DEPARTMENT *of*
PRIMARY INDUSTRIES,
WATER *and* ENVIRONMENT

Tasmania

Water Quality Of Rivers In The Great Forester River Catchment

A Report Forming Part of The Requirements for State of Rivers Reporting

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Report Series WRA 99/05-1
June, 1999.

Executive Summary

This section of the 'State of Rivers' report for the Great Forester catchment presents and discusses in detail the results of a year long study into the water quality of rivers and streams in within the catchment. During 1998, sampling was carried out on a monthly basis at a number of sites on the Great Forester River and several of its tributaries. More intensive 'snapshot' surveys of the catchment were also conducted during summer and winter periods. Remote monitoring equipment was also deployed to examine short-term fluctuations in selected water quality variable.

The information contained in this report should be viewed together with the reports on river hydrology, aquatic ecology and river condition. These four reports combined form the "State of River Report ' for the Great Forester River drainage system.

The major findings arising from the study into water quality in the catchment are;

⇒ Rivers in the catchment are generally acidic, with pH levels at most times less than 6.5. Of the 9 sites monitored, pH was consistently lowest at the very top of the Great Forester River and also at Hogarths Rivulet.

⇒ The rivers in the Great Forester catchment are relatively dilute, but show a distinct increase in dissolved salts towards the bottom of the catchment. Conductivity levels range from 50 μS/cm in the upper catchment to 200 μS/cm near the coast. All waters can be classified as Class 1, very low salinity water.

⇒ Baseflow turbidity at most sites was low but can be variable depending on rainfall runoff. During flooding turbidity levels were found to be 200-300% above baseflow conditions, reflecting catchment runoff effects. Highest baseflow turbidity was recorded in the middle reaches of Tuckers Creek during both summer and winter 'snapshot' surveys.

⇒ Nitrogen concentrations in the Great Forester River were highest in the upper reaches during summer. During winter nitrogen levels in the upper and lower reaches of the river are more comparable. Nitrate is a large component of total nitrogen concentrations and is the main cause of seasonal patterns of change in nitrogen concentrations.

⇒ Phosphorus levels across the catchment ranged from very low in Pearly Brook, Hogarths Rivulet and the top of the Great Forester, to moderately high in the Great Forester River at Tonganah and the Arnon River.

⇒ Faecal coliform levels were higher during summer than in winter and on the main river, concentrations during the summer were higher in the upper catchment. Of the tributaries sampled, Tuckers Creek showed highest coliform levels. Results suggest that stock access to rivers may be the major cause for high coliform levels.

⇒ While the concentration of most heavy metals were at or near the limits of detection by laboratory analysis, aluminium concentrations in some rivers ranged from 314 - 431 μg/L. It is likely that the presence of these high levels of aluminium reflect the underlying granite geology and may not pose any environmental threat. Further study is needed to determine if there are any possible impacts of this on aquatic biota.

⇒ Iron levels at several sites were found to be sufficiently high to affect the taste of the water.

⇒ Many water quality parameters were found to be significantly elevated during flooding in September, 1998. Nutrient concentrations were 10 time higher than baseflow conditions. At Forester Rd, instantaneous loads of suspended solids, nitrogen and phosphorus being transported by the river were calculated at 21,470 kg/hr, 328 kg/hr and 39 kg/hr respectively.

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A GLOSSARY OF TERMS

Baseflow
Flow in a stream is essentially a function of overland flow, subsurface flow and groundwater input. During periods when there is no contribution of water from precipitation, flow in a stream is composed of water from deep subsurface and groundwater sources and is termed 'baseflow'.

Bioavailable
The fraction of the total chemical in an environment that can be taken up by living organisms. In water, most chemicals which are attached to particulate material are less bioavailable than forms which are dissolved.

Box and Whisker Plots
One common method of examining data collected at varous sites is to plot the data from each site as a 'box and whisker' plot. These plots display the median (or the middle of the data) as a line across the inside of the box. The bottom and top edges of the box mark the first and third quartiles respectively, indicating the middle 50% of the data. The ends of the whiskers show the extremes of the data and together enclose 95% of the data.

Catchment
The land area which drains into a particular watercourse (river, stream or creek) and is a natural topographic division of the landscape. Underlying geological formations may alter the perceived catchment area suggested solely by topography (limestone caves are an example of this).

Discharge
The volume of water passing a specific point during a particular period of time. It usually refers to water flowing in a stream or drainage channel, but can also refer to waste water from industrial activities.

Dissolved Oxygen
Oxygen is essential for all forms of aquatic life and many organisms obtain this oxygen directly from the water in the dissolved form. The level of dissolved oxygen in natural waters varies with temperature, turbulence, photosynthetic activity and atmospheric pressure. Dissolved oxygen varies over 24 hour periods as well as seasonally and can range from as high as 15 mg/L to levels approaching 0 mg/L. Levels below 5 mg/L will begin to place stress on aquatic biota and below 2 mg/L will cause death of fish.

Ecosystem
An environment, the physical and chemical parameters that define it and the organisms which inhabit it.

Electrical Conductivity (EC)
Conductivity is a measure of the capacity of an aqueous solution to carry an electrical current, and depends on the presence of ions; on their total concentration, mobility and valence. Conductivity is commonly used to determine salinity and is mostly reported in microSiemens per centimetre (µS/cm) or milliSiemens per metre (mS/m) at a standard reference temperature of 25^o Celsius.

Eutrophication
The enrichment of surface waters with nutrients such as nitrates and phosphates, which cause nuisance blooms of aquatic plants and algae.

Export Loads / Export Coefficients
The calculation of export loads of nutrients, or any other parameter, involves using nutrient concentration data collected over a wide variety of flow conditions and from various seasons. This information, when plotted against flow at the time of collection, can reveal relationships between flow and concentration which can then be used to estimate the load of a particular nutrient leaving the catchment (estimates of export loads should be regarded as having no greater accuracy than +/- 15%).

The export coefficient (also known as the Runoff Coefficient) corrects for catchment size so that export loads from variously sized catchments can be compared. The most commonly used formula to perform this correction is;

Discharge (ML) / **Catchment Area** (km^2) = **X** ($mm\ km^{-2}$)
Total Load (kg) / **X** = **Y** ($kg\ mm^{-1}$)
Y / **Catchment Area** (km^2) = **Export Coefficient** ($kg\ mm^{-1}km^{-2}$)

Where Z is the Export Coefficient and is equivalent to Total Load (kg) / Discharge (ML).

Faecal Coliforms (also known as 'thermotolerant coliforms' - eg. *E.coli*)
Faecal coliform bacteria are a sub-group of the total coliform population that are easy to measure and are present in virtually all warm blooded animals. Although measurement of this group is favoured by the NHMRC (1996) as suitable indicators of faecal pollution, it is recognised that members of this group may not be exclusively of faecal origin. However their presence in samples implies increased risk of disease. Pathogenic bacteria are those which are considered capable of causing disease in animals.

General Ions
General ions are those mineral salts most commonly present in natural waters. They are primarily sodium, potassium, chloride, calcium, magnesium, sulphate, carbonates and bicarbonates. Their presence affects conductivity of water and concentrations variable in surface and groundwaters due to local geological, climatic and geographical conditions.

Hydrograph
A plot of flow (typically in a stream) versus time. The time base is variable so that a hydrograph can refer to a single flood event, to a combination of flood events, or alternatively to the plot of all flows over a month, year, season or any given period.

Macroinvertebrate
Invertebrate (without a backbone) animals which can be seen with the naked eye. In rivers common macroinvertebrates are insects, crustaecans, worms and snails.

Median
The middle reading, or 50^{th} percentile, of all readings taken.
i.e. Of the readings 10, 13, 9, 16 and 11
{Re-ordering these to read 9, 10, 11, 13 and 16}

The median is 11.

The **Mean** (or Average), is the sum of all values divided by the total number of readings (which in this case equals 11.8).

Nutrients

Nutrients is a broad term which encompasses elements and compounds which are required by plants and animals for growth and survival. In the area of water quality the term is generally used with only phosphorus and nitrogen in mind, though there are many other elements that living organisms require for survival.

pH and Alkalinity

The pH is a measure of the acidity of a solution and ranges in scale from 0 to 14 (from very acid to very alkaline). A pH value of 7 is considered 'neutral'. In natural waters, pH is generally between 6.0 and 8.5. In waters with little or no buffering capacity, pH is related to alkalinity which is controlled by concentrations of carbonates, bicarbonates and hydroxides in the water. Waters of low alkalinity (< 24 ml/L as $CaCO3$) have a low buffering capacity and are susceptible to changes in pH from outside sources.

Riparian Vegetation

Riparian vegetation are plants (trees, shrubs, ground covers and grasses) which grow on the banks and floodplains of rivers. A 'healthy' riparian zone is characterised by a homogeneous mix of plant species (usually native to the area) of various ages. This zone is important in protecting water quality and sustaining the aquatic life of rivers.

Suspended Solids

Suspended solids are typically comprised of clay, silt, fine particulate organic and inorganic matter and microscopic organisms. Suspended solids are that fraction which will not pass through a 0.45µm filter and as such corresponds to non-filterable residues. It is this fraction which tends to contribute most to the turbidity of water.

Total Kjeldahl Nitrogen (TKN)

The Kjeldahl method determines nitrogen in water and is dominated by the organic and ammoniacal forms. It is commonly used to determine the organic fraction of nitrogen in samples and when the ammonia nitrogen is not removed, the term 'kjeldahl nitrogen' is applied. If the ammonia nitrogen is determined separately, 'organic nitrogen' can be calculated by difference.

Total Nitrogen (TN)

Nitrogen in natural waters occurs as Nitrate, Nitrite, Ammonia and complex organic compounds. Total nitrogen concentration in water can be analysed for directly or through the determination of all of these components. In this report, Total Nitrogen has been calculated as the sum of Nitrate-N + Nitrite-N + TKN.

Total Phosphorus (TP)

Like nitrogen, phosphorus is an essential nutrient for living organisms and exists in water as both dissolved and particulate forms. Total phosphorus can be analysed directly, and includes both forms. Dissolved phosphorus mostly occurs as orthophosphates, polyphosphates and organic phosphates.

Turbidity

Turbidity in water is caused by suspended material such as clay, silt, finely divided organic and inorganic matter, soluble coloured compounds and plankton and microscopic organisms. Turbidity is an expression of the optical properties that cause light to be scattered and absorbed rather than transmitted in a straight line through the water. Standard units for turbidity are 'nephelometric turbidity units' (NTU's) standardised against Formazin solution.

Units and Conversions

mg/L = milligrams per litre (1000 milligrams per gram)
µg/L = micrograms per litre (1000 micrograms per milligram)
e.g. 1000 µg/L = 1 mg/L
µS/cm = Microsiemens per centimeter
m^3s^{-1} = cubic metre per second (commonly referred to as a 'cumec')
ML = 1 million litres (referred to as a 'megalitre')

Acronyms

ANZECC - Australian and New Zealand Environment and Conservation Council
ARMCANZ - Agricultural and Resource Management Council of Australia and New Zealand
DPIWE - Department of Primary Industries, Water and Environment
DPIF - Department of Primary Industry and Fisheries (replaced by DPIWE)
DCHS - Department of Community and Health Services
NHMRC - National Health and Medical Research Council
RWSC - Rivers and Water Supply Commission

B SUMMARY OF NATIONAL GUIDELINES FOR WATER QUALITY

Australian Water Quality Guidelines as per ANZECC (draft - 1998)

As part of a National strategy to "pursue the sustainable use of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development' the Australian and New Zealand Environment and Conservation Council (ANZECC) has been developing guidelines for water quality for a range of Australian waters. Since 1992, a document titled 'Australian Water Quality Guidelines For Fresh and Marine Waters (1992) ' has been available for use as a reference tool for catchment management plans and policies. At the time of its release, the guidelines were based on the best scientific information available.

Since 1995, that document has been under review, and a new draft has recently been released for public comment [ANZECC, draft 1998 #185]. The updated version has changed the emphasis of guideline setting, suggesting a 'risk assessment' approach which utilises the concept of increased risk with increasing departure from 'safe' levels. It also restates the principle that they are simply guidelines to be used in the absence of local data, and that where local data can be obtained, they should be used to develop local water quality standards. This needs to be kept in mind when examining the following tables which summarise the new draft guidelines. The figures quoted are suggested as interim trigger levels for assessing risk of adverse effects on different ecosystem types (for essentially natural ecosystems).

1. Proposed Trigger Levels for Nutrients

Ecosystem Type	**TP** (µg/L)	**TN** (µg/L)	**Key Ecosystem-specific factors**
Lowland River	37	1600	- light climate (turbidity)
			- flow
			- grazing
			- bioavailable nutrient [ ]
Upland River	35	340	- light climate (turbidity)
			- substrate type
			- bioavailable nutrient [ ]
			- grazing
Lakes and Reservoirs	50	440	- light climate (turbidity)
			- mixing (stratification)
			- bioavailable nutrient [ ]

2. Proposed Trigger Levels for Dissolved Oxygen, Suspended Particulate Matter and Turbidity.

Ecosystem Type	**DO** (%sat)	**Susp. Solids#** (mg/L)	**Turbidity** (NTU)
Lowland River	90	6*	10
Upland River	92	2*	5
Lakes and Reservoirs	90	2*	4.5

Recommend additional work to establish load based trigger levels;
* Professional judgement

3. Proposed Trigger Levels for Conductivity, Temperature and pH.

Ecosystem Type	**EC (mS/cm)**	**Temp. Increase**	**Temp. Decrease**	**pH**
Lowland River	> 500*	< 80^{th} %ile	>20^{th} %ile	6.6 - 8.0
Upland River	> 110*	< 80^{th} %ile	>20^{th} %ile	6.5 - 7.5
Lakes and Reservoirs	> 60*	< 80^{th} %ile	>20^{th} %ile	7.8 - 8.3

* Professional judgement;

4. Proposed Microbiological Guidelines

The new guidelines for recreational waters propose a ‘Bacterial Indicator Index’ which requires routine sampling (at least 5 samples over a regular period not exceeding one month). It utilises statistics of the entire dataset to form the index in the following manner;

Bacterial Indicator Index = 2.5 x median/100mL + 80^{th} percentile/100mL

Using this formula to calculate the index, the following guideline has been suggested;

Primary Contact (eg swimming)

Bacterial Indicator Index should not exceed 800 for thermotolerant coliforms
or 300 for enterococci

Where more intensive monitoring is carried out the index should not exceed 550 for thermotolerant coliforms, or 200 for enterococci

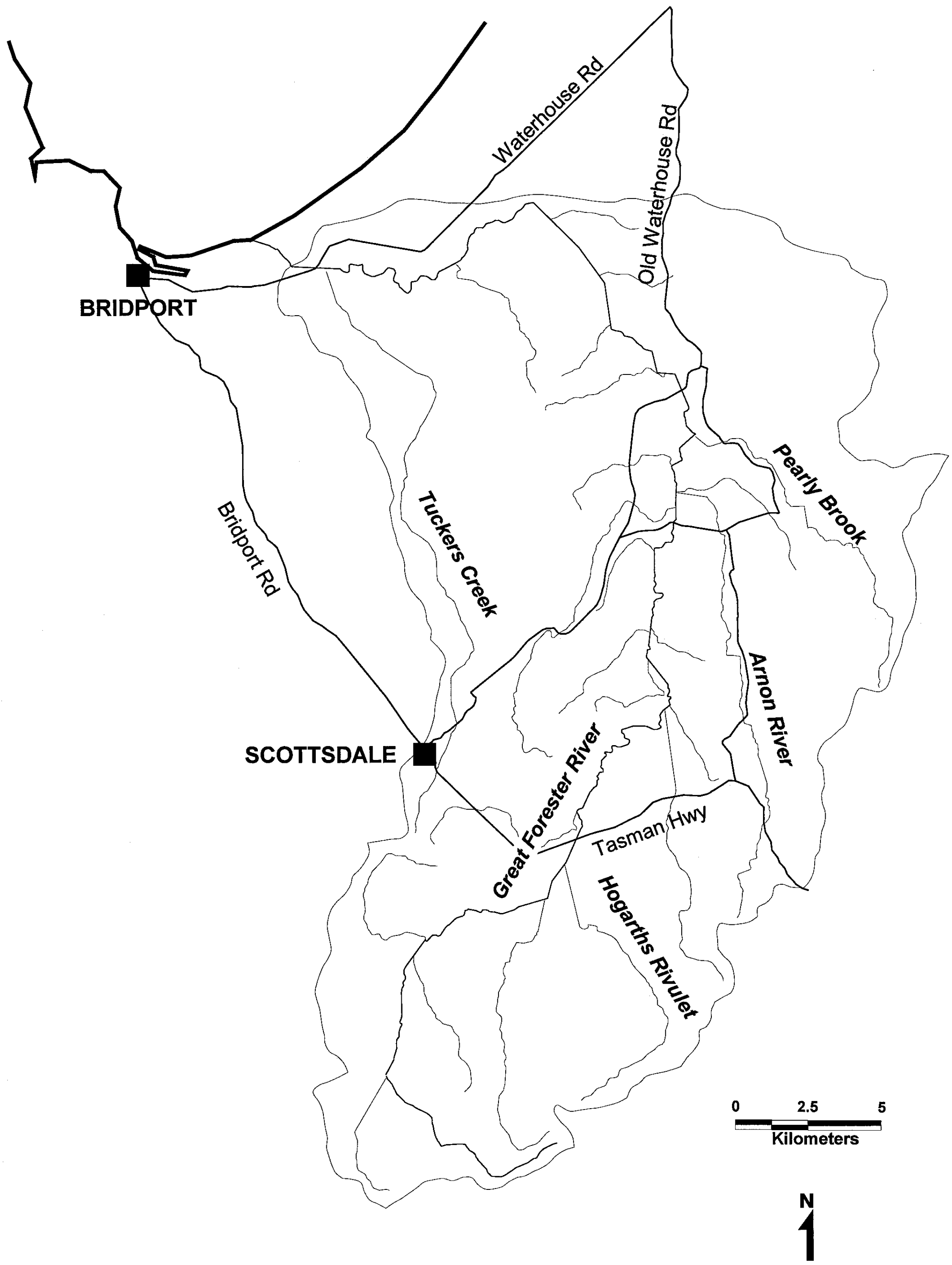
Secondary Contact (eg boating)

Bacterial Indicator Index should not exceed 5000 for thermotolerant coliforms
or 2000 for enterococci

National Health and Medical Research Council - Drinking Water

For drinking water, guidelines published by the National Health and Medical Research Council [NHMRC, 1996 #34] suggest that no thermotolerant coliforms (eg *E. coli*) should be present in water used for drinking.

Figure 1.0 Great Forester River Catchment



Water Quality of Rivers in the Great Forester Catchment

1 Historical Data

The lack of a centralised database which is actively used and updated regularly by all Government agencies engaged in water monitoring makes it difficult to collate and report on historical data from the catchment. However, the database currently used by the DPIWE contains some data collected by water managers in the past (DPIF, RWSC, DCHS, etc.). It is this data which will be briefly presented and commented on in this section. Significantly more resources would be needed to carry out a comprehensive report of all the data which has been collected by the various agencies and was considered beyond the capabilities of this study. It was also considered more important that data on the current conditions within the catchment be collected. Although every effort has been made to check data where possible, the quality of this data is generally unknown and therefore should be viewed with this in mind.

Interrogation of the HYDROL database at DPIWE revealed that some intermittent water quality sampling has occurred at two sites in the catchment; Great Forester at Forester Rd (Site #19201) and to a lesser extent at Great Forester downstream of Ruby Creek (Site # 1153). The following discussion will centre on the site with the most data (Site # 19201) where various water samples and tests appear to have been carried out during routine visits to the site for maintenance of stream gauging equipment.

Figure 1.1 shows the river level recorded during each visit when some water quality monitoring was carried out. It is important to note that the large majority of site visits were carried out at or below 0.5 metres, which corresponds to flows less than 5 m^3s^{-1}. One visit was carried out during a significant flood of over 3.5m (corresponding flow of over 80 m^3s^{-1}).

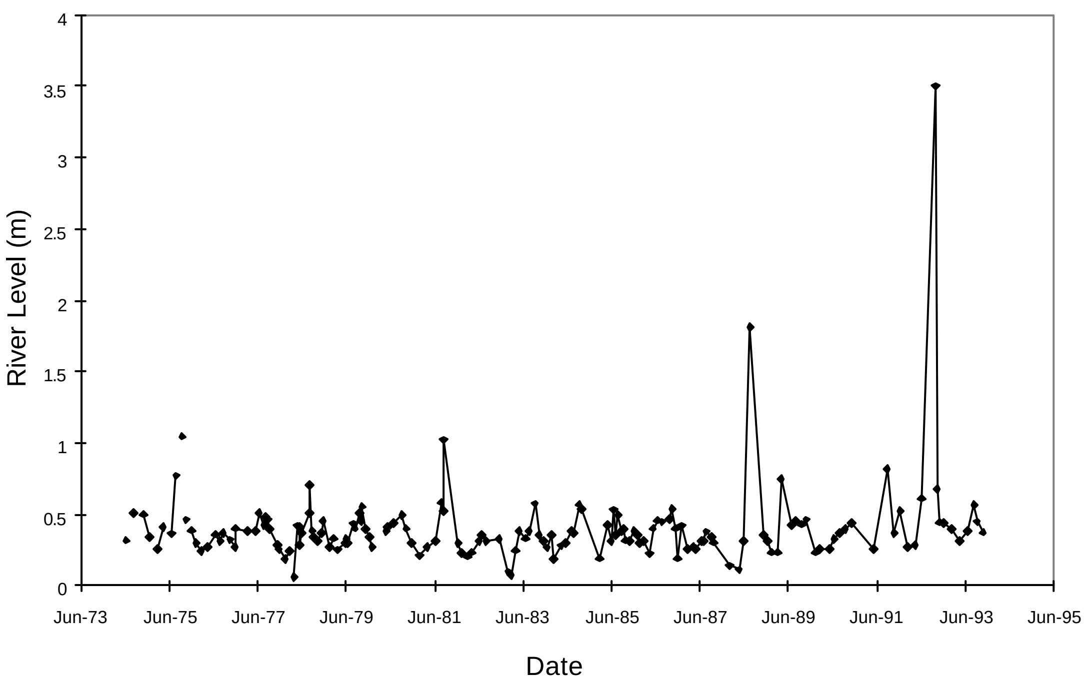


Figure 1.1 River level recorded during site visits when water quality records were taken.

Tables 1.1a - 1.1e give statistics of the majority of data collected at this site. Most of the data has been gathered between 1974 and 1989, when there appears to have been some effort made to collect data on at least an intermittent basis. The largest datasets are for water temperature and pH, both of which appear to have been collected during routine visits to the site to maintain stream flow recording equipment.

Table 1.1a Statistics of Historical Record - Great Forester River upstream Forester Road (Hydrol 19201)

	River Level (m)	Temperature (°C)	Lab pH	Field pH	Turbidity (NTU)
Parameter Number	100	101.00	154.01	154.08	136.01
Number of Readings	180	179	100	75	13
Period of Record	1974 - 1996	1974 - 1996	1974 - 1993	1982 - 1994	1986 - 1989
Maximum	3.5	21	8.6	7.4	63
Minimum	0.064	2	5	5.2	2.3
Average	0.40	11.41	6.55	6.35	11.69
Median	0.361	11	6.6	6.2	5.6

Water temperature in the Great Forester has been measured as low as 2 °C (winter 1976) and as high as 21 °C (summer 1989). The time series plot of this data shows the seasonal changes in water temperature as well as the scale of inter-annual variation (Figure 1.2). From this graph it can be seen that in general winter temperature in the river drops to about 6 °C and summer water temperature reaches about 18 °C. As this data has been collected on an infrequent and intermittent basis, no valid test for trends can be undertaken.

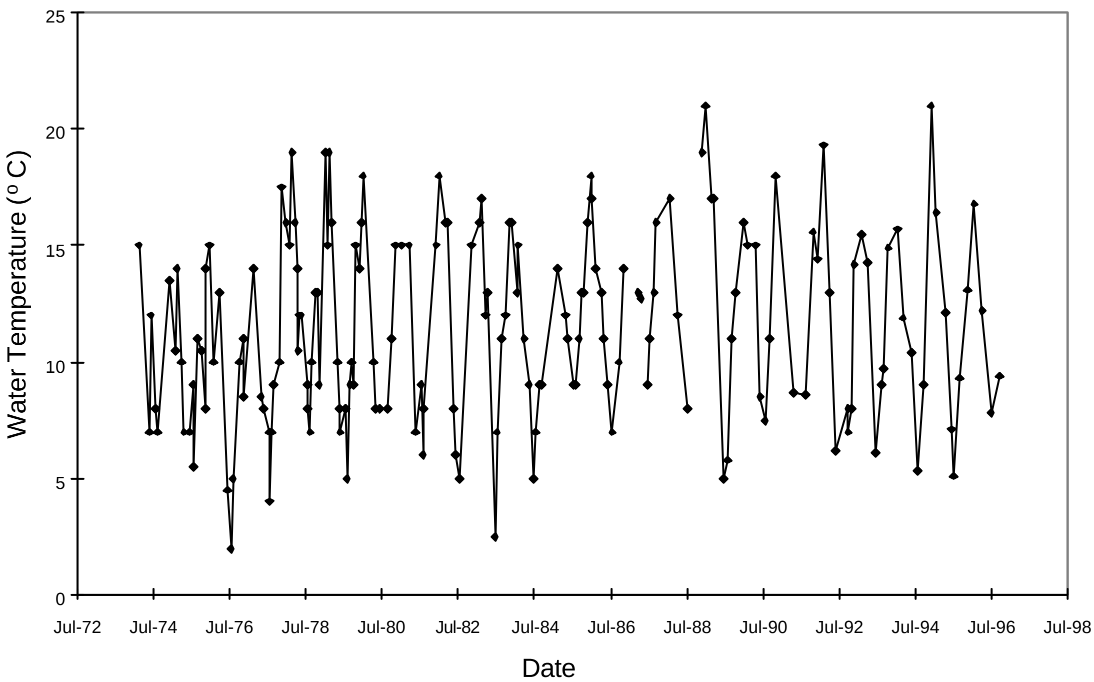


Figure 1.2 Time series plot showing seasonal and inter-annual variation in water temperature in the Great Forester River at Forester Rd (HYDROL Site # 19201).

The pH of the Great Forester at Forester Rd appears to be generally acidic, with an average pH of about 6.35 or 6.55 depending on the method of measurement. The combined data from both laboratory testing of bottled samples and field tests using Litmus paper is plotted below in Figure 1.3. The data recorded from bottled samples (mostly prior to 1980) appears to fluctuate between 5.7 and 7.6, with the exception of a two samples which are significant outliers. The variance of both datasets are comparable, and neither show obvious seasonal changes. It should be noted that both methods of pH testing are not particularly robust in terms of measuring environmental water and should be viewed as low quality data.

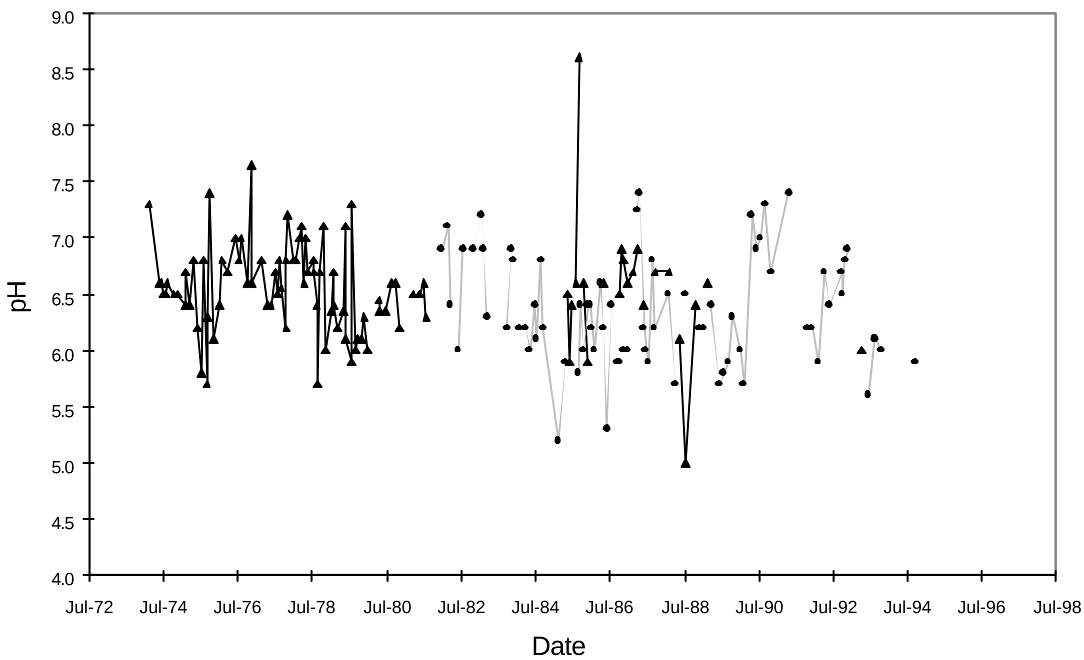


Figure 1.3 Plot showing variation in field pH in the Great Forester River at Forester Rd (HYDROL Site # 19201). {pH recorded from bottled samples plotted as solid triangles; pH measured on-site using litmus paper plotted as diamonds}.

