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WATER QUALITY

in the Upper Tweed Catchment

Tweed Shire Council & the Tweed River Management Plan Advisory Committee

Prepared by

KEC science

Scientific Services for Catchment Management and the Aquatic Environment

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1.0 Executive Summary

The current study examined water quality data collected at 16 freshwater sites in the Upper Tweed Catchment for the period 1988 to 1998. Water samples were examined in relation to faecal coliform, total phosphorus, total nitrogen, chlorophyll-a, suspended solids, pH and biological oxygen demand. The following report presents detailed statistical assessments that determine compliance to ANZECC water quality guidelines. This report also elucidates some key factors which influence the state of water quality within the catchment. Methods which may enhance the long-term prospects for improved water quality in this system are explored Implications for catchment management and future monitoring activities conclude this report. A brief summary of the findings have been presented in this section.

Water Quality Compliance

- According to bacterial guidelines, five sites within the Oxley River and Tweed River sub-catchments reached or exceeded the threshold for primary contact recreation.
- Nitrogen concentrations exceeded applicable guidelines for the control of excessive algal growth at all sites in the Upper Tweed Catchment.
- Phosphorus concentrations also exceeded these guidelines at a lesser number of sites in both the Oxley River and Tweed River sub-catchments.
- Chlorophyll-a concentrations monitored at the five water supply stations in the Upper Tweed Catchment exceeded applicable guidelines for algal growth for an extended period during 1997.
- Suspended solids concentrations exceeded applicable guidelines at a number of sites in both the Oxley River and Tweed River sub-catchments.
- pH within the Upper Tweed Catchment did not exceed applicable guidelines for the protection of aquatic ecosystems.

Stormwater Impact

- Stormwater appeared to subject a significantly impact on water quality at the two sites examined in detail within the Oxley River and Tweed River sub-catchments.
- In general, water quality worsened in response to increasing rainfall.
- The impact of stormwater generally accounted for 70 - 90% of the variation in water quality at these sites.
- It was concluded that the impacts of stormwater were related to the various land uses of the surrounding catchment.

Sources of Contamination

- The greatest elevations in faecal coliform and nutrient concentrations occurred at a monitoring site down stream from high density animal husbandry.
- Faecal coliform and nutrient concentrations were also elevated at sites down stream from townships, or where domesticated stock readily accessed water.

- It is suggested that these land uses played a significant role in the determination of bacterial and nutrient concentrations in the Upper Tweed Catchment.
- As such, these land uses are also implicated in the occurrence of nuisance algal growth.
- Suspended solids increased proportionally with rainfall at most sites and it was assumed that soil erosion was the primary source of suspended solids in the catchment.

Catchment Management

- The present study underscored the important role played by catchments in determining water quality in the aquatic environment.
- Land use and catchment management processes should be recognised as critical determinants of water quality.
- Future improvements in water quality will rely upon the sound application of Land Use Planning and Catchment Management strategies.
- Suspended solids and nutrient concentrations are generally elevated in the Upper Tweed Catchment. Strategies which are intended to address these issues must be developed in response to prevailing land use activities and catchment conditions.
- Implementation of a targeted nutrient reduction strategy within the Upper Tweed Catchment is likely to afford protection against the occurrence of nuisance algal growth.
- Water quality management of the Lower Tweed Estuary System is likely to be determined by the application of sound catchment management strategies throughout the entire Tweed catchment.

Appraisal of Monitoring Efforts

- There is no evidence to suggest that either formal objectives or a formal process of site selection have previously been applied to the current routine water quality monitoring program.
- Collection of water quality data at most monitored sites in the Upper Tweed Catchment appears to be useful in the assessment of ambient water quality and catchment condition.
- At some monitored sites however, water quality would appear to fluctuate in response to localised point source discharges. While monitoring at these sites has provided useful information, it is questionable whether further documentation of these contributions is necessary.
- The assessment of point source contamination is a useful tool in water quality management and should be undertaken through separate short-term monitoring projects.
- The current routine water quality monitoring program would benefit from an increase in sample frequency, even if this must be accommodated through a reduction in the number of monitored sites.

Recommendations

Catchment Management

- Management strategies should be developed to address water quality issues in the Upper Tweed Catchment.
- The present assessment indicates that these strategies should focus towards land use issues like stock control, soil erosion and point source effluent discharge.
- A formal process of on-site inspection and auditing should be undertaken to assist in the development of management strategies.

Statistical assessment

- Water quality trends in the Rous River sub-catchment remain undetermined in the present context. It is likely that the Rous River plays a significant role in water quality within the Lower Tweed Estuary System. As such, management of the Tweed estuary would benefit from a detailed statistical assessment of water quality in the Rous River.

Future monitoring

- The current routine water quality monitoring program requires a formal process of review and refinement.
- This review process should lead to the adoption of formal objectives and reporting structures for the program.
- Formal criteria for site selection must be applied to current monitoring sites to ensure their suitability for future assessment.
- The current routine water quality monitoring program should increase sample frequency to accommodate monthly sampling.

2.0 Introduction

While numerous water quality studies have been conducted in the Tweed estuary system (KEC science, 1998), few investigations have examined the quality of freshwater in the upper reaches of the Tweed catchment. Regular water quality monitoring is currently being undertaken by the Tweed Shire Council and the NSW Department of Land and Water Conservation (DLWC). The Tweed Shire Council water quality monitoring program was initiated in 1988. It currently monitors 16 freshwater sites, focussing primarily on the Clarrie Hall dam and other stations used for water supply. To date, no significant assessment has been undertaken on the water quality data that has resulted from this program. The DLWC water quality monitoring program was initiated in 1970. It has monitored one site in the Tweed Valley catchment, at Eungella on the Oxley River, as part of the state wide Key Sites Water Quality Monitoring Program. Reports indicate that recent water quality at this site satisfied bacteriological guidelines for primary contact recreation (DLWC, 1998a) and physicochemical guidelines for ecosystem protection (DLWC, 1998b). A short-term water quality monitoring program was also undertaken over a 12 month period during 1995/96 by the NSW Environment Protection Authority (NSW EPA). At this time, 20 freshwater sites were sampled on seven occasions. The resulting report indicated that water quality was 'generally good' in the freshwater sections of the Tweed River Catchment (NSW EPA, 1996).

It is evident that each of the three water quality monitoring programs mentioned, are limited in some degree in their capacity to either describe the ambient state of water quality, or define catchment issues, in the freshwater reaches of the Tweed Catchment. With this in mind, the sampling regime currently undertaken by the Tweed Shire Council would appear most suitable to provide water quality data that would fulfil this task, due to the breadth, frequency and duration of monitoring employed by the program. It is the key aim of the present report to undertake detailed statistical assessment of Tweed Shire Councils water quality data to determine the ambient state of water quality in the freshwater reaches of the Tweed Catchment. This report will also provide a preliminary assessment of catchment performance in relation to rainfall within this system and attempt to define catchment and water quality management issues in the sub-catchments of this region. Implications for stormwater and catchment management and recommendations for future works conclude this report.

3.0 Methods

3.1 Sampling

Most recently, sixteen sites have been monitored for water quality in the freshwater reaches of the Tweed Valley catchment (refer to figure 1). The sampling regime for these sites has been varied, from weekly and monthly sampling to quarterly sampling. Table 1 provides site codes, descriptions and periodicity of monitoring for each of these water quality sites.

Table 1. Site codes, site descriptions and periodicity of monitoring for all water quality test sites in the Upper Tweed Valley Catchment. Abbreviations; u/s, upstream.

Site Code	Site Description	Periodicity of Monitoring
CAT1	Oxley R. at Sharp's Crossing	Quarterly
CAT2	Oxley R. at Tyalgum	Quarterly
CAT3	Pumpenbil Ck u/s of Fowler's Ck.	Quarterly
CAT4	Tweed R. u/s of Byangum Bridge	Quarterly
CAT5a	Tweed R. below junction with Smith's Ck.	Quarterly
CAT5b	Uki raw water intake	Weekly/Monthly
CAT6	Byrill Ck. u/s junction of South Arm	Quarterly
CAT7	South Arm u/s junction of Byrill Ck.	Quarterly
CAT8a	Clarrie Hall Dam at boat ramp	Quarterly
CAT8c	Clarrie Hall Dam, pontoon at Cram's Farm	Quarterly
CAT8d	Clarrie Hall Dam intake tower 2m	Weekly/Monthly
CAT9	Doon Doon Ck., inflow to dam	Quarterly
CAT10	Fowler's Ck.	Quarterly
CAT11a	Bray Park intake, surface	Weekly/Monthly
CAT11b	Bray Park intake, 4m	Weekly/Monthly
CAT12	Tyalgum, raw water intake	Weekly/Monthly

For all stations, water samples were collected and stored in appropriate containers by experienced field technicians for immediate transport to the Tweed Laboratory Centre (Tweed Shire Council), a NATA registered water testing Laboratory. These samples have most recently been analysed according to the methods detailed in 'Standard Methods for the Examination of Water and Wastewater' (American Public Health Association, 1995). Analysis was undertaken for faecal coliform (method 9222 D), total phosphate (TPO_4; method 4500-PB.5), total nitrogen (derived from the addition of total Kjeldahl nitrogen [TKN; method 4500-Norg B] and nitrate [NO_3N, Hach Method 8192], chlorophyll-a (method 10200 H.2.), suspended solids (method 2540 D) and biological oxygen demand (method 5210 B). Methods for analysis which predate current assessment techniques can be obtained directly from the Tweed Laboratory Centre.

