Jane L

TWEED RIVER WATER QUALITY REVIEW

Prepared for: Tweed Shire Council

Prepared by: WBM Oceanics Australia
99 Leichhardt Street
SPRING HILL QLD 4004

Telephone: (07) 3831 6744
Fax: (07) 3832 3627

Document: 10655.1.1

CONTENTS

Contents i
List of Figures ii
List of Tables ii

1 INTRODUCTION 1

2 METHODOLOGY 2

2.1 Background 2
2.2 Discretise Study Area 4
2.3 Defining Environmental Values 6
2.3.1 Environmental Values Adopted 6
2.3.2 Environmental Values Selection 8
2.4 Define Water Quality Criteria 8
2.5 Develop Water Quality Objectives 8
2.6 Compare Existing Water Quality with Water Quality Objectives 9
2.7 Assess Water Quality Exceedences 9
2.8 Assess Causes of Water Quality Exceedences 11
2.9 Assess Management Options 11

3 ENVIRONMENTAL VALUES 13

4 WATER QUALITY OBJECTIVES 15

5 WATER QUALITY EXCEEDENCES 17

5.1 EPA Northern Rivers Report 19
5.1.1 Water Quality Criteria Adopted 20
5.1.2 EPA Conclusions 21
5.1.3 Comparison with WBM Oceanics Australia Study 23

6 CAUSES OF WATER QUALITY EXCEEDENCES 24

6.1 *State* of the Tweed River System 24
6.2 *Pressures* on the Tweed River System 24
6.2.1 Sources of Nutrients 24
6.2.2 Sources of Sediment 25
6.2.3 Sources of Bacteria 26
6.2.4 The Role of Riparian Vegetation 26
6.2.5 Summary of Pressures 26
6.3 *Responses*/Management Options 27
6.3.1 Tweed Shire Council Actions 27
6.3.2 State and Federal Actions 29
6.3.3 Community Education 29
6.4 Water Sensitive Urban Design 31

7 REFERENCES 33

8 GLOSSARY 34

APPENDIX A: STUDY RESULTS A-1

LIST OF FIGURES

Figure 2.1 Water Quality Management Strategy Process 3
Figure 2.2 Defined Study Area Segments 5
Figure 2.3 Water Quality Sampling Locations 10
Figure 2.4 State of the Environment Reporting Format 12
Figure 6.1 Water Sensitive Urban Design Illustration 32

LIST OF TABLES

Table 3.1 Environmental Values Defined for the Tweed River 13
Table 4.1 Interim Water Quality Objectives 15
Table 5.1 Water Quality Exceedences in Each Segment 17
Table 5.2 Environmental Values Met in the Tweed River System 19
Table 5.3 EPA Ranking Schedule 22
Table 6.1 Pressures on Water Quality in the Tweed River System 27

1 INTRODUCTION

Tweed Shire Council commissioned WBM Oceanics Australia to perform a review of the report recently released by the EPA entitled "The Northern Rivers - A Water Quality Assessment" (EPA, 1996). For various reasons, including media overplay and misunderstanding of the report, a considerable amount of poor publicity was generated regarding the water quality of the Tweed River by this report.

In order to review the Northern Rivers report, WBM Oceanics Australia undertook the first steps toward the development of an Interim Water Quality Management Strategy for the Tweed River. This included defining interim environmental values, developing water quality criteria and objectives, comparing the existing water quality with the water quality objectives and identifying probable causes of the identified water quality problems.

In order to comprehensively assess existing water quality in the Tweed River system, WBM Oceanics Australia utilised the long term Tweed Shire Council water quality data set and the EPA data collected for the Northern Rivers report.

2 METHODOLOGY

2.1 Background

The methodology for this study was based on the National Water Quality Management Strategy (NWQMS) process which was developed by two Ministerial Councils, the Australian and New Zealand Environment and Conservation Council (ANZECC) and the Agriculture and Resource Management Council of Australia and New Zealand. The NWQMS was developed to provide a process by which strategic water quality and resource planning investigations could be performed to protect and enhance the quality of Australia's national water resources.

The NWQMS recommends a water quality management approach that involves the following steps (ANZECC 1992):

- identify environmental values of particular waterbodies that are to be protected;
- establish the objectives that will achieve the required level of protection. These objectives are established in terms of key indicators of quality (physico-chemical and biological) using collated scientific information relating to each indicator and each environmental value;
- establishing Water Quality Management Strategies (eg policies covering receiving water, effluent, non-point source and catchment management) that will provide the instruments for achieving the desired water quality objectives;
- developing and initiating a monitoring and surveillance program to ensure that the water quality (or environmental) objectives are being maintained or approached;
- initiating a research program to fill in the unknowns and to refine scientific information relating to each particular aquatic system.

This process of developing a Water Quality Management Strategy is illustrated in Figure 2.1. This study relates to the first of these steps, ie. developing interim environmental values, water quality criteria, interim water quality objectives and assessing probable causes for any water quality problems which may be identified. The terminology 'interim' is used as comprehensive definition of environmental values requires considerable community consultation, which was beyond the scope of this study.

Following this study, further steps would include a refinement of environmental values held by the community for each defined river section and more detailed investigation of whether water quality objectives defined in this study are appropriate for the Tweed River system. In order to define locally specific water quality objectives, investigations into water quality required to protect the unique aquatic ecosystems found in the Tweed River may be required. Additionally, different water quality objectives may be appropriate for different river segments. For example, a different water quality objective may be appropriate for the Terranora Broadwater and the lower estuary, as the ecosystems are very different and the water quality objectives may need to reflect this difference.

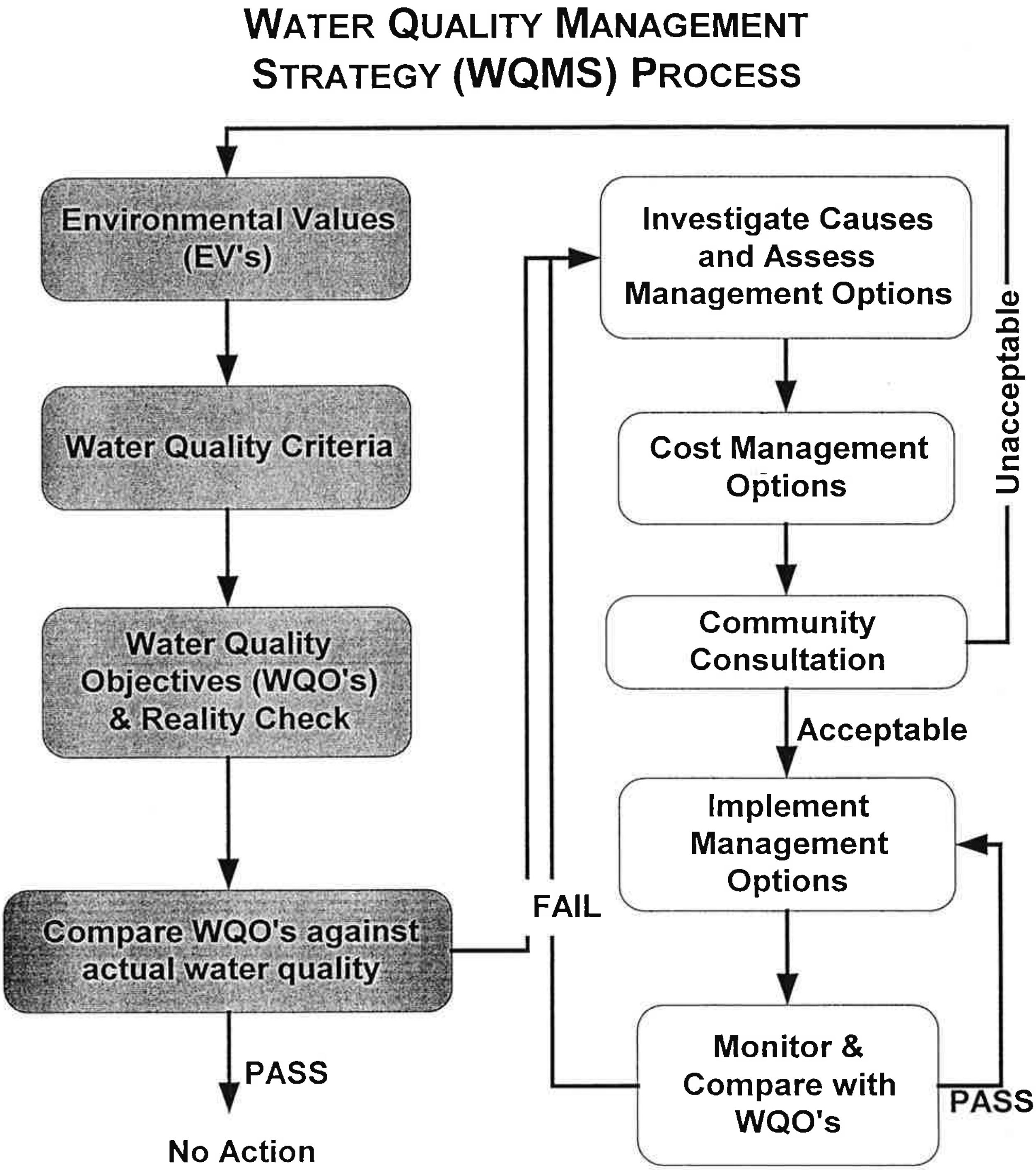


Figure 2.1 Water Quality Management Strategy Process

(Shaded boxes indicates stages undertaken as part of this study)

In addition to investigations to define locally specific water quality objectives, investigations into causes of water quality exceedences and management options are also required. Once appropriate management options have been identified, the cost of implementing these management options needs to be assessed. These costs can then be taken to the community.

