Lower Nambucca River Estuary Water Quality Study

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STUDY SUMMARY

The lower Nambucca River estuary is renowned for its beautiful scenic vistas, extensive water based recreational opportunities, and its capacity for producing high quality Sydney rock oysters. However, recent scientific and management reports (eg. Nambucca River Estuary Management Plan 2008 and Shellfish Quality Assurance Program 2007) have identified that poor quality runoff is impacting the health and quality of water in the main estuary.

Limited water quality monitoring and anecdotal evidence from oyster growers and other river users suggest that poor quality water is entering the lower estuary from minor tributaries feeding directly into the main river. Therefore in order to address poor water quality in the main estuary, the root causes of poor water quality in the tributary subcatchments needs to be accurately determined. In this way, remedial actions which are most likely to be effective can be developed and the water quality of the lower estuary can be protected and improved for the benefit of all users.

The purposes of this study are to clearly identify the root causes of diffuse source water pollution entering the lower Nambucca River estuary, document specific actions required in each subcatchment within the study area, and to recommend ways of improving communication between those involved in managing the estuary and the local land managers and residents who use and value the estuary. The study area included approximately 70km2 of the lower Nambucca catchment with direct inputs into the lower estuary between Macksville and the estuary mouth at Nambucca Heads including;

- the predominantly urban catchments of Beer Creek and East Street Drain;
- the mixed urban, industrial, and agricultural catchment of Tily Wily Creek;
- the predominantly agricultural catchments of Watt Creek and Gumma Gumma Creek; and,
- the mixed urban, rural residential, agricultural catchments of Teagues and Belwood Creeks.

The major subcatchment of Newee Creek was excluded from the study as it was already subject to an extensive investigation under the Newee Creek Water Quality Project.

A review of water quality and ecosystem health management projects undertaken over recent years in both NSW and in other eastern States of Australia (*Part 1* of this report) was undertaken to assist in designing the water quality sampling program used as the basis for management recommendations in this study. As a consequence of this review, the sampling strategy was based around sampling stormwater events, where possible at multiple locations in each subcatchment, and taking multiple samples during each event. Water levels were recorded during sampling with the intention of attempt to gauge discharge from the sampled tributaries and drains during the events, although in most cases determining event discharge was not possible using the equipment and resources available.

Event based water quality monitoring occurred at twelve sites in the six subcatchments over a seven month period between November 2008 and June 2009. A total of 48 samples were analysed by the Coffs Harbour Water Laboratory including 11 dry weather samples. Parameters sampled at all sites included pH, turbidity, Total Nitrogen (TN), Total Phosphorous (TP), Total Suspended Solids (TSS), and Enterococcus. Some additional parameters were tested where known issues wiuth acid sulfate soils occur including Titratable acidity, chloride to sulphate ratio, and soluble Aluminium and Iron.

The results of sampling are presented as comparative summaries of the main parameters tested in *Part 4* of the report and as individual subcatchment reports in *Part 5*.

The results showed that in terms of elevated nutrients the subcatchments of Watt Creek (specifically Lumsdens Lane and Wrights Corner) were the highest priority with concentrations of TN up to four times higher and TP up to five times higher than the average of all other subcatchments. Beer Creek,

Tilly Willy Creek and East Street Drain are considered medium priority, while Bellwood Creek, Teagues Creek and Gumma Gumma Creek were considered low priority in terms of nurients.

In terms of bacterial contamination, Watt Creek (particularly Lumsdens Lane) and Beer Creek are considered highest priority with *Enterococcus* concentrations in excess of 13 and 9 times the median results of all other subcatchments respectively. Tilly Willy Creek, Bellwood Creek and East Street Drain and considered medium priority while Teagues Creek and Gumma Gumma Creek are low priority for bacterial contamination.

In terms of suspended sediment and turbidity, Beer Creek is considered highest priority after showing the highest levels after a comparatively minor storm event. Tilly Willy Creek is considered medium priority although the results require clarification as Tilly Willy Creek was the last site sampled and so was subject to the most antecedent conditions prior to sampling. The levels in Tilly Willy Creek may be higher after an extended dry period. All other subcatchments are low priority in term of suspended sediment and turbidity.

In terms of acid export and associated heavy metal contaminants, Gumma Gumma Creek is regarded as the highest priority subcatchment for further investigation. Watt Creek (particularly Wrights Corner) showed lower than would be expected pH reading during the sampling and so is considered medium priority for further investigation to determine the extent if any of acid sulfate soil related pollution.