Upper Tweed Catchment

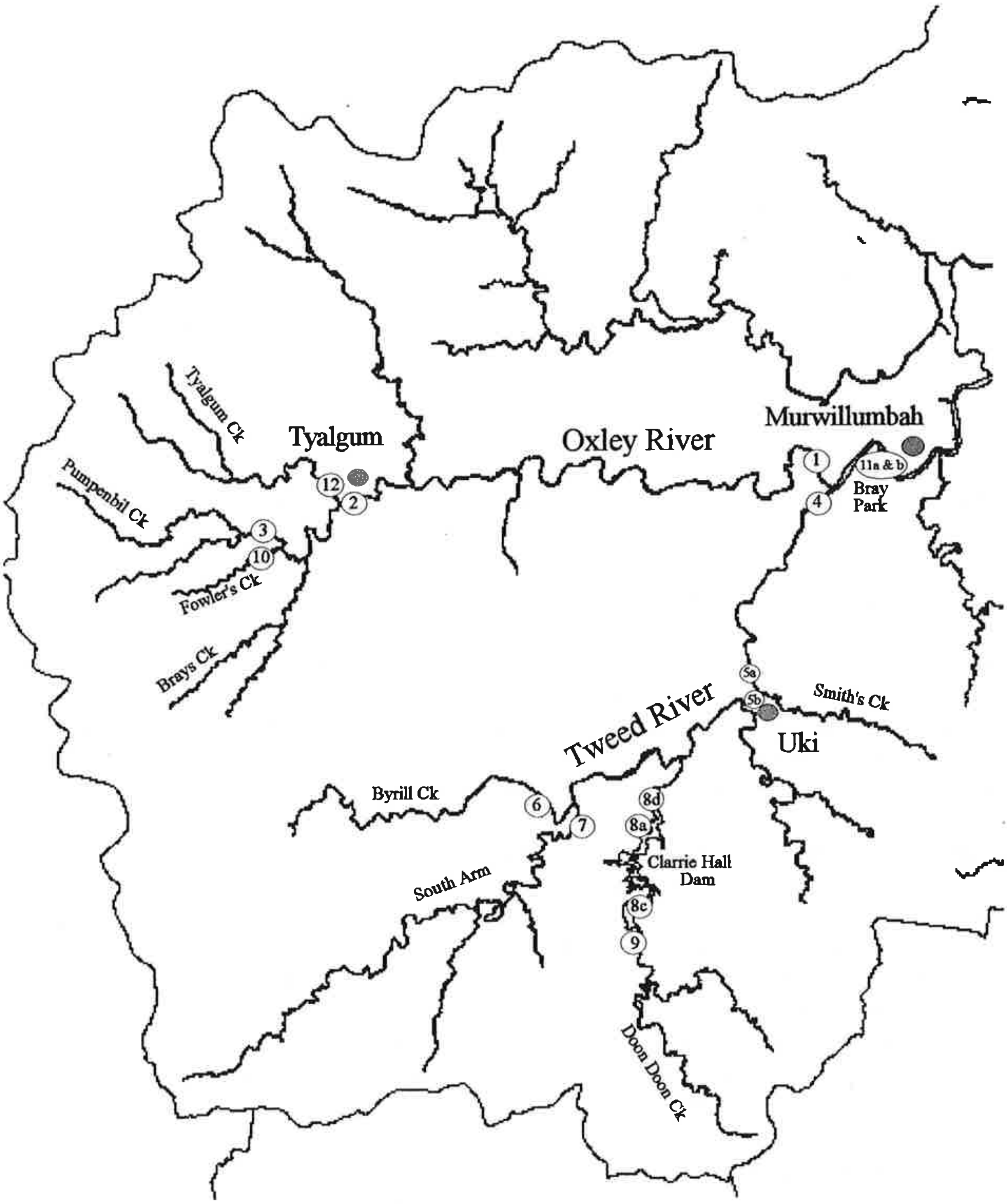

Figure 1. Location of Tweed Shire Council water quality monitoring sites within the Upper Tweed Catchment. Refer to table 1 for the site description and sample frequency pertaining to each site.

3.2 Rainfall Data

As part of the present assessment, water quality data from sites 1, 4, 5a, 5b and 11a were examined in relation to rainfall. Rainfall data for this assessment was obtained from the Bureau of Meteorology via three rain gauge stations located within the catchment (Table 2). Daily rainfall collected by individual gauges was matched to specific sites, as set out in table 2.

Table 2. Bureau of Meteorology rain gauge stations and corresponding Tweed Shire Council water quality monitoring sites used in the comparative assessment of the relationship between water quality and rainfall.

Bureau of Meteorology Rain Gauge Stations		Tweed Shire Council Water Quality Sites
Station Name	Station Number	
Brays Creek (Misty Mt)	58005	Cat1
Kunghur (The Junction)	58129	Cat4, Cat5a, Cat5b
Murwillumbah (Bray Park)	58158	Cat11a

3.3 Statistical assessment

Compliance to ANZECC Guidelines

The assessment of environmental data is generally made difficult by a large degree of natural variation and a propensity for most parameters to be distributed in a non-parametric fashion. Because of these characteristics, it is usually inappropriate to compare either raw data or mean statistics derived from such environmental parameters to threshold limits (KEC science, 1998). ANZECC water quality guidelines (ANZECC, 1992) address this issue by suggesting that non-parametric data should, in the first instance, be subjected to non-parametric statistical assessment. In the present study, the parametric or non-parametric nature of the data was determined by four separate analyses including the Kolmogorov-Smirnov test, Lilliefors Probability test, Shapiro-Wilk test and the Chi-square test. Compliance to ANZECC water quality guidelines was determined by comparing median water quality statistics for each site to applicable threshold limits. The use of this method has been discussed more fully in the associated report 'Water Quality in the Lower Tweed Estuary System' (KEC science, 1998).

Temporal Change in Water Quality

The extent to which water quality changes over time is referred to as temporal change. Where the degree of change is statistically significant, its direction is referred to as the trend. The ability to determine trend is confounded by the influence of seasonal variation (eg. increased values during summer), cyclic variation (eg. periodic impact of drought) and the natural variation in the variable (noise). While temporal change in water quality may sometimes be visualised quite easily, in most cases, the influence of seasonal, cyclic and noise variations will disguise the obvious nature of any trend. It is thus necessary to quantify and compensate for these types of variation so that the underlying trend can be identified. Seasonal Decomposition Time Series

Analysis is a statistical method which employs this process to produce transformed data that highlights any underlying trend. The significance of this trend can then be determined through Multiple Regression Analysis. Temporal change in water quality was examined at site 1 (Oxley River sub-catchment) and site 4 (Tweed River sub-catchment) to determine whether significant temporal change in water quality had occurred over the 10 year monitoring period for the Upper Tweed Catchment.

Water Quality and Rainfall

The relationship between the various water quality parameters and daily rainfall was first examined using Pearson Product Moment Correlation by comparing each parameter against daily rainfall data for the 14 day period prior to sampling. This assessment was undertaken on both raw data and data which had been smoothed using 4253H filtering transformation (Statistica, 1997). Forward Stepwise Multiple Linear Regression Analysis was then employed to quantify the relationship between water quality and rainfall while allowing for the removal of redundant relationships. Analysis was performed by treating each water quality parameter as the dependant variable and applying daily rainfall data for the 14 days prior to sampling as multiple independent variables. This assessment was undertaken on both raw and smoothed data.

Spatial Differences in Water Quality

The significance of any spatial differences in water quality between sites was determined using Analysis of Variance (ANOVA), Kruskal-Wallis non-parametric ANOVA and the Median test (non-parametric alternatives to ANOVA) and the Wilcoxon Matched Pairs test (a non-parametric alternative to the t-test). Sites were also ranked according to their overall water quality performance by applying Cluster Analysis (Joining and K-Means Analysis) and Multidimensional Scaling (MDS). Further information regarding Cluster Analysis and MDS are presented in Appendix A.

4253H Filtering

A significant element of the current statistical analyses was the application of the 4253H filtering transformation technique (Statistica, 1997). Filtering is a commonly used tool in the assessment of environmental data to emphasise trends in a time series while minimising random variation. 4253H is a filtering method which produces a smoothed time series while maintaining the salient characteristics of the original data. The usefulness of this technique has been demonstrated in figure 2. In figure 2a raw data from the present study for both rainfall and faecal coliform were plotted together. No particular relationship between the two parameters was immediately apparent. After T4253H transformation (figure 2b), marked correlation between these two parameters was graphically illustrated. The smoothed data which results from this type of transformation can be applied to further statistical assessment.

Software

All statistical analyses were performed using Statistica Version 5 statistical software (StatSoft Inc, 1997).

a

b

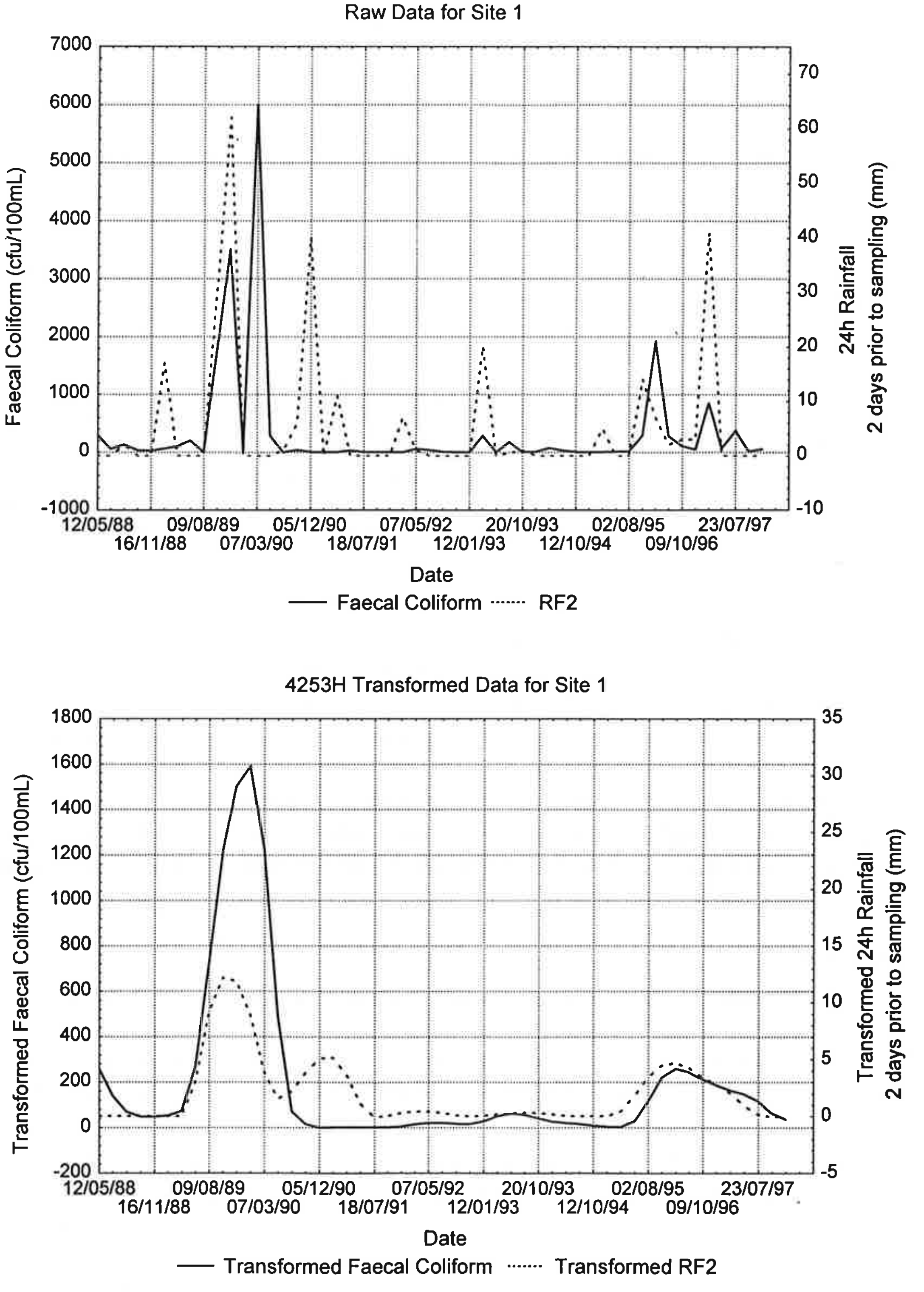

Figure 2. 4253H Transformation of raw data (faecal coliform and rainfall) for site 1 in the Upper Tweed catchment. 2a, raw data is difficult to interprete. 2b, data transformation assists the process of interpretation. RF2, rainfall for the 24h period 2 days prior to sampling.