If the community determines the costs required to implement the management options or the consequences of these management options are unacceptable, the community must accept the environmental values defined are not practicable. Therefore, a process of redefining the environmental values, setting water quality objectives and assessing new management options to achieve the redefined water quality objectives is required.

Ultimately, management options will be found that are both acceptable to the community and which can be readily implemented. Once these management options are implemented, monitoring to assess the efficacy of the management options is required. Should the management options not achieve expected results, additional management measures may be required.

This process is an ongoing one which aims to achieve the defined water quality objectives and environmental values. The Water Quality Management Strategy may be developed to meet these water quality objectives and environmental values in the long, medium or short term. However, monitoring to ensure objectives are being met (or worked toward at an acceptable rate) and keeping informed of scientific studies on appropriate water quality criteria and water quality objectives is also required.

2.2 Discretise Study Area

The Tweed River catchment was divided into a number of segments for the purposes of this study. These segments were designed to represent the differing attributes across the catchment, including land uses, point source discharges and river characteristics. The nine segments which were defined, in consultation with representatives of the Tweed River Management Plan Advisory Committee (TRMPAC), are illustrated in Figure 2.2 and are as follows:

1. Upper Freshwater Catchment;
2. Lower Freshwater Catchment;
3. Upper Estuary;
4. Mid Estuary;
5. Lower Estuary;
6. Terranora Inlet;
7. Terranora Broadwater;
8. Cobaki Broadwater, including tidal sections of Cobaki Creek; and
9. Other, including freshwater sections of Cobaki Creek, Bilambil Creek etc.

For each of these sections, environmental values and water quality objectives were defined.

Defined Study Area Segments

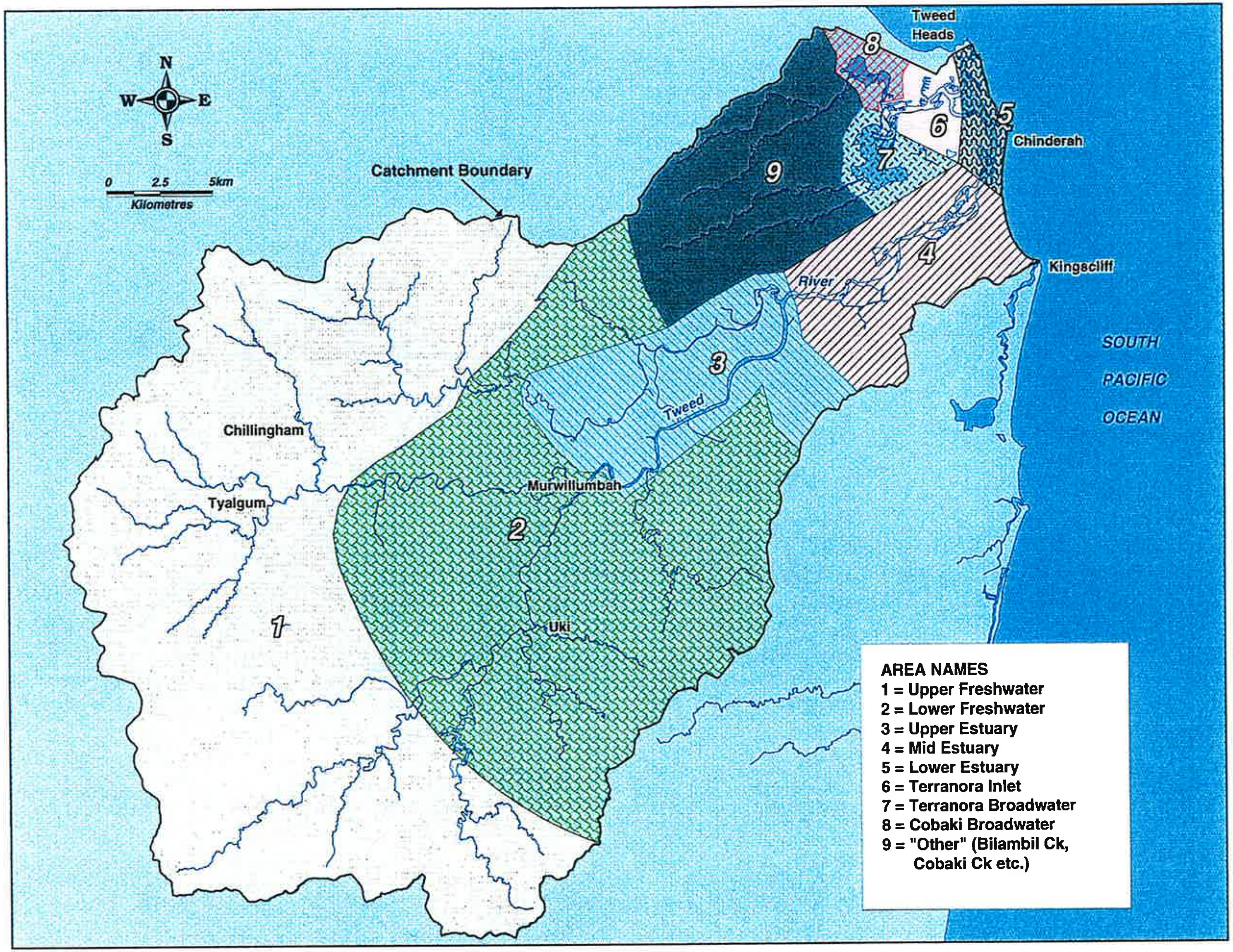


Figure 2.2

2.3 Defining Environmental Values

2.3.1 Environmental Values Adopted

In this study, environmental values are defined as :

Particular values or uses of the aquatic environment that society determines should be maintained and/or enhanced.

Eight environmental values (EV's) were considered possibly appropriate for the various segments within the study area. These EV's were generally based on values outlined in the ANZECC Guidelines (1992) and were:

- Aquatic ecosystem protection
- Production of edible raw shellfish
- Potable water
- Primary body contact recreation (swimming and action sports)
- Secondary body contact recreation (boating)
- Agricultural irrigation water supply
- Livestock drinking water
- Homestead water supply (non potable)

Aquatic ecosystem protection

This environmental value relates to the protection of water quality to ensure that all elements of the freshwater, estuarine and marine aquatic ecosystem are protected. It is not designed to protect a particular species, or for commercial farming of fish/shellfish, but is intended to ensure that all essential ecological processes can be performed, and the ecological integrity of the system is maintained.

Production of edible raw shellfish

This environmental value should not be confused with the commercial production of shellfish. Commercially produced shellfish are grown under an industry guideline, with careful supervision of conditions, specific water quality criteria, treatment of the shellfish and testing requirements before sale. As the industry guidelines are constantly monitored and updated with increasing knowledge, it is not appropriate to include the commercial production of shellfish as an environmental value in this study.

This environmental value relates to maintaining water quality at sufficiently high levels to eat raw shellfish, taken directly from the water or off rocks, without requiring treatment or cooking. Shellfish are filter feeders and have the capacity to bioaccumulate some pollutants and grow bacteria within the organism. If shellfish (particularly oysters) are eaten raw and

the whole organism is consumed there could be some risk to human health, unless adequate water quality is maintained.

As some toxins and bacteria are destroyed in the cooking process, this environmental value does not relate to cooked fish, cooked shellfish or other commercially grown shellfish.

Potable water

This environmental value relates to the water being of sufficiently high quality to drink when taken directly from the waterbody, without any sterilisation or treatment. It does not relate to the supply of potable water for treatment nor the ability to drink treated water from the reticulated water mains.

Primary body contact recreation (swimming and action sports)

This EV is to protect the waterbody for use in primary human contact activities, such as swimming, bathing or other activities in which the user comes in frequent direct contact with the waterbody and is likely to ingest significant quantities of water.

Secondary body contact recreation (boating)

This environmental value is to protect the waterbody for use in secondary human contact activities, such as boating, fishing or other activities where there is less frequent (or unintentional) direct contact with the waterbody.

Agricultural irrigation water supply

The ability to use water for irrigation of crops is also a value held for many sections of the Tweed River. Irrigation waters need to be of a particular quality to ensure adequate crop growth, and that neither alteration of the soil structure nor environmental harm is caused. Numerous farms in the study area require irrigation waters for their crops to be viable.

Livestock drinking water

The environmental value for livestock drinking water ensures water can be safely used as a dinking water supply for a variety of animals (cattle, pigs, sheep etc.). Water of lower quality may be able to be drunk by livestock for short durations without ill effect, however long term sources of drinking water should meet this environmental value to maintain healthy and successful livestock production.

Homestead water supply (non potable)

Numerous farmsteads are not connected to reticulated water supply in the Tweed River catchment, and one of their sources for water supply is abstractions directly from the Tweed River, or a tributary of the river. This environmental value does not aim to provide potable water (ie. drinking water with no treatment), which is covered by the potable water supply environmental value. Homestead water supply aims to ensure water can be used for

washing, cooking and other domestic purposes safely, however water may need to be sterilised before it is suitable to be used for drinking.

2.3.2 *Environmental Values Selection*

Preliminary environmental values for each of the defined segments were defined by WBM Oceanics Australia, and these preliminary environmental values were refined in a workshop with members of TRMPAC and the Tweed River Catchment Management Committee (TCMC). The environmental values defined during this workshop (refer Section 3) for each segment were considered to be the interim environmental values for the purposes of this study.

These interim environmental values are considered to be initial values, and they may be subsequently refined during further stages of the Water Quality Management Strategy process, based on community values, costs associated with achieving these environmental values etc.

2.4 Define Water Quality Criteria

A set of indicator water quality parameters and criteria were defined for each environmental value, based on the well accepted ANZECC Water Quality Guidelines for Fresh and Marine Waters (1992) and other appropriate sources, where necessary.

Where an absolute ANZECC criterion was not available for an indicator parameter (eg. suspended solids), a literature review of other available water quality standards, relevant scientific studies and available data sets were used to define a particular criterion.