Management recommendations to address the identified issues are presented in *Part 6* and include subcatchment specific management actions and a proposed future monitoring framework.The monitoring framework outlines three main areas of future focus including;

- Collecting additional data to allow quantification of total exports of contaminants during storm events to facilitate subcatchment comparisons and more accurate priority setting;
- Additional sampling programs in low and medium priority subcatchments; and
- Further sampling programs in highest priority subcatchments of Gumma Gumma Creek, Watt Creek and Beer Creek.

Lastly, recommendations with respect to improving community awareness of estuary related issues including water quality issues in the lower Nambucca are provided at the end of Part 6. These recommendations are based on the findings of the 2009 Lower Nambucca Estuary Residents Survey which collated the results of the 511 responses to the survey.

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Introduction

The lower Nambucca River estuary is renowned for its beautiful scenic vistas, extensive water based recreational opportunities, and its capacity for producing high quality Sydney rock oysters.

However, recent scientific and management reports have identified that poor quality runoff is impacting the health and quality of water in the main estuary. The potential for water quality problems to impact estuary values (such as healthy ecosystems), recreational uses (including primary contact recreation such as swimming), and commercial uses (such as the shellfish production) have been seen in many NSW estuaries. For example closures in recent years in adjoining catchments such as the Bellinger and Kalang rivers have decimmated the oyster industry in those valleys and poor water quality after runoff has been identified as a significant threat to the viability of the Nambucca River oyster industry (Nambucca River Estuary Management Plan 2008, Shellfish quality assurance program, 2007). In many respects the threats to the Nambucca's oyster industry can be seen as a biological indicator providing an early warning sign about the health of the estuary and its catchment.

Limited water quality monitoring and anecdotal evidence from oyster growers and other river users suggest that poor quality water is entering the lower estuary from minor tributaries feeding directly into the main river. Landuse in these tributary subcatchments is variable and includes urban residential, rural residential, industrial estates, horticulture, native forest and agricultural landscapes. Each of these landscapes has the potential to contribute to poor quality stormwater runoff in different ways with the main concerns generally being the delivery of high levels of bacterial contamination, acidity, nutrients and turbidity. The different mix of landuses in each subcatchment and other factors such as slope, soil type, and catchment size, mean that generic recommendations for minimizing the potential for poor water quality impacts on the estuary are unlikely to be effective. Therefore in order to address poor water quality in the main estuary, the root causes of poor water quality in the tributary subcatchments needs to be accurately determined. In this way, remedial actions which are most likely to be effective can be developed and the water quality of the lower estuary can be protected and improved for the benefit of all users.

Background to the Lower Nambucca Estuary Water Quality Study

In 2008, in response to the issues outlined above, Nambucca Valley Landcare (with the support of the Department of Environment and Climate Change and Nambucca Shire Council) applied to the NSW Environmental Trust for funding for a three year program to;

Objective 1. Build a common understanding amongst industry sectors (aquaculture, agricultural, horticultural), residents, and managers about the diffuse water pollution issues specific to the lower Nambucca and the management of those issues.

Objective 2. Clearly identify the root causes of diffuse water pollution issues directly affecting estuary water quality in the lower Nambucca River estuary.

Objective 3. Compile a Lower Nambucca River Water Quality Strategy that documents specific actions required in each target subcatchment that will lead to improved water quality and estuary health in the oyster harvest zone.

Objective 4. Improve the capacity of the community and key players to put in place effective action to address poor quality runoff through the use of a community survey and communications strategy.

Objective 5. Implement priority actions from the Strategy in cooperation with partnership organisations.

This document, *The Lower Nambucca Estuary Water Quality Study*, specifically addresses Objectives 1, 2, 3 and 4 above and in its conclusions makes recommendations to assist in the implementation of Objective 5.

The Project Study Area

The focus of this Study is on approximately 70 km^2 of coastal catchments with direct inputs into the estuary between Macksville and the estuary mouth at Nambucca Heads. This reach of the estuary is a focal point for recreational users including fishers, boaters, and swimmers and broadly correlates with the Nambucca River "Oyster harvest zone".

The study area includes;

- the predominantly urban catchments of Beer Creek and East Street Drain;
- the mixed urban, industrial, and agricultural catchment of Tily Wily Creek;
- the predominantly agricultural catchments of Watt Creek and Gumma Gumma Creek; and,
- the mixed urban, rural residential, agricultural catchments of Teagues and Belwood Creeks.