4.0 Results

4.1 Normality of Distribution

The manner in which observations for a parameter are distributed across the parameters range can greatly influence the performance of subsequent statistical methods. In general, such distributions can be referred to as parametric (normal) or non-parametric. Parametric distributions are symmetrically distributed about the mean statistic, forming the characteristic bell-shaped curve. Non-parametric distributions are asymmetrically distributed, skewing the curve to one side or creating more than one peak. In the current study, the manner in which water quality parameters were distributed varied widely. At some sites, parameters such as pH, total nitrogen and total phosphorus were generally normally distributed. However, at most sites the various water quality parameters were not normally distributed. When observations for all sites in the catchment were combined, only pH approximated a normal distribution (figure 3) and all parameters were distributed non-parametrically according to Kolmogorov-Smirnov test ($p<0.01$), Lilliefors Probability test ($p<0.01$) and the Shapiro-Wilk test ($p<0.001$). As a result of this finding, non-parametric analyses were applied in the following assessment. More commonly used parametric statistics were also applied in those cases where non-parametric alternatives were not available, or to supplement the findings of the non-parametric analyses.

4.2 Compliance to ANZECC Guidelines

4.2.1 Faecal Coliform

ANZECC guidelines set a median threshold limit for faecal coliforms in primary contact waters at 150 cfu/100mL (ANZECC, 1992). A number of sites in the Upper Tweed Catchment reached or exceeded this limit, including sites 2, 3, 10 and 12 in the upper reaches of the Oxley River sub-catchment and site 5b at Uki (refer to figure 4a). Faecal coliform counts appreciably exceeded the ANZECC limit at sites 10 and 3 with median counts of 1350 cfu/100mL and 403 cfu/100mL respectively. Counts of faecal coliform at these two sites were significantly greater than at any other site in the upper catchment according to both Kruskal Wallis nonparametric ANOVA ($p<0.02$) and the Median test ($p<0.05$). Analysis of Variance confirmed these findings ($p<0.05$).

4.2.2 Total Phosphorus

Guidelines and threshold limits for the concentration of nutrients within waterways were set by ANZECC (1992) to prevent eutrophication and excessive algal growth. ANZECC (1992) set a threshold limit on total phosphorus in freshwater streams and rivers at 0.1mg/L. Median total phosphorus concentrations approached or exceeded this threshold for sites 3 and 10 in the upper Oxley River sub-catchment, site 9 at the

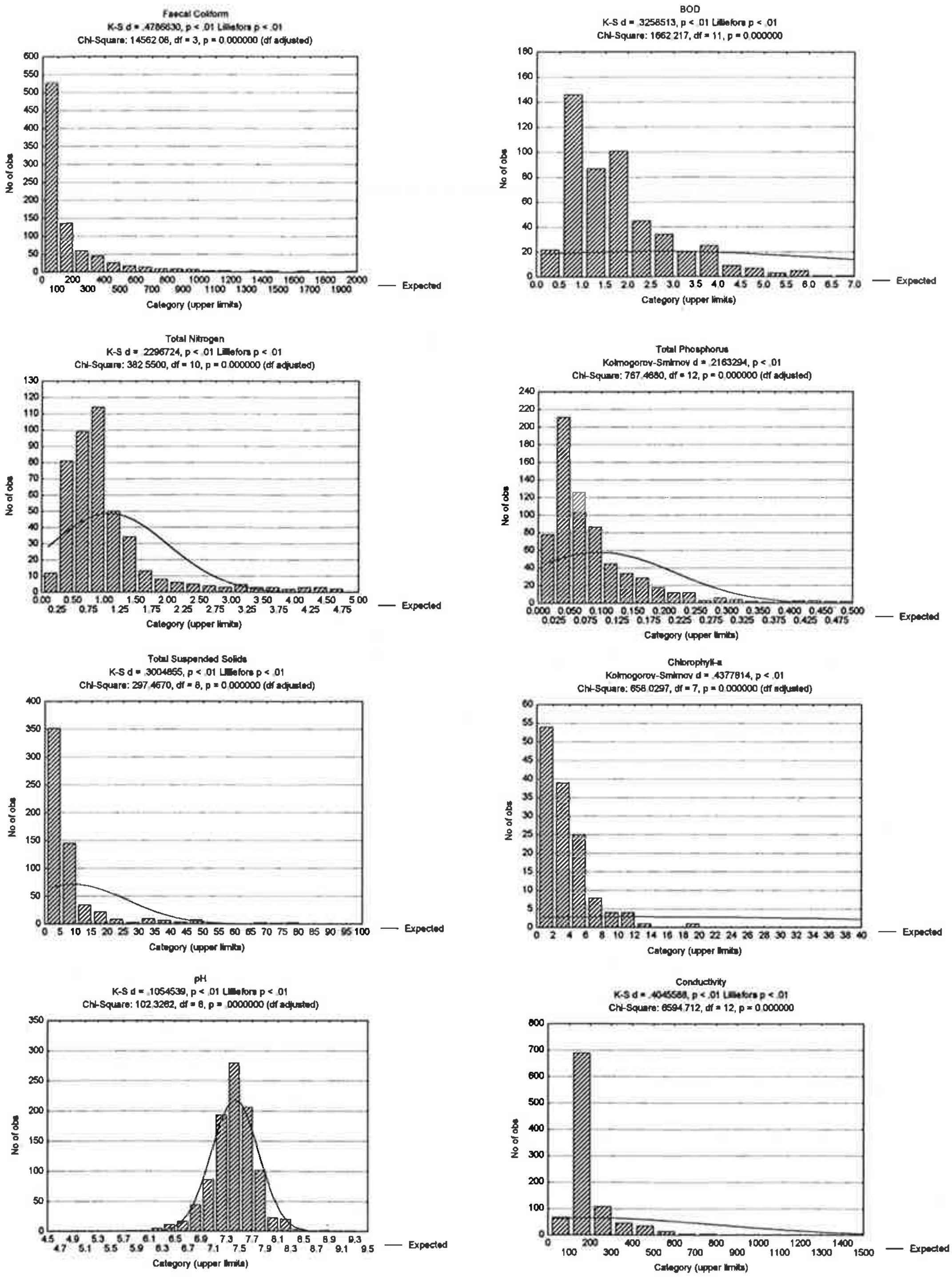

Figure 3. Frequency distribution for water quality parameters measured during regular monitoring of 17 sites in the Upper Tweed Catchment for the period 1988-1998.

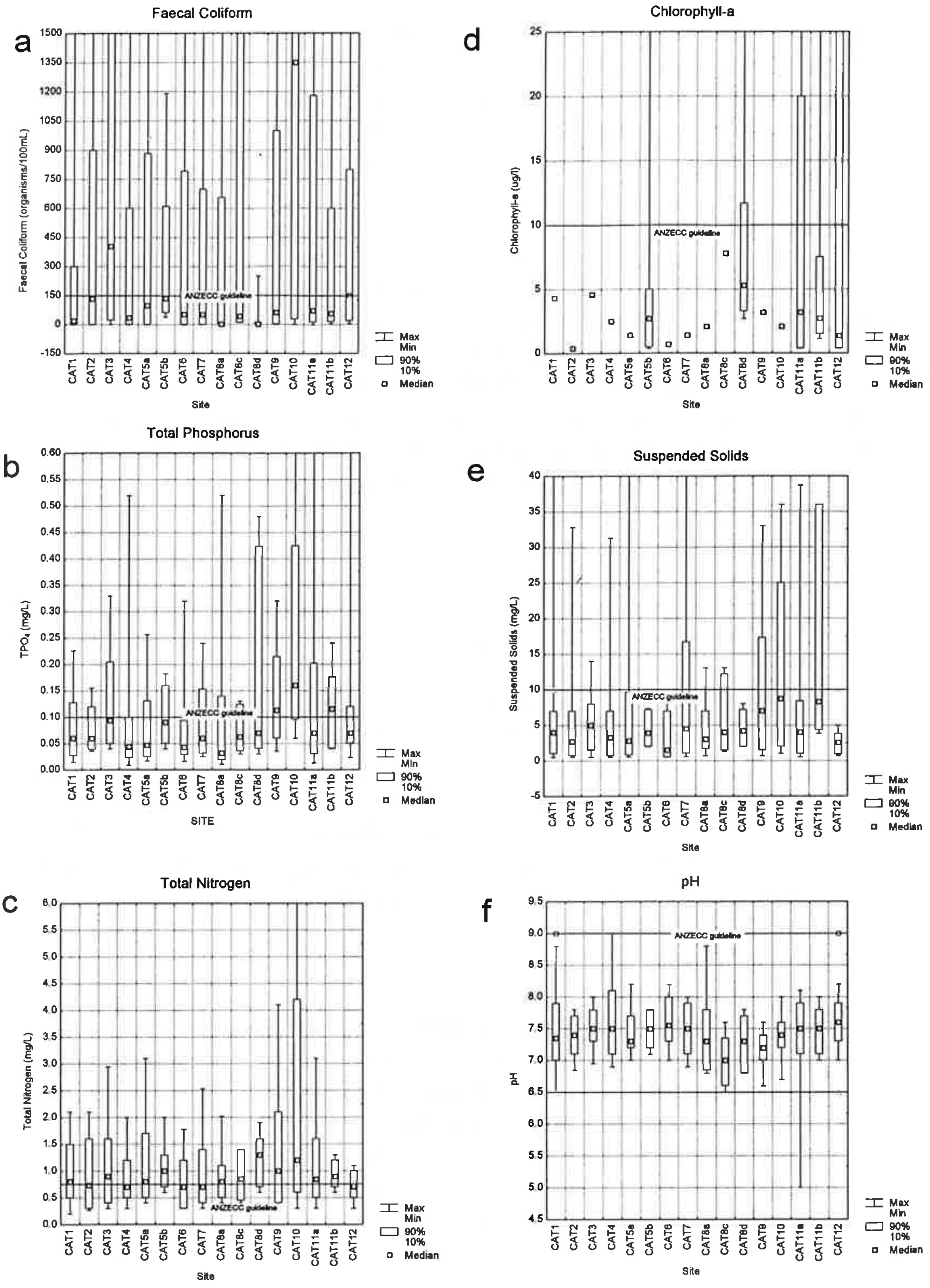

Figure 4. Median water quality for sites in the Upper Tweed Catchment. ANZECC Guideline for each parameter denoted by horizonal line

Doon Doon Creek inflow into the Clarrie Hall dam, site 5b at the Uki water supply and site 11b at the Bray park intake (refer to figure 4b). The elevated levels of total phosphorus at site 10 (0.16mg/L) were significantly greater than total phosphorus concentrations at any other site (Kruskal-Wallis nonparametric ANOVA, $p<0.05$; Median test, $p<0.05$) with the exception of site 9 (0.113mg/L), site 11b (0.115mg/L) and site 8d (0.07mg/L). Analysis of Variance confirmed this finding ($p<0.05$).

4.2.3 Total Nitrogen

ANZECC (1992) set a threshold limit on total nitrogen for freshwater streams and rivers at 0.75mg/L. Median total nitrogen concentrations either approached or exceeded this limit at all sites in the Upper Tweed Catchment with median concentrations ranging from 0.7 to 1.3mg/L (refer to figure 4c). Concentrations at sites 8d and 10 were elevated to a significantly greater degree than most other sites according to Kruskal-Wallis nonparametric ANOVA ($p<0.05$) and the Median test ($p<0.05$). Analysis of Variance confirmed this finding ($p<0.05$).

