
81	2.73	30.1	30.1	100.0	7	2	4	50	1	2	3	88	9	4	221	19	102	6	129	10	6.9	75	15.2	91.22	40	0.59	323	25
82	4.78	75.8	57.9	65.5	7	4	0.63	<10	5	2	10	2	6	1	164	18	92	14	161	12	7	90	17	61.04		8.62	256	32
83	1.91	29.6	29.6	12.7	11	1	0	<10	3	4	27	5	9	0	246	15	423	46	241	6	6.6	4900	19	104.74		15.79	669	61
84	0.19	2.9	2.9	0.0	11	1	0	<10	3	4	32	2	7	0	329	30	975	18	327	23	3.2	1500	23	100.30		21.80	1304	48
85	2.24	35.6	12.5	42.0	11	3	0	<10	3	4	70	3	8	2622		15		8		7	3.2	3500	28	94.63				23
86	1.45	23.1	23.1	49.0	9	2	1.11	<10	5	2	50	3	8	11		31		51		23	5.9	140	19	32.34				82
87	4.06	63.8	28.2	47.5	9	3	0	<10	3	4	8	2	10	0		17		5		7	6.5	8600	22	116.98		2.94		22
88	1.05	17.9	17.9	73.0	9	2	4.62	40	1	2	6	236	16	3	407	32	73	8	168	16	7.1	90	16	89.15	50	0.96	480	40
89	0.56	9.5	9.5	0.0	9	2	2.31	25	5	2	25	3	7	15	350	20	15	7	332	13	6.8	145	19.6	102.55			365	27
90	0.68	7.5	7.5	70.0	10	2	3.75	20	4	2		256	6	12							6.5	93	16.9	64.22	4800			
91	0.13	1.4	1.4	0.0	11	1	10	20	4	2	70	36	7	6	263	20	676	7	221	13	7.4	108	18.5	32.01	30	6.79	939	27
92	131.53	7311.7	16.5	46.1	12	5	3.64	<10	10	stp	18	245	84	119	660	108	390	65	296	24	7.8	203	19.2	120.35	20	25.95	1050	173
93																												
94																												
95	0.57	3.8	3.8	0.0	11	1	0	<10	10	4	67	36	20	510	1893	139	383	55	1347	119	7.4	478	17.5	29.29	3500		2276	194
96	0.87	5.8	2.0	0.0	11	1	0	<10	3	4	14	2	114	10	885	181	319	63	873	67	7	841	23.2	87.60	60	1.40	1204	244
97	1.29	8.6	8.6	0.0	12	1	0	<10	3	4	7	2	8	1	348	11	171	10	345	3	3.9	4400	22.1	74.97	10		519	21
98																												
99	0.44	6.8	6.8	91.2	10	2	3.64	<10	5	2	11	9	6	5	169	20	37	6	155	14	7	110	20.3	95.36	400		206	26
100																												
101	129.02	7294.5	6053.0	45.1	13	5		<10	10	stp	19	250	116	170	712	163	471	57	292	47	7.7	165	19.2	121.21	30		1183	220
102																												
103																												
104	25.42	220.7	3.1	65.8	5	4		<10	2	2	4	13	7	0	73	21	31	3	60	14	7	660	17.4	76.68	156		104	24
105	61.85	433.2	7.1	53.2	13	5		<10	5	2	7	3	8	3	130	23	105	12	124	15	6.9	102	18	82.17	525		235	35
106	184.92	7917.1	2.4	41.2	12	5		<10	9	est	8	3	8	0	221	17	94	10	218	9	7.7	29000	19.8	89.53	0	9.30	315	27
106ii	184.60	7914.7	36.6	41.2	12	5		<10	9	est	11	3	19	1	165	30	66	5	161	11	7.6	26900	20	89.80	0		231	35
107	169.56	7749.5	15.1	42.0	12	5		<10	9	est	12	2	25	0	149	35	152	14	147	10	7.5	20100	19.8	93.12	0	9.60	301	49
108	166.84	7728.6	23.5	42.7	12	5		<10	9	est	12	2	5	0	141	14	211	14	139	9	7.5	17400	19.7	92.25	20		352	28
109	1.03	12.9	12.9	0.0	12	5		<10	9	est	13	2	5	0	193	15	136	14	191	10	7.4	16300	20.8	92.19	50		329	29
110	158.03	7625.9	65.6	44.9	12	5		<10	9	est	14	2	8	0	266	17	189	30	264	9	7.9	4330	19.4	111.19	20		455	47
111	15.58	203.8	23.0	53.6	12	4		<10	9	est	18	90	12	18	342	30	337	41	234	18	7.4	544	17.7	73.99	90		679	71
112	135.97	7354.2	42.5	44.9	12	5		<10	9	est	20	3	8	2	283	28	440	44	278	20	8.1	1770	19.2	124.51	20	19.10	723	72
113	127.84	1241.5	8.2	45.6	12	5		<10	10	est	14	35	31	5	352	55	239	48	312	24	7.5	121	19.1	121.18	30	13.20	591	103
114	123.99	1153.3	52.0	46.7	12	5		<10	9	est	8	3	8	0	167	22	62	15	164	14	7.3	100	18.8	86.10	140		229	37
115	119.42	1101.3	42.8	47.5	12	5		<10	9	est	9	3	7	0	199	22	31	16	196	15	7.4	96	18.9	88.96	150		230	38
116	0.09	1.4	1.4	100.0	12	5		<10	9	est	9	2	13	0	164	16	68	9	162	3	7.7	19900	19.8	91.28	10		232	25
117	180.92	7869.9	41.7	41.1	12	5		<10	9	est	11	2	17	0	127	17	105	12	125	0	7.6	22600	20.1	93.77	20	8.90	232	29
118	6.11	70.1	31.8	42.4	12	5		<10	9	est	9	5	13	0	153	17	142	9	148	4	7.5	19300	19.1	82.34	30		295	26
119	165.04	7705.1	20.5	43.1	12	5		<10	9	est	12	2	11	0	202	19	144	19	200	8	7.5	11100	19.7	94.63	10		346	38
120	162.52	7681.7	13.3	43.8	12	5		<10	9	est	10	2	9	0	137	19	138	23	135	10	7.6	7660	19.6	97.92		12.40	275	42