There is limited historical data available for nephelometric turbidity in the Great Forester River although there is more record for the older hellige version (Table 1.1b). What data is stored in HYDROL shows that turbidity during baseflows appears to be about 5.6 NTU (or about 5.8 Hellige). The average (in both cases) is higher than the median due to single high readings which were measured when the site was visited during minor flooding in July 1988 (1.8 m) and a small 'fresh' in June 1985 (0.53m).

Table 1.1b Statistics of Historical Record - Great Forester River upstream Forester Road (Hydrol #19201)

	Turbidity (Hellige)	**Field Conductivity T_{ref} 25°C (mS/cm)**	**Apparent Colour (Hazen Units)**	**Suspended Solids (mg/L)**
Parameter Number	136.08	141.01	123.01	171.00
Number of Readings	34	47	43	44
Period of Record	1974 - 1986	1983 - 1996	1974 - 1989	1974 - 1989
Maximum	64	171	250	66
Minimum	0.5	50	5	0.4
Average	9.28	99	58	13.5
Median	5.78	97.4	50	8.5

The historical record also shows that conductivity generally fluctuates around 100 µS/cm but can reach as high as 171 µS/cm and get as low as 50 µS/cm. A graphical presentation of this data is given in Figure 1.4 and shows that while some data was collected around 1983, the majority is for the period 1989 to 1996.

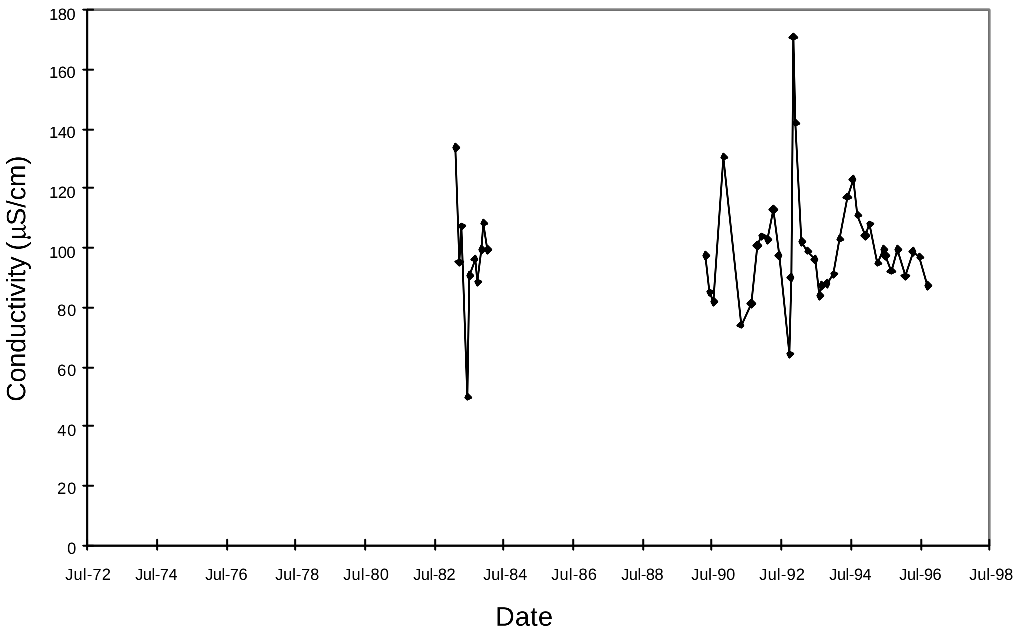


Figure 1.4 Plot showing variation in conductivity (T_{ref} 25 ^{o}C) in the Great Forester at Forester Rd using the historical data (HYDROL Site # 19201).

Apparent colour, which is a measure of the amount of dissolved and very fine organic material in water, appears to vary around 50 - 70 Hazen Units under normal flows in the Great Forester River (Figure 1.5). Colour also tends to increase during higher flow events when finer material is present in greater quantities in the water column.

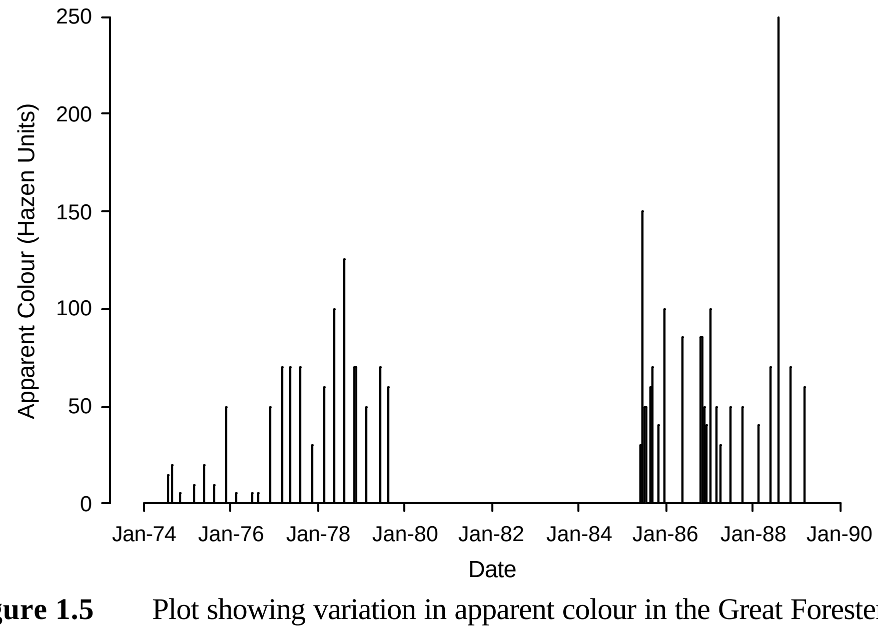


Figure 1.5 Plot showing variation in apparent colour in the Great Forester at Forester Rd using the historical data (HYDROL Site # 19201).

Suspended solids is generally less than 15 mg/L, but like turbidity and colour, the data for suspended solids shows that concentrations can increase during higher flows. Concentrations of suspended solids greater than 50 mg/L were record in the Great Forester during the winters of 1978 and 1985. The data for suspended solids is presented graphically in Figure 1.6.

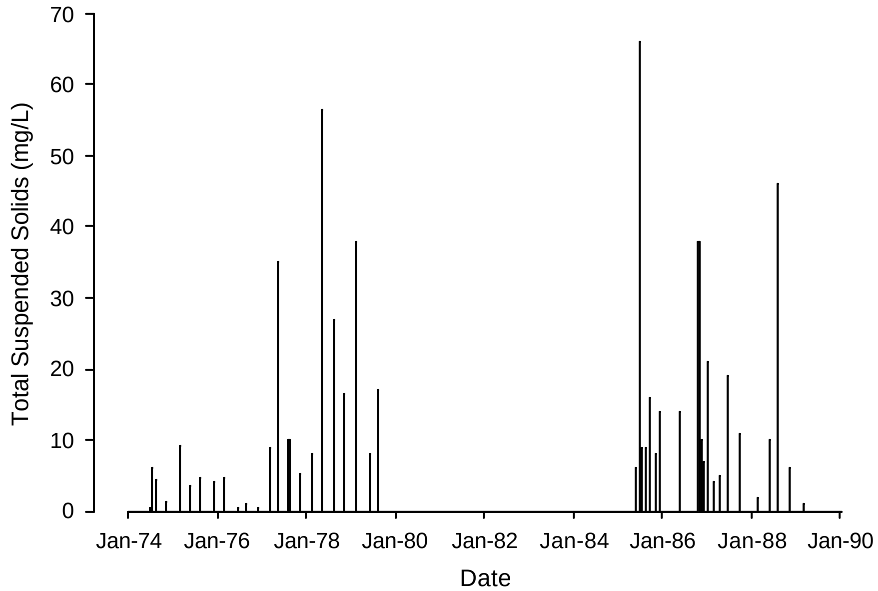


Figure 1.6 Plot showing variation in suspended solids in the Great Forester at Forester Rd using the historical data (HYDROL Site # 19201).

The summary statistics of all other data presently stored on HYDROL is presented in Tables 1.1c - 1.1e. The data of most interest is that for dissolved oxygen, which indicates that past conditions in the Great Forester at Forester Rd have been quite healthy. Other data in these tables (most of which was collected during a short period between 1974 and 1979) indicate that the Great Forester is generally dilute and contains very low concentrations of dissolved minerals. The 6 records for nutrients tend to indicate that levels in the river are relatively low, but can reach moderately high levels (ie maximum Nitrate/N and Phosphate concentrations 0.994 mg/L and 0.41 mg/L respectively).

Table 1.1c Statistics of Historical Record - Great Forester River upstream Forester Road (Hydrol #19201)

	Filterable Residues (mg/L)	**Dissolved Oxygen (mg/L)**	**Total Calcium (mg/L)**	**Total Iron (mg/L)**
Parameter Number	32901	26600	21800	24800
Number of Readings	45	19	6	6
Period of Record	1974 - 1989	1974 - 1983	1974 - 1979	1974 - 1979
Maximum	92	11.9	2.6	0.8
Minimum	34	8	1.6	0.02
Average	65	10.4	2.07	0.39
Median	67	10.4	2.05	0.37

Table 1.1d Statistics of Historical Record - Great Forester River upstream Forester Road (Hydrol #19201)

	Total Magnesium (mg/L)	Total Potassium (mg/L)	Silica as SiO2 (mg/L)	Total Sodium (mg/L)
Parameter Number	254.00	273.00	275.00	280.00
Number of Readings	6	6	6	6
Period of Record	1974 - 1979	1974 - 1979	1974 - 1979	1974 - 1979
Maximum	1.8	1.35	13	10.5
Minimum	0.4	0.6	6.3	4.3
Average	1.27	0.83	9.93	7.42
Median	1.45	0.73	10.35	7.45

Table 1.1e Statistics of Historical Record - Great Forester River upstream Forester Road (Hydrol #19201)

	Total Sulphate (mg/L)	Nitrate / N (mg/L)	Total Phosphate (mg/L)	Free Ammonia / N (mg/L)
Parameter Number	283.00	260.02	268.02	260.09
Number of Readings	6	6	6	6
Period of Record	1974 - 1979	1974 - 1979	1974 - 1979	1974 - 1979
Maximum	2.5	0.994	0.41	0.16
Minimum	0.4	0.124	0.003	0.02
Average	1.48	0.52	0.08	0.07
Median	1.25	0.486	0.01	0.06

What appears to have been a short-term study was also undertaken at a site upstream of Forester Rd, at a location labelled Great Forester downstream Ruby Creek (HYDROL Site #1153). This site is approximately 2 km upstream of the stream gauging site which is currently still in operation by the DPIWE. Every three months between November 1979 and March 1982, sampling was carried out at this site by the RWSC. During that time a total of 10 visits were undertaken, and two water samples were collected for comprehensive analysis. The results of this brief study are summarised in Table 1.2a&b and highlights of the laboratory analysis results are shown in Table 1.3 below.

Comparison of the data in Table 1.2a with data from Table 1.1a&b shows that there are some differences in water quality between the two sites. especially with respect to colour and turbidity (Hellige), both of which are higher at this site compared to the greater dataset for Site #19201. Water at this site also appears to be less acidic. However, in all other respects, water quality at this site is similar to that at Site #19201.

Table 1.2a Statistics of Historical Record - Great Forester River downstream Ruby Creek (Hydrol #1153)

	River Flow (m)	Temperature (°C)	Lab pH	Apparent Colour	Turbidity (Hellige)
Parameter Number	140	101.00	154.01	154.08	136.01
Period of Record	1979 - 1982	1979 - 1982	1979 - 1982	1979 - 1982	1979 - 1982
Maximum	7.21	19	7.6	125	37.5
Minimum	0.66	7	6.9	20	3.1
Average	2.43	13.15	7.23	70	15.83
Median	2.07	13.0	7.25	72.5	10.1

(n = 10)

Table 1.2b Statistics of Historical Record - Great Forester River downstream Ruby Creek (Hydrol #1153)

	Dissolved Oxygen (mg/L)	**Filterable Residues (mg/L)**	**Suspended Solids (mg/L)**
Parameter Number	266.00	329.01	171.00
Period of Record	1979 - 1982	1979 - 1982	1979 - 1982
Maximum	11.2	83	49
Minimum	7.4	48.5	4
Average	9.34	67.6	17.5
Median	9.2	69	8

(n = 10)

Other features of the data are that lowest concentrations of most parameters were recorded on 13/2/80, when flows were lowest. Highest levels of suspended solids, turbidity and colour were recorded during 2/9/80 when river flow was higher (7.21 m^3s^{-1}).

Table 1.3 Data from laboratory analysis of two samples taken from the Great Forester River d/s Ruby Creek. Sample dates are shown.

Analyte		**3/6/80**	**10/3/81**
Nitrate N	(mg/L)	0.29	0.42
Silica	(mg/L)	11.2	13.6
Calcium	(mg/L)	3.6	2.8
Total Sulphate	(mg/L)	3	3.1
Sodium	(mg/L)	9.6	10.4
Total Hardness	(mg/L)	15	14.5

2 Waterwatch Activities

Waterwatch activities began in the Scottsdale area following the accidental release of pyrethrum and caustic soda into the Great Forester River in April 1994. The spill killed all of the macroinvertebrate and fish life in a section of the Great Forester River, and together with mounting community concern over other pollution incidents and perceptions of atrazine contamination of town water resulted in a public meeting from which 'Dorset Waterwatch' was formed. The members of this group represent a wide range of interests including education, forestry, local government, agriculture, aquaculture, industry, health services and recreation.

The Dorset Sustainable Development Strategy, developed by Dorset Council through consultation with all stakeholders and sectors of the community, has identified water as a key issue in terms of protection of natural resources. Dorset Council have been most supportive of Waterwatch and provided a chairperson in the initial stages of forming the group and $3,000 for the purchase of chemicals and equipment. They continue to provide administrative support in the form of office space, computer, phone, postage, photocopying and an annual audit. Since 1996 Dorset Waterwatch have received financial assistance through NHT to employ a regional coordinator.

The group monitors water quality in the 3 major rivers in the municipality, the Brid, Ringarooma and Great Forester as well as Cox's Rivulet and waterways in the Waterhouse Protected Area. The data is used to gain a picture of baseline results as well as highlighting areas in need of improvement. The group also runs a community education campaign which has been fuelled by issues such as elevated turbidity levels during flood events in the major rivers and high phosphate levels in Coxs's Rivulet.

In the Great Forester River system, Waterwatch has sampled at 11 sites since the start of monitoring in 1995. A significant amount of water quality data has been collected at 2 sites on the Great Forester River (Table 2.1); at the water supply intake for the township high in the headwaters of the Great Forester and at a site down in the lower reaches of the river near to the stream flow monitoring site operated by the DPIWE. Most other sites have only had infrequent visits.

TABLE 2.1 Location of sites sampled by Dorset Waterwatch group between June 1995 and November 1998.

Site	Code	Easting	Northing	Site Visits
Great Forester at WS Intake	GFO010	542200	5431600	11
Great Forester at Fish Farm	GFO011	542300	5432300	5
Great Forester at Harris Br	GFO021	542400	5432500	3
Great Forester at 10-Mile Track	GFO030	542500	5435600	3
Great Forester at Tonganah - Shearer's	GFO039	548600	5440300	4
Great Forester at Tonganah - Hwy	GFO040	548500	5440300	7
Great Forester - SG Stn	GFO068	551100	5447400	4
Great Forester - Forester Rd	GFO070	551900	5451100	17
Great Forester - Scout Cabin	GFO075	552400	5454400	1
Great Forester - Waterhouse Rd	GFO080	539500	5460000	6
Hogarths Ck u/s Plant	HOG020	547400	5438700	2

At the water supply intake the data (Table 2.2a&b) clearly shows that water quality is very good, with healthy dissolved oxygen levels, low turbidity and conductivity and cool water temperatures. The pH at this site is quite low and nutrient levels (as indicated by ortho-phosphorus) on all sampling occasions was at the detection limits of the testing kit used by the group.

TABLE 2.2 Dorset Waterwatch monitoring data from the Great Forester River at town water supply offtake (collected 17/6/96 - 20/10/98).

(2.2a)

	Temperature (^{o}C)	Field pH (litmus)	Dissolved O_2 (mg/L)	Dissolved O_2 (% Sat)
Number of Readings	9	7	6	6
Maximum	13.1	6	12	100
Minimum	5.4	5.5	9	75
Average	8.0	5.8	10.7	90
Median	7.6	6	10.5	91

(2.2b)

	Turbidity* (NTU)	Ortho-phosphorus as P* (mg/L)	Conductivity (mS/cm)
Number of Readings	9	9	7
Maximum	< 7	0.015	30
Minimum	< 7	0.015	10
Average	< 7	0.015	17.1
Median	< 7	0.015	20

* Where data has been recorded as "<", half the limit of detection was used to calculate statistics. This is standard practice for calculation of summary statistics. The limit of detection for the Waterwatch ortho-phosphorus test is 0.015 mg/L.

Further down the Great Forester, where Forester Road crosses the river, temperature and conductivity are slightly higher, dissolved oxygen is slightly lower and pH is much the same as at the uppermost site (Table 2.3a&b). Unlike the upper site, higher turbidity and ortho-phosphorus levels were measured at this site, although the majority of readings were still near the detection limits of the monitoring equipment.

TABLE 2.3 Dorset Waterwatch monitoring data from the Great Forester River at Forester Road (collected 17/6/96 - 20/10/98).

(2.3a)

	Temperature (^oC)	**Field pH (litmus)**	**Dissolved O_2 (mg/L)**	**Dissolved O_2 (% Sat)**
Number of Readings	15	13	8	9
Maximum	18.0	6.5	11	110
Minimum	5.7	5	6	52
Average	10.4	5.9	9.4	95.4
Median	10.0	6	10	100

(2.3b)

	Turbidity* (NTU)	**Ortho-phosphorus as P* (mg/L)**	**Conductivity (mS/cm)**
Number of Readings	17	17	15
Maximum	29	0.045	100
Minimum	< 7	< 0.015	10
Average	9.3	0.018	51
Median	< 7	0.015	50

* Where data has been recorded as "<", half the limit of detection was used to calculate statistics. This is standard practice for calculation of summary statistics.

Graphs showing the relative differences in water quality at three sites on the Great Forester are plotted below (Figures 2.1, 2.2 and 2.3). As would be expected in any reasonably large river, water temperature and conductivity increase towards the river mouth. This is also true for nutrients, however the results for ortho-phosphorus are especially noteworthy as they indicate that there may be some nutrient enrichment of the Great Forester in the locality of Tonganah. Between Tonganah and Forester Road, the ortho-phosphorus levels appear to decrease as inputs to the river drop off. However, this is not statistically significant as fewer samples were taken at Tonganah compared to Forester Road, making calculation of the mean concentration at Tonganah less accurate.

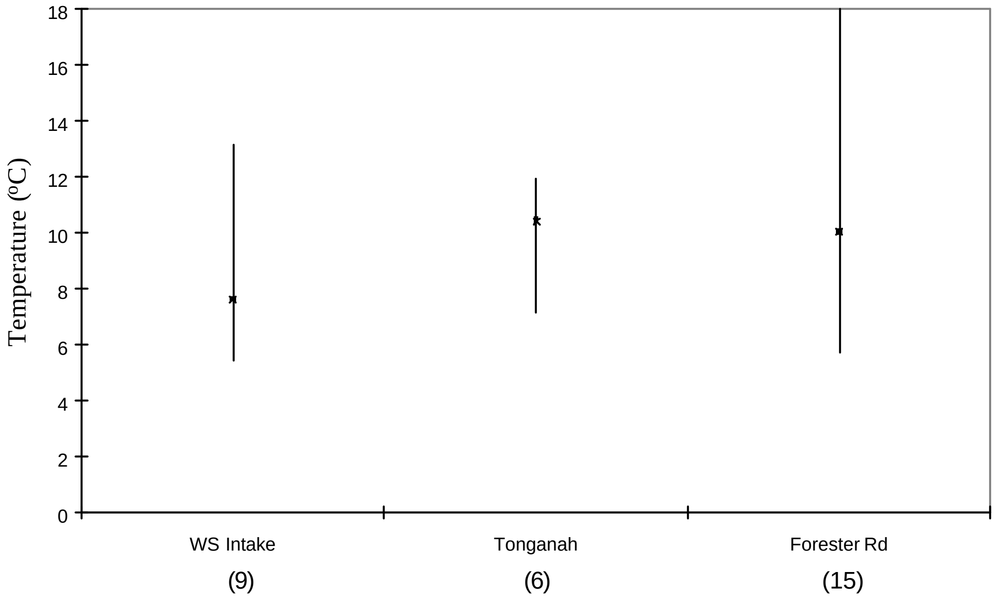


Figure 2.1 Difference in water temperature at three sites down the length of the Great Forester River (numbers in brackets indicate the number of records at each site). # The vertical bars show the spread of the data.

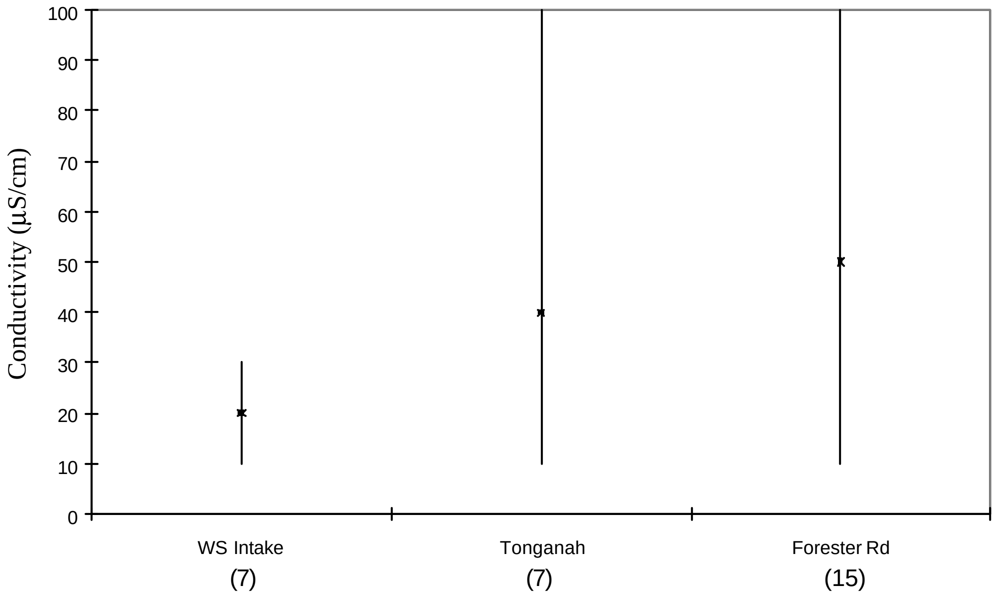


Figure 2.2 Difference in conductivity at three sites down the length of the Great Forester River (numbers in brackets indicate the number of records at each site). # The vertical bars show the spread of the data.

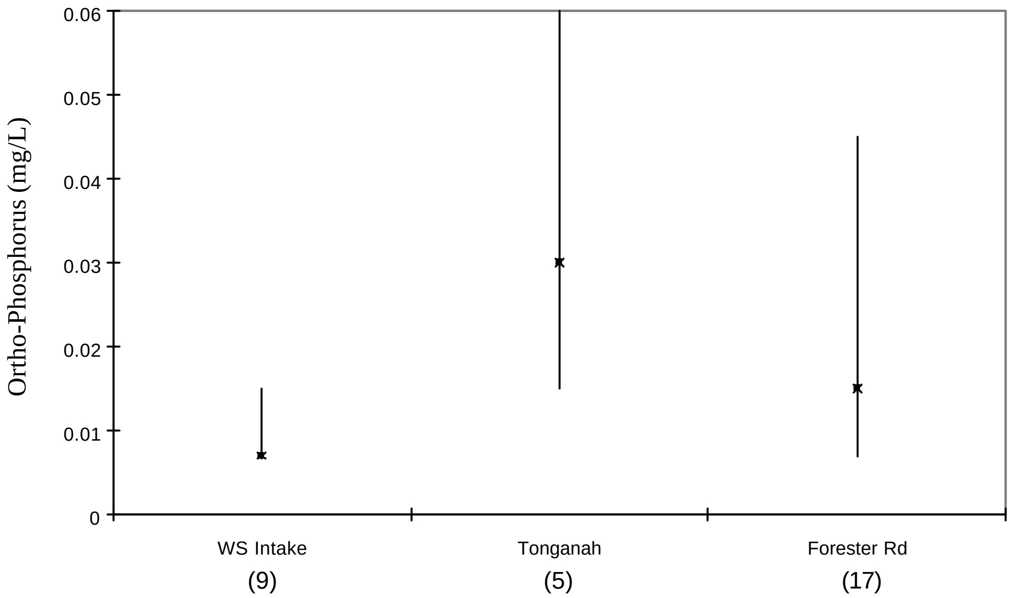


Figure 2.3 Difference in ortho-phosphorus at three sites down the length of the Great Forester River (numbers in brackets indicate the number of records at each site). # The vertical bars show the spread of the data.

Although the resources of the Dorset Waterwatch group are relatively restricted, the data they have collected has demonstrated some of the basic features of water quality in the Great Forester and has highlighted one area where nutrient input to the main river may be having an impact. As part of the present DPIWE study, sites were chosen at both Tonganah and Forester Road so as to over-lap these Waterwatch sites and provide confirmation of their nutrient status.

3 Current Study

The following water quality data was collected during 1998 in response to a need for information on water quality in the catchment for the purpose of catchment management and water allocation planning. The main aim of the project was to collect current data on the ambient quality of water throughout the catchment and report on background conditions as well as highlight areas where water quality is degraded. These data, when viewed in conjunction with land use and river condition information, should assist in identifying sites or areas which could be targeted for remediation activities in the future.

The strategy for data collection was three tiered. Monthly visits were undertaken at some sites to determine the physico-chemical nature of water quality. At two of these sites, sampling for nutrients and dissolved material was carried out. The second tier of sampling involved catchment-wide ‘snapshot’ surveys covering a multitude of sites throughout the catchment, in both the main river and its tributaries. The third tier of sampling involved the use of in-stream logging equipment to examine diurnal changes in dissolved oxygen and other water quality parameters at two sites.

No sampling for pesticides was undertaken due to the lack of available funds (as testing is very expensive) and also because of difficulties with regards to effective sampling for these compounds. Very often, these chemicals are present in the water column for a brief time and cannot be detected only a short while later. Sampling therefore needs to be very targeted and is usually very site specific and was considered outside the scope of this study.

3.1 Monthly Monitoring

Monthly sampling was carried out at 2 sites on the Great Forester River while field testing for physico-chemical parameters was carried out at a further 7 sites on both the main river and tributaries. The location and grid references of all sites are listed in the table below (Table 3.1) and shown in a catchment map in Figure 3.1.

Table 3.1 Location of sites where monthly water quality monitoring was carried out during the present study.

Site Name	Code	Easting	Northing	Monitoring Type
Tuckers Ck u/s Gt Forester	GF18	539925	5459725	Phys-chem
Gt Forester at Old Waterhouse Rd	GF4	552400	5455750	Phys-chem + Samples
Gt Forester at Forester Rd	GF6	551900	5451125	Phys-chem
Arnon River at Forester Rd	GF25	553550	5450750	Phys-chem
Pearly Brook	GF22	553650	5453875	Phys-chem
Gt Forester at Tonganah	GF10	548525	5440250	Phys-chem + Samples
Hogarths Rivulet at Cuckoo Rd	GF30	548900	5437100	Phys-chem
Gt Forester at 10 Mile Track (No. 1)	GF13	545125	5437625	Phys-chem
Gt Forester u/s trout farm	GF16	542350	5431300	Phys-chem

The physico-chemical parameters tested on site included pH (compensated for temperature), electrical conductivity (corrected to reference temperature 25 ^oC), water temperature, turbidity and dissolved oxygen. Water samples were taken monthly and analysed for the following nutrients; ammonia nitrogen (NH_3/N), nitrate nitrogen (NO_3/N), nitrite nitrogen (NO_2/N), total Kjeldahl nitrogen (TK/N), dissolved reactive phosphorus (DR/P) and total phosphorus (TP). Total nitrogen (TN) was derived using the formula;

$$TK/N + NO_3/N + NO_2/N.$$

Every 2 months samples were also taken for general ion analysis to determine the content of various dissolved salts. These included determination of iron, calcium, magnesium, sulphate, chloride, sodium, potassium, silica, hardness, colour, alkalinity and suspended solids concentrations.