4.2.4 Chlorophyll-a

To assist in the control of eutrophication and excessive algal growth within Australian waterways, ANZECC (1992) set a threshold limit on chlorophyll-a concentrations (a measure of algal content) for rivers and streams at 10ug/L. Only five sites have been regularly monitored for chlorophyll-a in the Upper Tweed Catchment. These sites are situated at the drinking water supply reservoirs at Clarrie Hall dam (site 8c), Tyalgum Creek (site 12), Uki (site 5b) and Bray Park (sites 11a and 11b). While median values for Chlorophyll-a at these sites were below 10ug/L, a significant algal bloom occurred from July to September, 1997 at all sites (refer to figure 4d). Chlorophyll-a concentrations exceeded 100ug/L at this time and in the case of Bray Park, elevated levels persisted through to October, 1997.

4.2.5 Suspended Solids

ANZECC (1992) recognised that significant variation in suspended solids concentrations existed in Australian waterways, with marked seasonal differences apparent in many catchments. In consideration of this, guidelines were established which refer to levels of acceptable seasonal change in suspended solids, rather than in the setting of threshold concentrations. It is apparent that the setting of guidelines in suspended solids concentrations is not straightforward. ANZECC (1992) suggested that nephelometric turbidity may be a more practical measurement in most systems and proposed that seasonal mean nephelometric turbidity should not change by more than 10%. Canadian water quality guidelines (CCREM, 1991) suggested that suspended solids should not change by more than 10mg/L in systems where background concentrations do not exceed 100mg/L. The recent report concerning water quality in the Lower Tweed Estuary System (KEC science, 1998) applied a range of criteria to suspended solids data to determine the most appropriate guidelines for compliance reporting. It was suggested that the performance of the Lower Tweed Estuary system should be gauged against the following criteria.

With the wet season extending from November to May and the dry season extending from June to October:

(1) Seasonal median and mean suspended solids concentration should not exceed 10mg/L, as derived from the Tweed River Water Quality Review (WBM Oceanics, 1997).

(2) Seasonal median and mean suspended solids concentrations should not change by more than 10%, as derived from ANZECC guidelines (ANZECC, 1992).

(3) Seasonal median and mean suspended solids concentrations should not change by more than 10mg/L, as derived from ANZECC guidelines (ANZECC, 1992).

(4) The 90-percentile limit should not exceed 20mg/L.

These criteria were applied to the data collected for the Upper Tweed River Catchment.

Seasonal median suspended solids values did not exceed the 10 mg/L threshold during the dry season and only site 9 exceeded this limit during the wet season. Seasonal mean suspended solids values did exceed the 10mg/L threshold during the dry season for sites 10 and 12 and during the wet season for sites 1, 5a, 7, 9 and 10, Most sites exceeded both the median and mean seasonal change of 10% although a seasonal change of 10mg/L was not exceeded by any site (median change, 0.1 - 7.3 mg/L; mean change, 0.1 - 5.2 mg/L). During the dry season, sites 10 and 11b exceeded the 90 percentile threshold of 20mg/L. During the wet season this threshold was exceeded by sites 7, 9 and 11b. Only sites 5a and 7 recorded values greater than 50 mg/L. Median suspended solids results for the sample period are presented in figure 4e.

4.2.6 pH

ANZECC (1992) recognised that the pH (acidity) of a water body influences the physiological processes of aquatic biota and that pH outside the range of 6.5 – 9.0 is generally of detriment to such biota. According to the present study, pH in the Upper Tweed Catchment satisfied current guidelines for environmental protection, with only one observation at site 11a (Bray Park reservoir) below the lower limit (refer to figure 4f).

4.3 Temporal Change in Water Quality

Temporal change in water quality in the Upper Tweed Catchment was examined for sites 1 and 4, located upstream of the junction between the Oxley and Tweed Rivers respectively. These two sites were chosen to elucidate any significant shift in water quality for the Tweed and Oxley River sub-catchments. Both sites have been monitored at quarterly or greater frequencies since 1988 and as such satisfy the requirements of Seasonal Decomposition Time Series Analysis. This assessment examined data for faecal coliform, BOD, total nitrogen, total phosphorus, total suspended solids and pH. The resulting water quality trends for sites 1 and 4 have been presented in figures 5 and 6 respectively.

Multiple Regression Analysis was applied to the resulting trend data to determine the direction and significance of any trend. According to the results of site 1, faecal coliform (slope=0.633, $p<0.003$, $r^2=0.40$), total suspended solids (slope=0.459, $p<0.041$, $r^2=0.21$) and pH (slope=0.495, $p<0.0075$, $r^2=0.24$) increased over the study period in the Oxley River sub-catchment (figure 5). BOD decreased over this time (slope=-0.503, $p<0.0064$, $r^2=0.25$) while no significant change was recorded for either total nitrogen ($p<0.944$) or total phosphorus ($p<0.261$). According to the results of site 4, both suspended solids (slope=-0.571, $p<0.0015$, $r^2=0.33$) and total phosphorus (slope=0.696, $p<0.0001$, $r^2=0.485$) increased over the study period, while the presence of faecal coliform approached a significant increase ($p<0.067$) in the Tweed River sub-catchment (figure 6). BOD decreased over this time (slope=-0.528, $p<0.0039$, $r^2=0.28$) while no significant change was recorded for either total nitrogen ($p<0.436$) or pH ($p<0.244$).

These results suggest an overall increase in suspended solids within the two sub-catchments over the 10 year period from 1988 to 1998. The assessment also indicates that faecal coliform may have increased over this time. Concentrations of total phosphorus and total nitrogen did not appear to change over time in the Oxley River sub-catchment but total phosphorus did increase in the Tweed River sub-catchment according to the assessment of sites 1 and 4. While these results indicate a shift in water quality over the time period, this may have been due to the interaction of some other determining factor rather than any change in catchment inputs.

4.4 Rainfall and Water Quality

Rainfall significantly influenced the state of water quality in the Lower Tweed Estuary system (KEC science, 1998). The presence of a similar interaction in the Upper Tweed Catchment was determined for sites 1, 4 and 5a (monitored quarterly) and sites 5b and 11a (monitored weekly or monthly). Rainfall data for each 24 hour period for 14 days prior to sampling was compared to the water quality results for each site. The correlation between water quality and rainfall was determined with Pearson Product-Moment Correlation and Forward Stepwise Multiple Linear Regression Analysis using 4253H smoothed data.

Water quality was significantly influenced by recent rain events at site 1 in the Oxley River sub-catchment. Faecal coliform, total suspended solids, BOD and total phosphorus were positively correlated to the level of rain which fell on the 2 days prior to sampling. Interestingly, the concentrations of total nitrogen, ammonia and nitrate appeared to be negatively correlated to rainfall (greater rainfall reduced nitrogen concentration) although the effect of this was lagged across the 14 day period prior to sampling. Forward Stepwise Multiple Linear Regression Analysis determined that fluctuations in rainfall accounted for greater than 80% of the variation in faecal coliform, BOD, total suspended solids, pH, and total nitrogen ($r^2=0.89$-0.99). This relationship was not as strong for total phosphorus ($r^2=0.49$).

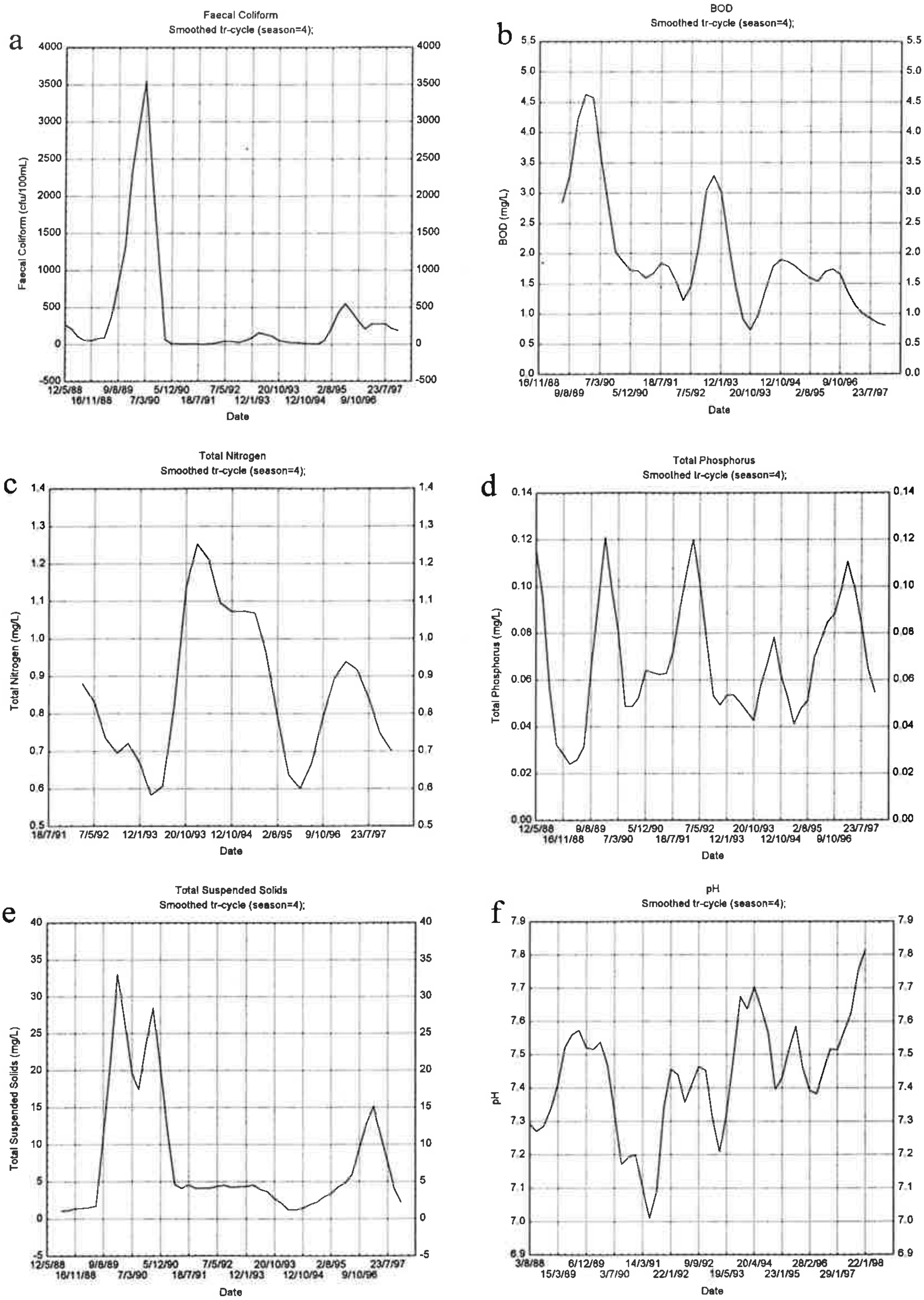

Figure 5. Temporal change in water quality at site 1(Oxley River sub-catchment) for the period 1988-1998. Data treated by Seasonal Decomposition Time Series Analysis. BOD, Biological Oxygen Demand.