Newee Creek is included within the Study's project area. However, to avoid overlap with the concurrently running Newee Creek Water Quality Project (run through University of Newcastle) it has not been included in the water quality sampling program associated with this project. A summary of the results of the Newee creek Water Quality Study can be found in *Part 2* of the report.

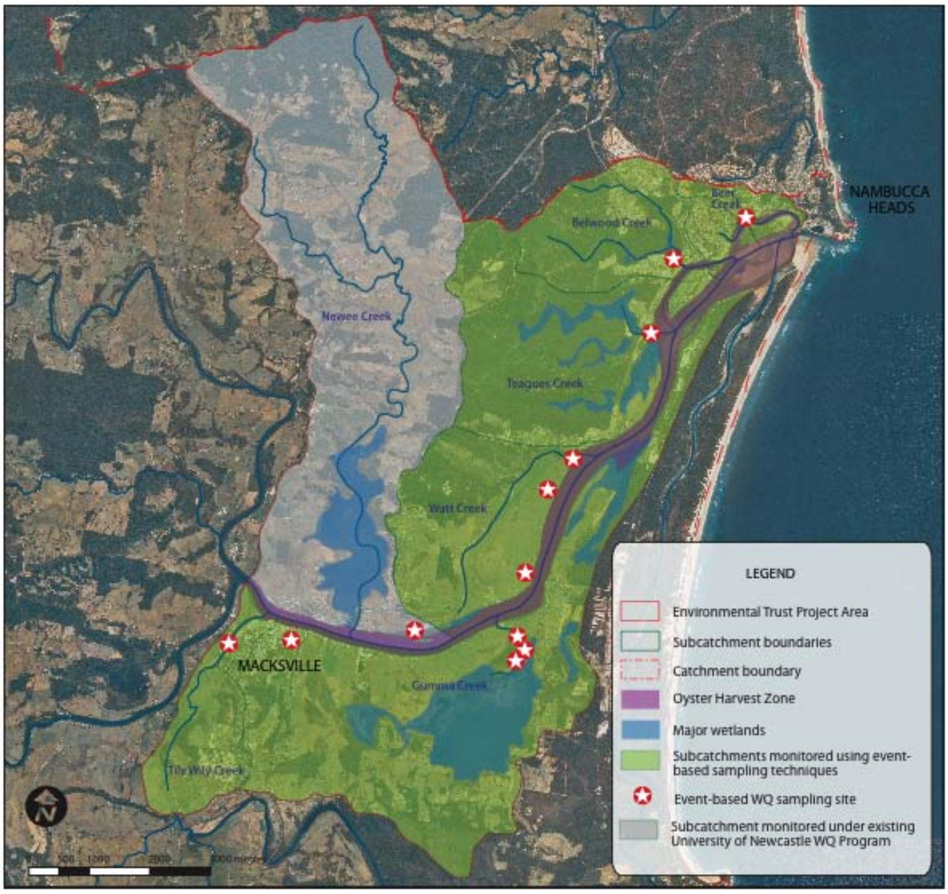


Figure 1 *Lower Nambucca River estuary health project study area*

What is in this Study?

The Study is divided into six main parts;

Part 1 ***Review of previous water quality related projects and programs, New South Wales and Interstate.***

Contributes to *Objective 2* above by reviewing a number of existing programs that have used different approaches to determining catchment exports of pollutants, assessing catchment loads, and assessing the effects of acid export on estuarine health and aquaculture. Includes an assessment of the how the lessons learnt from these various projects can be incorporated into the Lower Nambucca Estuary Water Quality Study.

Part 2 ***Existing water quality assessment in the Nambucca Valley***

Contributes to *Objectives 1* and *2* above by reviewing the body of existing data relating to water quality in the lower estuary area including data collected for the NSW Shellfish Quality Assurance Program, the Newee Creek Water Quality Study, Nambucca Shire Council monitoring, and the DECC Statewide Nutrient Exports Hotspots program.

Part 3 ***Community views of the estuary, its health and management***

Contributes to *Objective 4* by presenting the results of the Lower Nambucca River Health Resident's survey 2009. This survey assessed the level of community awareness of various estuary health and water quality related issues and sort respondent's opinions on current management efforts and how best to engage community support for future estuary management programs.

Part 4 ***Lower Nambucca Estuary Water Quality Study Sampling Program 2008-2009***

Contributes to *Objectives 1* and *2* by providing a comparative summary of the results of event based water quality sampling over the period November 2008 to May 2009.

Part 5 ***Subcatchment water quality report cards***

Contributes to *Objectives 1, 2* and *3* by presenting individual subcatchment results from the 2008-2009 water quality sampling program. This section includes a discussion of each subcatchment's results and recommendations for management to address identified water quality issues.