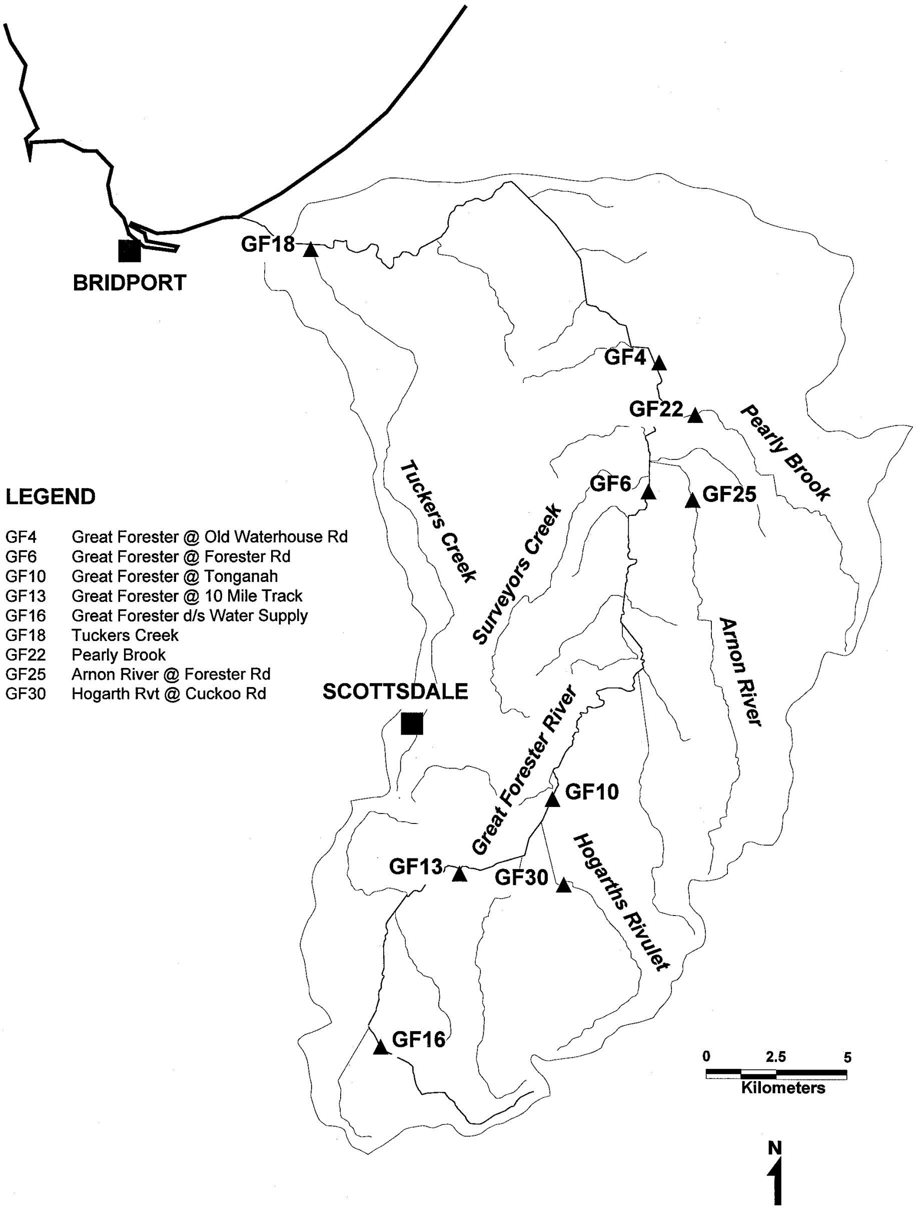
3.2 Physico-Chemical Results

Water Temperature

Water temperature is relatively uniform throughout the length of the Great Forester River (Figure 3.2). With the exception of the uppermost site (GF16) where temperature was much lower than other sites in the main river, water temperature at all sites in the river varied between a minimum of about 5 ^oC and a maximum of about 19.5 ^oC. The difference between the uppermost site and the next site downstream at Ten Mile Track is most likely due to canopy cover of the upstream site which prevents direct sunlight warming the stream bed. The top reaches of the Great Forester flow through pine plantations which totally cover the stream, preventing any light penetration along much of the river in this area.

The difference between GF16 and sites lower on the river are shown in another plot in Figure 3.3. This graph shows the seasonal variation in water temperature at several sites in the Great Forester. The difference between the sites higher in the catchment and the lower site is most significant during the warmer months (November - March).

Figure 3.1 Locations of sites monitored monthly in the Great Forester catchment during 1998.



Most tributary sites showed temperatures which were lower than main river sites, except Tuckers Creek which is low in the catchment and is fairly exposed (ie is in a farming area with open paddocks surrounding it). Shading is also the likely explanation for slightly lower water temperatures at sites located on other tributaries.

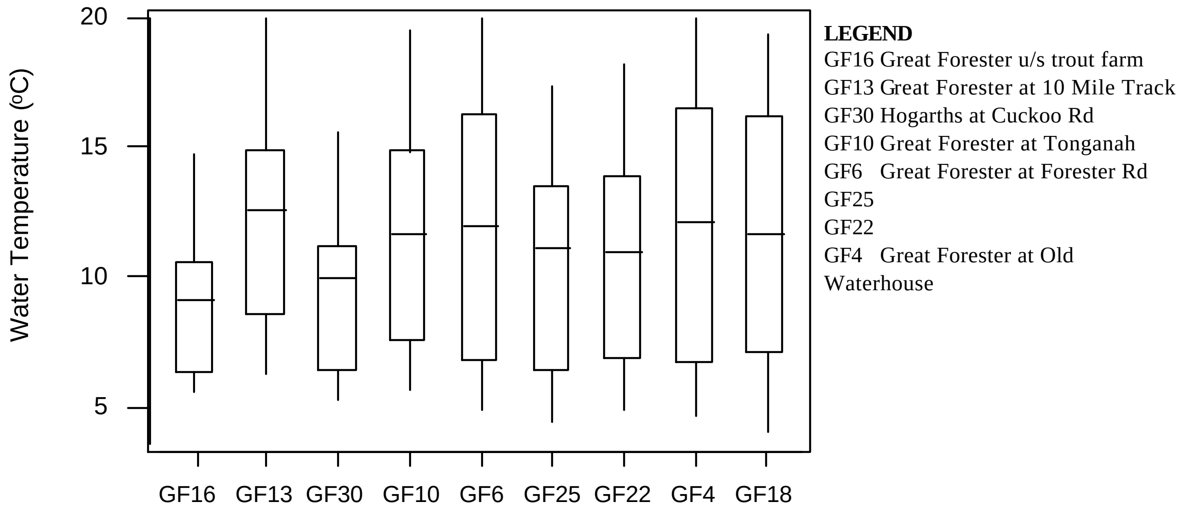


Figure 3.2 Statistics for water temperature at sites in the Great Forester catchment (Jan - Dec, 1998)

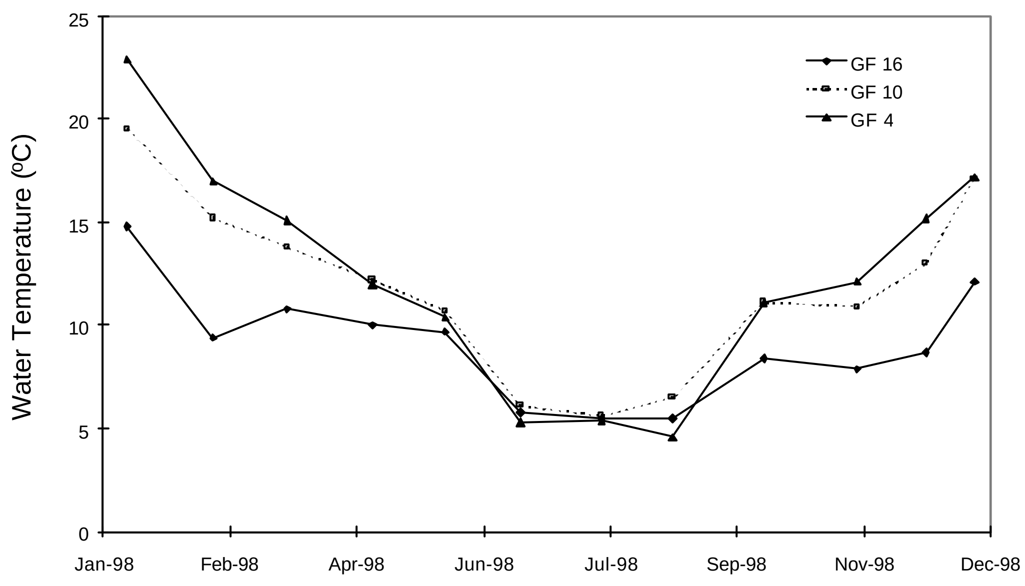


Figure 3.3 Monthly water temperature at three sites in the Great Forester River (Jan - Dec, 1998).

In-stream pH

The acidity of river waters varies greatly in the natural environment. The pH of rivers are subject to many influences, the primary factors being the underlying geology and soil chemistry as well as vegetation cover and land use practices [Cresser, 1988 #167]. In naturally dilute waters, where the buffering capabilities are limited, pH variations can also be quite marked as a result of biological and atmospheric processes [UNESCO, 1992 #49].

In the Great Forester catchment, most sites which were monitored showed pH levels which were marginally or moderately acidic. The most acid sites were on the Great Forester upstream of the trout farm (GF16) and at Hogarths Creek (GF30) both of which had median pH levels of less than 6.3 (Figure 3.4). The minimum pH recorded was 5.8 in mid-winter at the top of the Great Forester. In the Great Forester River, there is a tendency for increasing pH towards the bottom of the catchment, however it was apparent that there is some disturbance to this pattern at Ten Mile Track, where pH increased dramatically. Variation in pH at this site was also quite high.

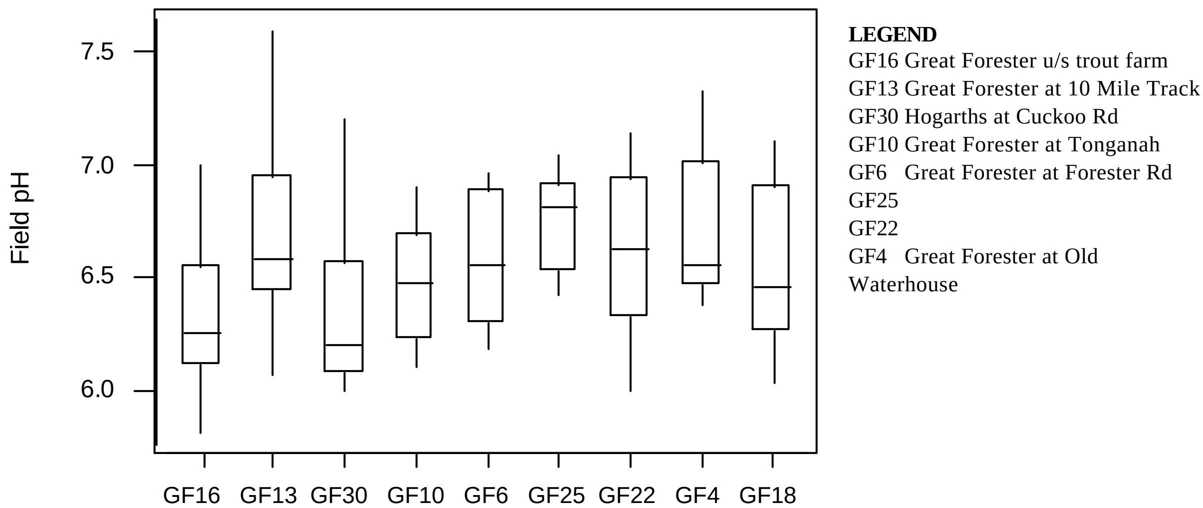


Figure 3.4 Statistics for field pH at sites in the Great Forester catchment (Jan - Dec, 1998).
Field pH is compensated for temperature.

As was stated earlier, seasonal fluctuations of pH is a natural phenomenon in rivers and has been found in other Tasmanian rivers [Bobbi, 1999 #179] & (unpublished data). Unlike the situation described in rivers in the nearby Ringarooma catchment [Bobbi, 1999 #179], the pattern of change of pH in the Great Forester River is not as clearly seasonal (Figure 3.5), though pH appears to be slightly lower during winter months. It is likely that the monthly frequency of monitoring during this project was insufficient to allow any seasonal pattern to be detected in the Great Forester River. The short time period of the study (a single year) also makes any seasonal trend difficult to determine.

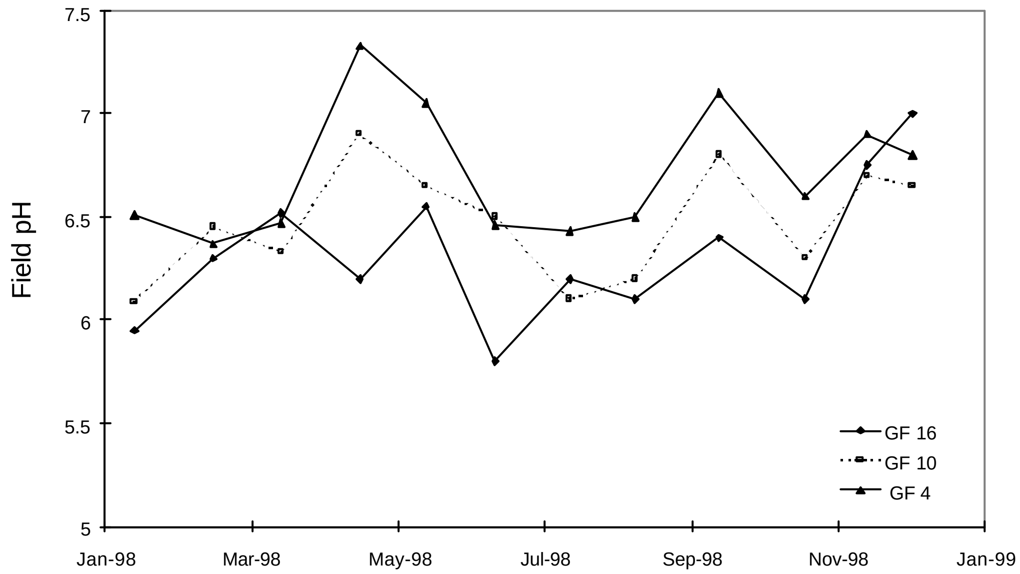


Figure 3.5 Monthly change in pH at three sites in the Great Forester River (Jan - Dec, 1998).

Conductivity

The electrical conductivity of water reflects the amount of dissolved material present and is what is sometimes called ‘salinity’. In general the rivers in the Great Forester catchment are relatively dilute, but show a distinct increase in dissolved salts towards the bottom of the catchment (Figure 3.6). Except for a significant increase in conductivity at Ten Mile Track, there is a gradual increase down the length of the Great Forester River. Tributaries in the lower catchment (Arnon River, Pearly Brook and Tuckers Creek) are all more conductive than the main river. In terms of agriculture and domestic use, these levels reflect the low salinity of water in the catchment and is well within the guidelines for use on most crops [ANZECC, 1992 #4].

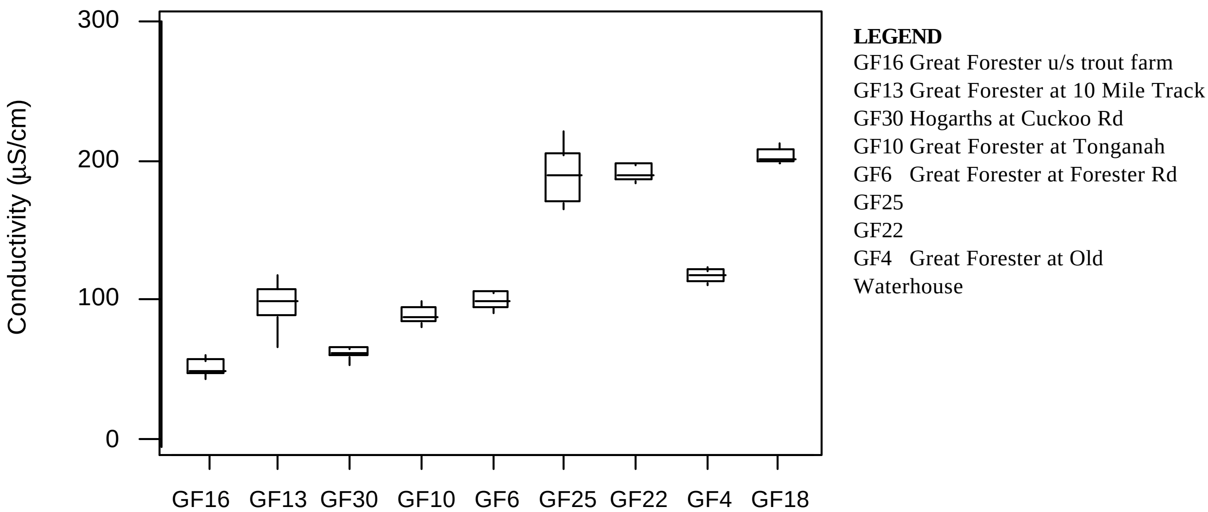


Figure 3.6 Statistics for conductivity at sites in the Great Forester catchment (Jan - Dec, 1998). # Conductivity corrected for temperature to T_{ref} 25 ^oC.

Turbidity

Turbidity in flowing water is an indicator of the amount of suspended material being transported by the river at the time of sampling. In agricultural regions, the majority of this material comes from diffuse sources such as soil disturbance or stream bank erosion. When seeking to determine the ambient (or baseline) turbidity levels in rivers, it is important to avoid collecting samples during or immediately following rainfall events when runoff water carries most material into streams. Separate sampling during rainfall events can then be compared against what the river is normally like and is often useful in showing how levels increase with entry of runoff to rivers.

The monthly data from the 9 sites in the Great Forester catchment illustrates how rainfall did influence turbidity on one occasion when sampling took place after a rainfall event. This resulted in outliers at Tonganah and the Arnon river (Figure 3.7). Turbidity at all sites is generally below 9 NTU during normal baseflow conditions. The Arnon River had the highest turbidity (median of 8.16 NTU), while in the Great Forester River the sites at Ten Mile Track had the highest median turbidity (5.97 NTU). Turbidity was lowest in the Great Forester upstream of the trout farm (median of < 1 NTU) and at Pearly Brook (median of 2.0 NTU).

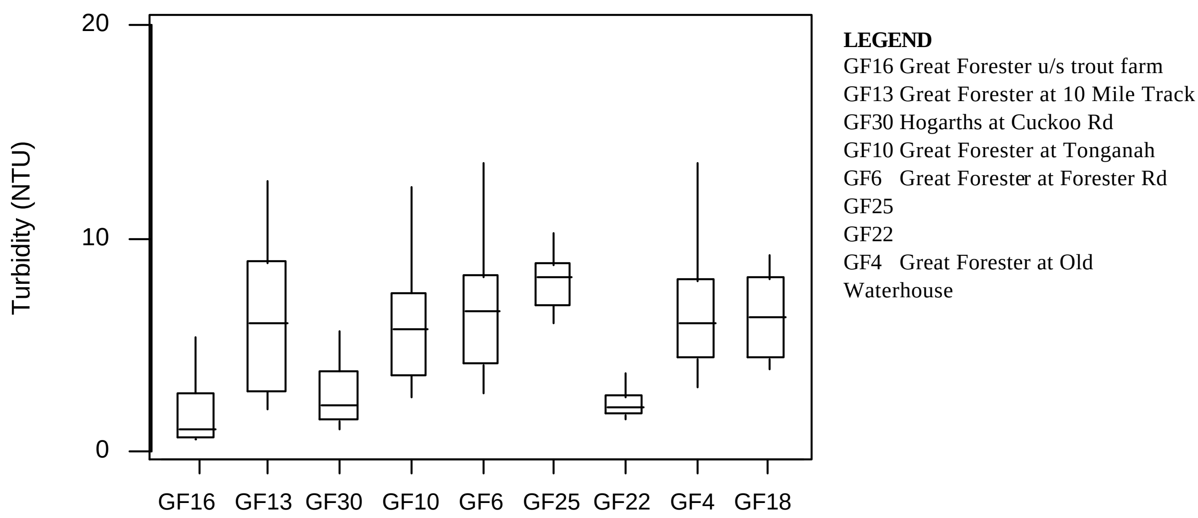


Figure 3.7 Statistics for turbidity at sites in the Great Forester catchment (Jan - Dec, 1998).

Examining the seasonal change in turbidity at three sites on the Great Forester (Figure 3.8 below), the outlier at Tonganah occurred in February, 1998 and is not mirrored by data at either of the other sites. The records show that there had been some local rain the night before sampling and the river at Tonganah was up slightly, while the site near the top of the catchment had already dropped back to baseflow conditions. The other feature of the plot is that there is no distinct seasonal pattern of turbidity variation.

A comparison of these data with what occurs during flood conditions will be made in a later section where flood loads of suspended solids and nutrients will be discussed.

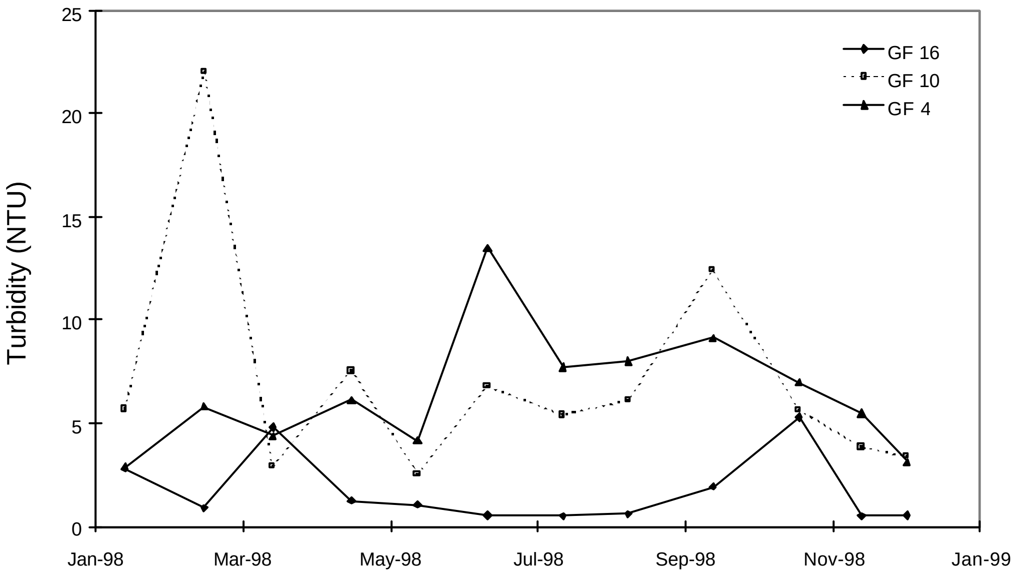


Figure 3.8 Monthly change in turbidity at three sites in the Great Forester River (Jan - Dec, 1998).

Dissolved Oxygen

Dissolved oxygen is a good indicator of the biological health of rivers and in the Great Forester River dissolved oxygen levels clearly reflect a very healthy system (Figure 3.9). While there is some indication that sites lower in the catchment have slightly lower oxygen levels, median concentrations at all sites are above the level normally considered as detrimental to aquatic organisms [ANZECC, 1992 #4] and ecosystem functioning [Cooke, 1995 #91].

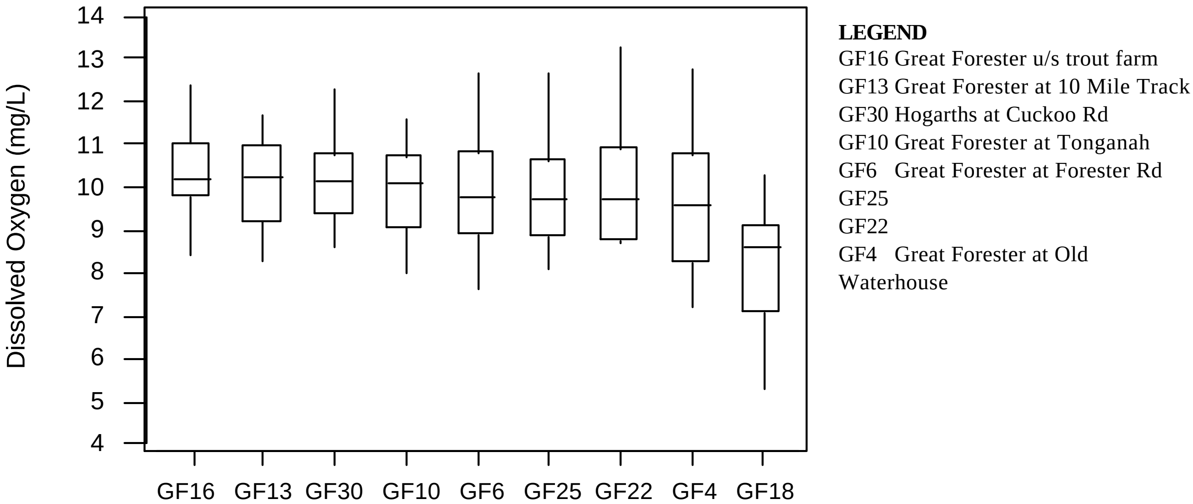


Figure 3.9 Statistics for dissolved oxygen at sites in the Great Forester catchment (Jan - Dec, 1998).

The lowest dissolved oxygen concentration was measured at Pearly Brook (4.6 mg/L) and Tuckers Creek (5.3 mg/L) during low flows in December, 1998. Further investigation of summer dissolved oxygen levels may be required to determine if low concentrations frequently occur at these sites. Tuckers Creek lies in the coastal plain and may experience some organic enrichment as it flows though flat land which is subject to agricultural activities (livestock grazing). There is also considerable sedimentation of the stream through this stretch, which suggests that there may be greater amounts of organic decay, which during the summer can cause significant oxygen depletion. At Pearly Brook, which lies in an essentially unmodified area, the low dissolved oxygen concentration occurred when flow almost stopped during summer. This was considered an outlier when compared to the rest of the data collected from this site, and as such is not shown in the boxplot in Figure 3.9.

The seasonal change in dissolved oxygen in the Great Forester River (Figure 3.10) is fairly typical of many rivers, with concentrations highest during the winter months. During the winter, when water temperature is lowest and river flows are highest, dissolved oxygen levels are generally very healthy. During the summer months, the plot for the Great Forester River clearly illustrates the difference between dissolved oxygen at sites based on their location higher or lower in the river. The site nearest the river mouth (at Old Waterhouse Rd) has lowest dissolved oxygen concentrations during summer. This is characteristic of most larger rivers, as deposition of sediment and suspended material in the lower reaches normally results in oxygen deficit as organic material is broken down by bacteria [Moss, 1988 #182].

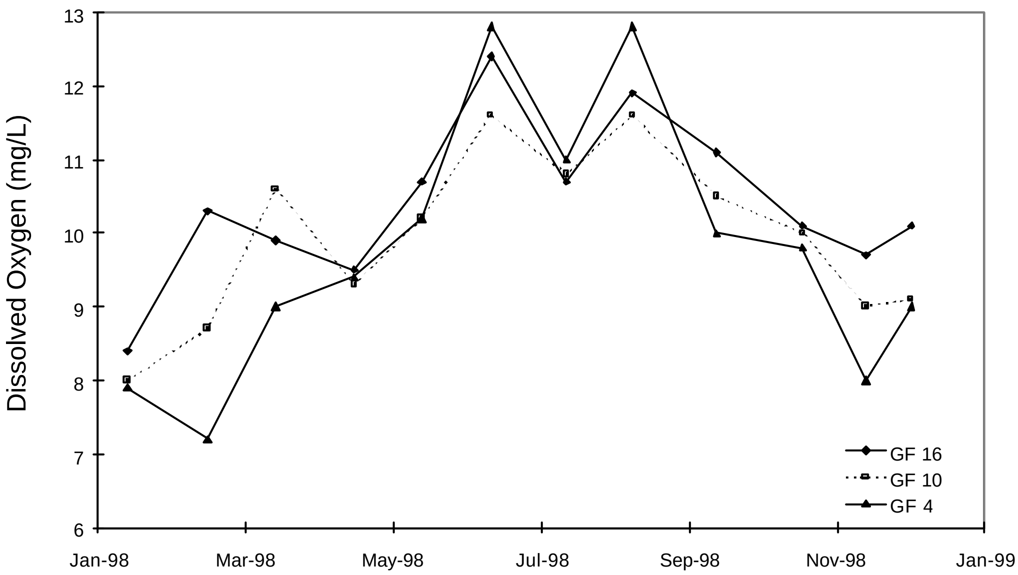


Figure 3.10 Monthly change in dissolved oxygen at three sites in the Great Forester River (Jan - Dec, 1998).

3.3 General Ionic Composition

Samples were also collected at Tonganah and Old Waterhouse Rd every two months for analysis of ionic composition. These analyses included variables like apparent colour, hardness, alkalinity, suspended solids and dissolved minerals and salts. Many of these reflect the geochemical composition of the rocks and soils of the area, although they can be influenced to some degree by human related activities such as agriculture and forestry.

The apparent colour of river water usually reflects the concentration of dissolved organic material (eg. humic substances) present. In the Great Forester River, apparent colour is moderate compared with rivers such as those draining button grass areas on Tasmania's west coast. As illustrated in Figure 3.11, colour tends to increase towards the lower reaches of the river, however both sites appear to follow a similar seasonal pattern with lower values in winter than in summer.