Thus for each environmental value, a set of water quality criteria were developed to ensure the protection of the environmental value in the waterway. Where necessary (eg. protection of aquatic ecosystems), criteria for both fresh and marine waters were developed.

2.5 Develop Water Quality Objectives

From the previous definition of the environmental values for each of the nine river segments (refer Section 2.3.2) and the water quality criteria developed for each environmental value, the most stringent of each *criteria* for each environmental value was adopted to be the water quality objective for each segment. Therefore, a series of water quality objectives were defined to ensure the protection of all environmental values selected for each segment.

For example, a river segment which has both primary and secondary contact defined as environmental values will adopt the more stringent criteria from each EV as a water quality objective. Primary contact has one requirement for a geometric mean of five water samples to be less than 150 faecal coliforms/100mL and secondary contact requires a geometric mean of less than 1,000 faecal coliforms/100mL. Therefore the water quality objective which would be adopted in this river segment (assuming no other environmental values were defined) is the criterion for primary contact of a geometric mean of five water samples to be

less than 150 faecal coliforms/100mL. This water quality objective results in the protection of both environmental values in the river segment.

ANZECC (1992) emphasises that water quality objectives are of little value unless compared with 'natural' or 'background' water quality levels. Therefore, this selection of water quality objectives also included an investigation of 'background' water quality levels from similar, and relatively undisturbed, waterways in Queensland and NSW. As few completely undisturbed catchments remain in this region and no two catchments can be considered to be identical, this assessment should not be considered as developing locally specific water quality objectives.

Rather, a 'reality check' of the water quality objectives developed from the ANZECC guidelines and other sources was made. This assessment was used to ensure the water quality objectives developed were realistic and achievable for a catchment such as that of the Tweed River.

2.6 Compare Existing Water Quality with Water Quality Objectives

Once realistic and achievable water quality objectives were defined for each river segment, each objective was compared with existing water quality levels in the Tweed River. This comparison was undertaken using the long term Tweed Shire Council data set and the data collected by the EPA for the Northern Rivers report.

The locations of the various water quality sampling locations of the Tweed Shire Council and the EPA are shown in Figure 2.3. It may be seen that some river sections (eg. lower estuary) had a large number of water quality sampling locations and a large amount of water quality data, whilst other elements (eg. Terranora Broadwater) had limited water quality sampling locations and less water quality data. This available data limitations will require attention in the future.

2.7 Assess Water Quality Exceedences

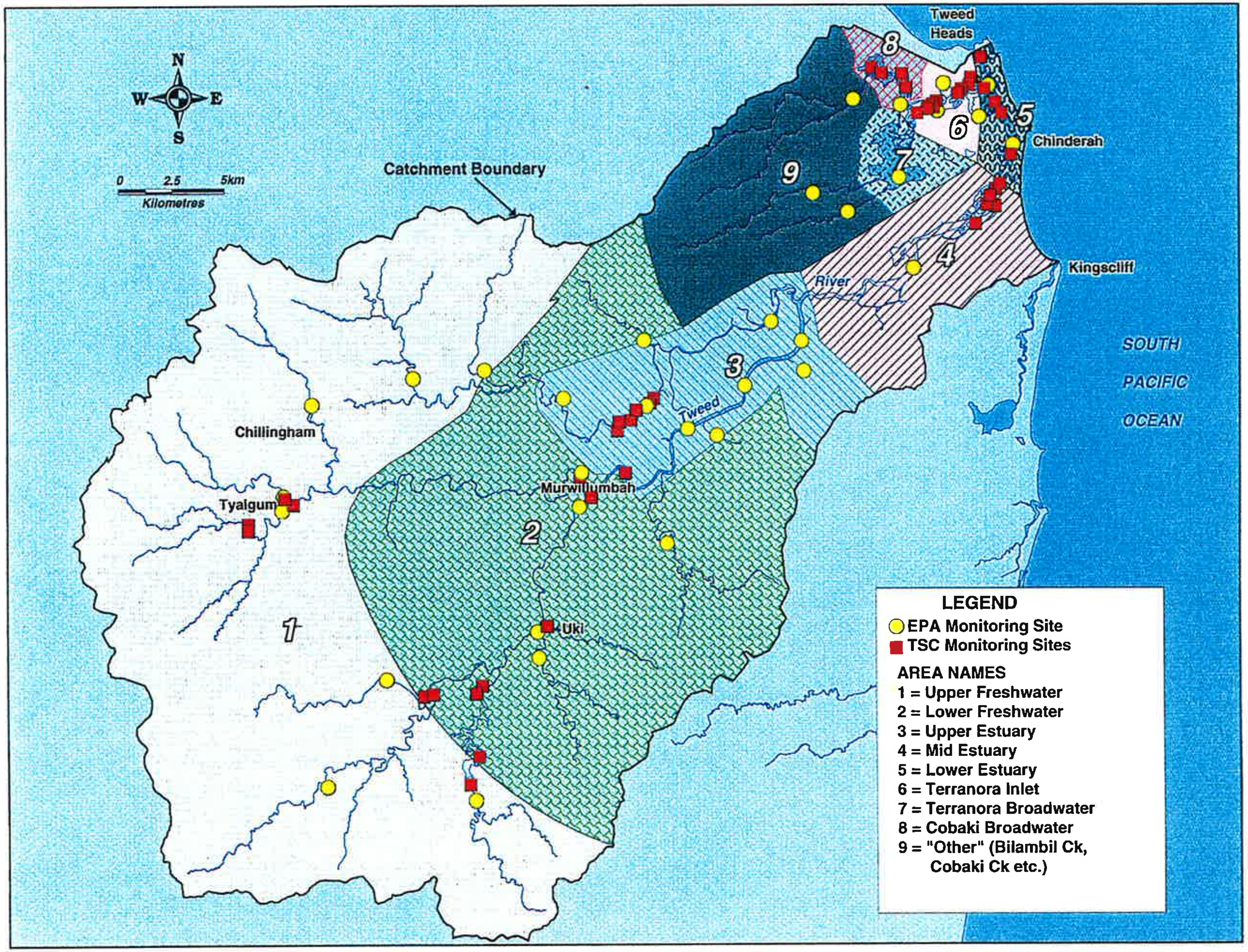
River segments where existing water quality data did not meet the water quality objectives defined for each segment were identified as part of this study.

Consideration of wet weather and atypical events were included in this assessment. Where the typical water quality of a river segment did not meet the water quality objectives for the segment, it was defined that all environmental values were not being met.

As the water quality objectives are set to achieve <u>all</u> the defined environmental values, a failure to meet all water quality objectives may result in only one of the environmental values not being met. However, other environmental values may still be held despite the water quality objectives not being met.

Figure 2.3

Water Quality Sampling Locations



2.8 Assess Causes of Water Quality Exceedences

Where water quality exceedences were defined in this study, a preliminary assessment was made of the probable causes of these exceedences. This assessment was only of a 'qualitative' nature, and subsequent studies would be required to confirm the relative magnitudes of impact for each cause.

Land uses, water quality data trends and point source discharges were all considered in the assessment of probable causes of the water quality exceedences observed in each river segment.

Following this preliminary assessment, a workshop was held with TRMPAC and TCMC representatives to discuss the findings of the study and to discuss some of the probable causes of the water quality exceedences.

State-Pressure-Response Variables

Following the workshop, WBM Oceanics Australia collated the study information and prepared material to be distributed to the community. This information was prepared using the widely adopted State of the Environment reporting format, which is based on the Organisation for Economic Cooperation and Development's (OECD) *Pressure-Condition-Response* model which has been refined for local application in various parts of the world. In the case of this study, the *Pressure-Condition-Response* format has been modified to a "*State-Pressure-Response*" model, in order to simplify the terminology used.

The model, as modified from the Australian State of the Environment Report and incorporating the Tweed River terminology, is illustrated in Figure 2.4. The illustration shows various broad categories of *states, pressures*, and *responses* which are relevant to the Tweed River system.

2.9 Assess Management Options

Management options to address the causes of water quality problems identified were also considered as part of this study. These management options should be considered to be preliminary, and additional management options may be identified following further research.