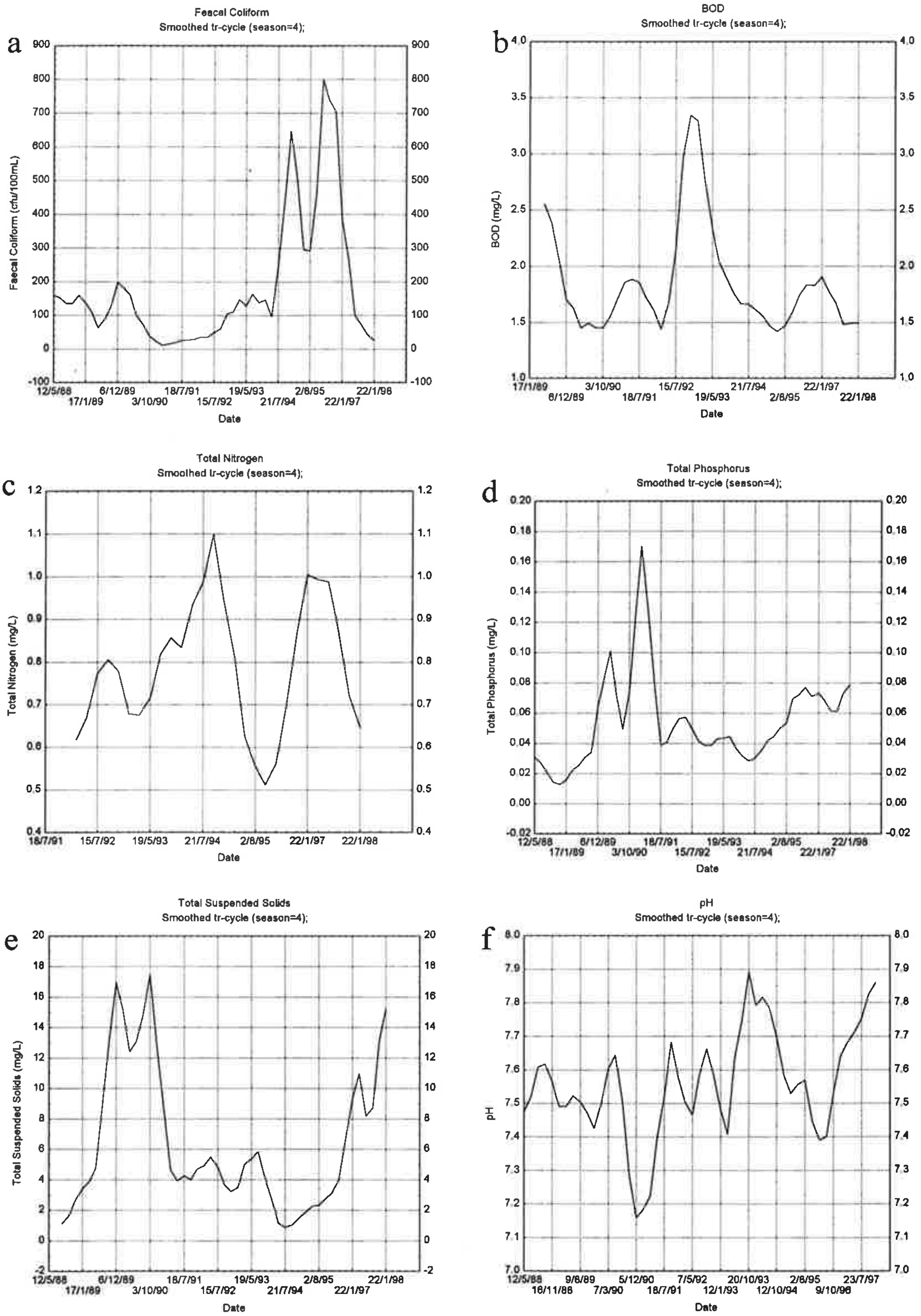

Figure 6. Temporal change in water quality at site 4 (Tweed River sub-catchment) for the period 1988-1998. Data treated by Seasonal Decomposition Time Series Analysis. BOD, Biological Oxygen Demand.

Rainfall exerted a more prolonged influence over water quality at site 4 in the Tweed River sub-catchment. Faecal coliform, BOD, total suspended solids, pH and total phosphorus were positively correlated to rainfall which fell across the 14 day period prior to sampling. Total nitrogen, ammonia and nitrate were negatively correlated to rainfall which fell a week or more prior to sampling. Forward Stepwise Multiple Linear Regression Analysis determined that fluctuations in rainfall accounted for greater than 70% of the variation in the water quality parameters examined (r^2=0.70-0.99). The relationship between water quality and rainfall was similar further upstream at sites 5a and 5b.

Variation in water quality at site 11a (Bray Park reservoir) was not overwhelmingly influenced by rainfall according to the results of faecal coliform (r^2=0.12), BOD (r^2=0.34), total nitrogen (r^2=0.25), total phosphorus (r^2=0.49) or pH (r^2=0.53). Total suspended solids proved the exception (r^2=0.74), with rainfall in the week prior to sampling exerting a substantial influence over this water quality parameter.

4.5 Contributions to the Nutrient Load

The total nitrogen load that is present in any waterway is usually derived from a number of different catchment sources. These sources provide nitrogen in forms that are generally specific to the land uses or processes that have contributed them. Contributions by animal and sewage waste are generally reflected in the presence of both ammonia and TKN while the contribution made by fertilisers can be estimated from the presence of nitrate. Ammonia concentrations at site 10 (median 0.35mg/L) were elevated to a significantly greater degree than concentrations found at other sites in the Upper Tweed Catchment (median 0.08mg/L) according to Kruskal-Wallis non-parametric ANOVA ($p<0.05$). TKN concentrations at site 10 (median 0.9mg/L) were also elevated to a significantly greater degree than other sites in the catchment (median 0.4mg/L) except sites 5b and 8d (Kruskal-Wallis non-parametric ANOVA, $p<0.05$). There was no significant difference in nitrate concentrations between any sites in the Upper Tweed Catchment according to either Kruskal-Wallis non-parametric ANOVA or ANOVA (median concentrations of 0.4 mg/L respectively).. The relative nitrogen contributions made by potential effluent and fertiliser sources (TKN and NO_3N respectively) was similar in the Upper Tweed River Catchment according to the Wilcoxon Matched Pairs test (p=0.6103). The high concentrations of TKN and nitrate found in samples (mean catchment values of 0.53 mg/L and 0.43 mg/L respectively) indicate that such contributions may be significant.

4.6 Defining Catchment Issues

A common expectation of most ambient water quality monitoring programs is for the resulting data to be able to identify problem areas and define catchment issues at a variety of spatial scales. While the design of the monitoring program plays a crucial role in the success of this objective, it is equally important that the correct statistical analyses are applied to assist in interpretation and reporting. A key task of these statistical analyses is to (1) rank sites according to their general water quality performance, (2) group sites according to their similarities and differences in water quality performance and (3) highlight water quality issues common to each group. Both Cluster Analysis and Multidimensional Scaling provide the means to achieve these goals. These assessment techniques have been applied to the current data with the results detailed in the following sections.

4.6.1 Cluster Analysis

Cluster Analysis is a series of statistical methods that have been used in the present assessment to organise the monitored sites into meaningful groups based upon similarities and differences in water quality. Technical notes on cluster analysis are provided in appendix A. Joining Cluster analysis was performed on the water quality data for all sites in the Upper Tweed Catchment. Standardised water quality results for faecal coliform, pH, total suspended solids, total nitrogen, total phosphorus, chlorophyll-a and BOD were used as water quality criteria for this assessment. Cluster analysis used this data to produce a dissimilarity (distance) matrix of the water quality sites. At the squared Euclidean distance of 10, four distinct clusters formed (refer to figure 7a). The groups of sites which make up these clusters are thus bound by similarities and differences in water quality. K-Means Cluster analysis illustrated the similarities and differences in water quality between the clusters via a means plot (figure 7b). Briefly, cluster 2 (site 10) was regarded as highly different from any other site in the Upper Tweed Catchment according to Joining Cluster Analysis (figure 7a). Site 10 exhibited highly elevated concentrations of faecal coliform, suspended solids and nutrients according to K-means Analysis (figure 7b). Cluster 3 differed from clusters 1 and 4 due to higher concentrations of chlorophyll-a, moderately elevated total phosphorus concentrations and reduced levels of suspended solids. Cluster 1 differed from cluster 4 due to elevations in nutrients and reduced pH. Cluster 4 was made up of sites with the highest quality of water in the catchment according to the parameters used in this assessment.

4.6.2 Multidimensional Scaling

Multidimensional scaling (MDS), like Cluster Analysis, also uses a distance matrix to detect relationships between sites in the Upper Tweed Catchment. In the case of MDS, the distances are plotted out like a map. The position of each site is then moved around so that agreement between all distance values is maximised (and the raw stress decreased). The use of one or two dimensions may be adequate to determine the relationships between sites but sometimes multiple dimensions are required to produce satisfactory results. While the use of lower numbers of dimensions simplifies interpretation, the accuracy of the results are enhanced as the number of dimensions increases. A well accepted method of selecting the correct number of dimensions is to plot the raw stress for each assessment against an increasing number of dimensions.

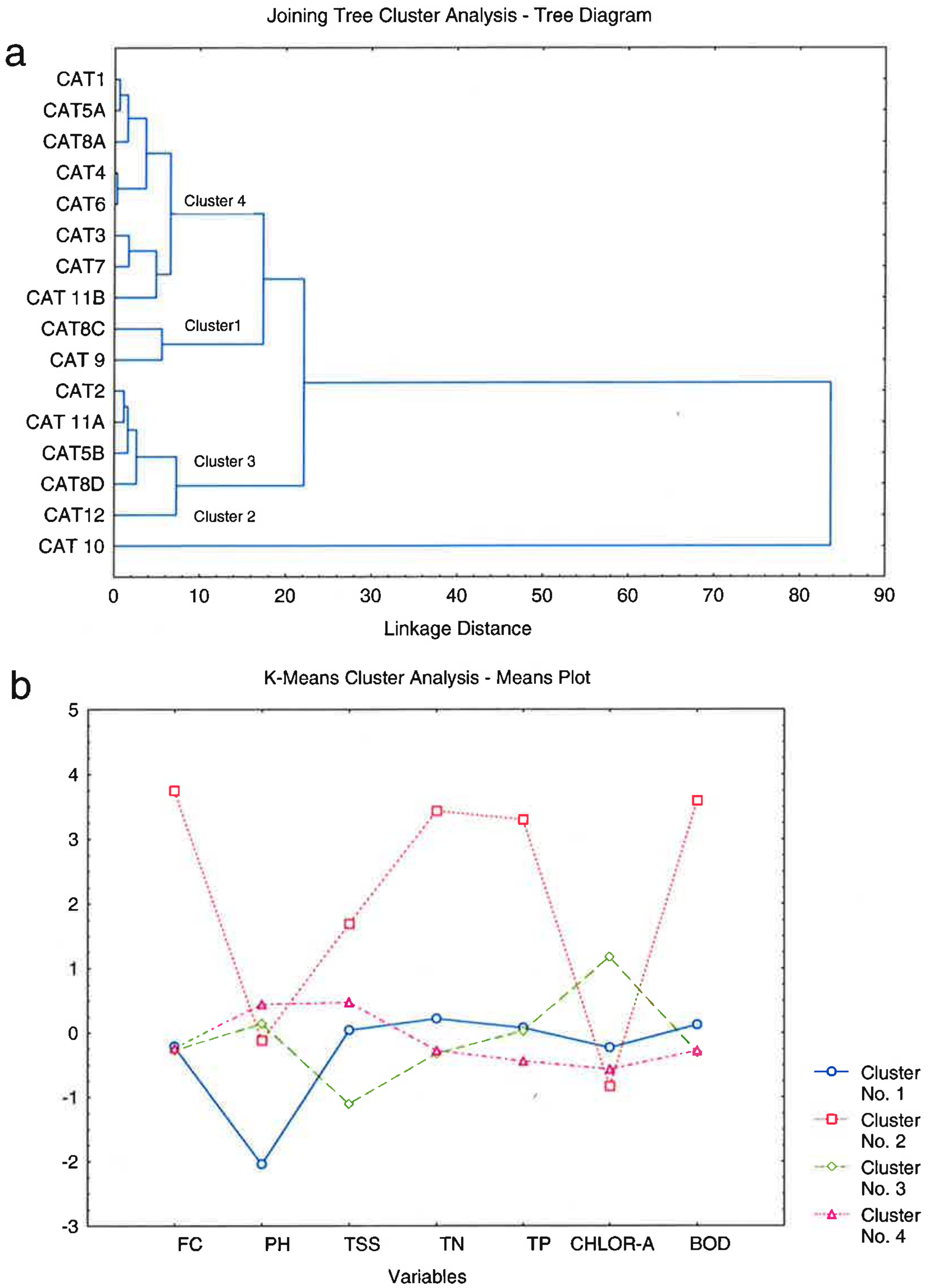

Figure 7. Cluster Analysis of water quality sites in the Upper Tweed Catchment. 7a, Joining Tree Cluster Analysis with four clusters formed at a linkage distance of 10. 7b, K-Means Cluster Analysis illustrating differences in water quality among the four clusters.