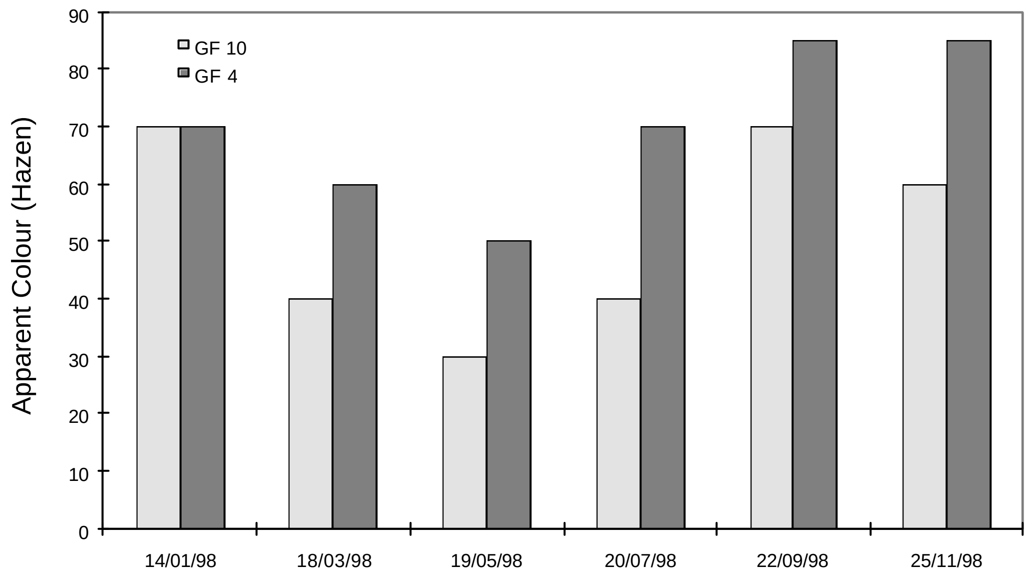


Figure 3.11 Monthly levels of apparent colour in the Great Forester River at Tonganah (GF12) and Old Waterhouse Road (GF5) during 1998.

A table presenting the summary statistics for all parameters covered by these analyses is shown below (Table 3.2). Many of these constituents are considered 'conservative', that is they tend not to vary significantly over time. Despite the limited number of samples taken (n = 6), the data does tend to show this.

Another feature of the data is that while water in the upper reaches of the river is slightly more dilute than lower down, the Great Forester River generally has low concentrations of all parameters, especially chloride, sulphate, calcium, magnesium, and iron. The water in the river is also 'soft' (as indicated by low hardness) and has low buffering capacity (indicated by low alkalinity), which means that the water has little ability to withstand pH changes and may explain the fairly wide variation in field pH shown at some sites (Figure 3.4).

Table 3.2(a) Statistics for parameters describing the ionic composition of water in the Great Forester River. Site code; GF10 - Great Forester at Tonganah, GF4 - Great Forester at Old Waterhouse Road. (n = 6).

	Colour (mg/L)		Dissolved Solids (mg/L)		Suspended Solids (mg/L)		Hardness (mg/L)	
Site Code	GF10	GF4	GF10	GF4	GF10	GF4	GF10	GF4
Average	70	52	61	76	<10	12	15	17
Median	70	50	61	76.5	<10	<10	15	17
Max	85	70	70	90	<10	43	16	18
Min	50	30	51	65	<10	<10	14	16

Table 3.2(b) Statistics for parameters describing the ionic composition of water in the Great Forester River. Site code; GF10 - Great Forester at Tonganah, GF4 - Great Forester at Old Waterhouse Road. (n = 6).

	Alkalinity (mg/L)		Chloride (mg/L)		Sulphate (mg/L)		Iron (mg/L)	
Site Code	GF10	GF4	GF10	GF4	GF10	GF4	GF10	GF4
Average	20	17	15.5	22.7	2.9	3.5	0.5	0.61
Median	19	18	15.5	23	3	3.6	0.42	0.61
Max	38	26	17	24	2.3	4.2	0.9	0.7
Min	10	10	14	21	2.4	2.7	0.36	0.49

Table 3.2(c) Statistics for parameters describing the ionic composition of water in the Great Forester River. Site code; GF12 - Great Forester at Tonganah, GF5 - Great Forester at Old Waterhouse Road. (n = 6).

	Calcium (mg/L)		Magnesium (mg/L)		Potassium (mg/L)		Silica (mg/L)	
Site Code	GF10	GF4	GF10	GF4	GF10	GF4	GF10	GF4
Average	2.95	2.9	1.85	2.4	1.63	1.8	12.3	11.3
Median	2.9	2.9	1.8	2.4	1.65	1.8	12.5	11.5
Max	3.3	3.1	2	2.5	1.9	1.9	14	14
Min	2.8	2.7	1.8	2.3	1.4	1.7	8.8	8.6

Comparison of the results listed in these tables with data collected in the nearby Ringarooma catchment [Bobbi, 1999 #179] shows that water in the two catchments is very similar. Iron concentrations are slightly less in the Great Forester, and chloride and calcium concentrations are slightly higher. Water in both the Great Forester and Ringarooma rivers is relatively dilute and both have low alkalinity.

3.4 Nutrient Results

The concentrations of nutrients such as nitrate, ammonia, organic nitrogen and the various forms of phosphorus are normally present at low levels in rivers draining most agricultural areas in Tasmania. This generally makes field analysis for these parameters difficult as most field detection kits cannot operate accurately at these levels. Therefore samples of water were collected during site visits and frozen until delivery to a NATA (National Association of Testing Authorities) registered laboratory which could then perform the relevant tests. These laboratories operate under strict quality control and are able to deliver results which are quality assured. Occasional duplicate and blank samples were delivered to further check field collection and preservation methods.

Nitrate/N

Nitrate nitrogen (NO_3/N) is very mobile in the environment and easily passes through soil into groundwater where it can strongly influence concentrations in rivers during baseflow conditions. Natural sources of NO_3/N are geological and plant and animal breakdown products. In the rural environment, the use of inorganic fertilisers, and increased levels of animal and plant wastes can have a significant impact on surface water NO_3/N concentrations [UNESCO, 1992 #49]. Clearing of land for cultivation and grazing also increases soil aeration, enhancing the action of nitrifying bacteria which increases the soil NO_3/N concentrations.

The results from monitoring in the Great Forester River (Figure 3.12) show that NO_3/N concentrations are significantly higher (Two sample t-test; $T = 3.45$, $p = 0.0024$) in the upper reaches than lower down the river. This result is not unexpected, since the most intensive agricultural and land clearing activity is located in the upper part of the catchment. In the area around and upstream of Tonganah, lack of a good riparian strip would also facilitate the unimpeded passage of NO_3/N to the river. Along the lower reaches of the river, good riparian cover would intercept at least some of the NO_3/N moving into the river, as it is well known that riparian vegetation can reduce nitrate concentrations in groundwater as it enters waterways [Nelson, 1995 #184][Hill, 1996 #183][Groffman, 1996 #73]. Where there is little or no riparian vegetation, denitrification processes are much reduced, allowing more nitrate to enter streams. In the lower reaches of the Great Forester River there is also less intensive agricultural activity and less cleared land from which NO_3/N could originate.

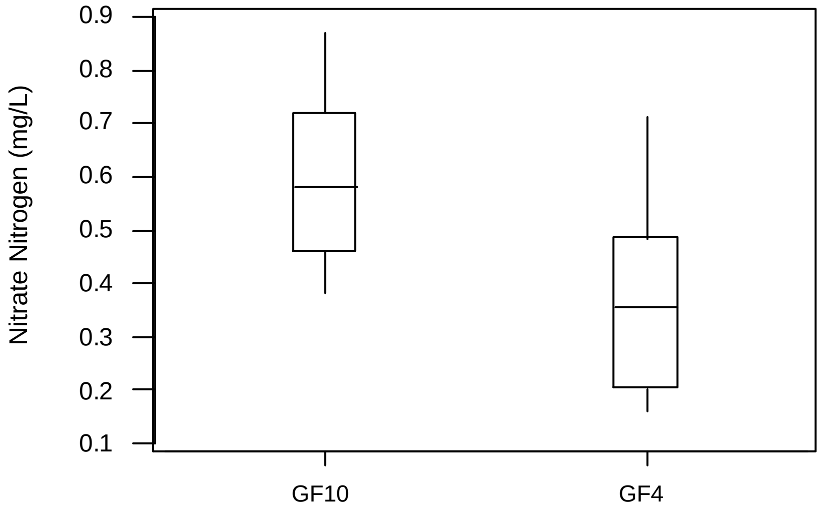


Figure 3.12 Summary statistics for Nitrate/N concentrations at Tonganah (GF10) and Old Waterhouse Road (GF4) from monthly data collected during 1998.

The difference between NO_3/N concentration at Tonganah and Old Waterhouse Rd during each of the monthly site visits is illustrated in Figure 3.13 below. It shows that during the first three months of the study, NO_3/N is much higher at Tonganah, while later in the winter and spring, concentrations at both sites are more comparable.

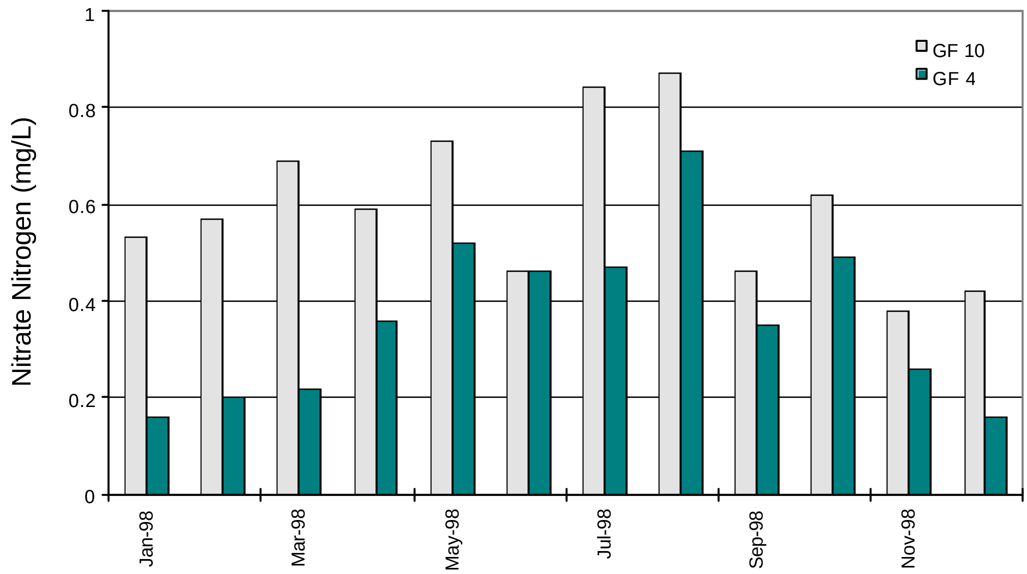


Figure 3.13 Monthly changes in Nitrate/N concentrations in the Great Forester River at Tonganah (GF10) and Old Waterhouse Road (GF4), 1998.

At GF5 there is a distinct increase in NO_3/N concentration during winter, a pattern which is reflected by river flows at the time of site visits (Figure 3.14). In general, higher NO_3/N concentrations in the river occur during higher baseflow periods, when groundwater discharge is highest. It is likely that NO_3/N levels are therefore more reflective of groundwater concentrations in the catchment, as NO_3/N is easily transported by subsurface water movement.

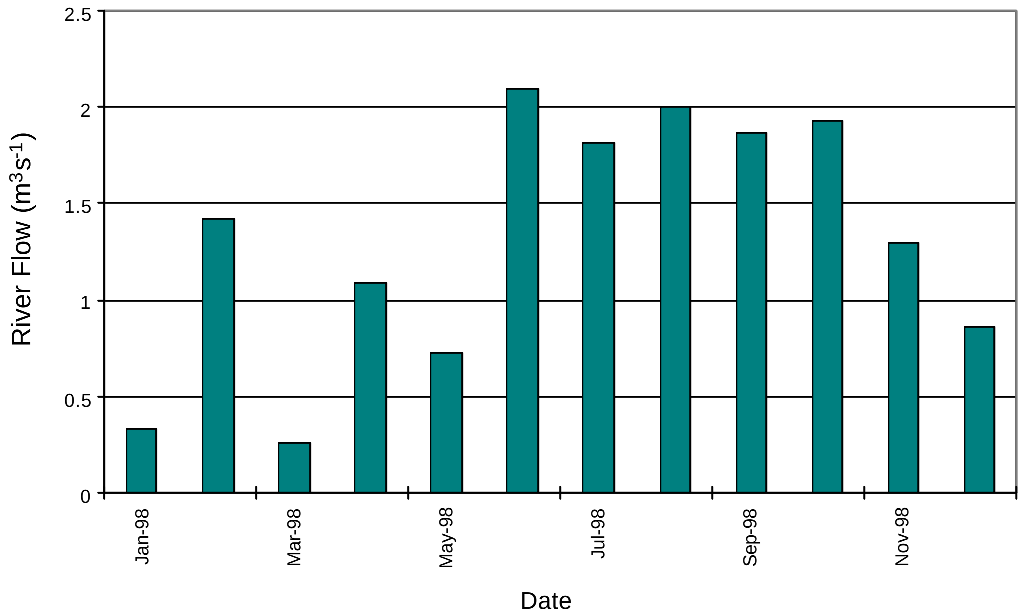


Figure 3.14 Flow in the Great Forester River at Forester Road on the date of each monthly monitoring visit during 1998.

Total Nitrogen

Total nitrogen (TN) is simply the sum of Kjeldahl nitrogen (TKN), nitrate nitrogen (NO_3/N) and nitrite nitrogen (NO_2/N), though NO_2/N is not normally detected in environmental waters unless there is recent faecal pollution. Nitrite was only detected at trace levels in four of the twelve samples taken at Tonganah. No NO_2/N was detected in any of the samples taken at Old Waterhouse Rd. The data for TN (Figure 3.15) therefore reflect patterns of the combined concentrations of NO_3/N and TKN at each site.

As was shown for NO_3/N, the median concentration of TN was significantly higher at Tonganah than at Old Waterhouse Rd (Two sample t-test; T = 3.06, p = 0.0059). ANZECC (draft - 1998) suggests that for upland rivers, concentrations of 0.34 mg/L could be used as trigger levels for assessing risk of adverse effects due to nutrients in 'essentially natural' systems. While the guidelines also suggest trigger concentrations for lowland rivers, these are not considered appropriate for the Great Forester River which is only 60 km in length and cannot be regarded in the same category as other Australian lowland rivers such as the Murray or Darling rivers, or the South Esk River in Tasmania. With this in mind, it appears that there is significant TN enrichment in the Great Forester River in the area of Tonganah (median concentration of 0.996 mg/L), and to a lesser degree at Old Waterhouse Rd (median concentration of 0.685 mg/L).

The monthly pattern of TN concentration change (Figure 3.16) is also very similar to that shown by NO_3/N, which indicates that the underlying component distinguishing TN concentrations at both sites is NO_3/N and this is the primary cause of the seasonal pattern of change in TN.

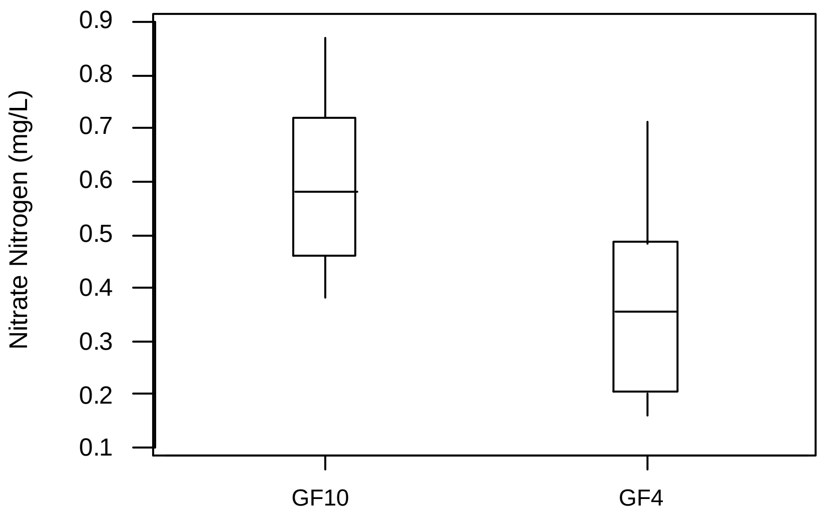


Figure 3.16 Summary statistics for Total N concentrations at Tonganah (GF10) and Old Waterhouse Road (GF4) from monthly data collected during 1998.

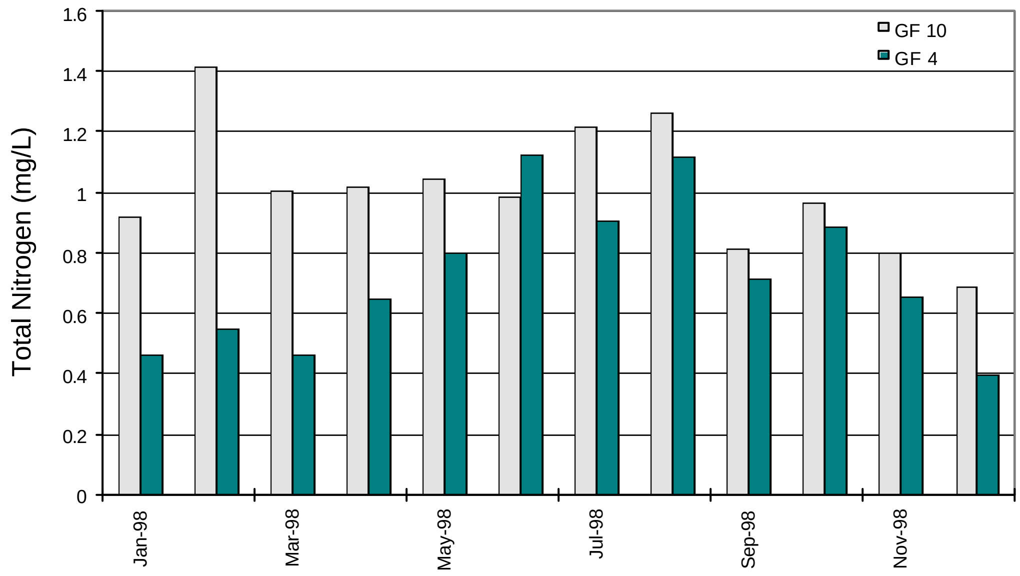


Figure 3.16 Monthly changes in total nitrogen concentrations in the Great Forester River at Tonganah (GF10) and Old Waterhouse Road (GF4), 1998.

Total Phosphorus

While phosphorus is essential for growth and reproduction of aquatic plants, it is normally present in natural surface waters at very low levels and is the nutrient which limits algal growth. When it is present in excess due to artificial inputs to rivers and lakes, it can trigger algal blooms which are a feature of eutrophication. Although plants generally require phosphorus in its dissolved form, it moves between various dissolved and particulate forms continuously depending on environmental conditions and biological processes [UNESCO, 1992 #49] [Correll, 1998 #81]. Therefore it is best to measure total phosphorus (TP) which includes particulate and dissolved forms, as at some stage most of this may become available for plant uptake. In most natural waters, phosphorus is also normally attached to organic and inorganic particulate material and can often be related to turbidity levels [Bobbi, 1996 #9].

Total phosphorus concentrations at the two sites in the Great Forester River is shown in Figure 3.17. Concentrations are variable at both sites, but the highest and lowest concentrations (0.092 and 0.005 mg/L respectively) were recorded at Tonganah. The two highest concentrations at Tonganah where recorded during the January and February site visits (Figure 3.18). While the February visit was undertaken following a rain event and also corresponds with high turbidity, the concentration measured in January was recorded during low river flows and relatively low turbidity (5.7 NTU). At this time, the level of dissolved phosphorus was also high (0.037 mg/L), which tends to indicate that there may have been some other cause for the high phosphorus levels in the river such as local fertiliser input or effluent discharge.

During most of the rest of the year, TP concentrations at Tonganah were below 0.04 mg/L, while at Old Waterhouse Rd concentrations were generally below 0.03 mg/L. The data shows that during higher flows in June, there was some elevation in TP concentration at both sites, but especially at Old Waterhouse Rd where turbidity was also elevated.

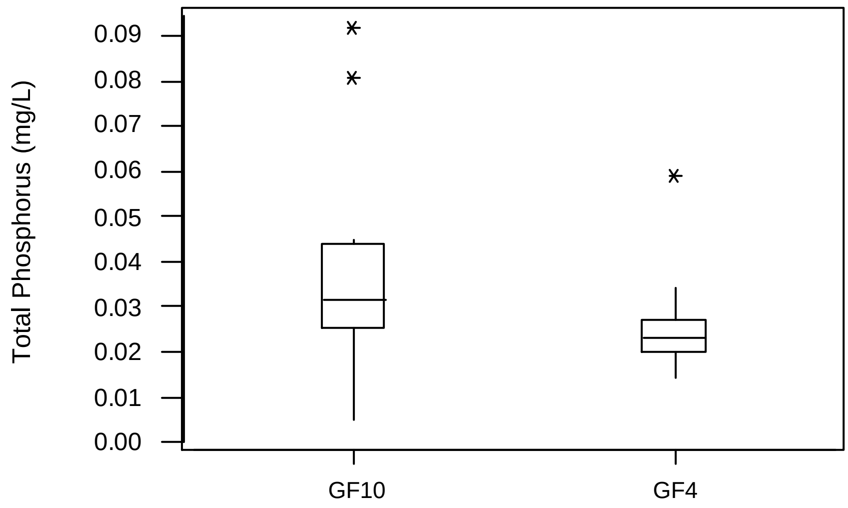


Figure 3.17 Summary statistics for total phosphorus concentrations at Tonganah (GF10) and Old Waterhouse Road (GF4) from monthly data collected during 1998.

The data supports the conclusion that most of the input of phosphorus to the river during low summer flows may occur in the upper part of the river which corresponds to the area of more intense agricultural activity. This is also consistent with Waterwatch data (discussed in an earlier section). Various factors may be facilitating this input including; direct access to the river and tributaries by stock, drainage activities which increase the effective delivery of runoff and nutrients to the river and the lack of an adequate riparian buffer strip to intercept those nutrients.

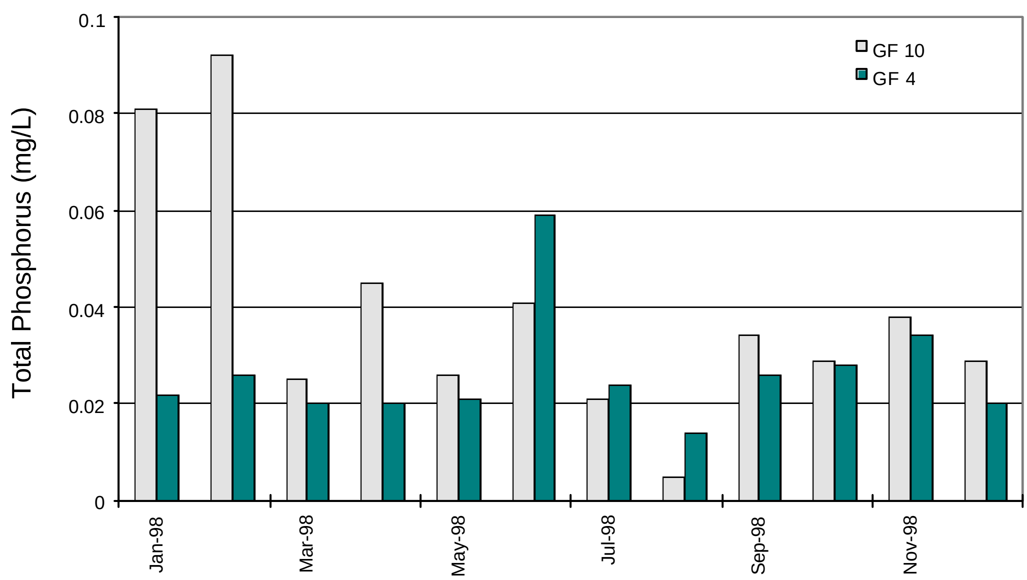


Figure 3.18 Monthly changes in total phosphorus concentrations in the Great Forester River at Tonganah (GF10) and Old Waterhouse Road (GF4), 1998.

When the high readings for phosphorus were recorded at Tonganah, further investigation was undertaken to try and determine whether this might be a localised impact from a pig farm situated just upstream of this site. However sampling at sites above the pig farm on the Great Forester River and at Hogarths Rivulet showed that higher levels of nutrients are present in the Great Forester River further upstream and that the pig farm appeared to be having no significant impact ono nutrient levels at Tonganah. Nutrient concentrations in Hogarths Rivulet were much lower than in the main river. The results of this investigation are shown in Table 3.3 below.

Table 3.3 Investigation into elevated nutrient concentrations in the Great Forester River in the area of Tonganah (Visit 1 - 29/10/98; Visit 2 - 25/11/98).

	Ammonia/N (mg/L)		**Nitrate/N** (mg/L)		**Total P** (mg/L)	
SITE	Visit 1	Visit 2	Visit 1	Visit 2	Visit 1	Visit 2
Great Forester at Cuckoo Rd	0.008	0.016	0.74	0.55	0.029	0.039
Hogaths Rvt u/s Great Forester	0.008	0.008	0.25	0.20	0.016	0.015
Great Forester at Tasman H'way (Tonganah)	0.009	0.011	0.62	0.38	0.029	0.038

In summary, the monthly nutrient data clearly show that there are increased concentrations of nutrients in the upper parts of the Great Forester River. This result is not surprising as this part of the catchment contains the most productive land and is subject to most intensive agricultural activity. How these nutrients are entering the river and specifically from where they are originating requires further study, as limited resources meant that only two sites could be monitored for nutrients during this project. Any future sampling should focus on tributary streams and drains in this part of the catchment.

3.5 Catchment Survey

Catchment 'snapshot' surveys were conducted during stable baseflows in summer (20-21st January) and winter (26th August) with the aim of highlighting areas where water quality was degraded relative to the rest of the catchment. This technique has been used in the past both in Tasmania [Bobbi, 1996 #10] [Bobbi, 1997 #11] [Bobbi, 1998 #178] and interstate [Grayson, 1997 #23] and has proved useful. As rainfall and runoff variation across a catchment can negate the validity of assessments such as this, it is important that such 'snapshot' surveys are undertaken during stable climatic and hydrological conditions.

During the summer survey 16 sites were sampled across the catchment. This was increased to 18 during the winter with the inclusion of two further sites (Figure 3.19; site coordinates are listed in Appendix 1). At all sites physical-chemical testing was performed. During the summer survey, water samples were taken at a subset of 8 sites, with analysis for nutrients, heavy metals and bacteria being undertaken. During the winter survey a subset of 10 sites were sampled for nutrients, heavy metals and bacterial analysis. Nutrient samples were also collected upstream and downstream of the trout farm at Springfield during the winter survey as a difference in physical water quality had been detected using field equipment on the first survey. Dorset Waterwatch group had also requested nutrient testing to tie into their monitoring station in the area.

Catchment Survey - pH

All of the sites sampled during the surveys were generally acidic (pH less than 7). As the pattern across all sites was similar during both surveys, only the summer survey data is shown (Figure 20). On both occasions, the lowest pH measured was at Surveyors Creek at Old Waterhouse Rd, where pH was recorded at 5.38 during summer and 5.74 during winter. It is not obvious why this stream was so acidic, being at least half a pH unit below the median of all the sites sampled. During the summer survey, a further 4 sites had pH levels less than 6, while 9 more sites showed pH levels between 6 and 6.5.

Catchment Survey - Turbidity

The summer survey data for turbidity shows that water clarity was very good at most sites in the catchment (Figure 21a). In the Great Forester River, 9 of the 10 sites sampled had turbidity levels less than 5 NTU. Several sites located on tributary streams, especially Tuckers Creek, had higher turbidity levels. Highest turbidity was recorded at the upper site on Tuckers Creek during both surveys (11.2 NTU during summer and 20 NTU during winter). This site was downstream of forestry operations which were underway during the period of the study.

Turbidity was exceptionally low at the top end of the Great Forester River during both the summer and winter (Figure 22b) surveys. However, on both occasions there was a noticeable increase between the uppermost site (GF16) and the next site downriver (GF15), which is the first site in agricultural land. There is also a trout farm between these two sites.

The pattern for turbidity during the winter survey is very similar to that from the summer survey, although turbidity was higher across the catchment generally (median 7.12 NTU during winter, median 3.3 NTU during summer). The most noticeable difference was at site GF14 (Ten Mile Track) which had a much higher turbidity level than expected. The pattern of increasing turbidity with distance from source in the Great Forester River was also more obvious in winter than summer (Figure 3.22) .

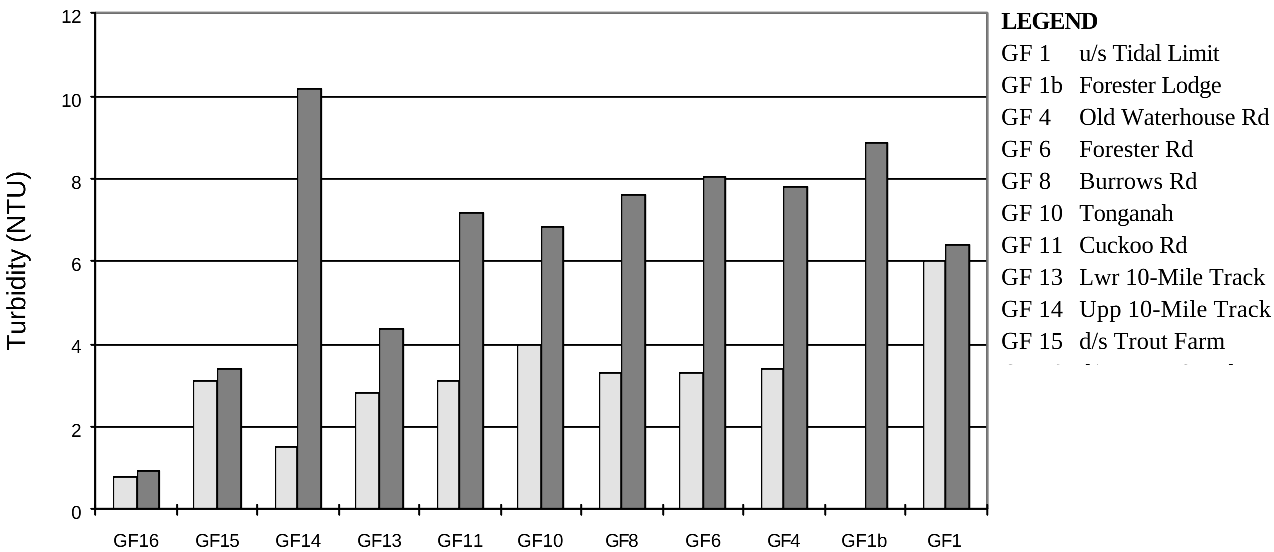


Figure 3.22 Turbidity down the length of the Great Forester River during snapshot surveys in summer and winter, 1998. (Darker bars represent winter data; lighter bars represent summer data)

Figure 3.19 Locations of sites sampled in the Great Forester River and tributaries during 'snapshot' surveys, 1998.