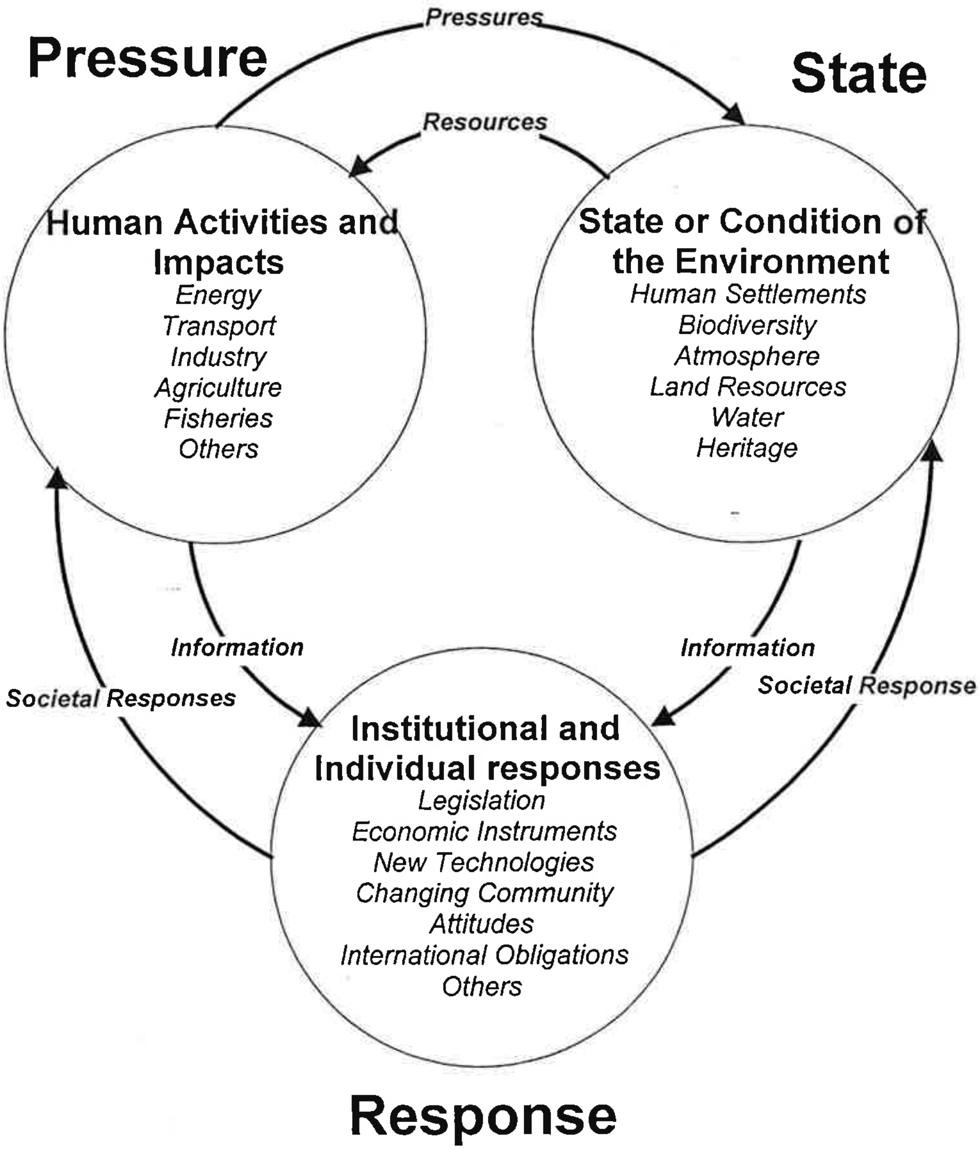


Figure 2.4 State of the Environment Reporting Format

3 ENVIRONMENTAL VALUES

As discussed above, environmental values for the Tweed River were defined through a workshop with TRMPAC representatives. These environmental values are of an interim nature, and subsequent stages of the Water Quality Management Strategy development may result in some changes being made to these environmental values.

The environmental values defined during the workshop are summarised in Table 3.1 below.

Table 3.1 Environmental Values Defined for the Tweed River

Environmental Value	1. Upper Freshwater	2. Lower Freshwater	3. Upper Estuary	4. Mid Estuary	5. Lower Estuary	6. Terranora Inlet	7. Terranora Broadwater	8. Cobaki Broadwater	9. Other (Bilambil Ck,Cobaki Ck etc.
Aquatic Ecosystems Protection	✓	✓	✓	✓	✓	✓	✓	✓	✓
Edible Molluscs (Raw)			✓	✓	✓	✓	✓	✓	
Potable Water	✓	✓							✓
Primary Contact Recreation	✓	✓	✓	✓	✓	✓	✓	✓	✓
Secondary Contact Recreation	✓	✓	✓	✓	✓	✓	✓	✓	✓
Agricultural Irrigation Water	✓	✓							✓
Livestock Drinking Water	✓	✓							✓
Farmstead Supply (non potable)	✓	✓							✓

Some discussion was held during the workshop regarding the consumption of raw seafood other than molluscs, for example raw fish and raw freshwater crayfish. An investigation was made into these issues, and of whether water quality criteria to ensure such consumption of raw fish/crayfish was safe were available. Few studies could be found which have investigated this matter in Australian waters, although some studies made mention that because the muscle tissue is consumed, rather than the entire organism (including the gut), less stringent bacteriological conditions would be required to ensure safe consumption than those which apply for molluscs. This issue, if regarded as an important environmental value for the Tweed River, would require further investigation to determine what water quality objectives would be required to protect this environmental value.

It should be noted that the environmental values defined for all the freshwater segments (1,2 & 9) were identical, and were as follows:

- Aquatic ecosystem protection;
- Direct potable water;
- Primary body contact recreation (swimming and action sports);
- Secondary body contact recreation (boating);
- Agricultural irrigation water supply;
- Livestock drinking water; and
- Homestead water supply (non potable).

Similarly, all the estuarine segments (3,4,5,6,7 & 8) had identical environmental values defined, which were as follows:

- Aquatic ecosystem protection;
- Production of edible raw shellfish;
- Primary body contact recreation (swimming and action sports); and
- Secondary body contact recreation (boating).

4 WATER QUALITY OBJECTIVES

For each environmental value, water quality criteria were developed to ensure the water quality was adequate to protect the environmental value. These water quality criteria are well presented in the ANZECC Water Quality Guidelines for Fresh and Marine Waters (1992). Where ANZECC did not outline a criteria, other appropriate sources were consulted where necessary.

The interim water quality *objectives* were then defined by adopting the most stringent *criteria* for each segment. As the environmental values in all the fresh and all the estuarine segments were identical, only freshwater and estuarine water quality objectives were required to be developed.

An assessment of 'background' water quality levels from relatively undisturbed catchments, with similar characteristics to that of the Tweed River, was also made. This included particular consideration of water quality data from selected waterways within the Burrum, Burnett, and Maroochy River catchments in South East Queensland. These river systems were considered to have the most similarity to the Tweed River system, and are largely undeveloped and can be considered to be quasi-undisturbed catchments.

The background bacterial level of undisturbed waterways is difficult to predict, as native wildlife can contribute bacteria to waterways. Even remote mountain streams may contain up to one hundred faecal bacteria per 100mL (Chapman, 1992).

The assessment of 'background' water quality levels allowed a 'reality check' of the defined interim water quality objectives. Once satisfied that the water quality objectives were realistic and achievable for the Tweed River catchment, the interim water quality objectives were defined. These interim water quality objectives are summarised in Table 4.1 below.

Table 4.1 Interim Water Quality Objectives

Water Quality Objectives			
Parameter	Units	**Fresh Segments**	**Estuarine Segments**
pH	pH units	6.5 - 9	7 - 9
Dissolved Oxygen	mg/L	> 6	> 6
Suspended Solids	mg/L	< 20	< 10
Total Phosphorus	mg/L	< 0.10	< 0.05
Total Nitrogen	mg/L	< 0.75	< 0.5
Chlorophyll *a* *	µg/L	< 10	< 10
Faecal Coliforms	No/100mL	< 150	< 14

* Chlorophyll *a* is a indicator of algal populations - refer to Glossary

Further investigations to determine locally specific water quality objectives may be undertaken in subsequent stages of the Water Quality Management Strategy. These investigations could involve study and consideration of the specific water quality requirements of the particular organisms present in the Tweed River, the hydraulic

characteristics of the system (mean residence time of water within the estuary, for example), actual background levels in the Tweed River (by monitoring relatively undisturbed subcatchments, particularly in the upper catchment) and the selection of more appropriate indicators of water quality.

The latter point is particularly relevant for bacterial "indicator organisms". Indicator organisms are not necessarily harmful, however their presence indicates that other disease forming ("pathogenic") micro-organisms, with which they are often associated, may also be present. Testing for the pathogenic organisms routinely would be impossible, because of technical complexities and cost, so indicator bacteria are tested for instead.

Faecal coliforms are commonly used as an indicator organism, as this bacteria is derived from warm blooded animal faeces. Therefore, a high faecal coliform count could indicate a large population of birds or cows, rather than human faecal contamination. The potential for disease forming micro-organisms (for humans) may be lower when the faecal contamination is derived from birds or animals, than if the contamination source is human. However, some disease forming organisms can be passed to humans from warm blooded animals, such as sheep or cows.

Much research has been made into the most appropriate indicator organism, and a large number of organisms have been proposed, however at present faecal coliforms remain one of the more commonly accepted indicator organisms. Should future research reveal a more appropriate indicator, it may be inserted/substituted into the water quality objectives.

Therefore, future research and refinement of these interim water quality objectives may be appropriate in subsequent stages of the Water Quality Management Strategy.

5 WATER QUALITY EXCEEDENCES

The existing water quality in each of the nine segments was compared against the available water quality data. Plots of these comparisons have been included in Appendix A.

The following levels of compliance have been used for this study:

- acceptable - water quality objectives are generally met (✓);
- slight non-compliance - numerous occasions of water quality objectives exceeded (✗); and
- non-compliance - water quality objectives not generally met (✗✗).

A summary of compliance in each segment is included in Table 5.1 below.

Table 5.1 Water Quality Exceedences in Each Segment

Segment No. / Parameter	1.	2.	3.	4.	5.	6.	7.	8.	9.
Faecal Coliforms	✗✗	✗✗	✗✗	✗✗	✗✗	✗✗	✗	✗	✗✗
Total Nitrogen	✗✗	✗✗	✗✗	✗✗	✗✗	✗	✓	✗✗	✓
Total Phosphorus	✗	✗✗	✗✗	✗✗	✗✗	✗	✓	✗	✓
Suspended Solids	✓	✓	✗	✓	✓*	✓*	✗✗	✗✗	✓
Chlorophyll *a*	✓	✓	✓	✓	✓	✓	✓	✓	✓
DO	✓	✓	✓	✓	✓	✓	✓	✓	✓
pH	✓	✓	✓	✓	✓	✓	✓	✓	✓

Notes: * Trend indicates acceptable levels in more recent data

1. Upper Freshwater Catchment.
2. Lower Freshwater Catchment.
3. Upper Estuary.
4. Mid Estuary.
5. Lower Estuary.
6. Terranora Inlet.
7. Terranora Broadwater.
8. Cobaki Broadwater.
9. Other - including freshwater sections of Cobaki Creek, Bilambil Creek etc.