Known as the Scree Test, the corresponding plot will initially fall sharply until a point is reached where the curve flattens out. After this point, any increase in dimensions will only marginally reduce raw stress. Consequently, only that number of dimensions which significantly reduces raw stress should be used. The Scree Test has been undertaken for sites in the Upper Tweed River Catchment (figure 8a). It is evident that the scree curve flattened markedly after 2 dimensions. Two dimensions were chosen for subsequent assessments.

All water quality sites were subjected to 2 dimensional MDS (figure 8b). Site 10 (referred to in cluster analysis as cluster 2) was clearly different to other sites in the catchment when plotted against the X axis (dimension 1). This difference related to the very high elevations in both faecal coliforms and nutrients at site 10 (refer to K-means cluster analysis, figure. 7b). Other sites in the assessment ranged along the Y axis. Sites that were lower in nutrients and chlorophyll-a congregated at the lower end of the Y axis while sites in which Chlorophyll-a and or nutrients were elevated were placed at the upper end of the Y axis. This cluster of sites was reassessed with the omission of site 10 (refer to fig. 8c). In this second assessment, sites displaying best water quality performance congregated towards the lower left hand side of the plot. This group (cluster 4) included sites 1, 2, 4, 5a, 6, 7 and 8a. Sites 8c and 9 (cluster 1), demonstrated episodic elevations in nutrient concentrations and BOD and were plotted to the top of the graph. Sites which demonstrated elevations in chlorophyll-a congregated to the right of the graph (Cluster 3). These sites included 3, 5b, 8d, 11a, and 12. Site 11b which had been previously grouped with these sites had migrated towards sites with better water quality.

4.7 Suspended Solids and Turbidity

The measurement of suspended solids is a useful parameter for gauging processes like erosion. This method, which involves the filtering of water to determine the weight of suspended particulate matter, provides direct information regarding catchment erosion and the movement of suspended matter. Unfortunately the method is time consuming and thus relatively expensive to apply to intensive investigations. The measurement of turbidity, using a hand-held probe or logger, is an indirect measure of the relative amount of suspended particulate matter in water. While this method is rapid and cost-effective, its relationship to the measurement of suspended solids is not always linear and is sometimes confounded by other processes. The use of turbidity within an intensive sampling program may be useful in determining future erosion processes in the Upper Tweed Catchment. To assist this process the current study has investigated the relationship between turbidity and total suspended solids.

The measurement of turbidity and suspended solids was taken simultaneously on 405 occasions during the ten year sampling period in the Upper Tweed Catchment. Multiple Regression Analysis determined that a significant linear relationship existed between the two parameters based on this data ($p<0.0001$; $r2=0.46$). It was evident from a plot of this relationship that a small number of outliers where compromising the fit of the regression line (figure 9a).

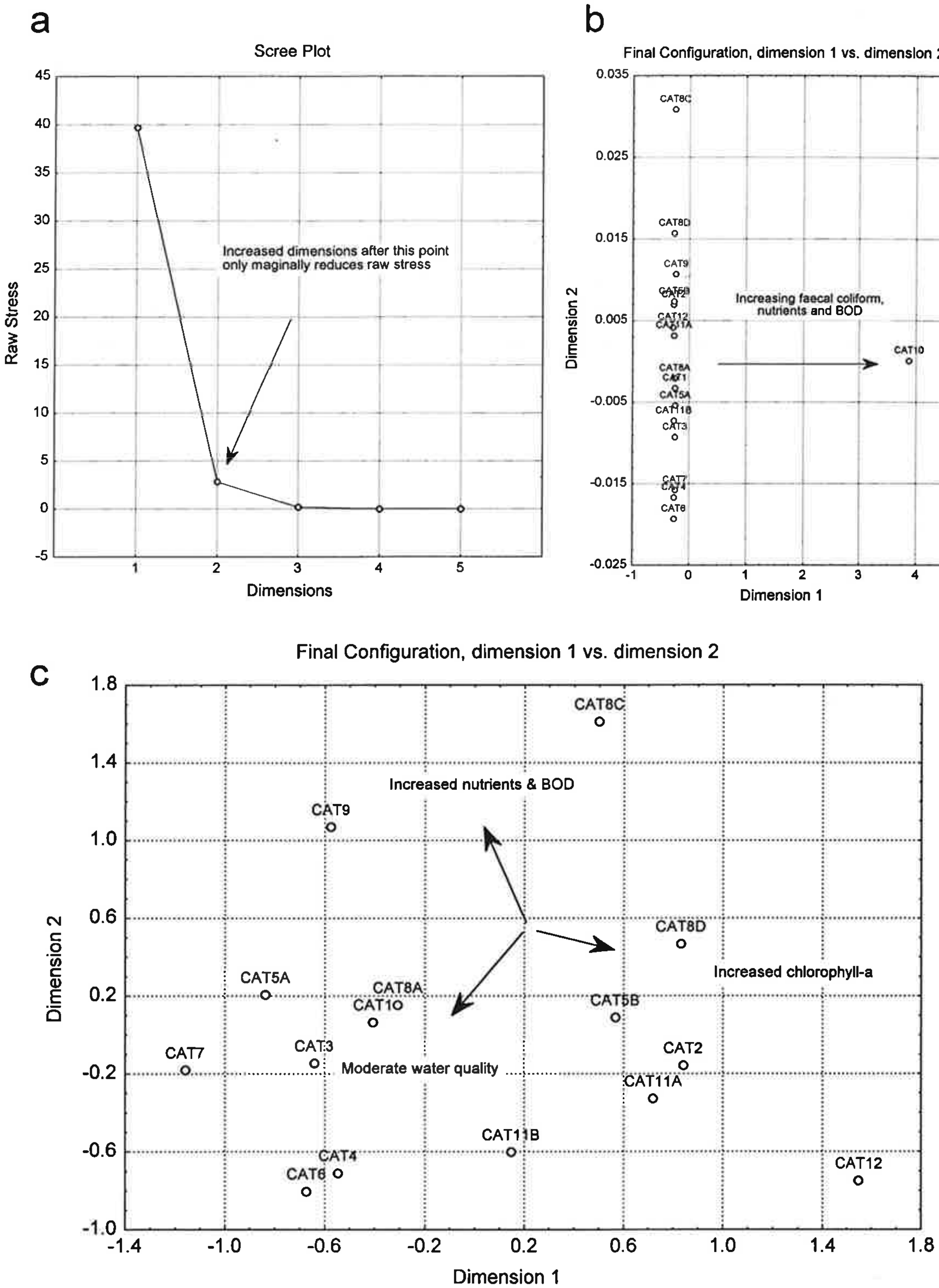

Figure 8. Multidimensional scaling (MDS) of water quality sites in the Upper Tweed Catchment based upon the dissimilarity matrix generated by cluster analysis (figure 7). 8a, scree test; 8b, 2 dimensional MDS on all sites; 8c, 2 dimensional MDS with site 10 omitted.

These six outliers were characterised as displaying high suspended solids values (>40 mg/L) and low turbidity values (<10 ntu, nephelometric turbidity units). When the outliers were removed the fit was substantially improved ($p<0.0001$; $r2=0.76$; figure 9b). The linear model for predicting total suspended solids from turbidity was:

TSS predicted = 0.4084 + 0.7247*turbidity

Predicted total suspended solids data was generated using this model and then compared to actual observations. The generated data was not significantly different from actual observations according to Wilcoxon Matched Pairs test ($z=0.0947$; $p=0.9245$) and t-test for dependant samples ($t=0.2437$; $p=0.8076$). Figure 9c demonstrates this good fit using data for site 1.