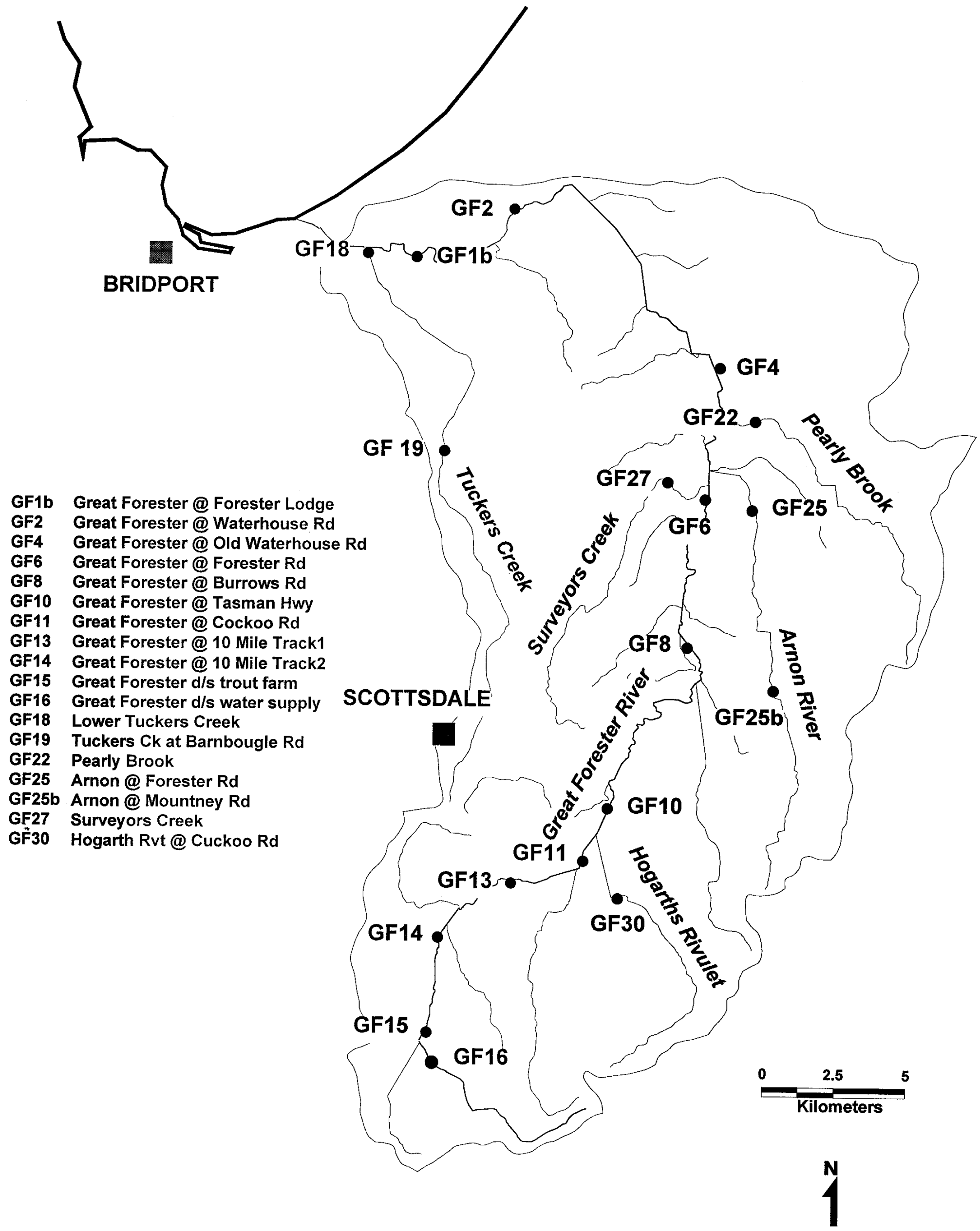


Figure 3.20 pH at sites in the Great Forester River and tributaries during the summer survey, 1998.

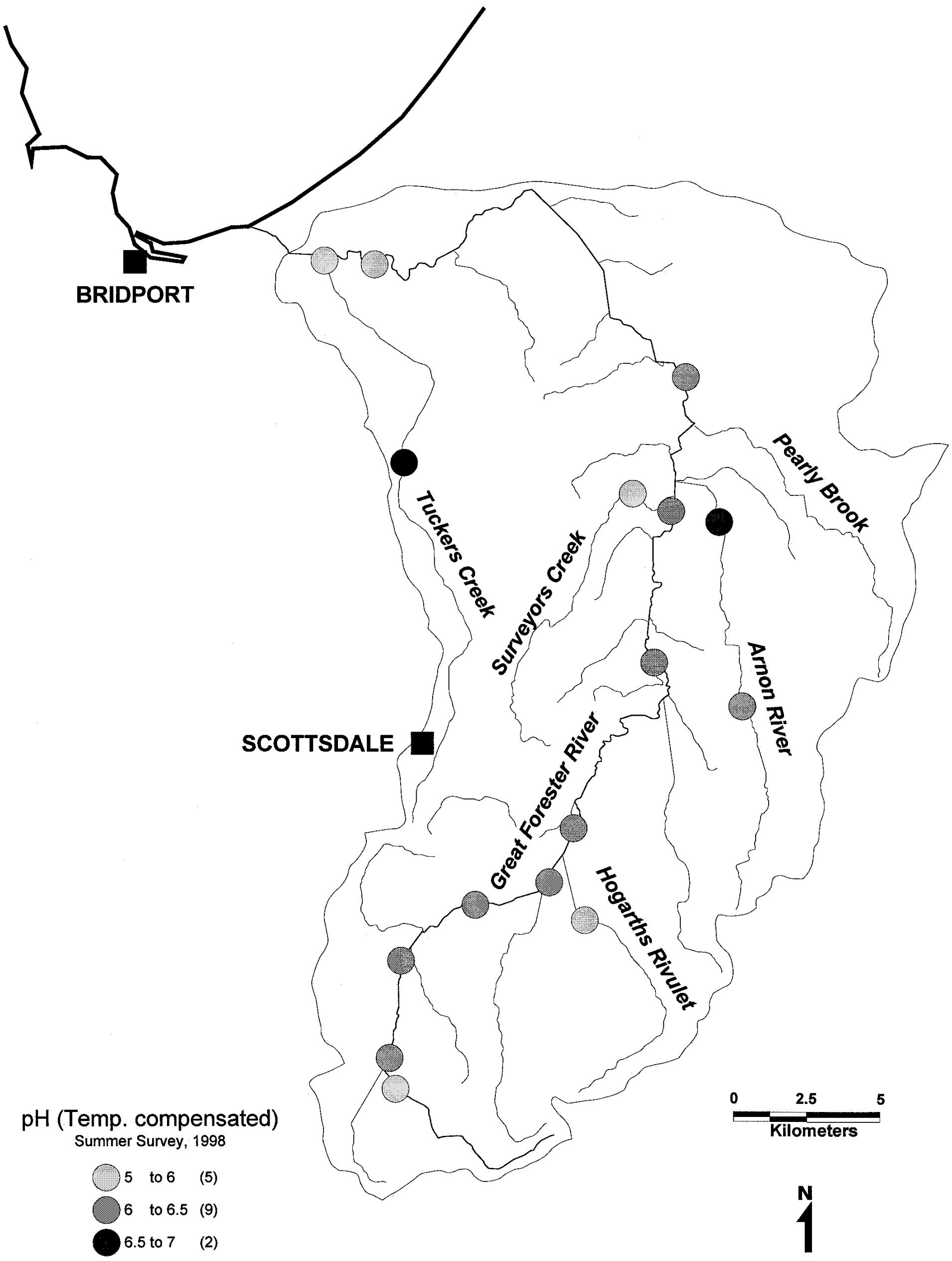


Figure 3.21a Turbidity levels at sites in the Great Forester River and tributaries during the summer survey, 1998.

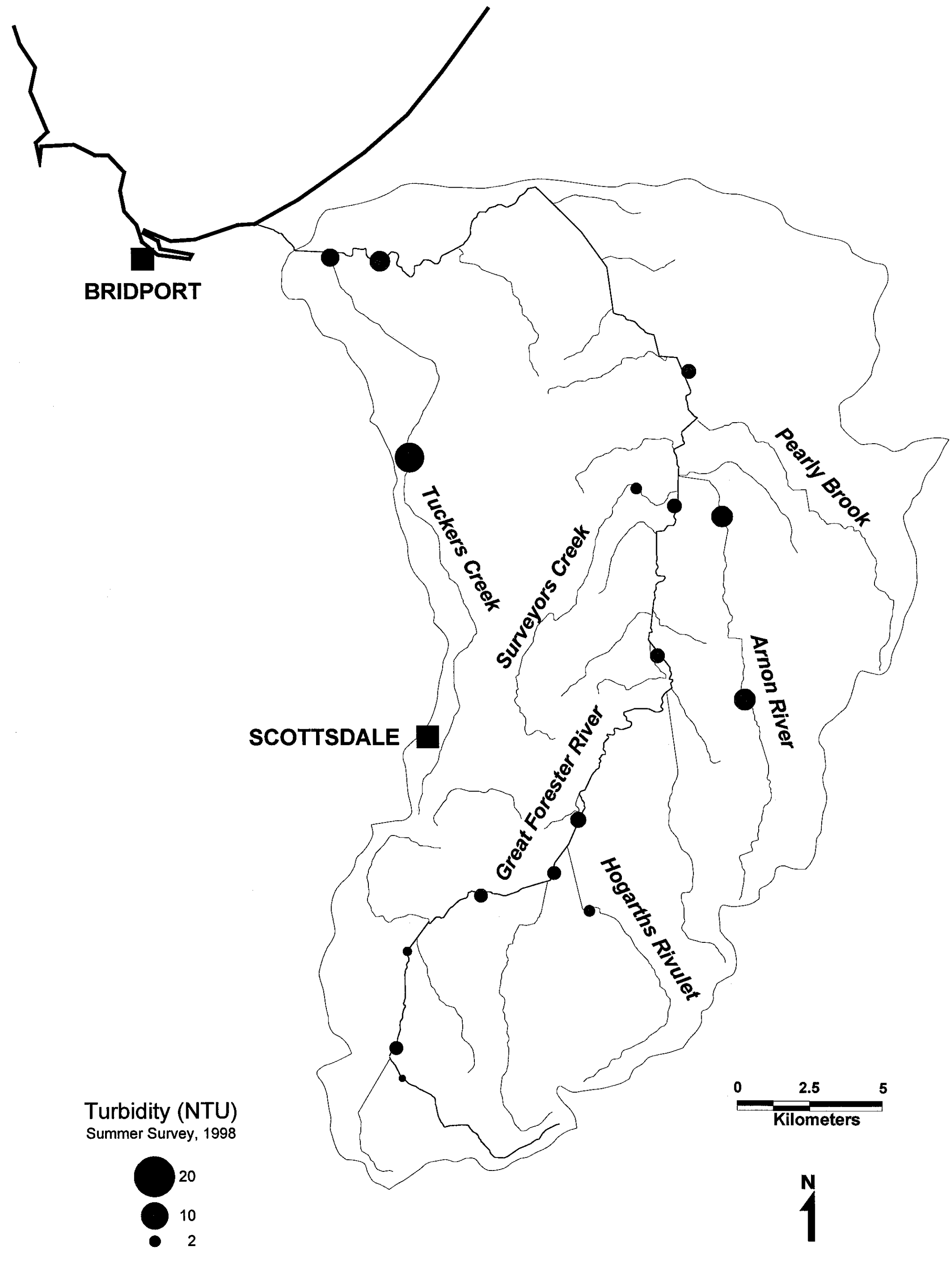
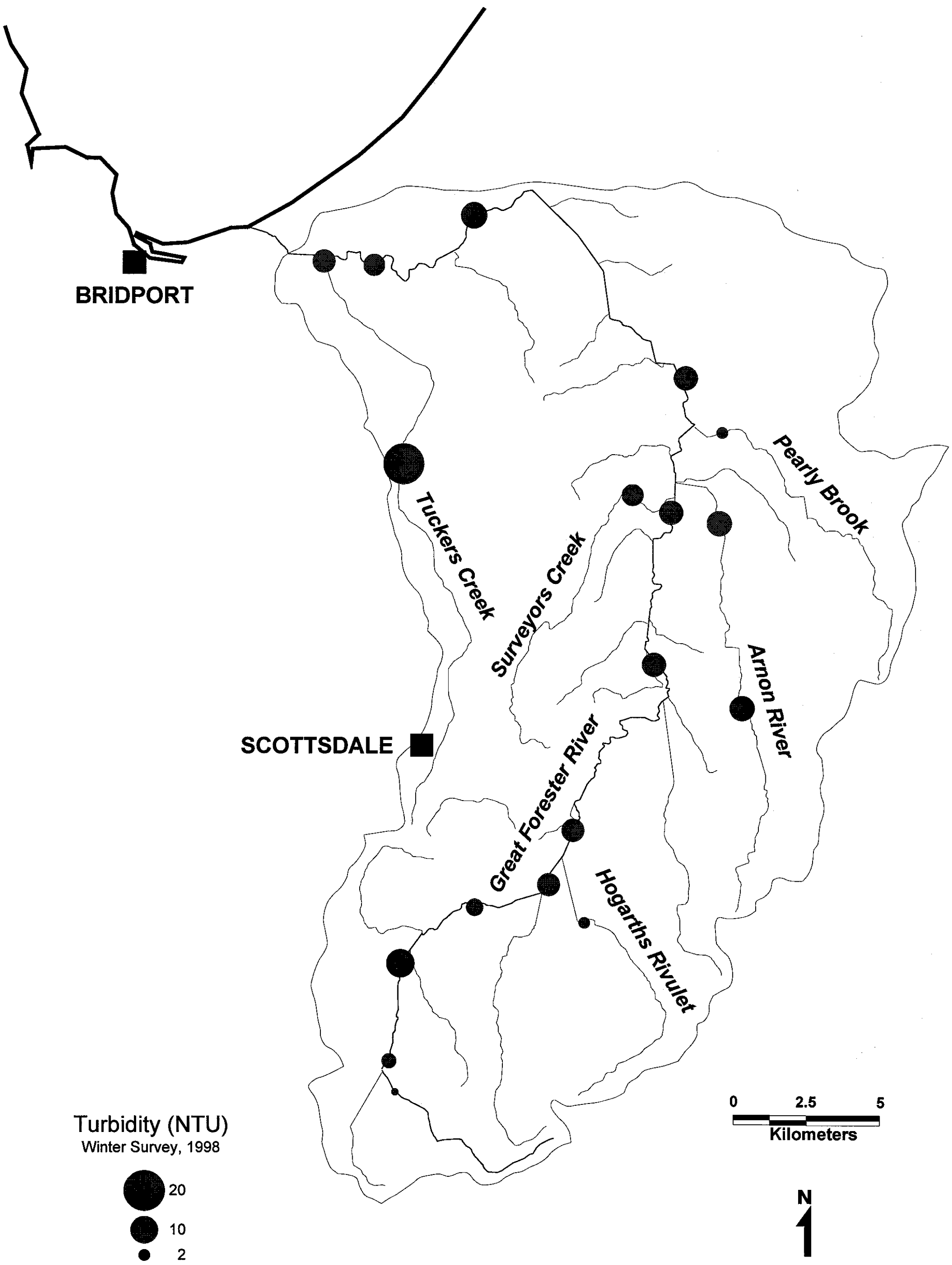


Figure 3.21b Turbidity levels at sites in the Great Forester River and tributaries during the winter survey, 1998.



Catchment Survey - Conductivity

Like turbidity, conductivity at all sites was generally low (during both summer and winter surveys), demonstrating the good quality of water across the catchment in terms of dissolved salts. On both occasions conductivity was below 120 µS/cm at all but the lowermost sites in the Great Forester River. The trend for increasing conductivity with distance from source is clearly displayed by both summer and winter data (Figure 3.23) .

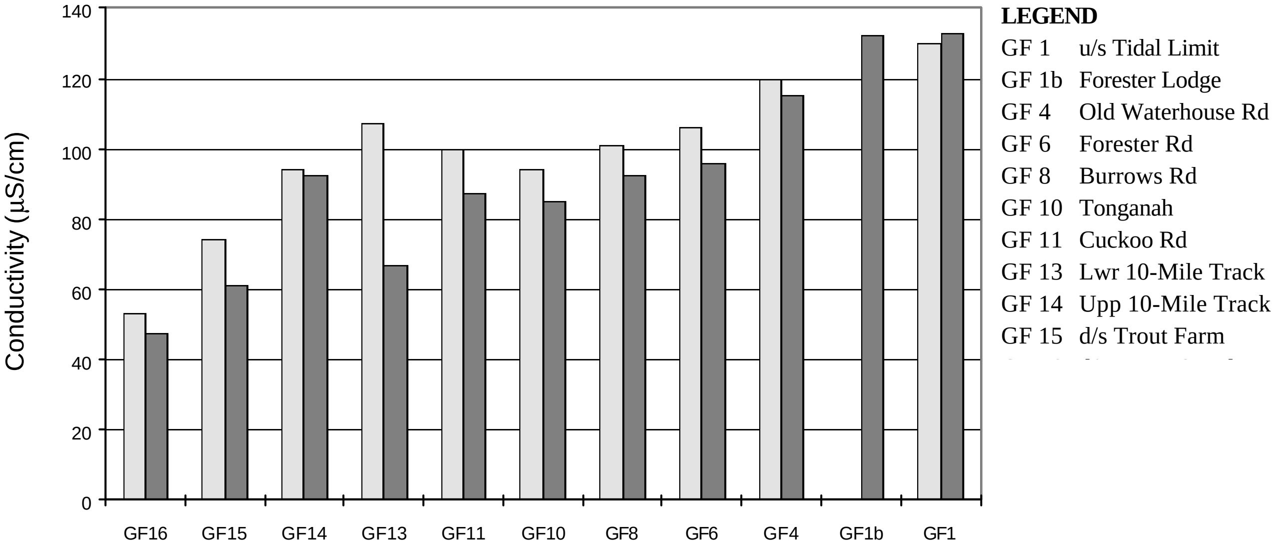


Figure 3.23 Conductivity down the length of the Great Forester River during snapshot surveys in summer and winter, 1998. (Darker bars represent winter data; lighter bars represent summer data)

The data from the summer survey (Figure 3.24) shows that highest conductivity occurs in Tuckers Creek (209 and 260 µS/cm at upper and lower sites, respectively) and the Arnon River (180 and 224 µS/cm at upper and lower sites, respectively). While these levels are high relative to other sites in the catchment, water with this level of salinity (Class 1 - Low salinity) presents no impediment to its use for agriculture or most other purposes [ANZECC, 1992 #4].

Catchment Survey - Dissolved Oxygen

The level of dissolved oxygen was much more varied across sites during summer than in winter. During summer, when river flow is low and water temperature is high, instream decomposition of organic material and plant respiration are significant processes determining oxygen levels in streams. Streams which have higher organic and nutrient inputs will generally have lower levels of dissolved oxygen than those which do not. In larger rivers, slower flow velocity in the lower reaches also tends to encourage settlement of particulate material, including organic matter, hence decomposition (and biological oxygen consumption) is greater. The data from the summer survey demonstrates this in the Great Forester River (Figure 3.25), where sites higher in the catchment have much healthier oxygen levels than lower down. The lowest oxygen concentration measured during this survey (6 mg/L) was in Tuckers Creek upstream of the Great Forester River.

During the winter survey, dissolved oxygen levels were all relatively healthy, with values ranging from 8.8 mg/L low down in the Great Forester River to well over 11 mg/L at many of the middle and upper catchment sites.

Figure 3.24 Conductivity at sites in the Great Forester River and tributaries the summer survey, 1998.

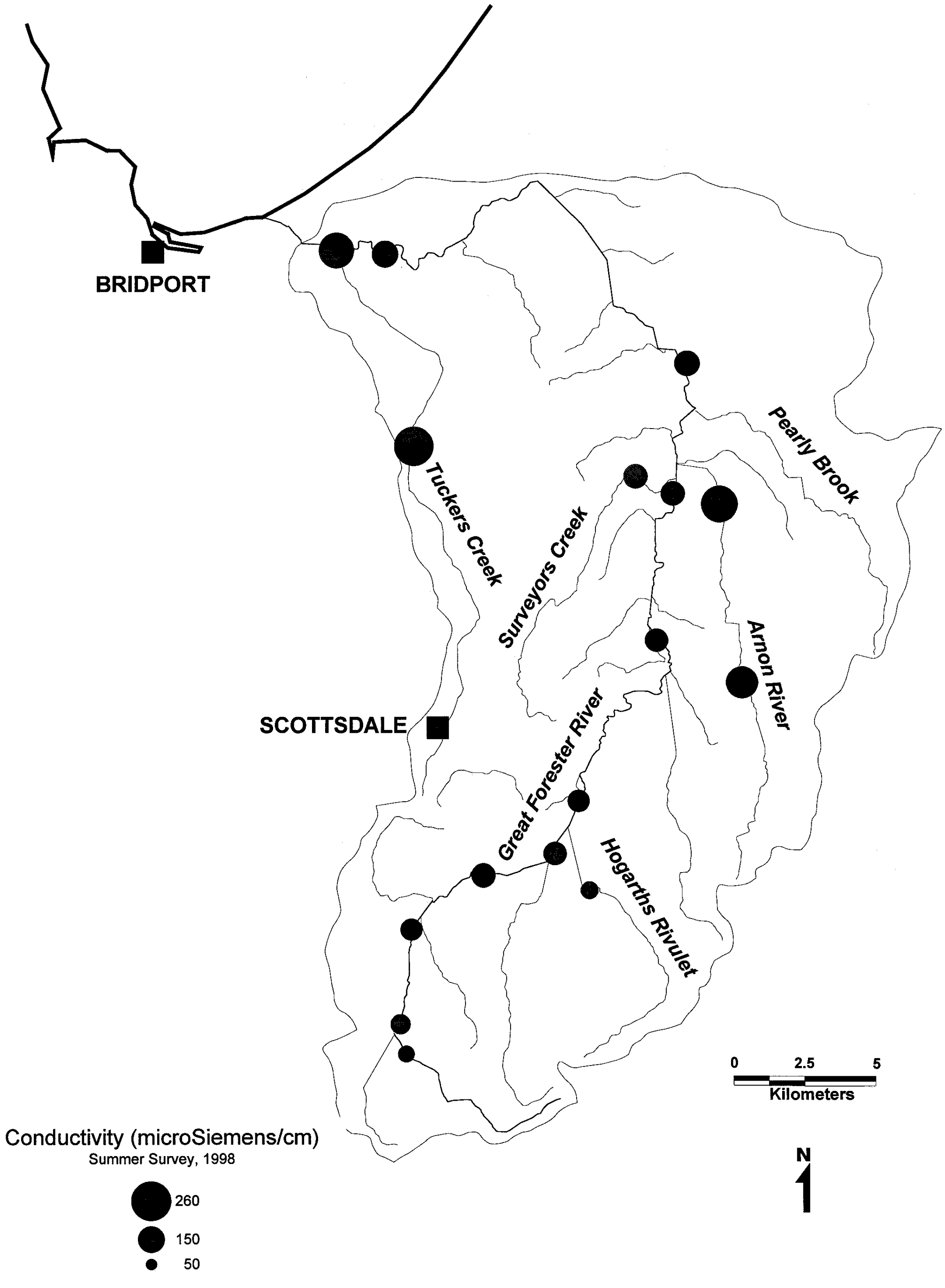
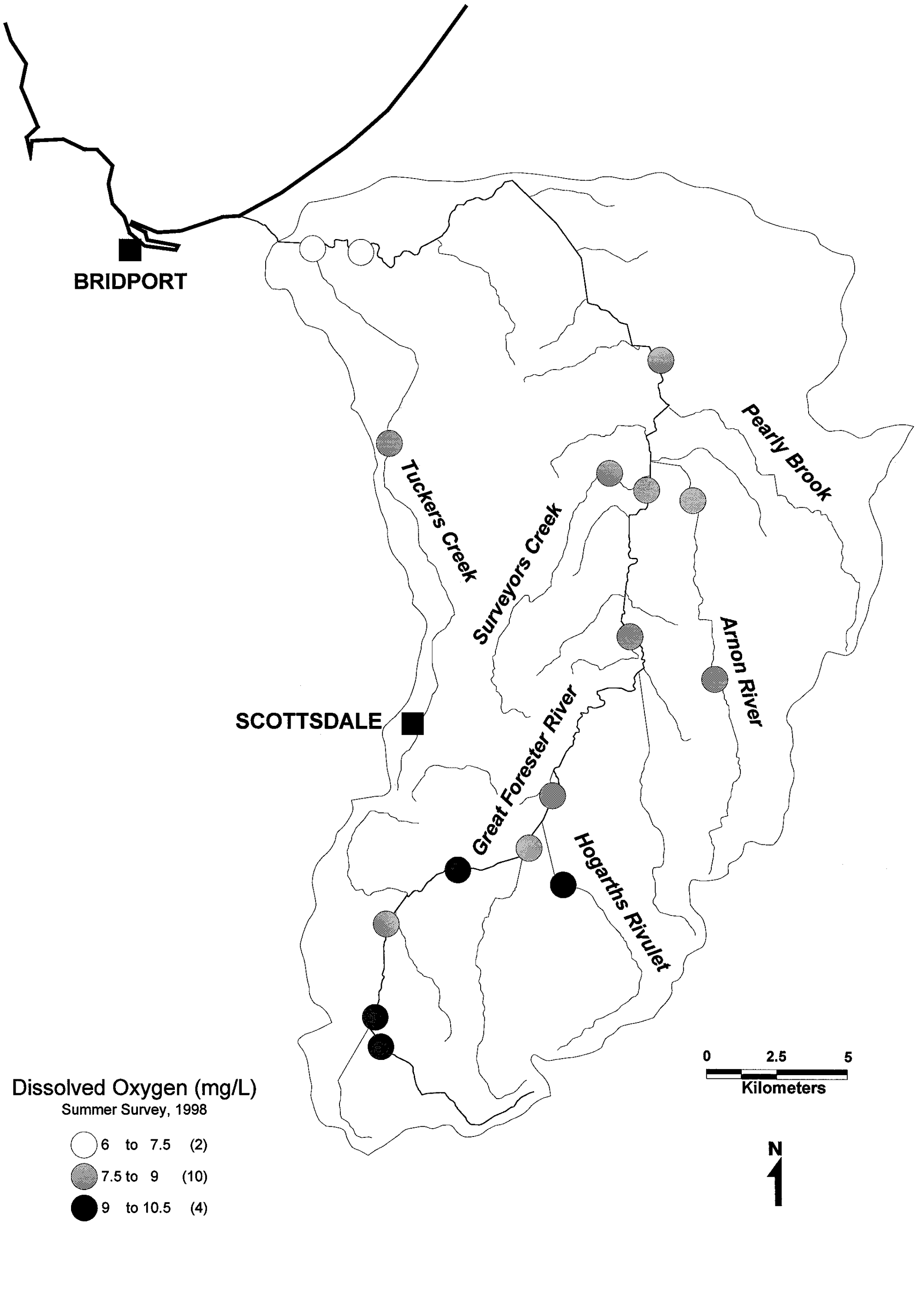


Figure 3.25 Dissolved oxygen at sites in the Great Forester River and tributaries the summer survey, 1998.



Catchment Survey - Bacteria

Sampling for coliforms was conducted at selected sites during both summer and winter surveys. Although most sites were sampled on both occasions, two additional sites were tested during the winter survey while one site sampled in summer was omitted. Testing on both occasions was carried out for total coliforms, faecal ('thermotolerant') coliforms (as *E. coli*) and faecal streptococci. As faecal coliforms are the indicator most often used to assess the bacterial contamination of waters, only the *E. coli* results will be discussed in this section. The raw data from these surveys is given below in Table 3.4.

Table 3.4 *E. coli* concentrations (colony count per 100mL) for sites sampled during summer and winter snapshot surveys in the Great Forester catchment, 1998.