Therefore, the water quality objectives were not met in any of the nine segments, as one or more parameters exceeded the objectives defined.

All nine segments showed higher than desirable faecal coliform concentrations and most of the segments showed higher than desirable nutrient levels (both nitrogen and phosphorus). All other parameters, except suspended solids in Terranora and Cobaki Broadwater, complied with the water quality objectives.

However, regardless of all the water quality objectives not being met in the segments, some environmental values may still be held in the waterways. A summary of the environmental values met in each of the nine segments is presented below in Table 5.2.

Table 5.2 Environmental Values Met in the Tweed River System

Segment No. / Environment Value	1.	2.	3.	4.	5.	6.	7.	8.	9.
Aquatic Ecosystems	✗	✗✗	✗✗	✗✗	✗	✗	✗	✗	✓
Edible Molluscs (Raw)			✗✗	✗✗	✗	✗✗	✗	✗	
Potable Water	✗✗	✗✗							✗✗
Primary Contact Recreation	✗✗	✗✗	✗	✓	✓	✗	✗	✓	✗
Secondary Contact Recreation	✓	✓	✓	✓	✓	✓	✓	✓	✓
Agricultural Irrigation Water	✓	✓							✓
Livestock Drinking Water	✓	✓							✓
Farmstead Supply (non potable)	✗✗	✗✗							✗

1. Upper Freshwater Catchment.
2. Lower Freshwater Catchment.
3. Upper Estuary.
4. Mid Estuary.
5. Lower Estuary.
6. Terranora Inlet.
7. Terranora Broadwater.
8. Cobaki Broadwater.
9. Other - including freshwater sections of Cobaki Creek, Bilambil Creek etc.

1.

Therefore, it can be concluded that:

- water quality criteria are met across all nine segments for secondary contact, agricultural irrigation water, and livestock drinking water;
- the water quality criteria for ensuring the following environmental values are protected were not met in some or all of the nine segments:
  - ◊ protection of aquatic ecosystems;
  - ◊ consumption of raw molluscs;
  - ◊ potable water supply;
  - ◊ primary contact; and
  - ◊ farmstead supply (non potable).

5.1 EPA Northern Rivers Report

The Northern Rivers - A Water Quality Assessment Report (EPA, 1996) adopted a similar approach to this study, by defining environmental values, water quality criteria and examining water quality exceedences. However, slightly different environmental values and water quality criteria were adopted by the EPA study. Additionally, only the EPA data collected were used to examine the water quality status of the river, although some consideration of historical datasets held by the Department of Land and Water Conservation (DLWC) was made.

5.1.1 *Water Quality Criteria Adopted*

The water quality criteria for the environmental values were as detailed below. Where there were significant differences between the WBM Oceanics Australia and EPA water quality criteria adopted, the WBM Oceanics Australia criteria are indicated in brackets following the EPA criteria.

Protection of Aquatic Ecosystems:

• TP	<0.05mg/L **(0.10mg/L Fresh & 0.05mg/L Estuarine)**
• TN	<0.50mg/L **(0.75mg/L Fresh & 0.50mg/L Estuarine)**
• N:P Ratio	>10:1 if TP>0.05mg/L
• Chlorophyll a	Estuarine <0.01mg/L **(0.01mg/L Fresh & Estuarine**
• pH	Fresh: 6.5-9.0 Estuarine: 7.0-8.5 **(7.0-9.0)**
• Salinity (as Total Dissolved Solids)	Fresh: <1,000mg/L
• Dissolved oxygen	>6.0mg/L and >80% saturation
• Suspended solids	Fresh <10.0mg/L **(20mg/L)** Estuarine <5.0mg/L **(10mg/L)**

Potable Water

• Total Coliforms	0 cfu/100mL
• Faecal Coliforms	0 cfu/100mL
• Ammonia (as N)	<0.1mg/L
• Nitrate	<10mg/L
• Chloride	<400mg/L
• Salinity (as Total Dissolved Solids)	<1,000mg/L
• Dissolved oxygen	>6.5mg/L and 80% saturation
• pH	6.5-8.5
• Sodium	<300mg/L
• Sulphate	<400mg/L

Primary Contact Recreation

• Faecal Coliforms	<150 cfu/100mL
• Enterococci	< 35 cfu/100mL
• pH	6.5-8.5
• Clarity	Secchi >1.6m or Turbidity ≤ 6NTU

Secondary Contact Recreation

• Faecal Coliforms	<1,000 cfu/100mL
• Enterococci	< 230 cfu/100mL
• pH	6.0-9.0

Irrigation Water

- Faecal Coliforms <1,000 cfu/100mL
- Chloride < 100mg/L
- Salinity (as Electrical Conductivity) <0.28mS/cm
- SAR <8
- pH 4.5-9.0

Livestock Drinking Water

- Faecal Coliforms <1,000 cfu/100mL
- Nitrate <30mg/L
- Calcium <1,000mg/L
- Sulphate <1,000mg/L
- Chloride < 1,600mg/L
- Magnesium <600mg/L
- Salinity (as Total Dissolved Solids) <4,000mg/L
- pH 6.5-9.2

Edible Seafood - Shellfish

- Total Coliforms <70 cfu/100mL
- Faecal Coliforms <14 cfu/100mL

Some differences between the water quality criteria adopted by WBM Oceanics Australia and the EPA for the protection of aquatic ecosystems. The main differences in the water quality criteria adopted related to suspended solids and nutrients. WBM Oceanics Australia adopted the rivers and streams nutrient criteria for freshwater sections of the river, as opposed to the EPA which adopted the criteria for lakes and reservoirs. As rivers have shorter detention times, higher nutrient levels may not result in high algal populations, as occurs in longer retention waterbodies such as lakes.

The suspended solids concentrations selected by the EPA were considered too stringent for the Tweed River system. Based on the comparison with background water quality levels performed as part of this study, values of 10mg/L and 20mg/L were adopted for estuarine and fresh river segments respectively.

5.1.2 EPA Conclusions

The EPA water quality review concluded that the water quality in the Tweed River catchment was "generally good, with fifty-eight percent of site ranks being *Good* or *Fair*." A summary from the EPA report findings where environmental values were ranked from *Good*, *Fair*, *Poor* and *Very Poor* is outlined below. The percentage of observations required to pass for each of these four ranks is summarised in Table 5.3 below.

Table 5.3 EPA Ranking Schedule

Ranking	Lower Limit	Upper Limit
Good	75%	100%
Fair	50%	74%
Poor	25%	49%
Very Poor	0%	24%

Aquatic Ecosystems Protection

From the 35 sites monitored in the EPA study, 46% were ranked *Good* or *Fair*, whilst 54% were ranked either *Poor* or *Very Poor*.

The primary reason for failure in freshwater sections of the river were due to low values of dissolved oxygen (24%), pH outside the guideline range (11%) and total phosphorus elevation (5%).

In the estuarine sections, eighty percent of the sites were ranked *Poor* or *Very Poor*. The predominant reason for failure was suspended solids concentrations (56%), with some other failures caused by low pH, high nutrient concentrations and low dissolved oxygen.

Potable Water

None of the freshwater sites monitored met the water quality criteria for potable water, which was caused by high levels of both faecal and total coliform bacteria. Water treatment would eliminate this bacteria, however direct drinking water sources require zero bacterial levels.

Primary Contact Recreation

Sixty percent of all sites monitored were classified as *Very Poor* or *Poor* for primary contact recreation. More than 70% of estuarine sites and 50% of freshwater sites fell into one of these ranks. The most common causes of failure to meet the water quality criteria were faecal coliforms (35%) and clarity (37%). The other criteria (pH and enterococci) also caused some failures (10-15%).

Secondary Contact Recreation

All sites monitored were classified as *Good* for secondary contact recreation. Faecal coliform levels exceeded the water quality criteria on only 2% of observations, whilst pH and enterococci were always within the acceptable limits.

Irrigation Water

Seventy-five percent of freshwater sites were listed as *Good*, with 10% achieving a *Fair* classification. Only scattered sites across the catchment were classified as *Very Poor*, which was mainly caused by high salinity or an unsuitable sodium absorption ratio.

Livestock Drinking Water

Eighty five percent of freshwater sites were classified as *Good* or *Fair* for livestock drinking water supply. Fifteen percent of sites were considered to be *Poor* livestock drinking water supplies, with no *Very Poor* sites identified. Occasional failures were caused by low pH or high salinity.

Edible Seafood

Forty percent of estuarine sites were classified as *Good* or *Fair*. However, the majority of sites were classified as *Poor* or *Very Poor* (20% and 40% respectively). Sixty percent of the faecal coliform levels exceeded the water quality criteria, as did approximately 30% of total coliform observations.

5.1.3 Comparison with WBM Oceanics Australia Study

Similar conclusions were reached by the two studies. Both the WBM Oceanics Australia and the EPA studies found that the water quality criteria for secondary contact recreation, irrigation water supply and livestock drinking water were met in the majority of areas in the Tweed River system.

However, the water quality criteria for primary contact, potable water, edible seafood and, to a lesser extent, protection of aquatic ecosystems were widely exceeded in the river system. Failure to meet bacterial and nutrient criteria were the primary causes of these exceedences, although the EPA report indicated dissolved oxygen, suspended solids and pH were also above relevant criteria for some environmental values.

6 CAUSES OF WATER QUALITY EXCEEDENCES

The causes of water quality exceedences are discussed in the sections below in a modification of the OECD State of the Environment reporting format. The reporting format adopted details the *states*, *pressures* and *responses* which are relevant to the Tweed River system.