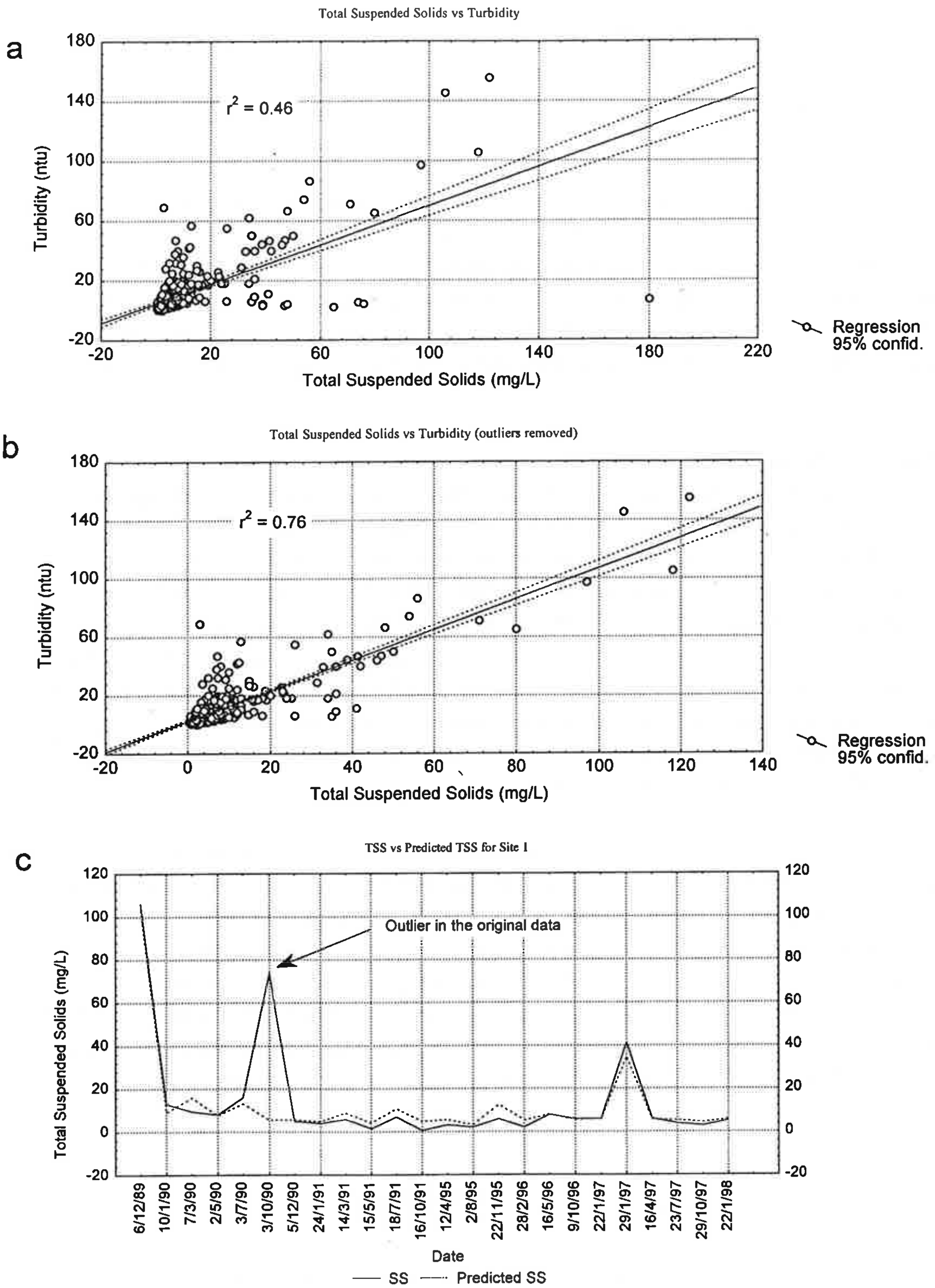

Figure 9. The relationship between total suspended solids (TSS) and turbidity. 9a, linear relationship with outliers included; 9b, linear relationship with outliers removed; 9c plot of TSS versus predicted values of TSS for site 1.
ntu, nephelometric turbidity units

5.0 General Discussion

5.1 Faecal coliform

Compliance

According to the current microbiological guidelines on aquatic health (ANZECC, 1992), five sites reached or exceeded the threshold value for contact recreation. Four of these sites where located near the township of Tyalgum in the Oxley River sub-catchment and included sites at Fowlers Creek, Pumpenbil Creek, Oxley River at Tyalgum and the Tyalgum raw water supply. One site was also located in the Tweed River sub-catchment at the Uki water supply near the township of Uki.

Sources of contamination

Potential sources of contamination can be identified by examining the land uses which occur adjacent to those sites where bacterial levels exceed current guidelines or where episodic elevations are significant. Episodic elevations in faecal coliform of between 10,000 and 50,000 cfu/100mL have been recorded in waters adjacent to dairy/beef cattle activities at Fowlers Creek, Crams farm and Bray Park. The impact of urban stormwater may also contribute to episodic elevations exceeding 25,000 cfu/100mL at the township of Uki, and at Bray Park. It is likely that adjacent land use contributions from high density animal husbandry, urban stormwater and/or septic effluent disposal contribute to the elevated bacterial loads present in localised areas of the Upper Tweed Catchment.

The present study also determined that rainfall significantly increased bacterial loads in the Upper Tweed Catchment. Because stormwater acts as a key transport mechanism of surface pollutants (UNESCO/WHO/UNEP, 1992), these elevations may be attributed to surface deposited sources of faecal matter such as those originating from domesticated and wild animals. Recent studies by the CSIRO attributed up to 90% of faecal coliform loads within the Wyong catchment to birds and domesticated stock (Leeming *et al.*, 1994; Leeming and Nichols, 1995a & b). It is advised that the Tweed Shire Council undertake to identify sources of bacterial contamination prior to the implementations of any management strategy to reduce bacterial loads within the catchment.

5.2 Nutrients and Chlorophyll-a

Guidelines and threshold limits for the concentration of nutrients (phosphorus and nitrogen) within waterways were set by ANZECC (1992) to prevent eutrophication and excessive growth of aquatic algae. These limits were developed according to the levels at or above which problem growths were known to occur in specific waterways. ANZECC (1992) recognised that the impact of nutrients vary according to the characteristics of each waterway, and that nutrient concentrations above the guidelines may not cause excessive algal growth in some systems. ANZECC (1992) advised that following site-specific investigations, appropriate nutrient threshold limits could be set which reflected local processes.

The current monitoring program examined total phosphorus (TPO_4), total Kjeldahl nitrogen (TKN), ammonia (NH_3N), nitrate (NO_3N), total nitrogen (TN) and chlorophyll-a. The measurement of chlorophyll-a concentration was used in the present study to determine compliance to ANZECC guidelines. It was also used to provide a sound assessment of the performance of current nutrient threshold limits in preventing nuisance algal growth in the Upper Tweed Catchment.

5.2.1 Nutrients

Compliance

Concentrations of total nitrogen approached or exceeded applicable ANZECC guidelines at all sites in the Upper Tweed Catchment. Concentrations of total phosphorus also approached or exceeded these guidelines at a smaller number of sites in both the Oxley and Tweed River sub-catchments. Prominent elevations in nutrients occurred at Fowlers Creek, Pumpenbil Creek and Doon Doon Creek (areas notes for their dairy/beef cattle activities) and at water storage facilities at Uki, Clarrie Hall dam and Bray Park.

Sources of contamination

The total loads of both nitrogen and phosphorus that exist within a waterway are usually contributed by a variety of catchment sources (UNESCO/WHO/UNEP, 1992). These sources provide nutrients in forms that are often specific to the processes that created them. Contamination by faecal matter is found to elevate both ammonia and TKN concentrations in water. This is because high concentrations of ammonia are found in the faeces of animals, while ammonia concentrations significantly contribute to the measurement of TKN. Nitrate is a common form of nitrogen found in fertilisers. High concentrations of nitrate may infer impact by fertiliser application. Phosphorus is also found in fertilisers and the guano of birds and bats. Elevated phosphorus concentrations may thus result from these variety of sources.

The present study determined that the elevated total nitrogen load in the Upper Tweed Catchment was made up of similar contributions from both TKN and nitrate. Intensive animal husbandry occurs upstream from site 10 at Fowler's Creek and both ammonia and TKN concentrations were highly elevated at this site. Increased nitrogen loads at other sites frequented by cattle suggest that domesticated stock may significantly contribute to the current nitrogen load. Elevations in nitrogen also occurred adjacent to townships suggesting some contribution from septic effluent. Total phosphorus was particularly elevated at two sites where beef cattle activities operate (Fowler's Creek and Doon Doon Creek). It is not known whether the application of fertilisers contributed to this. Total phosphorus was also elevated at the Bray Park water supply where fertiliser run off may be more likely to occur.

The present assessment indicated that excessive nutrient loading may be linked to specific land uses in the Upper Tweed Catchment. It is suggested that any remedial strategy employed to reduce the nutrient load in this system should be targeted towards such land uses. To assist in the development of a remedial strategy, a greater understanding of important land use processes is required. This understanding may be gained by simple data collection methods such as site inspections or formal audits. Other avenues of investigation may include nutrient process studies or intensive targeted monitoring programs.

5.2.2 Chlorophyll-a

The growth of aquatic algae is influenced by a variety of factors including water temperature, light attenuation (the depth of light penetration and its intensity at particular depths) and the availability of nitrogen and phosphorus. Only five sites in the Upper Tweed Catchment were regularly monitored for Chlorophyll-a. These sites were located at the water supply facilities at Clarrie Hall Dam, Uki, Tyalgum Creek and Bray Park. While median chlorophyll-a concentrations were below the guideline limit set by ANZECC (1992), persistent elevations exceeding the limit by ten fold occurred during 1997. The cause of such elevations was undetermined. However, it is reasonable to assume that the high nutrient load in the Upper Tweed Catchment would substantially support occurrences of excessive algal growth. It is also likely that reductions in the nutrient load would reduce the occurrence of excessive algal growth in the future. Implementation of a targeted nutrient reduction strategy within the Upper Tweed Catchment may facilitate such protection of the waterway.

5.3 Suspended Solids

Compliance

While suspended solids can arise from a variety of point source industrial discharges, the largest contributions come from non-point source soil and stream bank erosion. The sedimentation which results from this erosion is regarded by ANZECC (1992) as probably the most significant human impact in Australian waters. A variety of threshold limits for suspended solids can be drawn from current guidelines (ANZECC, 1992). When the most applicable of these were applied to the current assessment, sites at Doon Doon Creek, the south arm of the Tweed River, the Tweed River at Uki, Fowler's Creek and Bray Park exceeded acceptable limits for most or all of the criteria used. While performance to the different criteria varied, most sites in the catchment exceeded the guideline of 10% seasonal change in suspended solids.

Sources of contamination

The present study identified a strong positive relationship between total suspended solids concentrations and rainfall in the Upper Tweed Catchment. This is not surprising, considering that suspended solids concentrations are influenced by the stability of catchment soils and the magnitude of stormwater flows (Doyle, 1996; Cullen 1992). It is concluded that erosion is the most likely contributor of suspended solids in both the Oxley River and Tweed River sub-catchments. Reductions in erosion, suspended solids concentrations and the deposition of sediments is likely to be achieved through the application of erosion control strategies that have been developed to address prevailing land use management practices. Point source discharges like those identified at Fowler's Creek appear to cause significant localised elevations in suspended solids. Reducing or treating such discharges is likely to lower suspended solids concentrations at these sites.

5.4 pH

pH is a measure of how acidic or alkaline a water body is, and ranges from 1 (very acidic) to 14 (very alkaline), with 7 being neutral. Most undisturbed natural systems exhibit a stable pH ranging from 6.5 – 9.0. However, pH can rise or fall outside this normal range. This usually results from disturbance of soils in the catchment (typically from mining, agricultural or building activity), or the point-source release of chemical contaminants. In such cases this change may affect the ability of aquatic organisms to undertake necessary biological functions and result in the mass death of sensitive species. Measurement of pH can thus indicate the waterways capacity to support complex biological communities. ANZECC (1992) set a guideline pH range of 6.5 - 9.0 to protect the ecological integrity of aquatic systems. According to the current study, pH at the monitored sites in the Upper Tweed Catchment satisfied applicable guidelines for the protection of aquatic systems. Only one observation at the Bray Park reservoir was below the lower threshold of pH 6.5.

5.5 Water Quality and Rainfall

Water quality in the Upper Tweed Catchment appeared to progressively worsen in response to increasing levels of rainfall. Rainfall was found to be an extremely important determinant of water quality and its fluctuations accounted for much of the observed variation in most water quality parameters. This may be expected considering that stormwater is an important transport medium of surface pollutants in a catchment. It is generally accepted that the level of impact exerted by stormwater is closely related to both the magnitude of the rainfall event and to the various land uses operating within the catchment (Cullen, 1992; UNESCO/WHO/UNEP, 1992). This may explain the differing responses to rainfall between the Oxley River and Tweed River sub-catchments.

Important implications arise from the relationship between rainfall and water quality in the Upper Tweed Catchment. Firstly, any determination of ambient water quality must be taken from a data set that encompasses the normal range and frequency of rainfall events common to the region. As such, assessment of data sets collected over short time periods will require a higher sample frequency than assessments using data collected over longer periods. Comparative assessment of water quality data over time will also be vulnerable to episodic events such as drought and flood which may compromise interpretation even when sample frequency is high. It is evident that the most appropriate way of expressing water quality performance within the catchment is in relation to rainfall. Suitable methods for determining the significance of any future change in water quality performance have been briefly explored in the recent water quality assessment of the Lower Tweed Estuary System (KEC science, 1998).