		E. coli (count per 100 mL)	
SITE NAME	**Site No.**	**Summer Survey**	**Winter Survey**
Gt Forester u/s Trout farm	GF 16	*	*
Gt Forester d/s Trout farm	GF 15	*	*
Gt Forester at 10 Mile Track (No. 2)	GF 14	510	100
Gt Forester at 10 Mile Track (No. 1)	GF 13	*	*
Gt Forester at Cuckoo Rd	GF 11	*	*
Hogarths Rivulet at Cuckoo Rd	GF 30	140	20
Gt Forester at Tasman H'way (Tonganah)	GF 10	660	120
Arnon River at Mountney Rd	GF 25b	*	*
Gt Forester at Burrows rd	GF 8	460	30
Arnon River at Forester Rd	GF 25	100	40
Pearly Br. (Pearly Brook Rd)	GF 22	*	5
Gt Forester at Forester Rd	GF 6	110	70
Surveyors Ck at Old Waterhouse Rd	GF 27	*	*
Gt Forester at Old Waterhouse Rd	GF 4	*	*
Gt Forester at Forester Lodge	GF 1b	*	160
Tuckers Ck at Barnbougle Rd	GF 19	330	*
Tuckers Ck u/s Gt Forester	GF 18	270	240
Gt Forester off Waterhouse Rd (u/s tidal limit)	GF 1	200	50

As this sampling was also only a 'snapshot', it is not valid to compare results against either the ANZECC (1992) guidelines or the more recent, revised version of that document. Both these documents state that evaluation of microbiological quality should be based on median levels from data collected through frequent monitoring. However, the data collected during the surveys can be used to highlight areas in the catchment where water quality is affected by faecal pollution. Where higher levels of faecal bacteria are reported, further investigation may be needed to adequately determine the level and source of pollution.

As the data show, coliform levels were higher at all sites during summer than winter. Examination of the spatial plot of the summer data (Figure 3.26a) shows that on the main river, sites in the upper half of the catchment have highest concentrations indicating that faecal input to the river may be greatest in this area. Of the tributaries sampled, it is also clear that Tuckers Creek also experiences input of faecal material. Hogarths Rivulet and the Arnon River both appear to have the least faecal contamination and may be more representative of 'background environmental' levels.

Data from the winter survey (Figure 3.26b) suggests that the situation in the tributaries is much the same, with Tuckers Creek showing much higher faecal coliform concentrations than the others. *E. coli* are virtually absent from Pearly Brook, while levels in the Arnon River and Hogarths Rivulet are lower than their summer survey results.

Figure 3.26a Coliform concentrations at sites in the Great Forester River and tributaries the summer survey, 1998.

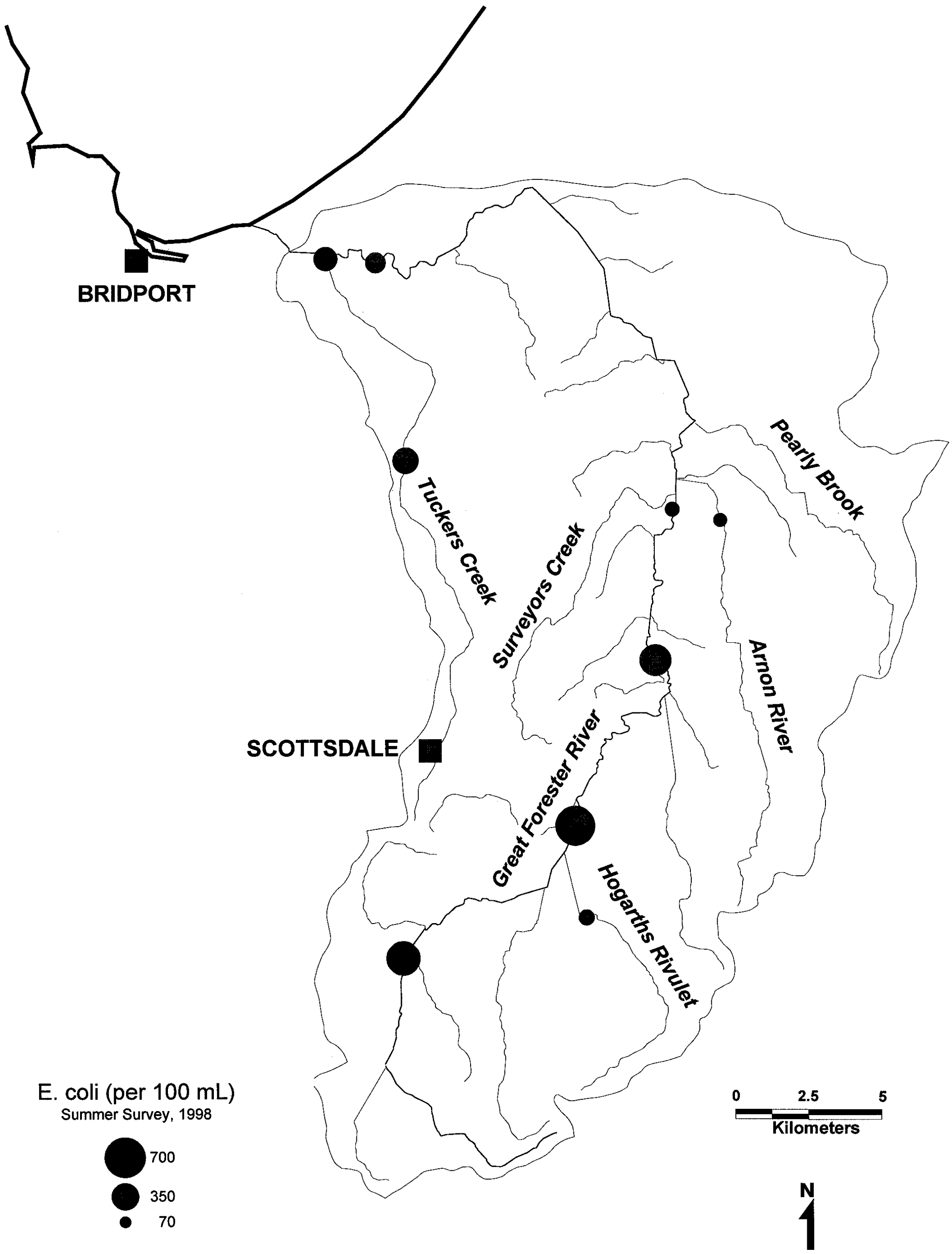
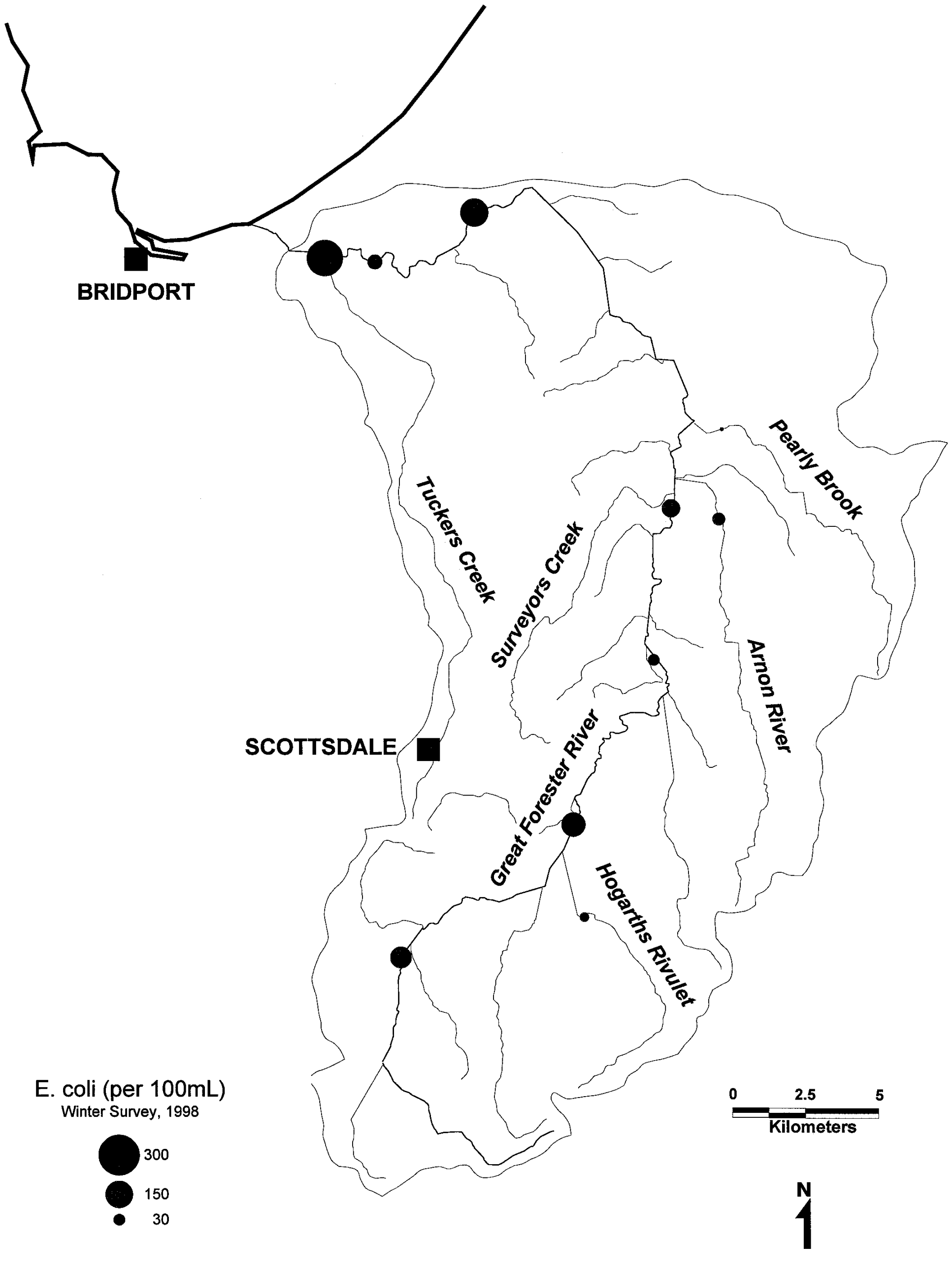


Figure 3.26b Coliform concentrations at sites in the Great Forester River and tributaries the winter survey, 1998.



In the main river, the pattern is less clear. While the concentrations of bacteria are lower overall, the site with highest concentrations is near the river mouth; a site not sampled during the summer survey. Stock access to the river and the swampy nature of that site are most likely to be responsible for these higher concentrations. Swampy, depositional areas are known to sustain faecal coliforms for a much longer period outside the gut as sediment can buffer environmental factors which tend to destroy them and provide nutrients to sustain them [Sherer, 1992 #40][Howell, 1996 #27]. As turbidity levels in the lower river at this time were higher (see previous section), these readings may reflect the *E. coli* concentrations in the sediments at this site and not recent faecal contamination of the waterway.

Catchment Survey - Total Nitrogen

The results for TN show that there was a distinct difference in conditions between summer and winter (Figure 3.27 a&b). In summer, it is clear that there is greater nitrogen input to the Great Forester River in the upper catchment. At Ten Mile Track, TN was measured at 1.9 mg/L while at Tonganah the concentration was 1 mg/L. This compares with TN concentrations of about 0.6 mg/L at sites lower down the river. Tributary TN concentrations are generally lower than in the Great Forester River. Further examination of the data from the Great Forester shows that most of the TN entering the river at the two upper sites is as NO_3/N (Figure 3.28). Eighty-five percent of the TN measured at Ten Mile Track was in the form of nitrate, which is very mobile in groundwater (see earlier section) and suggests that there may be impacts on groundwater in the upper catchment by land use practices.

During winter, TN concentrations are higher than in summer, but much more uniform across all sites (median Total N of 0.95 mg/L). While the site at Ten Mile Track still showed the highest TN concentration (1.47 mg/L), several sites elsewhere on the Great Forester and some tributaries (Arnon River and Pearly Brook) also showed concentrations of TN greater than 1 mg/L. Like the results from summer, for many sites, the majority of TN was in the form of nitrate, indicating the level of groundwater flushing occurring during winter baseflows. However at Tuckers Creek, TN on both occasions was made up primarily of organic and ammonia nitrogen (70 - 90%) indicating that biological sources of nitrogen are having greater impact on this stream.

Figure 3.27a Total N concentrations at sites in the Great Forester River and tributaries the summer survey, 1998.

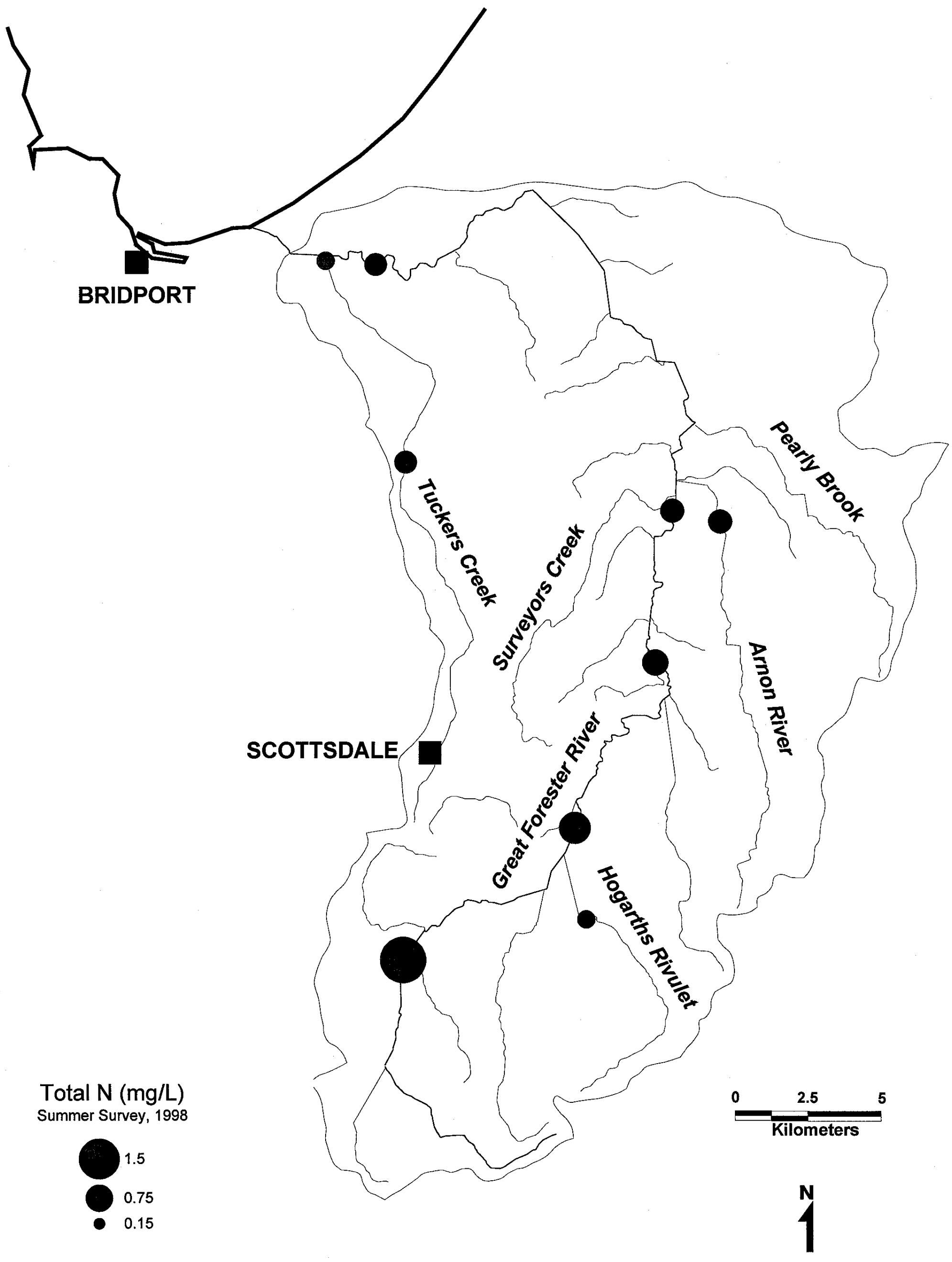


Figure 3.27b Total N concentration at sites in the Great Forester River and tributaries the winter survey, 1998.

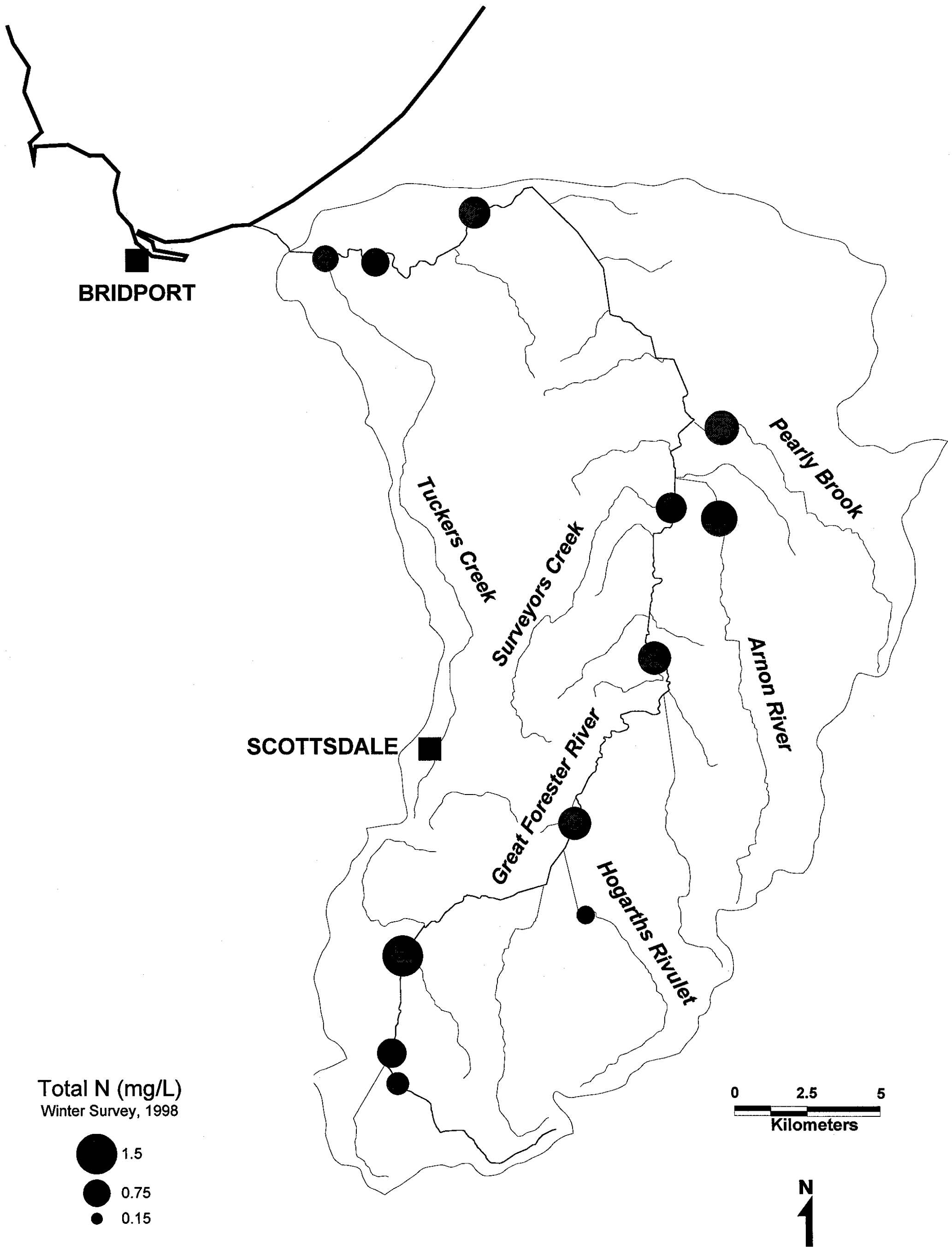
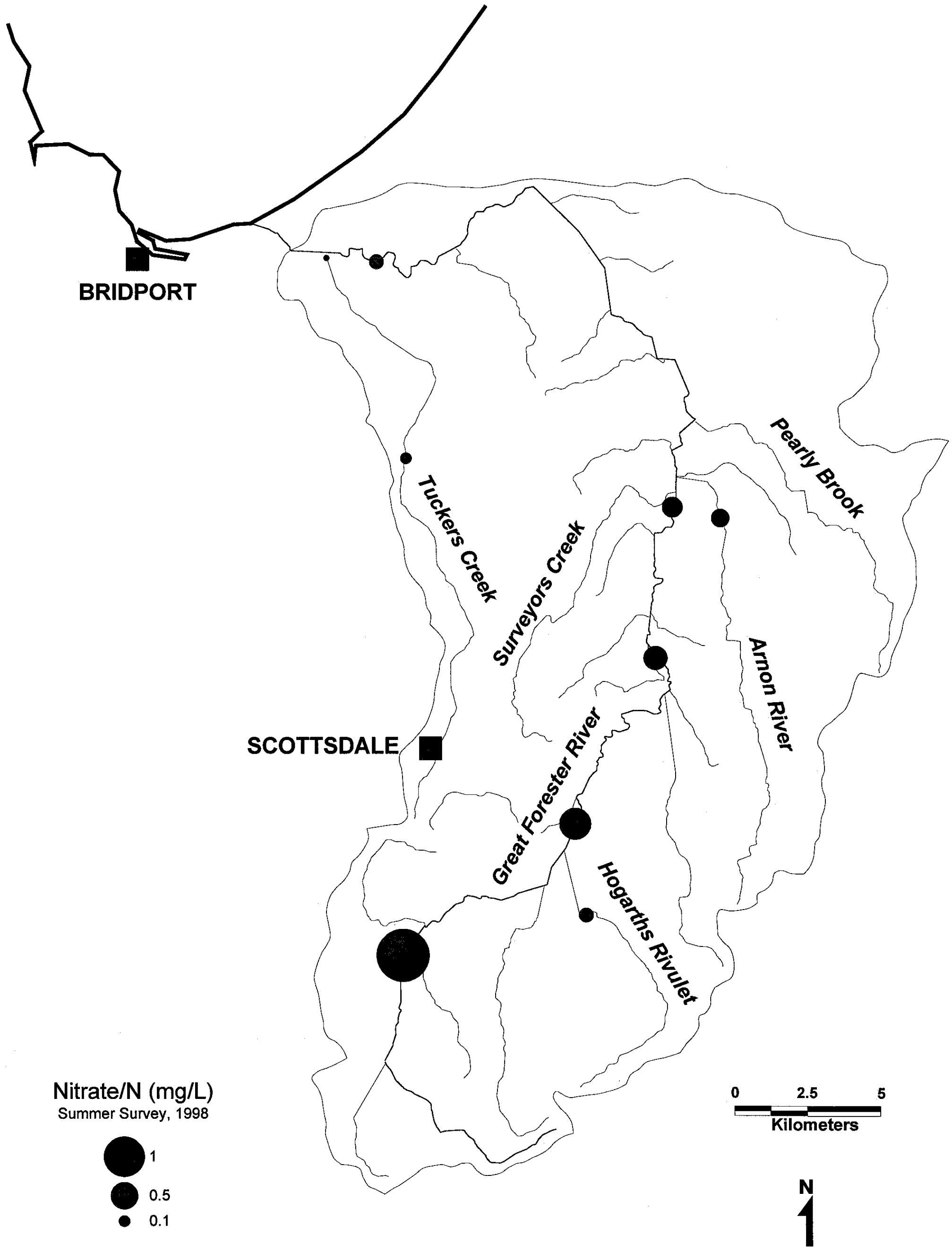


Figure 3.28 Nitrate/N concentration at sites in the Great Forester River and tributaries the summer survey, 1998.



Catchment Survey - Phosphorus

The survey results for TP from both summer and winter are very similar (Figure 3.29 a&b). The median concentration across all sites on both occasions was 0.03 mg/L. During summer, significant results were returned for the Arnon River (0.038 mg/L) and the Great Forester at Tonganah (0.035 mg/L). The concentration of TP at other sites in the Great Forester River varied between 0.024 - 0.029 mg/L, but did not show any trend for increasing or decreasing concentrations downstream.

The results from the winter survey once again showed that TP in the Arnon River was elevated (0.045 mg/L) relative to the rest of the catchment, while in the Great Forester River sites lower in the catchment showed highest TP concentrations. Together with the summer data, it is clear that there is phosphorus enrichment of the Arnon River. The cause of this is not obvious, as most of the land surrounding this site is subject only to forestry activities. However, about 6 km upstream, the Arnon River drains an area of land which is used for intensive agricultural production and the levels of both TP and TN which were found at this site probably reflect the impact of this.

The other significant feature of the data are the winter results from the two uppermost sites on the Great Forester River. The change in water quality between these two sites is noteworthy. The results from GF16 (Table 3.5), which is immediately downstream of the water supply offtake for Scottsdale, reflect the clear and low nutrient status of the river as is emerges from an essentially forested area. At the next site downstream (GF15), which is the first site in agricultural land, the increase in most parameters is marked. This is especially so for phosphorus and ammonia, which increase 5-fold and 20-fold respectively. Furthermore, a large percentage of the phosphorus detected was in the dissolved form (52%) which is generally indicative of effluent or fertiliser input to the river. The high concentration of ammonia supports the former conclusion. While dairy farming occurs in the general vicinity of GF15, a trout farm is also located between the two sites and uses Great Forester River water.

Table 3.5 Selected results from two sites on the Great Forester River recorded during the winter ‘snapshot’ survey, 1998.

Site	Turbidity (NTU)	Total P (mg/L)	Ammonia N (mg/L)	Total N (mg/L)
GF16	0.93	0.006	0.005	0.52
GF15	3.38	0.031	0.10	0.83

When viewed in relation to recommended ‘trigger levels’ proposed by the new draft water quality guidelines for freshwaters [ANZECC, draft 1998 #185], it is apparent that several sites have TP concentrations which are sufficient to promote nuisance algal blooms and other symptoms of nutrient enrichment. Whether blooms occur will depend on other factors such as the amount of sunlight striking the stream and the flow characteristics. At sites where riparian vegetation is degraded or absent, the occurrence of blooms is likely to be much higher.

As a comparison with another recent study in the nearby Ringarooma catchment [Bobbi, 1999 #179], median TP concentration across 11 sites during summer was 0.014 mg/L and across 19 sites during winter was 0.009 mg/L. In the Brid catchment (unpublished data) similar catchment surveys of 5-6 sites showed median TP concentrations of 0.045 mg/L during summer and 0.035 mg/L during winter. From this data it is clear that both the Great Forester and the Brid rivers are more nutrient enriched than the Ringarooma River.

Figure 3.29a Total P concentration at sites in the Great Forester River and tributaries the summer survey, 1998.