6.1 *State* of the Tweed River System

The water quality review performed by WBM Oceanics Australia (presented in previous sections) indicates the following points regarding the water quality in the Tweed River system:

- elevated bacterial and nutrient levels are exhibited in many areas of the river system, including both fresh and estuarine sections;
- aquatic ecosystems appear to be under greater pressures than is desirable;
- raw shellfish consumption is not recommended, other than commercially produced products;
- freshwater sections of Tweed River are not suitable for direct potable water;
- water quality throughout the Tweed River is suitable for secondary contact; and
- freshwater sections of Tweed River are suitable for both irrigation water supply and livestock drinking water.

6.2 *Pressures* on the Tweed River System

Maintaining good water quality in the streams and rivers within the Tweed River system is important to preserve ecological, visual and recreational values of the waterways. Many factors influence water quality, but the nutrient and sediment loads entering a waterway are the primary influences. Riparian vegetation also has a large role to play in maintaining good water quality and providing a viable, balanced ecosystem.

6.2.1 Sources of Nutrients

Nutrients can be derived from point or diffuse sources, such as sewage treatment plant discharges and stormwater runoff respectively.

Estuarine Sections of the Tweed River System

The most likely sources of nutrients in the estuarine section of the Tweed River System are sewage effluent discharges and stormwater runoff.

There are several sewage treatment plant discharges and various other wastewater discharges from industrial areas which contribute nutrients to the estuarine sections of the Tweed River. Sewage effluent from the Banora Point sewage treatment plant typically has 3mg/L of both total phosphorus and total nitrogen (based on 1997 effluent sampling data). Concentrations

in the sewage effluent from the West Tweed sewage treatment plant are typically 2.5mg/L of total nitrogen and 6.0mg/L of total phosphorus (based on 1997 effluent sampling data).

Stormwater inputs from urbanised areas in the lower catchment would also contribute significant quantities of nutrients to the Tweed River estuary. Stormwater from urban catchments can contain numerous pollutants, including nutrients, sediment, oils & greases, hydrocarbons, bacteria and oxygen demanding substances. Numerous urban stormwater management studies have been performed for many Australian and overseas catchments, which conclude that pollutant export rates of total nitrogen, total phosphorus and total suspended solids are all much greater from urban areas than from rural areas. Therefore, urban growth, which typically involves the subdivision of rural areas to create new urban developments, results in increased nutrients being exported from the catchment to the Tweed River.

Freshwater Sections of the Tweed River System

The most likely source of nutrients in the freshwater sections of the Tweed River System is from rural/agricultural areas. Most of the upper catchment is undisturbed or rural, and only smaller townships exist. These smaller centres may generate stormwater with high pollutant loads, however relative to the anticipated impacts of rural areas, the effects would be limited.

Excessive fertiliser use, poor timing of fertiliser application, high stock loading rates and poor riparian zone management are all agricultural practices which increase the nutrient washoff rates from rural areas. Additionally, agricultural practices which result in soil erosion also increase the nutrient loading to waterways. These issues are discussed in Sections 6.2.2 and 6.2.4 below.

6.2.2 Sources of Sediment

Modification of the Tweed River catchment has resulted in increased sediment loads to river causing sedimentation. This sedimentation has diminished visual and recreational values and can adversely affect aquatic ecosystems. Nutrients are also bound onto sediment particles, and the sediment which is washed into the Tweed River and its tributaries would also contribute significant quantities of nutrients.

Sediment loads entering the waterways are derived from such sources as urban areas, improperly managed construction sites, unsealed roads and road shoulders, vehicles, stream bank and bed erosion and erosion from rural/agricultural areas.

Urban development creates larger impervious areas which result in greater runoff volumes and faster velocities, which then cause scouring and erosion of waterways. Sediment accumulated on roadways can contain high levels of toxicants, such as heavy metals and oil residues, and these pollutants can also have adverse impacts on water quality and ecology in the waterways.

Many rural areas in the Tweed River catchment are eroding due to inappropriate farm management practices. Factors such as excessive vegetation clearing, ploughing land across

contours rather than forming contour banks, over irrigating and inadequate revegetation to stabilise exposed areas all contribute to rural erosion.

6.2.3 Sources of Bacteria

Bacteria are derived from animal faeces from native/wild animals, livestock and domestic animals entering the waterways in stormwater runoff. Urban stormwater runoff can also contribute bacteria due to domestic animal faecal material and sewer system overflows. Sewage treatment plant discharges also contribute significant bacterial loads to the Tweed River, as do poorly maintained/overloaded septic systems. Other lesser sources of bacteria include leachate from sanitary and urban solid waste landfills and other wastewater discharges.

The relative importance of each of these sources cannot be precisely quantified without further investigation, although it is likely that sewage treatment plant discharges and wildlife and livestock faeces entering waterways as stormwater are important in the Tweed River system.

The survival of bacteria in waterways is highly dependant on the water quality conditions, particularly dissolved oxygen, temperature, salinity and turbidity. Bacteria may be removed from the water column through adsorption onto clay or sediment particles and subsequent settling, natural die-off of the bacteria or through predation by aquatic fauna (eg. zooplankton).

6.2.4 The Role of Riparian Vegetation

Riparian vegetation is the term used to describe the bankside vegetation along waterways. Riparian vegetation plays a very important role in bank stabilisation, habitat provision and water quality improvement. Native riparian vegetation in many areas has been largely lost or severely degraded in the Tweed River catchment since European settlement. Native riparian vegetation has been degraded and replaced by exotic plant species due to clearing of vegetation, increases in nutrient levels (from fertiliser use) and modification of flow regimes in the waterways.

Although many of the riparian zones are infested with exotic species, these weeds still provide bank stabilisation and water quality improvement roles. However, their role in habitat provision and wildlife corridor preservation is greatly diminished.

6.2.5 Summary of Pressures

Water quality is therefore a reflection of catchment activities and the management of these activities. At present, there is a significant elevation of nutrient levels and bacteria in both the freshwater and estuarine sections of the Tweed river system, which may be adversely affecting the values of the river system. A summary of the most likely causes of water quality degradation in the Tweed River system is outlined in Table 6.1 below.

Table 6.1 Pressures on Water Quality in the Tweed River System

Issue	Primary Pressures/Causes
Water quality degradation	• urban growth; • industrial discharges; • high nutrient and pollutant export from existing rural and urban areas; and • sewage effluent discharge.
Erosion & sedimentation (urban and rural)	• high sediment loads from urban growth, particularly construction sites; • erosion from rural land; and • bed/bank erosion in high flow conditions.
Riparian vegetation degradation	• urban growth; • weeds displacing native species; • water demand/diversion causing changes to stream dynamics; • poorly managed stock access to waterways; • clearing; and • environmental ignorance.
Environmental ignorance	• insufficient/ineffective community education programs.

It is likely that water quality in the Tweed River and its tributaries will worsen unless appropriate management strategies are implemented to manage the pollutant loads to the waterways. Continuing soil erosion and nutrient export from rural lands and unmanaged future urbanisation in the catchment (with associated increases in stormwater pollutant loads and sewage treatment plant discharges) will place increasing pressure on the aquatic ecosystems. This increased pressure could in the future result in the collapse of the present ecosystem, and cause waterways to suffer symptoms such as continual algal blooms, fish kills and degraded water quality.

6.3 *Responses*/Management Options

There are many responses or management options which can be implemented in order to improve the water quality in the Tweed River. These management options will include:

- modification of Tweed Shire Council's environmental policies, programs and actions;
- modification of State and Federal environmental policies, programs and actions; and
- community education and awareness programs.

6.3.1 Tweed Shire Council Actions

Council has the opportunity to implement a variety of environmental initiatives to improve the water quality in the Tweed River. Such measures could include:

- the reduction of existing urban pollutant loads, through installation of Gross Pollutant Traps (GPT's), wetlands or other stormwater treatment devices;

- modification of Council visionary and planning strategies and plans (ie. DCP's and LEP's) to incorporate Water Sensitive Urban Design (WSUD) principles. This will ensure the impacts of increased pollutant loads from urban growth areas are mitigated. The principles of WSUD are outlined in Section 6.4. Council could require all new developments to demonstrate "no net increase in pollutant loads" is caused by the proposed development, through the incorporation of WSUD principles and water quality treatment devices.
- implementing stricter controls on sediment and erosion control from construction sites. Construction sites are a major source of sediment in developing urban areas, as erosion from exposed areas can be extremely high, unless adequate prevention mechanisms are put in place. Sediment and Erosion Control Plans need to be developed for construction sites, including measures such as filter fences, hay bales, sedimentation dams, diversion of runoff from exposed areas and revegetation following the completion of earthworks. Such measures also need to be properly installed (before construction/earthworks begin) and maintained to be effective. Tweed Shire Council could introduce a local law, or development condition, in the Town Plan that requires all developments which involve earthworks to submit a Sediment and Erosion Control Plan. This Plan should detail measures to be installed to prevent erosion from the exposed site. This also requires a considerable Council commitment to enforce the requirement and ensure the measures are installed, adequate maintenance of the sediment and erosion control devices (such as filter fences) occurs during earthworks and the devices are not removed from the site until vegetation is re-established and the site is not prone to future erosion;
- investigating alternatives to lower sewage loads to the Tweed River. These investigations are understood to be already initiated, and will include consideration of effluent reuse, land disposal and increased treatment before discharge;
- community education in ways to lower sediment and nutrient loads to the waterways in both urban and rural areas. Community education is discussed separately in Section 6.3.3; and
- develop Stormwater Management Plans for areas experiencing higher pressures from stormwater input. Stormwater Management Plans detail strategies for treating stormwater in an area, including proposed treatment devices, strategies for minimising pollutants entering the stormwater, other specific management options and the values of the waterway in that particular area.

However, even if the impact of all new urban growth areas are mitigated by adopting WSUD principles, the water quality of the river will only be maintained at present levels. Lowering of pollutant loads is required, and it is believed that this may be able to be achieved through treatment of stormwater from existing urban areas, implementing better farm management strategies and lowering sewage discharge loads to the river.