5.6 Temporal Change in Water Quality

As discussed in the previous section, the determination of temporal change (change over time) in water quality is vulnerable to compromise through the vagaries of the rain events operating at the time of sampling. This can be somewhat overcome by increasing sample frequency to encompass the common range of rain events for each cycle (year). The collected data can also be subjected to time series analysis, a set of statistical methods which compensate for natural variation and seasonal and cyclic trends. This assessment was undertaken in the present study for two sites situated in the lower reaches of the Oxley River and Tweed River sub-catchments. Results indicate that for both sub-catchments total suspended solids and faecal coliform concentrations increased over the 10 year period from 1988 to 1998. While total phosphorus appeared to significantly increase in the Tweed River sub-catchment over the time period no significant change in the nutrient load of the Oxley River sub-catchment was apparent.

5.7 Defining Catchment Issues

No single measure has been developed which can singularly describe the state of physicochemical water quality in the aquatic environment. Instead, a diverse range of parameters are used which separately describe important aspects of water quality. When viewed together it is hoped that these parameters provide a window on the general state of the waterway and its catchment, although this goal is somewhat confounded by the need to compare complex and sometimes unrelated measures. While each site in the Upper Tweed Catchment is unique in its water quality performance, they can be organised into meaningful groups based solely on their similarities and differences in water quality. This was undertaken for the present study using Cluster Analysis and Multidimensional Scaling.

Fowler's Creek (site 10), a site within the Oxley River sub-catchment noted for its intensive animal husbandry, was deemed to differ markedly in water quality performance from any other site in the Upper Tweed Catchment. This is not surprising considering the significant elevations in faecal coliform, suspended solids, nutrients and BOD which routinely occurred at this site. Such land uses as those prevailing at Fowler's Creek evidently require some form of management to reduce their localised impact on the waterway. It is suggested that a review of effluent management processes be undertaken at such operations and mechanisms developed and installed which afford protection to down stream water quality at these sites.

A second group determined by cluster analysis, which display enhanced nutrient concentrations and BOD, was made up by sites at Doon Doon Creek (site 9) and Cram's Farm (site 8a) within the Tweed River sub-catchment. Both sites appear to be heavily frequented by domesticated stock and it is likely that other sections of the waterway are subjected to similar pressures. It would appear that improved stock management practices may be an important tool in the maintenance of catchment water quality. The development and implementation of a stock management strategy should be viewed as an important facet of an overall catchment and water quality management plan for the Upper Tweed Catchment.

Sites at the various water supply facilities also formed a group according to cluster analysis, as did stream sites displaying moderate water quality performance. These groups of sites also appeared to aggregate towards opposite sides of the plot when MSD was applied. Because such clustering conformed to a logical expectation of how these sites should be grouped it is suggested that both cluster analysis and MDS performed adequately and the current data set was suitable for such application.

5.8 Implications for Catchment Management

Upper Tweed Catchment

The strong relationship between rainfall and water quality in the Upper Tweed Catchment underscores the important role played by catchments in determining the state of aquatic ecosystems. As such, land use and catchment management processes should be recognised as critical determinants of water quality and applied in the Upper Tweed Catchment to manage water quality. It is evident from the current assessment that total suspended solids and nutrients are generally elevated in the Upper Tweed Catchment. Strategies which are intended to minimise erosion and reduce the nutrient load in this system must be developed in response to prevailing land use activities and catchment conditions. Development of these strategies will be assisted by a greater understanding of the relevant land use processes currently in operation. This understanding can probably be gained most effectively by an on-site assessment and auditing process which leads to a preferred series of management options. Other avenues of investigation may include quantitative measurement of land use contributions.

Tweed Estuary System

The quality of water in the Lower Tweed Estuary System appears to be significantly influenced by stormwater contributions arising from upper catchment areas (KEC science, 1998). Based on the present assessment however, the magnitude with which water quality parameters become elevated in the Chinderah reach of the estuary suggest that the Upper Tweed Catchment is not the major contributor of storm water pollutants in this system. While the Rous River sub-catchment was not included in the present assessment its water quality is generally regarded as poor. It is suggested that stormwater originating from the Rous River sub-catchment probably plays an important role in estuarine water quality. Any catchment management strategy which is employed to enhance estuarine water quality must encompass land use activities throughout the entire Tweed River system. A detailed assessment of water quality performance in the Rous River sub-catchment is likely to assist in the development of such a strategy.

5.9 Implications for Future Monitoring Activities

A variety of land use activities appear to influence water quality performance in the Upper Tweed Catchment. This influence is usually mediated through the point source or non-point source release of contaminants (UNESCO/WHO/UNEP, 1992). Point source contamination refers to the active discharge of pollutants at designated points. In the Upper Tweed Catchment this may arise from activities like high density animal husbandry and septic waste disposal. The influence of point source contamination on water quality tends to be sustained, with downstream fluctuations in water quality being strongly related to the performance of the process which created the discharge. Non-point source contamination arises from catchment-wide land uses that do not cause point specific discharges. In the Upper Tweed Catchment, this may include contaminants such as sediment, faecal bacteria and nutrients which arises from activities like land-clearing and agriculture. Stormwater plays an important role in the transport and suspension of non-point source pollutants within the waterway. In the absence of point source contamination, catchment water quality responds strongly to rainfall in a manner that is relative to the magnitude of the rain event. The ability of a waterway to resist significant contamination after rain events is reliant upon broad trends in land use activity, the stability of catchment soils, status of vegetation and the episodic occurrence of events like drought, flood and fire. Thus in the absence of significant point source pollution, water quality data can be used to assess catchment condition.

The objective of most routine water quality monitoring programs is to determine ambient water quality and its temporal shifts as an indicator of catchment condition. To achieve this goal requires site selection that minimises the influence of point source contamination, as well as a monitoring frequency sufficient to capture the necessary range of rain events over a meaningful time period. Because most catchments exhibit a 'patchwork' of differing land uses, water quality in some sections of the waterway reflect broader catchment contributions, while in other sections, water quality reflects fluctuations in point source effluent discharge. It is evident that site selection determines the usefulness of water quality data for specific roles. Where the goal of the monitoring program is the determination of catchment condition, site selection should be undertaken using criteria that ensures minimal influence by point source contamination.

There is no evidence to suggest that either fixed objectives or a formal process of site selection have been applied in the current routine monitoring program for the Upper Tweed Catchment. It is advised that formal objectives in both monitoring and reporting are set for the monitoring program. Where the goal of monitoring is to determine ambient water quality, data collection and its subsequent assessment should be formally recognised as being separate to any investigation into point source impact assessment. It is also advised that formal criteria for site selection should be applied to the current set of monitoring sites to ensure their applicability to formal objectives. This will necessarily require the development of a site selection *pro forma*. This *pro forma* should be used in subsequent inspections of current monitoring locations. Where sites do not satisfy the criteria for site selection they should be removed from the current program.

It has already been demonstrated that rainfall plays an important role in the determination of water quality and catchment condition. It is suggested that sampling frequency should be increased so that a representative range of rain events are collected over a shorter time period. The greater cost associated with this increase in monitoring frequency may be offset by the expected removal of some sites as a result of the site selection process. Other methods of cost reduction may include the removal of redundant parameters from the current suite of water quality tests.

The Tweed Shire Council currently undertakes quarterly water quality monitoring at more than 40 stations within the Tweed valley catchment. A brief examination of this data indicated that the quarterly sampling regime currently in place is unlikely to serve the future needs of the Tweed Shire Council in respect to catchment management activities. It is advised that a formal process of site selection should be applied to all sites in the Tweed Valley catchment with a view to increasing the sampling frequency of current water quality monitoring at a reduced number of stations.

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Appendices

Appendix A - Cluster Analysis

No single measure has been developed which can singularly describe the state of physicochemical water quality in the aquatic environment. Instead, a diverse range of parameters are used which separately describe important aspects of water quality. When viewed together it is hoped that these parameters provide a window on the general state of water quality, although this goal is somewhat confounded by the complex relationships between the parameters. The combined influence of natural variation and the use of complex multi-parameter measures ensures that each site in the Upper Tweed River Catchment is unique in its water quality performance. Despite this uniqueness, these sites can be organised into meaningful groups based solely on their similarities and differences in water quality. The statistical method which facilitates this process is called Cluster Analysis.

The primary hurdle facing Cluster Analysis is the need to determine water quality performance based on comparisons between parameters with widely differing units of measure (ie. bacteria, nutrients, etc.). To overcome this, the first step is to standardise the various water quality observations under a single measure. In statistical methods, a value is standardised when it is expressed in terms of its difference from the mean, divided by the standard deviation (Statistica, 1997). In the present assessment, standard values for the various water quality parameters were calculated using the following equation.

$$SV_n = (\bar{x}_n - \bar{x}_{all}) / SD_{all}$$

Where SV_n = the standard value of a water quality parameter for site n.
$\bar{x}_n$ = the mean value of a water quality parameter for site n.
$\bar{x}_{all}$ = the mean value of a water quality parameter for all sites combined.
SD_{all} = the standard deviation of a water quality parameter for all sites combined.

The resulting data set contained a series of standardised values for each parameter which allowed sites to be ranked according to their variation from the catchment mean. Because of this, unrelated parameters could be directly compared. From this data set containing standardised values Cluster analysis produces a matrix in which the similarity between each site is given a distance value (a Euclidean distance). The larger the distance value between two sites, the less similar those sites are according to their general water quality. The matrix which is produced by cluster analysis is referred to as a dissimilarity matrix.

In the strictest sense, all sites are dissimilar. This is reflected by the independent listing of all sites on the left hand side of the Horizontal Hierarchical Tree Plot that is produced by Joining Cluster Analysis. If the criteria which constitute uniqueness is progressively relaxed then sites with similar water quality performance begin to aggregate into groups (clusters). When clear clustering patterns exist, distinct relations between groups of sites can be inferred.

Appendix B - Multidimensional Scaling

Multidimensional scaling, like Cluster Analysis, also uses a distance matrix. In the case of MDS, the distances are plotted out like a map. The position of each site is then moved around so that agreement between all distance values is maximised (and the raw stress decreased). The use of one or two dimensions may be adequate to determine the relationships between sites but sometimes multiple dimensions are required to produce satisfactory results. While the use of lower numbers of dimensions simplifies interpretation, the accuracy of the results are enhanced as the number of dimensions increases. A well accepted method of selecting the correct number of dimensions is to plot the raw stress for each assessment against an increasing number of dimensions. Known as the Scree Test, the corresponding plot will initially fall sharply until a point is reached where the curve flattens out. After this point, any increase in dimensions will only marginally reduce raw stress. Consequently, only that number of dimensions which significantly reduces raw stress should be used. The Scree Test has been undertaken for sites in the Upper Tweed River Catchment (refer to fig. 8a). It was evident that the scree curve flattened markedly after 2 dimensions. Two dimensions were chosen for subsequent assessments. A Shepard diagram was produced for 2 dimensions which showed good correlation between the observed versus predicted distances.