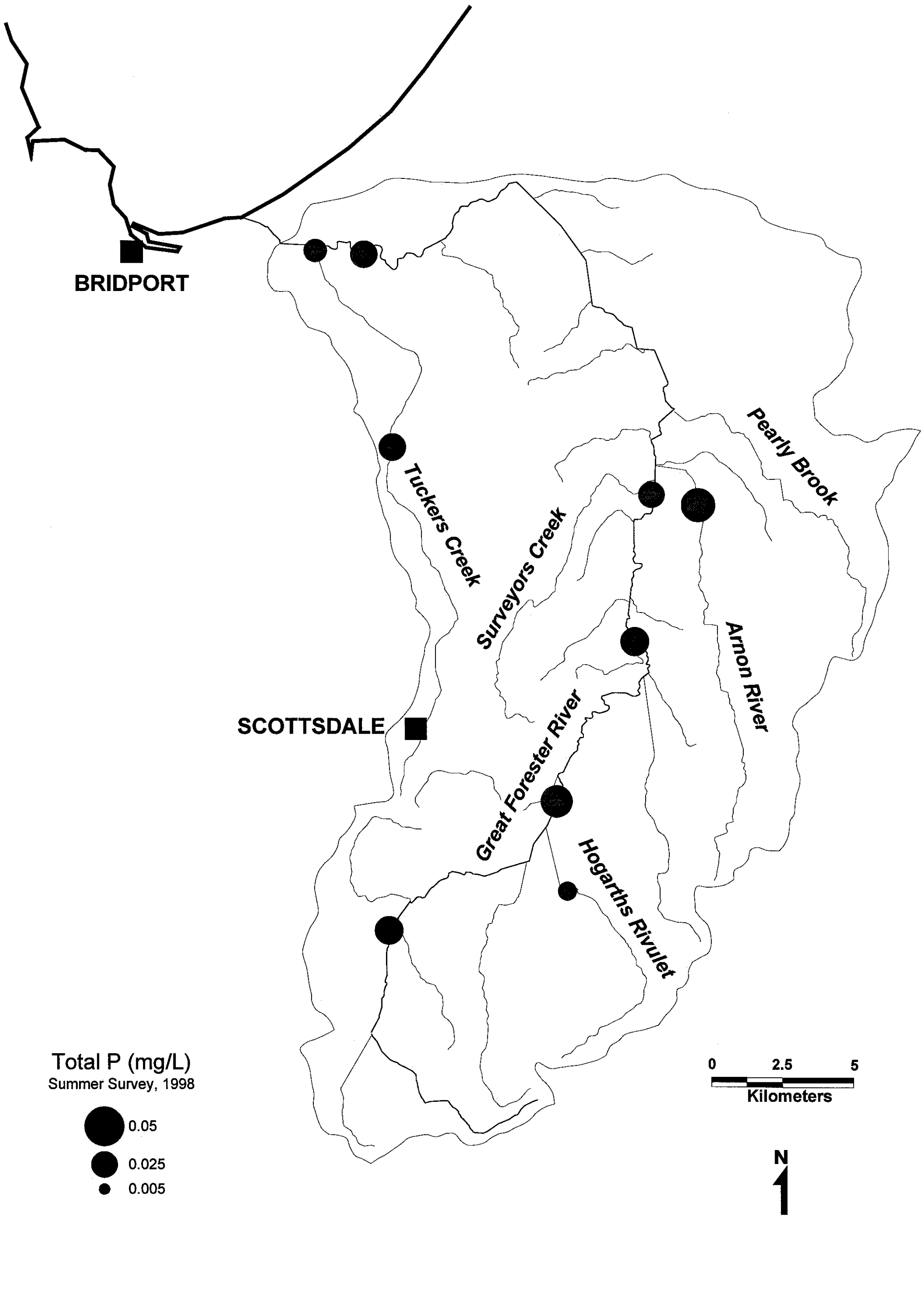
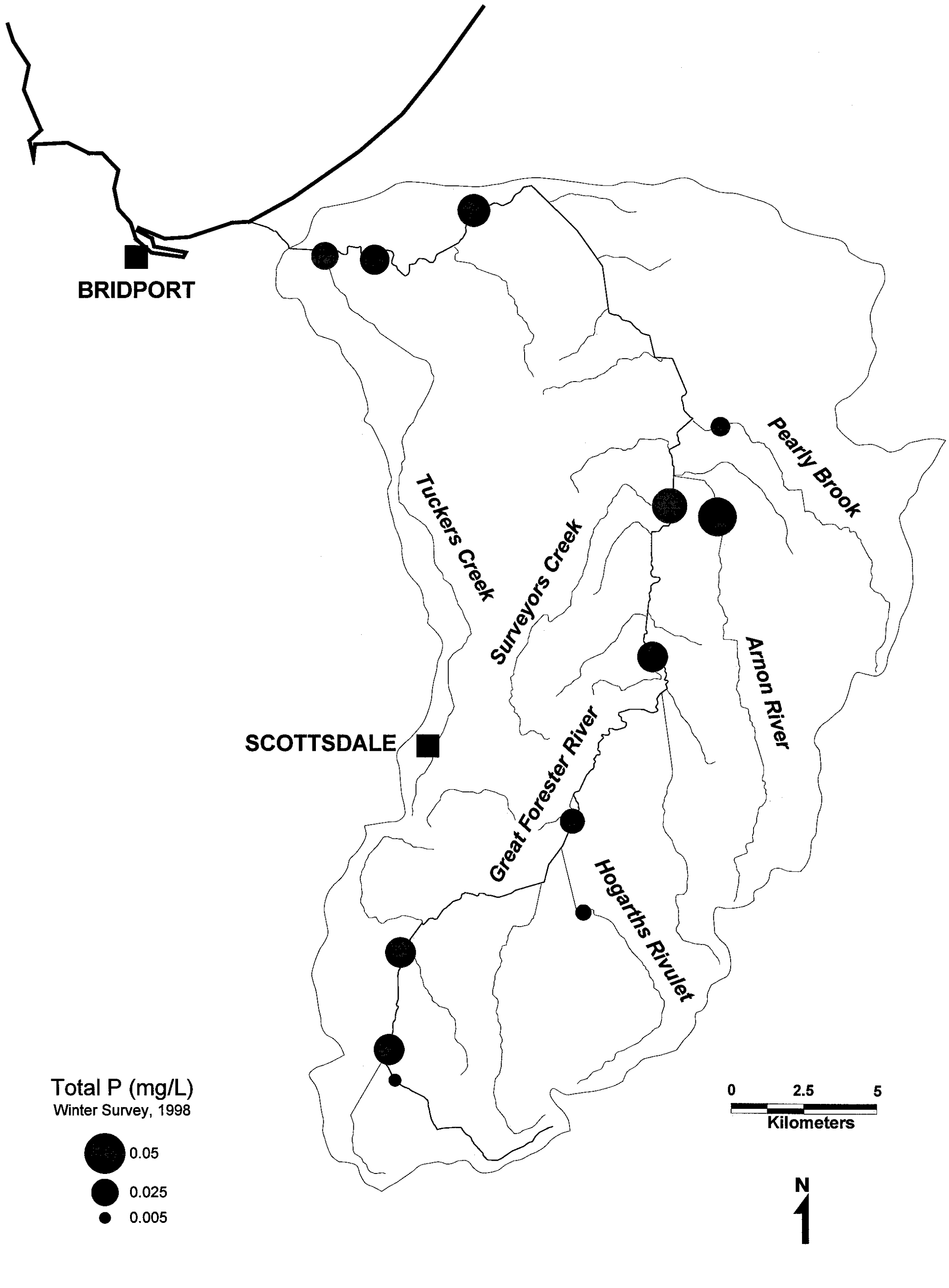


Figure 3.29b Total P concentration at sites in the Great Forester River and tributaries the winter survey, 1998.



Catchment Survey - Metals

Samples during the snapshot surveys were collected and analysed for some of the metals commonly found in environmental waters and which may pose some risk to aquatic organisms or human health. Due to budget limitations, only total metal concentrations were determined. The limit of detection of the various metals analysed for are listed below;

Metal	Limit of Detection
Aluminium	50 μg/L
Iron	20 μg/L
Zinc	1 μg/L
Copper	1 μg/L
Lead	1 μg/L
Cadmium	1 μg/L
Chromium	1 μg/L
Nickel	1 μg/L
Cobalt	1 μg/L

As significant results were only recorded for aluminium, zinc and iron, only these data will be discussed. The analyses for all other parameters showed levels at or below the detection limits of the instrumentation used. However, before discussing the results, it is worth mentioning some characteristics of metals and how they relate to published water quality guidelines.

Like many other chemical parameters commonly tested for in water, metals can be present in various forms, some of which are more toxic to aquatic life than others. They can be present in water attached to suspended matter, colloids, or complex organic compounds (eg humic substances). They can also be present in dissolved forms and these are generally the forms which are toxic to aquatic life [Dallas, 1993 #186].

The toxicity of metals can also vary according to the environment they are in. Acidic conditions tend to increase the toxicity of most metals, while high concentrations of hardness can reduce metal toxicity [ANZECC, 1992 #4]. It is therefore important to measure both pH and hardness when assessing metal concentrations in the environment.

To take all these factors into account, the revised National Water Quality Guidelines for Fresh and Marine Waters [ANZECC, draft 1998 #185] have proposed a strategy whereby basic testing begins with analysis for 'Total Metal' concentrations and if the result exceeds the guideline level, further analysis may be carried out to define the level and nature of toxicity. If for example total copper concentration in a sample exceeds the proposed guideline concentration of 0.33 μg/L, hardness of the water is tested to determine the toxicity. If the risk is still high, further testing for dissolved copper is then undertaken to determine whether the dissolved fraction poses a risk. If the risk is still considered high, then more specific testing to investigate its biological hazard may be needed.

This approach is termed 'hierarchical' and under this system, the first level of testing (in this case, for total metals) may be over-protective, as a large proportion of the metal may in fact be bound to particles. However, results from tests for totals is often the best and cheapest starting point. During these surveys, only total metal concentrations have been determined.

Hardness was measured at various sites during the summer survey and showed that across the catchment, all rivers are soft, with measured hardness (as $CaCO_3$) at or below 15 mg/L. At this level the following guidelines have been suggested to protect aquatic ecosystems [ANZECC, draft 1998 #185].

Table 3.6 Proposed guideline values for various metals whose toxicity is influenced by water hardness (metal concentrations in µg/ L).

Hardness	**(mg/L as $CaCO_3$)**	**Cd**	**Cr(III)**	**Cu**	**Pb**	**Ni**	**Zn**
Soft	(0 - 59)	0.013	9.0	0.33	1.2	0.68	2.4
Moderate	(60 - 119)	0.035	22.2	0.84	4.8	1.7	6.1
Hard	(120 - 179)	0.054	33.7	1.3	9.2	2.7	9.4

[ANZECC, draft 1998 #185]

For aluminium the guideline is not hardness dependent and a value of 1.2 µg/L is proposed. The bioavailability of metals is also greatest in acid waters (< 6.5). Maximum toxicity of aluminium has been found to occur at a pH of about 5.0 - 5.2 and is known to be toxic to fish, though not necessarily invertebrates. Therefore, bearing these issues and influences in mind, and recognising the cautious nature of the approach, the following results from the summer and winter surveys are discussed.

Aluminium

Of all the metals tested for, the most significant results were recorded for aluminium. Concentrations during the summer survey (Figure 3.30a) ranged from 314 - 431 µg/L, except at the uppermost site (at Ten Mile Track) which registered < 50 µg/L. Concentrations across all sites during the winter survey (Figure 3.30b) were not significantly different to that found during summer (range 87 - 464 µg/L) although a higher Al concentration was measured at Ten Mile Track (364 µg/L).

In the Ringaroma catchment, where high aluminium concentrations were also measured [Bobbi, 1999 #179], it was suggested that aluminium levels might be related to turbidity, as higher total aluminium concentrations were generally found when turbidity was also higher. A similar analysis of the results from the Great Forester catchment (Figure 3.31, below) is less clear. This plot includes all the data collected during both surveys. While aluminium levels also tend to be higher when turbidity levels are high, some of the data show that elevated aluminium can be found in lower turbidity water as well (suggested by points which are circled). The data within the circle come from summer samples at the following sites;

1. Hogarths Rivulet at Cuckoo Rd
2. Great Forester River at Forester Rd
3. Great Forester River at Burrows Rd
4. Great Forester River at Tonganah

The corresponding winter sample data for these sites is also indicated on the plot.

At these four sites, it appears that concentrations of aluminium may be independent of turbidity levels. If this is the case, there may some risk to the aquatic environment and further study may be required to determine the level of risk posed by these aluminium concentrations. It is likely that the presence of high levels of aluminium in rivers of this catchment reflects the underlying granite geology.

The possible presence of humic substances in rivers of this catchment may also be a factor reducing the toxicity of aluminium as these substances can effectively bind metals to them, forming relatively harmless metal-organic complexes [ANZECC, 1992 #4]. In rivers on the west coast of Tasmania, humic substances have been shown to bind large percentages of dissolved metals present in those waters [Koehnken, 1992 #188].

Figure 3.30a Total Al concentration at sites in the Great Forester River and tributaries the summer survey, 1998.

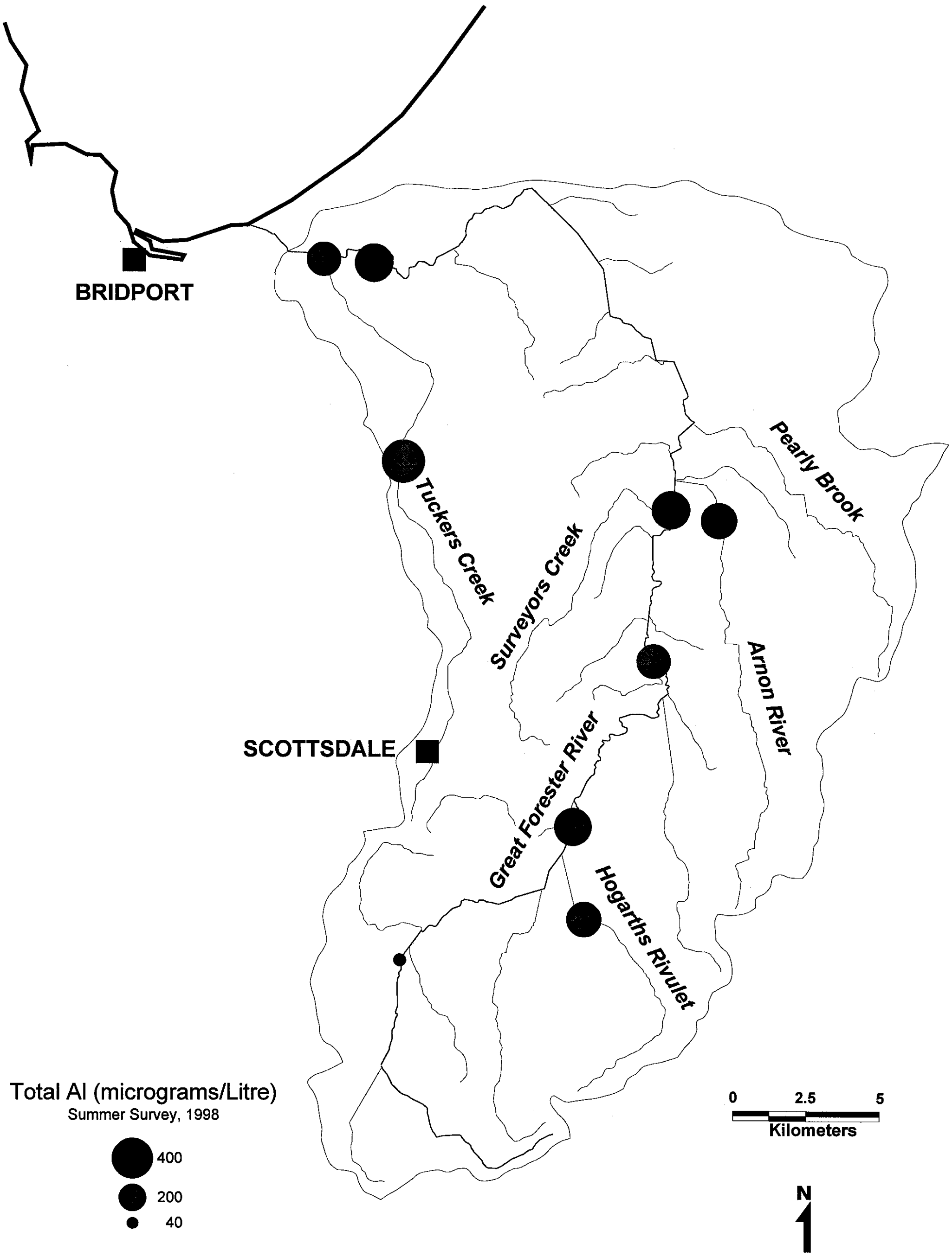
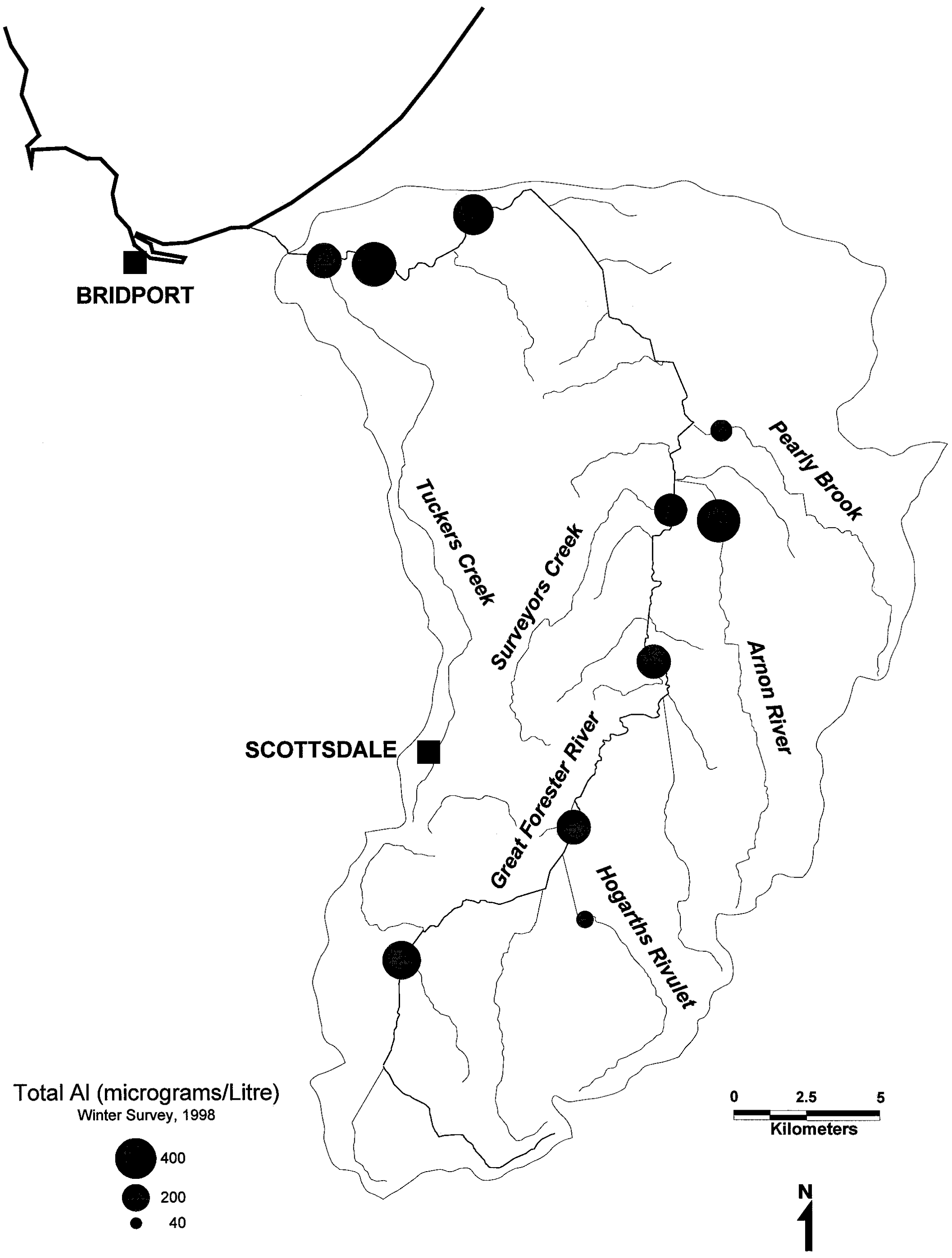


Figure 3.30b Total Al concentration at sites in the Great Forester River and tributaries the winter survey, 1998.



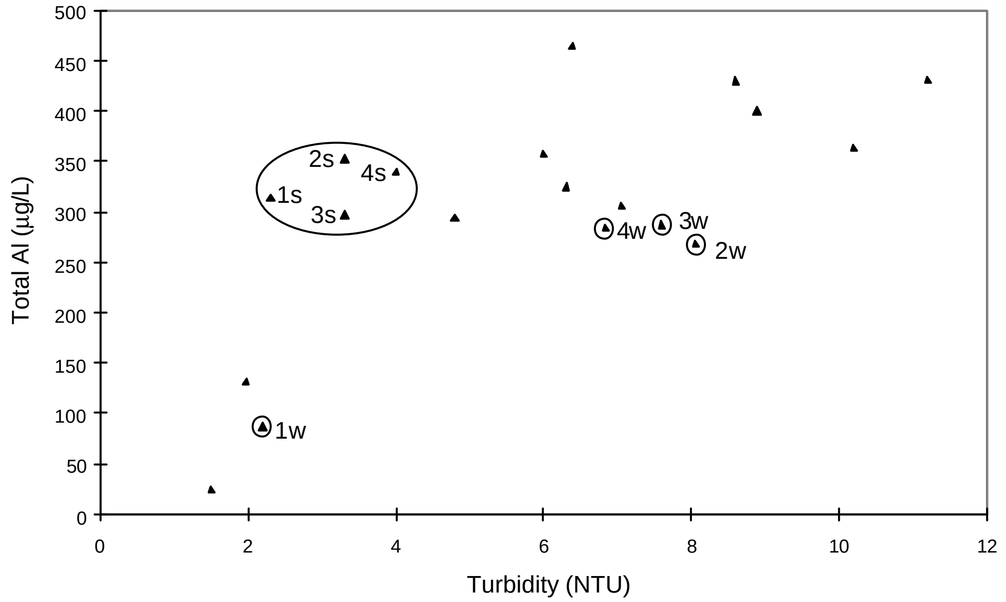


Figure 3.31 Relationship between Total Al concentration and turbidity at sites in the Great Forester Catchment sampled during summer and winter, 1998.

Zinc

Concentrations of Total Zn were detected at low levels at all sites sampled (Table 3.7) during both summer and winter surveys, with concentrations ranging between 1 µg/L and 5 µg/L. At the majority of sites, Zn concentrations were greater in the winter survey than in summer. Although several of the results are above the concentrations suggested as 'trigger levels' under the latest ANZECC guidelines [ANZECC, draft 1998 #185], they are not sufficiently high to warrant further discussion other than to mention that like aluminium they may be indicative of the granite geology underlying much of the catchment and represent naturally occurring trace levels in rivers throughout the region (see [Bobbi, 1999 #179]).

Table 3.7 Total zinc concentrations (µg/L) at sites in the Great Forester catchment during two snapshot surveys, 1998.

SITE NAME	**Code**	**Total Zn (summer)**	**Total Zn (winter)**
Gt Forester off Waterhouse Rd (u/s tidal limit)	GF 1	2	2
Tuckers Ck u/s Gt Forester	GF 18	1	4
Tuckers Ck at Barnbougle Rd	GF 19	3	*
Gt Forester at Forester Lodge	GF 1b	*	3
Gt Forester at Forester Rd	GF 6	1	2
Pearly Br. (Pearly Brook Rd)	GF 8	*	2
Arnon River at Forester Rd	GF 9	2	3
Gt Forester at Burrows rd	GF 8	1	2
Gt Forester at Tasman H'way (Tonganah)	GF 10	1	2
Hogarths Rivulet at Cuckoo Rd	GF 30	2	5
Gt Forester at 10 Mile Track (No. 2)	GF 14	1	4

* Denotes sites not tested.

Iron
Like zinc, iron (Fe) is an essential micronutrient for plant and animal growth [Dallas, 1993 #186] and is present in most surface waters. While it can be toxic to some aquatic animals at extremely high concentrations it more commonly presents difficulties in the use and distribution of water (ie iron deposits in piping) as it is easily oxidised and can affect taste. There is no health-based guideline value for iron.

The data collected during each of the surveys (Table 3.8) shows that Fe levels are very low throughout the catchment, with Tuckers Creek having highest concentrations at slightly over 1 mg/L. While low enough not to present concerns for environmental or agricultural use, many of the sites sampled contain concentrations which may affect the taste of the water, as the threshold for taste is 0.3 mg/L and can become objectionable at concentrations above 3 mg/L [NHMRC, 1996 #34]. It is therefore likely that water extractions from several sites for the purposes of domestic consumption may be affected on occasion.

Table 3.8 Total iron concentrations (mg/L) at sites in the Great Forester catchment during two snapshot surveys, 1998.

SITE NAME	**Code**	**Total Fe (summer)**	**Total Fe (winter)**
Gt Forester off Waterhouse Rd (u/s tidal limit)	GF 1	0.71	0.68
Tuckers Ck u/s Gt Forester	GF 18	1.19	0.9
Tuckers Ck at Barnbougle Rd	GF 19	1.13	
Gt Forester at Forester Lodge	GF 1b		0.61
Gt Forester at Forester Rd	GF 6	0.51	0.36
Pearly Br. (Pearly Brook Rd)	GF 8		0.24
Arnon River at Forester Rd	GF 9	0.83	0.90
Gt Forester at Burrows rd	GF 8	0.47	0.30
Gt Forester at Tasman H'way (Tonganah)	GF 10	0.39	0.31
Hogarths Rivulet at Cuckoo Rd	GF 30	0.15	0.09
Gt Forester at 10 Mile Track (No. 2)	GF 14	0.24	0.37

3.6 Instantaneous Nutrient Loads

Spot water quality sampling was carried out during a significant flood on 23rd September, 1998. Flood waters in the Great Forester River at Forester Rd reached 2.67m, which is equivalent to a flow of about 60 $m^3.s^{-1}$ (or 5184 $ML.day^{-1}$). Water sampling and field testing was performed at various sites down the length of the river, as well as at various sites on tributaries and other rivers in nearby catchments. That data will also be presented here for comparison, though it should be noted that catchment activities in other areas may be different to that in the Great Forester. The rainfall intensity will also have varied between catchments, having a significant impact on the carrying capacity of runoff waters and the pollutant load they carried during that particular event.

Concentrations measured during this runoff event are shown below (Table 3.9). Turbidity levels were measured at all sites, with highest readings taken in the Ringarooma River at Moorina, where flood levels in the river were very high. In the Great Forester River, highest turbidity levels were measured at Tonganah when river flows were near their peak. Turbidity in the Arnon River and Pearly Brook were much lower, possibly reflecting the greater forest cover in those catchments.

Flood flows in the Ringarooma were much higher than in the Great Forester and this, combined with the greater area of upper catchment being used for intensive agriculture, may explain the greater concentrations of nutrients measured in that river. Data from sites on the Brid and Pipers rivers, both of which are more distant, show that nutrient levels from the September '98 event were lower.

TABLE 3.9 Water quality data recorded during flooding in the Great Forester catchment on the 23rd September, 1998.

Site	Date	River Level	Turbidity (NTU)	TSS (mg/L)	TN (mg/L)	TP (mg/L)
Great Forester at Forester Rd	23/9/98 15:25	2.255	151	120	1.83	0.22
Great Forester at Tonganah	23/9/98 11:15		178	150	2.74	0.36
Arnon River u/s Gt Forester	23/9/98 15:40		63			
Pearly Brook u/s Gt Forester	23/9/98 16:10		35			
Ringarooma at Moorina	23/9/98 13:20	4.07	334	650	4.15	0.86
Brid River u/s Tidal Limit	24/9/98 10:30	0.998	92	85	1.76	0.17
Pipers River d/s Yarrow Ck	24/9/98 14:00	1.27	57	30	1.26	0.066

When compared to the monthly monitoring data (section 3.4) nutrient concentrations in the Great Forester River were up to 10 times higher during the flood than were found under average baseflow conditions and clearly demonstrate the impact of runoff water on water quality.

Where water quality was measured at stream gauging sites, the data was able to be used to calculate instantaneous loads at the time of sampling. Loads are easily calculated by multiplying the volume of water flowing down the river at the time by the concentration of the particular parameter measured. Results of these calculations are presented in Table 3.10 below.

TABLE 3.10 Instantaneous loads of suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP) measured in various rivers in the northeast during flooding in September, 1998.

Site	Date	Flow ($m^3.s^{-1}$)	TSS Load (kg/hr)	TN Load (kg/hr)	TP Load (kg/hr)
Ringarooma at Moorina	23/9/98 13:20	111.6	261,144	1,666	346
Great Forester at Forester Rd	23/9/98 15:25	49.7	21,470	328	39
Brid River u/s Tidal Limit	24/9/98 10:30	19.1	5,829	121	11.7
Pipers River d/s Yarrow Ck	24/9/98 14:00	43.2	5,740	241	12.6

Catchment areas for each site:

Ringarooma River at Moorina 606 km^2
Great Forester River at Forester Rd 193 km^2
Brid River u/s Tidal Limit 139 km^2
Pipers River u/s Yarrow Ck 298 km^2

The data show that highest loads were carried in the Ringarooma River, which was also discharging the largest volume of water at the time of sampling (111.6 $m^3.s^{-1}$). Relatively higher river gradient (and hence stream velocity) at this site would facilitate the transport of heavier suspended material and increase the delivery of this to flood-plain areas downstream. At the streamflow monitoring site on the Great Forester River, the bed gradient is much less (1:550 as compared to 1:200 at Moorina), and it is very likely that lower flow velocity means that the river is not able to carry larger particles. As a consequence of this, suspended solids loads at this site are an order of magnitude less than was measured in the Ringarooma River at Moorina.

Adjusting these figures for catchment size (Table 3.11) gives an indication of export loads (ie yield) leaving each catchment, and allows more valid catchment to catchment comparison. Like the load figures shown above, the instantaneous catchment yield data show that the Ringarooma catchment above Moorina was losing relatively higher amounts of suspended solids and nutrients during flood flows than the Great Forester and nearby catchments during that event. However, the difference between yields from the Ringarooma and Great Forester is not so great when corrected for catchment area.

TABLE 3.11 Measured instantaneous loads corrected for catchment size.

Site	TSS Yield (kg/km^2)	TN Yield (kg/km^2)	TP Yield (kg/km^2)
Ringarooma at Moorina	430.9	2.75	0.57
Great Forester at Forester Rd	111.2	1.7	0.20
Brid River u/s Tidal Limit	41.9	0.87	0.08
Pipers River d/s Yarrow Ck	19.3	0.81	0.04

The instantaneous yield of suspended solids (eg. soil and organic particulate material) at the time of sampling is almost four time higher from the Ringarooma upstream of Moorina than for the Great Forester River upstream of Forester Rd and more than ten times higher than was measured in the Brid River during concurrent flooding. Nutrient yields were also found to be highest in the Ringarooma River, although figures from the Great Forester River are more comparable.

3.7 Diurnal Water Quality Variations

During the study, continuous monitoring equipment was employed to gather information on diurnal changes in selected water quality parameters. It is well known that various water quality characteristics change on a 24 hour cycle (diurnal) and it is possible that parameters which appear to be within acceptable limits during daylight hours may well be of concern after sunset. Where rivers are receiving organic pollution or nutrient enrichment which encourages algal and aquatic plant growth, there can be large changes in pH and dissolved oxygen [Cooke, 1995 #91] which can have detrimental impacts on invertebrates and fish life. Streams in New Zealand which have depleted oxygen levels have been shown to be linked to elevated nutrients and organic loads [Wilcock, 1995 #52].

For the purposes of this study, two sites were chosen for investigation. One was located in the lower reaches of the Great Forester River, while the other was located on the Arnon River at Forester Rd. Two independent and fully submersible loggers were used to monitor dissolved oxygen and water temperature at each of the sites simultaneously on three occasions towards the end of the study, leading into summer. Each deployment was for a period of at least 36 hours.