6.3.2 State and Federal Actions

State and Federal authorities also have a significant role to play in improving the water quality of the Tweed River System. Agencies such as the EPA and DLWC have significant jurisdiction over issues which closely relate to water quality and catchment management.

State and Federal authorities can also contribute significant funding toward the implementation of water quality improvement measures.

6.3.3 Community Education

It is likely that many members of the community in the Tweed River catchment are not aware that their attitudes and behaviour may be causing environmental damage to the Tweed River and its tributaries. Education of the community plays a large role in modifying community behaviour and improving water quality.

Tweed Shire Council, TRMPAC and the TCMC have already implemented many successful public education programs, including the publication of brochures, seminars, information published in the 'Tweed Link' and school education programs. Expansion of education programs such as these would be beneficial.

In addition to the Tweed Shire Council, TRMPAC and the TCMC, there are several other community/local government groups in the Tweed River catchment area, and such groups should be fully supported and widely promoted.

Education programs for the Tweed River catchment community should focus on the following range of issues:

Rural Education Programs

Soil erosion and subsequent waterway sedimentation from rural areas should be initially addressed by education. Educating primary producers on best management practices (BMP's) for land management will not only lessen the impact of primary production on the environment, but may also decrease operating costs and increase the productivity of rural properties. Suitable BMP's that local landholders could be encouraged / educated to use include:

- efficient and sustainable ways to apply fertilisers;
- appropriate pesticide application;
- sustainable irrigation practices;
- management of stock access to watercourses (see below);
- riparian vegetation conservation, management and rehabilitation;
- guidelines for clearing of vegetation; and
- best management practices for cultivating agricultural land.

Minimising topsoil loss from cultivated areas will ensure the productivity of the land is not diminished, and high production rates can be sustained.

Additionally, appropriate management of stock access to waterways is important to prevent riparian zone degradation and stream bank erosion. Uncontrolled stock access to waterways can cause degradation of riparian vegetation, compaction of soil, overgrazing on bank stabilising vegetation and the introduction of weeds to the riparian zone. These impacts subsequently cause stream bank erosion. Stock also directly contribute significant nutrient, bacteria and virus loads to the waterway. The following options can be presented as alternatives for managing stock access to waterways:

- fencing to exclude stock from particularly degraded riparian areas;
- create access points to waterways which allow stock to access a waterway at a particular location which has a graded slope and may be further protected by concrete or compacted gravel;
- using alternative water supplies, such as farm dams, in some areas;
- pumping river water to a header tank or small trough away from the riparian zone;
- controlling the grazing pressure at particular times, such as when plants are starting their annual growth; and
- allowing recovery periods for the riparian vegetation, as continual grazing pressure will result in severely degraded riparian areas.

Urban Education Programs

High pollutant loads from urban areas should also be partially addressed by education. Increasing public awareness about the sources and consequences of polluting activities in the catchment will play a large role in decreasing pollutants at the source. The encouragement of education programs in schools and community groups can be an excellent method of teaching the community about environmental problems in the catchment and increasing awareness of the environment generally. These school and community groups can also perform water quality monitoring in local waterways, which contributes information on the health of the catchment and its waterways, but also leads to an increased feeling of stewardship over their local environment.

The urban community should be reminded that dumping of waste to stormwater drains, or leaving waste in areas where it can subsequently enter stormwater drains, results in this waste being flushed directly into the Tweed River and its tributaries. Typical examples of pollutants which are permitted to enter stormwater drains include grass clippings, litter, pet faeces, fertilisers, waste oil and detergents from car washing.

The community should be strongly encouraged to act responsibly themselves and also encourage others in the catchment to be environmentally responsible.

6.4 Water Sensitive Urban Design

Urban development has many environmental consequences, including increased pollutant loads, loss of vegetation, modification of the catchment's hydrology, increases in runoff volumes and velocities and adverse air quality impacts. Conventional urban design practices have been recognised for many years as causing significant environmental degradation, particularly to water quality and hydrology. An alternative, more sustainable approach to urban design has been recently emerging, known as Water Sensitive Urban Design (WSUD). The principles of WSUD attempt to mitigate the environmental degradation caused by urban development (both infill and new developments).

Water Sensitive Urban Design aims to retain stormwater, look for opportunities to utilise stormwater within the catchment, maximise infiltration in the catchment and use a sequence of smaller treatment devices throughout the catchment to improve stormwater quality and reduce the hydrological implications of catchment development. The key objectives of Water Sensitive Urban Design include:

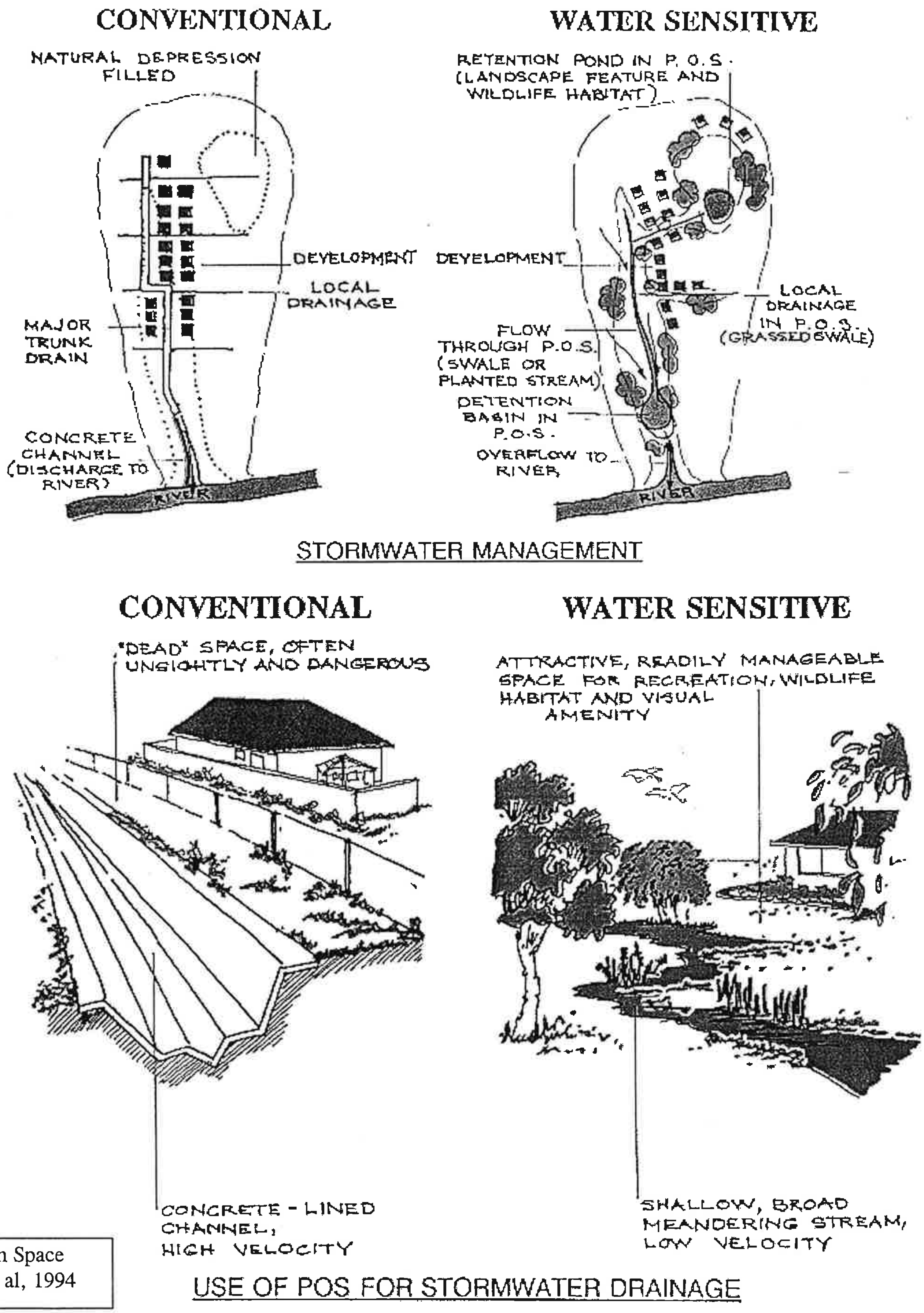
- to manage the water balance of a catchment;
- to maintain and where possible enhance water quality;
- to encourage water conservation; and
- to maintain water related environmental and recreational values.

Some of the management practices which are included in WSUD include:

- preservation of vegetation;
- grassy swales, as opposed to kerb gutters;
- infiltration trenches;
- sequenced detention and retention basins;
- gross pollutant traps;
- artificial wetlands;
- non-potable re-use of stormwater; and
- rainwater tanks.

Figure 6.1 illustrates the use of WSUD for urban areas.

Tweed Shire Council need to embrace the principles of WSUD, in order to lessen the environmental degradation caused by urban growth (infill and new development areas). As the water quality in the Tweed River has been shown to be elevated in nutrients and bacteria, this should be a high priority for Council.



POS = Public Open Space
Source: Whelans et al, 1994

Figure 6.1 Water Sensitive Urban Design Illustration

7 REFERENCES

ANZECC (1992) Australian Water Quality Guidelines for Fresh and Marine Waters.

Chapman (1992) Water Quality Assessments - A guide to the use of biota, sediments and water in environmental monitoring.

EPA (1996) The Northern Rivers - A Water Quality Assessment

Whelans and Halpern Glick Maunsell, in association with Thompson Palmer and Institute for Science and Technology Policy, Murdoch University (1994). Planning and Management Guidelines for Water Sensitive Urban (Residential) Design.

8 GLOSSARY

Adsorption: The adhesion of one substance to the surface of another; clays, for example, can adsorb phosphorus and organic molecules.

Aerobic: Describes life or processes that require the presence of molecular oxygen.

Anaerobic: Describes processes that occur in the absence of molecular oxygen.

Anoxia: A condition of no oxygen in the water. Often occurs near the bottom of fertile stratified lakes in the summer.

Benthos: Macroscopic (seen without aid of a microscope) organisms living in and on the bottom sediments of waterbodies. Originally, the term meant the bottom of a waterbody, but it is now applied almost uniformly to the animals associated with the substrate.

Biochemical oxygen demand (BOD): The rate of oxygen consumption by organisms during the decomposition (+ respiration) of organic matter in water, expressed as milligrams of oxygen per litre of water.

Biota: All plant and animal species occurring in a specific area.

Catchment: A drainage area or basin in which all land and water areas drain or flow toward a central collector, such as a creek, river or lake at a lower elevation.

Chlorophyll: A green pigment in algae and other green plants that is essential for the conversion of sunlight, carbon dioxide and water to sugar. Sugar is then converted to starch, proteins, fats, and other organic molecules.

Chlorophyll *a*: A type of chlorophyll present in all types of algae, sometimes in direct proportion to the biomass of algae. Measurement of chlorophyll *a* in waters gives an indication of algal population.

Conductivity: In the field, salinity is determined by measuring the electrical conductivity (or "specific conductance") and using graphs derived experimentally for seawater to convert to salinity. Conductivity is a measure of the ability of a medium to transmit an electric current and varies directly with temperature (ie. it increases with rising temperature).

The conductivity and salinity of true seawater are respectively about 5300 milliSiemens per cm at 25°C and 35 g/L. For coastal seawater however, the values are slightly lower, around 5000mS/cm and 33g/L respectively. Freshwater lakes generally have a conductivity less than 200mS/cm at 25°C.

Detritus: Nonliving dissolved and particulate organic material from the metabolic activities and deaths of terrestrial and aquatic organisms.

Dissolved Oxygen (DO): The dissolved oxygen concentration of the water is measured as a percentage of the saturation solubility of oxygen in water for a given temperature and salinity.

Oxygen is essential to most forms of aquatic life. To be used by organisms it must be in dissolved form and in sufficiently high concentration. Because there are usually substances or organisms which consume oxygen present to varying degrees, it is usual for DO levels to be just below the saturation value. In some situations, however, it is possible to have concentrations greater than the saturation value, when the water is said to be "supersaturated".

Ecology: Scientific study of relationships between organisms and their environment; also defined as the study of the structure and function of nature.

Ecosystem: A system of interrelated organisms and their physical-chemical environment. In this instance, the ecosystem would be defined to include the river and its catchment.

Effluent: Liquid wastes from sewage treatment, septic systems, or industrial sources that are released to a surface water.

Enterococci: A coccoid bacteria is used as an "indicator organism" in water samples ie. their presence indicates that other disease forming (pathogenic) micro-organisms with which they are often associated may be present. Enterococci counts (in addition to faecal coliforms) can indicate the suitability of a waterbody for human contact activities. Different limits are set for primary contact activities, such as swimming, and secondary contact activities, such as fishing or wading. Large numbers of these organisms indicate the presence of potentially human disease causing micro-organisms in the water.

Erosion: Breakdown and movement of land surface, which is often intensified by human disturbances.

Eutrophic: From Greek for "well-nourished", describes a waterbody of high photosynthetic activity and low transparency.

Eutrophication: The process of physical, chemical, and biological changes associated with nutrient, organic matter, and silt enrichment and sedimentation of a waterbody. It is commonly used when the natural nutrient accumulation of a waterbody is accelerated by man-made influences.

Faecal Coliforms: Faecal coliforms consist of various genera of Coliform bacteria *Escherichia, Citrobacter, Klebsiella, and Enterobacter* which are capable of growing in the presence of bile acid. They are often called "indicator organisms" ie. their presence indicates that certain other disease forming ("pathogenic") micro-organisms with which they are often associated may be present as well. To test for the pathogenic ones routinely would be impossible because of technical complexities and cost, so the indicator bacteria are looked for instead.

Faecal coliform test: Most common test for the presence of faecal material from warm-blooded animals. Faecal coliforms are measured because of convenience; they are not necessarily harmful but indicate the potential presence of other disease-causing organisms. Faecal coliform counts can indicate the suitability of a waterbody for human contact activities. Different limits are set for primary contact activities, such as swimming, and secondary contact activities, such as fishing or wading. Large numbers of these organisms indicate the presence of potentially human disease causing micro-organisms in the water.

Internal nutrient cycling: Transformation of nutrients, such as nitrogen or phosphorus, from biological to inorganic forms through decomposition, occurring within the waterbody itself.

Mesotrophic: Describes a waterbody of moderate primary productivity (photosynthetic activity) and water clarity.

Nitrate/Nitrite Nitrogen (NO_x): The nutrient nitrogen may be present simultaneously in water in a number of forms. Nitrate and nitrite nitrogen are two of the component forms of nitrogen compounds as they occur in water. Their concentration is measured in mg/L. They may be introduced directly to waters from excessive use of nitrogenous fertilisers and in treated sewage effluents. They are also produced in receiving waters as a result of nitrification of ammonia (NH_3).

Orthophosphorus: Phosphorous is another essential nutrient and is important in regard to the eutrophication (over enrichment) of water bodies. Orthophosphate is the primary nutrient necessary for the growth of aquatic plants (algae). It can originate from the use of phosphate fertilisers but the major non natural source is domestic sewage where it comes from proteinaceous wastes and detergent additives.

Pathogen: A micro-organism capable of producing disease. They are of great concern to human health relative to drinking water and swimming areas.

pH: The pH is a measure of the alkalinity or acidity of water. The pH scale ranges from 0 to 14 with the midpoint (7) indicating neutrality. A pH value less than 7 is acidic. As the pH scale is logarithmic, each unit change in the pH value expresses a change of 10 times the preceding state. Thus water of pH 5 is 10 times more acidic than water with a pH of 6.

Photic zone: The lighted region of a waterbody where photosynthesis takes place. Extends down to a depth where plant growth and respiration are balanced by the amount of light available.

Phytoplankton: Microscopic algae and microbes that float freely in open water.

Plankton: Planktonic algae float freely in the open water. Filamentous algae form long threads and may be seen as mats on the water surface in shallow areas of a waterbody.

Primary productivity: The rate at which algae and macrophytes fix or convert light, water, and carbon dioxide to sugar in plant cells. Commonly measured as milligrams of carbon per square meter per hour.

Respiration: Process by which organic matter is oxidised by organisms, including plants, animals, and bacteria. The process releases energy, carbon dioxide, and water.

Salinity: Salinity refers to the total concentration of "salts" in solution in mg/L and is a measure of the total ions present. Salinity is a critical factor in the life cycle of many organisms. Marine and freshwater organisms can usually tolerate only small variations in salinity, whereas estuarine ones must be able to withstand the range between these two extremes.

Secchi depth: A measure of transparency of water obtained by lowering a black and white, or all white, disc (30 cm in diameter) into water until it is no longer visible. This visible distance is measured in units of meters.

Secchi disc: The Secchi disc is a weighted circular disc used to measure the transparency of water. The disc is attached to a non stretch rope with graduated markings at 0.5m intervals. The Secchi disc gives a subjective, qualitative estimate of the transparency or clarity of a vertical water column at which sunlight reflected by the disc becomes extinguished to an observer viewing from above. The procedure is subject to a wide range of environmental influences such as cloud cover, time of day (angle of sun) and water currents which can have a significant effect on the visibility of the disc in the water.

Stratification: Layering of water caused by differences in water density. Thermal stratification is typical of most deep lakes during summer. Saline stratification can also occur in saline lakes.

Suspended Solids: Suspended Solids is the quantity of organic and inorganic matter (in mg/L) suspended in the water column which can be collected by filtration of the water sample. Typically the matter collected by filtration consists of sediment, which may be detrimental to aquatic organisms.

Total Kjeldahl Nitrogen (TKN): Total Kjeldahl Nitrogen is a measure of the component form of nitrogenous compounds existing in water, consisting of ammonia and organic nitrogen. Ammonia is a toxic substance to fish and other aquatic life forms. It is unstable and is broken down by bacteria into nitrite and then into nitrate. These processes require dissolved oxygen.

Organic nitrogen is primarily derived from the amino acids present in living tissue and may come from sources such as plant matter, faecal matter in sewage or food wastes. In the presence of oxygen it is readily degraded by bacteria into ammonia.

Total Nitrogen (TN): Total nitrogen consists of all nitrogenous compounds present in water organic nitrogen, ammonia nitrogen, nitrite and nitrate nitrogen, measured in milligrams per litre (mg/L).

Total Phosphorus (TP): The total phosphorus concentration consists of orthophosphate plus organic phosphorus (which may be bound to sediments within the water column), measured in milligrams per litre (mg/L).

Trophic state: A measure of the degree of eutrophication of a waterbody. Transparency, chlorophyll *a* levels, total nitrogen and phosphorus concentrations, amount of macrophytes, and the quantity of dissolved oxygen in the water can be used to assess the trophic state of a waterbody. The various categories are Oligotrophic (nutrient poor), Mesotrophic (moderate nutrient and productivity levels) and Eutrophic (nutrient rich).

Turbidity: Turbidity is a function of the quality and quantity of suspended particulate material in water, usually measured in Nephelometric Turbidity Units (NTU) as the proportion of incident light scattered at 90 degrees by suspended materials in the water.

Water column: Water between the interface with the atmosphere at the surface and the interface with the sediment layer at the bottom. The concept is derived from the vertical series of measurements (temperature, salinity, dissolved oxygen) used to characterise water quality.

Zooplankton: Microscopic animals that float freely in water, graze on detritus particles, bacteria and algae, and may be consumed by fish.