While the main aim was to deploy the instruments under stable climatic conditions, during the first deployment (September 21-24, 1998) there was a significant front which brought rain and caused minor flooding in the catchment. Some data was collected from the Arnon River during this event, and will be discussed. The logger recording in the Great Forester River was retrieved prior to the flood water rising due to concern over equipment loss or damage.

During the second two deployments (November 24-26 and December 14-16, 1998), climatic and hydrological conditions were stable. The data collected from these two deployments is more representative of 'normal' baseflow conditions.

The following two figures (Figure 3.31 & 3.32) illustrate the change in water temperature at each site on all three occasions. For both the November and December monitoring events, the graphs show how water temperature peaks in the mid-afternoon and troughs just after sunrise (7-8 am). The plot also shows how the size of diurnal change in water temperature increases approaching summer, when warmer daytime temperatures occur due to warmer air temperatures and greater sunlight penetration of the stream. Water temperature in the Arnon River is always a degree or two cooler than the Great Forester River.

At both sites, the arrival of the cold front has clearly altered the form of the plot of water temperature for September, resulting in graphs which are much flatter. The effects on dissolved oxygen concentrations in both rivers is even more obvious (Figure 3.33 &3.34). While dissolved oxygen levels in the period prior to the rain event in September are very stable, the arrival of the front (and runoff entry to the river) causes oxygen levels to plummet. A more detailed examination of the changes which occurred during this event is made later. The main features which should be noted from Figures 3.33 to 3.34 is that as summer approaches, dissolved oxygen levels generally decrease, and night-time levels become markedly lower than those which occur during the day. This is especially apparent for the Great Forester River during summer, where oxygen levels at night may reach relatively low levels.

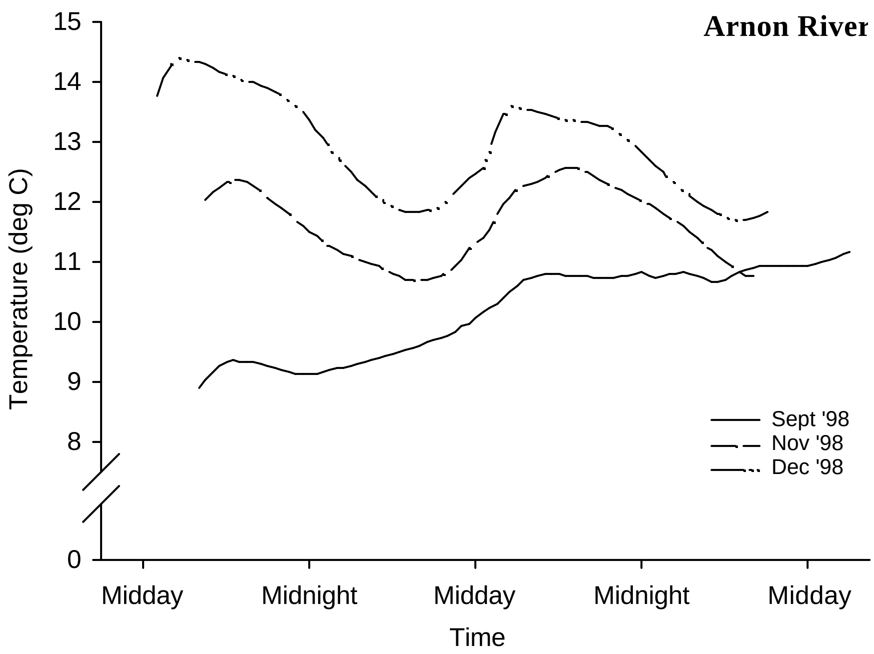


Figure 3.31 Diurnal variation in water temperature in the Arnon River at Forester Rd during three remote monitoring investigations in 1998.

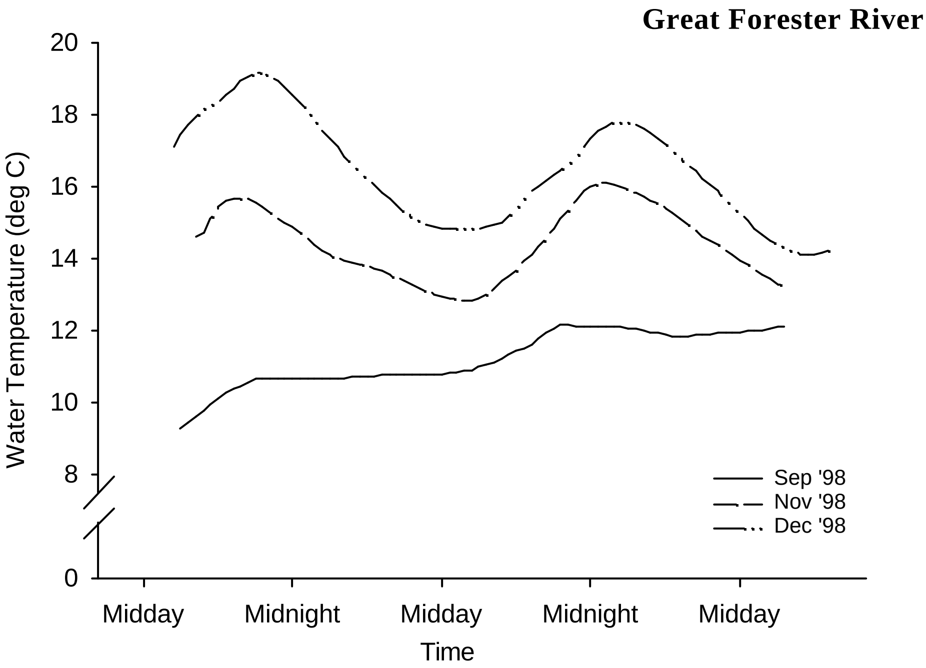


Figure 3.32 Diurnal variation in water temperature in the lower Great Forester River during three remote monitoring investigations in 1998.

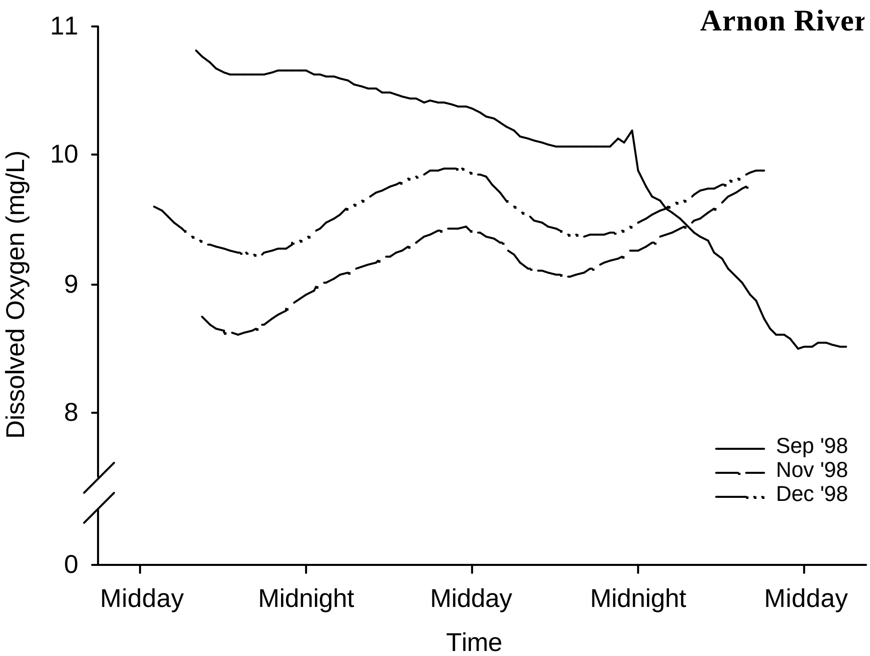


Figure 3.33 Diurnal variation in dissolved oxygen in the Arnon River at Forester Rd during three remote monitoring investigations in 1998.

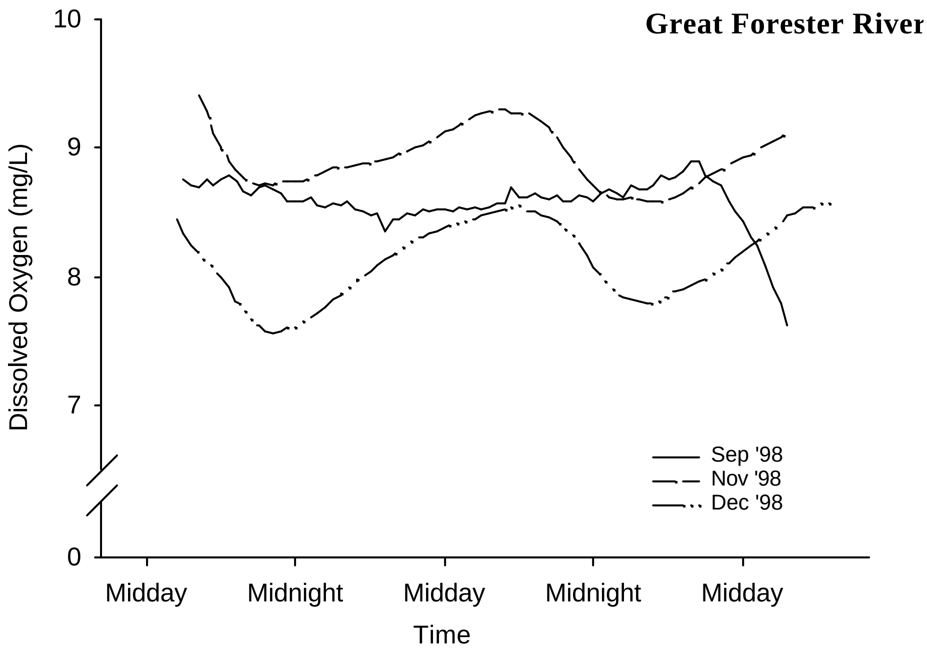


Figure 3.34 Diurnal variation in water temperature in the lower Great Forester River during three remote monitoring investigations in 1998.

Arnon River Flood Event

The water quality changes in the Arnon River during the minor flood event of September 21 - 24, 1998 are shown in more detail in Figures 3.35 - 3.38 below. Changes in temperature, conductivity, dissolved oxygen and pH are all presented alongside river level changes recorded during the event. The results show that impacts on some parameters occurs quite some time before significant river level rises (resolution of river level sensor is 10 cm). This is most apparent for water temperature and conductivity. Dissolved oxygen and pH are affected slightly later and tend to react in a similar way as conductivity. These parameters tend to decrease rapidly as river level rises. Conductivity drops most rapidly, decreasing by almost 30% (from 173 μS/cm to 121 μS/cm), while oxygen levels drop by more than 1.5 mg/L and pH levels fall from 6.85 to 5.8 over a 10-hour period.

The reasons for some of these changes are relatively clear. As runoff enters the river, this water will be carrying the highest concentrations of pollutants. At this time there is also a lesser volume of water in the river to dilute these pollutants and therefore their effects may be significant. This may explain the relatively rapid decrease in dissolved oxygen, which could be reacting to the BOD load entering the river or that being remobilised from the river bed. This commonly occurs in urban streams receiving stormwater [Goldman, 1983 #21] and has been referred to as the 'first flush' phenomenon [Bertrand-Krajewski, 1998 #187].

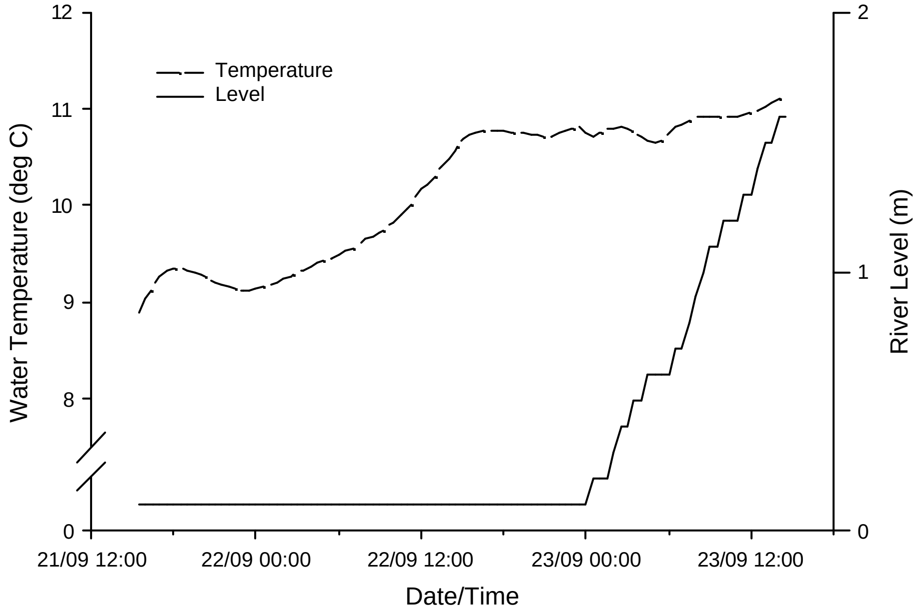


Figure 3.35 Water temperature changes during a minor flood event in the Arnon River between 21[st] - 23[rd] September, 1998. The change in river level for the corresponding period is also shown.

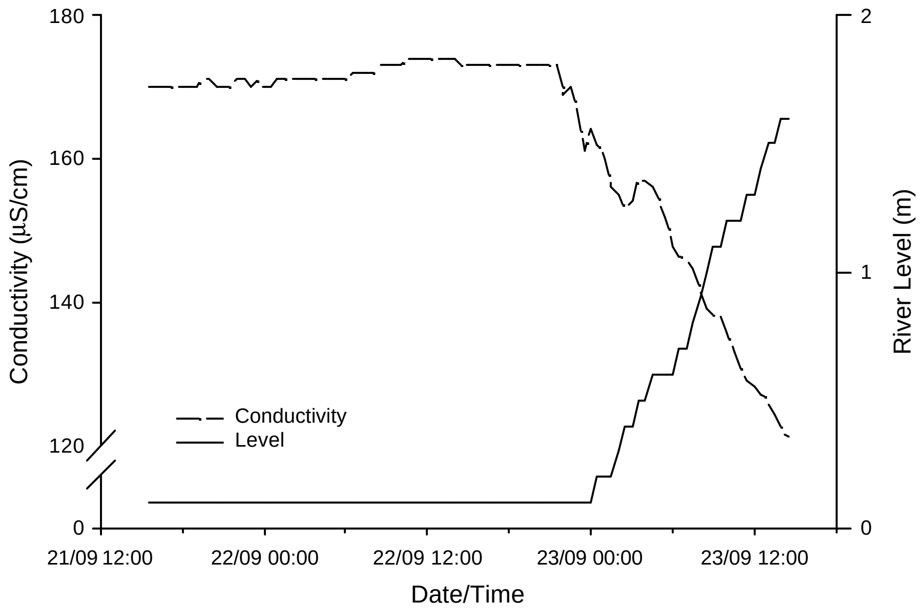


Figure 3.36 Conductivity changes during a minor flood event in the Arnon River between 21st - 23rd September, 1998. The change in river level for the corresponding period is also shown.

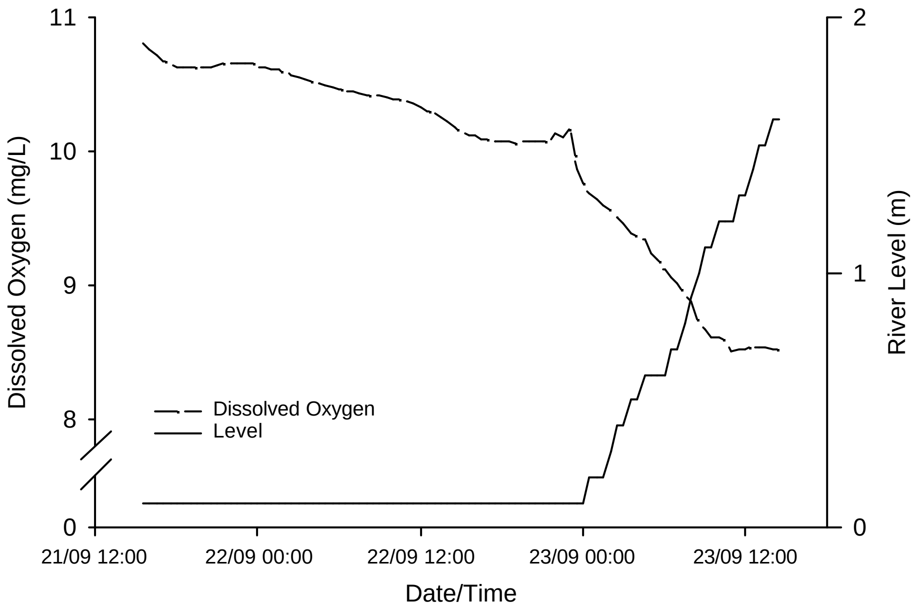


Figure 3.37 Dissolved Oxygen changes during a minor flood event in the Arnon River between 21st - 23rd September, 1998. The change in river level for the corresponding period is also shown.

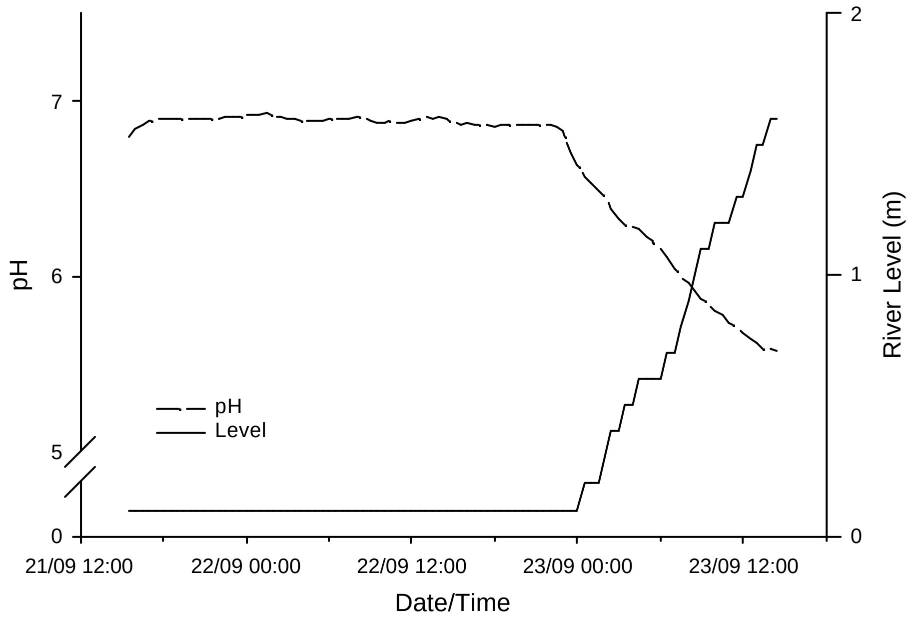


Figure 3.38 'In situ' pH changes during a minor flood event in the Arnon River between 21st - 23rd September, 1998. The change in river level for the corresponding period is also shown.

However this 'first flush' theory is not supported by the conductivity data (Figure 3.36), which does not show an expected peak early in the event indicating the entry to the river of pollutants. The data shows that conductivity immediately begins to plummet, reflecting the rapid dilution of river water by 'fresh' inflow. This fact is supported by the pH data, which shows that river water is becoming more acidic as dilution occurs. This reaction to rainfall has been described for other rivers in Tasmania [Bobbi, 1996 #10].

Altogether, these plots simply demonstrate the changes which can occur during flood events and which interrupt the normal cycle of variation in water quality and environmental conditions. While the original intention was not to collect data on flood conditions, it shows that some parameters can deteriorate quite quickly, even in a relatively unpolluted river such as the Arnon River. Any future similar studies in the catchment should consider carrying out monitoring of flood events in rivers where there is more likely to be significant inflows of pollutants (ie upper reaches of the Great Forester River).

4 Discussion and Summary

The data collected during this study confirms some of the historical data stored on the DPIWE archive and also the data collected by the Dorset Waterwatch group. The phosphorus data collected in the Great Forester River by the Waterwatch group suggested some nutrient input to the river at Tonganah, and this was supported by data collected during this study. As data from both the historical archive and Waterwatch showed, dissolved salt levels throughout the catchment (as indicated by conductivity and general ion data) are low and pH is slightly acidic.

While the majority of the data from all sources showed that turbidity was generally good during stable baseflows, significant rainfall events can cause dramatic increases in river turbidity. Localised land disturbances have also been shown to produce elevated turbidity in smaller creeks.

Monthly monitoring data clearly showed that the seasonal pattern of nitrogen variation in the Great Forester River is driven primarily by changes in nitrate concentration. Although this study was not exhaustive, the data collected supports the conclusion that a significantly higher concentration of nitrate is entering the river system in the upper catchment. It is also very likely that subsurface groundwater movement is the primary mechanism for this. Whether this nitrate is derived from the use of inorganic fertilisers or is due to the higher percentage of cleared land is not able to be accurately determined. However it is likely that the greater level of both these factors in the upper half of the catchment has a strong influence on nitrate levels in the Great Forester River. The phosphorus data collected by the Waterwatch group and this study tends to support this conclusion.

Catchment 'snapshot' surveys have provided more detailed coverage of the catchment and has highlighted the relative variation in water quality at the catchment level. Despite the temporal limitations of this technique, the data it yields can be very effective in pinpointing areas where relatively poor water quality occurs and can be used to help focus attention and resources on possible 'problem' areas. In the Great Forester catchment, the data has shown that dissolved oxygen levels are highest in the upper catchment, coliform inputs to the river are greatest in the upper catchment during summer and concentrations of TN and TP are similar at many locations during higher baseflows in winter.

The results from tests for heavy metals were not conclusive. While most of the common metals were below detection limits or detected at only very low levels, the results for aluminium were much higher. The concentration of aluminium across most sites in the catchment during 'snapshot' surveys were between 250 μg/L and 450 μg/L. While these levels are very high when compared to National water quality guidelines, it is possible that they reflect the presence of granite geology in the catchment and present no threat to the environmental health of the river system. Further testing is required to confirm this.

Flood samples were collected during the event of September, 1998 and provided data on the concentrations of various pollutants during rainfall runoff. From these samples estimates of instantaneous loads carried by the river were made allowing a glimpse of what levels of nutrients and sediment are carried by the river during floods. Further work is required if an annual export budget for the catchment is to be calculated.

Other data collected during flooding showed that dissolved oxygen levels can plummet as flood waters rise. While insufficient data was collected to provide conclusive evidence as to why this occurred, it was assumed that the rapid decrease in oxygen reflects the 'first flush', when pollutants enter the river as runoff. The data which was collected came from a catchment in which forestry operation were the main activities. Any future work to examine this effect and its severity should be undertaken in agricultural areas where runoff is likely to contain higher loads of pollutants.

In conclusion, the data presented and discussed in this report should be seen as introductory. Limited time and resources allowed only a small number of sites to be tested and only for a relatively short period. While catchment 'snapshots' have allowed a broader perspective to be taken, this information should be viewed as preliminary only and any ‘problem areas’ which have been highlighted should be further investigated prior to any significant action.

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6 Appendices

Appendix 1

Coordinates of sites tested during catchment surveys in the Great Forester catchment.

Site Name	Site Code	Easting	Northing
Gt Forester off Waterhouse Rd (u/s tidal limit)	GF2	541650	5459600
Tuckers Ck u/s Gt Forester	**GF18**	**539925**	**5459725**
Tuckers Ck at Barnbougle Rd	GF19	542675	5452800
Gt Forester at Forester Lodge	GF1b	545100	5461300
Gt Forester at Old Waterhouse Rd	**GF4**	**552400**	**5455750**
Surveyors Ck at Old Waterhouse Rd	GF27	550575	5451725
Gt Forester at Forester Rd	**GF6**	**551900**	**5451125**
Pearly Br. (Pearly Brook Rd)	**GF22**	**553650**	**5453875**
Arnon River at Forester Rd	**GF25**	**553550**	**5450750**
Gt Forester at Burrows Rd	GF8	551300	5445925
Arnon River at Mountney Rd	GF25b	554325	5444425
Gt Forester at Tasman H'way (Tonganah)	**GF10**	**548525**	**5440250**
Hogarths Rivulet at Cuckoo Rd	**GF30**	**548900**	**5437100**
Gt Forester at Cuckoo Rd	GF11	547675	5438400
Gt Forester at 10 Mile Track (No. 1)	**GF13**	**545125**	**5437625**
Gt Forester at 10 Mile Track (No. 2)	GF14	542550	5435700
Gt Forester d/s trout farm	GF15	542150	5432350
Gt Forester u/s trout farm	**GF16**	**542350**	**5431300**

Bolded sites are those monitored by monthly sampling.

Appendix 2

Summaries of physico-chemical data collected at the nine monitoring sites on the Great Forester River during monthly visits. (n=12 at all sites).

	Temperature (°C)				Turbidity (NTU)				Conductivity (µS/cm)				Field pH			
	Max	Min	Avg	Median	Max	Min	Avg	Median	Max	Min	Avg	Median	Max	Min	Avg	Median
GF16	14.8	5.5	9.1	9.1	5.31	0.51	1.73	0.98	60	43	50	49	7.0	5.8	6.3	6.2
GF13	21.1	6.2	12.7	12.6	12.7	1.95	6.03	5.97	117	66	97	99	7.6	6.1	6.7	6.6
GF30	15.6	5.3	9.6	9.9	5.65	0.98	2.51	2.13	66	53	61	62	7.2	6.0	6.3	6.2
GF10	19.5	5.6	11.8	11.7	22	2.56	7.02	5.68	98	80	89	88	6.9	6.1	6.5	6.5
GF25	17.4	4.4	10.6	11.1	38	2.58	10.0	8.16	220	107	183	190	7.1	6.4	6.8	6.8
GF22	18.2	4.9	10.8	11.0	8.44	1.49	2.64	2.02	288	165	200	190	7.1	6.0	6.6	6.6
GF6	20.5	4.9	11.9	12.0	13.5	2.6	6.76	6.46	212	89	107	97	7.0	6.2	6.6	6.5
GF4	22.9	4.6	12.4	12.1	13.5	2.9	6.45	5.98	210	110	124	118	7.3	6.4	6.7	6.5
GF18	19.4	4.0	12.3	12.0	9.17	3.12	6.02	6.21	234	112	197	202	7.1	6.0	6.5	6.5

	Dissolved Oxygen (mg/L)			
	Max	Min	Avg	Median
GF16	12.4	8.4	10.4	10.2
GF13	11.7	8.3	10.1	10.3
GF30	12.3	8.6	10.2	10.2
GF10	11.6	8.0	10.0	10.1
GF25	13.4	8.1	10.1	9.7
GF22	13.3	4.6	9.6	9.7
GF6	12.7	7.6	10.0	9.8
GF4	12.8	7.2	9.8	9.6
GF18	10.3	5.3	8.3	8.7

Summaries of chemical data collected at the two monitoring sites on the Great Forester River during monthly visits.
For the following parameters n = 12; ammonia/N, TKN, nitrate/N, nitrite/N, reactive P, total p
all others n = 6.

	Ammonia/N (µg/L)				TKN (µg/L)				Nitrate/N (µg/L)				Nitrite/N (µg/L)			
	Max	Min	Avg	Median	Max	Min	Avg	Median	Max	Min	Avg	Median	Max	Min	Avg	Median
GF10	54	< 5	17	12.5	840	260	410	380	870	380	596	580	7	< 5	< 5	< 5
GF4	94	< 5	16	8	660	230	360	350	710	160	363	355	< 5	< 5	< 5	< 5

	Reactive P (µg/L)				Total P (µg/L)				Apparent Colour				TDS (mg/L)			
	Max	Min	Avg	Median	Max	Min	Avg	Median	Max	Min	Avg	Median	Max	Min	Avg	Median
GF10	37	5	11	8	92	5	39	32	70	30	52	50	70	51	61	61
GF4	13	< 5	< 5	< 5	59	14	26	23	85	50	70	70	90	65	75.8	76.5

	Susp. Solids (mg/L)				Hardness (mg/L)				Total Alkalinity (mg/L)				Chloride (mg/L)			
	Max	Min	Avg	Median	Max	Min	Avg	Median	Max	Min	Avg	Median	Max	Min	Avg	Median
GF10	20	< 3	< 10	<10	16	14	15	15	38	< 20	< 20	< 20	17	14	16	16
GF4	43	< 10	< 10	< 10	18	16	17	17	26	< 20	< 20	< 20	24	21	22.7	23

	Flouride (mg/L)				Sulphate (mg/L)				Iron (mg/L)				Manganese (mg/L)			
	Max	Min	Avg	Median	Max	Min	Avg	Median	Max	Min	Avg	Median	Max	Min	Avg	Median
GF10	< 0.1	< 0.1	< 0.1	< 0.1	3.2	2.4	2.9	3.0	0.9	0.36	0.5	0.32	0.04	0.02	0.03	0.02
GF4	< 0.1	< 0.1	< 0.1	< 0.1	4.2	2.7	3.5	3.6	0.7	0.49	0.61	0.61	0.03	0.02	0.02	0.02

	Calcium (mg/L)				Magnesium (mg/L)				Potassium (mg/L)				Sodium (mg/L)			
	Max	Min	Avg	Median	Max	Min	Avg	Median	Max	Min	Avg	Median	Max	Min	Avg	Median
GF10	3.3	2.8	2.95	2.9	2.0	1.8	1.85	1.8	1.9	1.4	1.63	1.65	11	9.3	9.9	9.9
GF4	3.1	2.7	2.9	2.9	2.5	2.3	2.4	2.4	1.9	1.7	1.8	1.8	14	14	14	14