Part 6 ***Lower Nambucca Estuary Water Quality Strategy***

Contributes to *Objective 3* by providing a set of management recommendations which aim to address the water quality issues identified in the lower Nambucca estuary through the 2008-2009 sampling program. Recommendations include priority subcatchment for remediation, management strategies for remediation, and requirements for further monitoring to improve the understanding of the identified water quality issues.

PART 1 Review of Previous Water Quality Related Projects and Programs, New South Wales and Interstate

Many coastal catchment around Australia are experiencing high growth and development and so it is not surprising that in recent years there has been a good deal of attention on issues related to water quality in both rivers and estuaries. Several of these studies have been extensive and have relied on best-practice scientific investigations and ongoing monitoring and review to determine the effectiveness of the strategies employed to address identified issues. It would seem pertinent to review some of these existing programs to determine if their findings have any relevance for the Nambucca water quality Study. The aims of this section of the report therefore include;

- A review of relevant examples of integrated catchment export projects with respect to their objectives, achievements and lessons learnt;
- A summary of relevant material describing the impacts of acid sulfate soil (ASS) disturbance on coastal floodplains of NSW; and,
- The discussion of the implications of the review for this study.

Examples of Integrated Catchment Export Projects

Despite advances in modelling techniques and the relatively large body of literature covering the field, the use of integrated catchment export modelling and water quality monitoring studies has been limited largely to broad scale applications. Examples have been sediment and pollution management studies on the Great Barrier Reef catchments and studies on the Great Lakes of New South Wales. Smaller scale studies have tended to be focussed on testing model accuracy and improving methods such as Baginska *et al*. (2003b and 2005). As a relatively new scientific endeavour, the learning curve has been steep through the early application of modelling techniques and a number of important lessons have been learnt from the limited number of studies undertaken so far. These include;

- Relying only on data gathered in the field can be deceiving as a great deal of variation in catchment exports exists between individual rainfall events;
- Improvements in model accuracy are, however, gained when locally collected data is used in the calibration phase of modelling;
- In situations of severe data shortage modelling might be the only way to generate meaningful information about the sources and behaviour of pollutants in a catchment.
- Modelling can maximise the utility of existing data sets or limited data;
- Transparency of process throughout modelling applications is important to gain acceptance of output;
- Uncertainty analysis is a useful step as it helps with the interpretation of output; and
- The appropriate level of model complexity depends on the aim of the investigation.

South East Queensland Ecosystem Health Monitoring Program, QLD

The South East Queensland (SEQ) Healthy Waterways Program has resulted in the establishment of a long-term Ecosystem Health Monitoring Program (EHMP) in southeast Queensland. The SEQ EHMP has operated since 1999 and is a cooperative venture between State Government, Local Government and University Institutions. It aims to integrate flow monitoring, water quality monitoring and monitoring of biological indicators across freshwater, estuarine and marine sites. The monitoring results are collated and scored and then used to develop a report card and award an ecosystem health rating for each catchment on an annual basis. The SEQ EHMP is notable for its comprehensive approach, large scale and long-term vision. It represents the state of the art in the field of aquatic environmental monitoring for management purposes.

BMT WBM (2007) undertook a scoping study of the SEQ EHMP in order to assess its suitability for application across the Northern Rivers Catchment Management Authority (NRCMA). The scoping study identified the need for more integrated collection of aquatic resource information across the Northern Rivers. It identified shortfalls and complications with the current monitoring activities and assessed the number of existing programs that would benefit from information collected under an EHMP. The study concluded by proposing an indicative EHMP for the Northern Rivers and outlining particular considerations for the development of an EHMP.

The Northern Rivers Catchment Management Authority is now set to undertake a pilot EHMP on the Clarence, Hastings and Bellinger Rivers. In general an EHMP will provide many benefits for local resource management. The EHMP provides a framework for collecting information about river health that meets all the criteria for effective monitoring. Benefits of the EHMP scheme for water quality management include;

- A system-wide approach to water quality monitoring. This would reduce the current deficit in water quality information from the freshwater reaches and contributing to a Total Catchment Management approach to managing waterways;
- Regular, consistent information on which to base decisions as opposed to inadequate needs based sampling;
- A regular, consistent background of data to relate to special needs sampling programs that will help contextualise special needs sampling programs within a broader longer term picture of river water quality;
- More efficient, integrated water quality sampling, resulting in cost/benefit improvements;
- An integrated system of measuring river health, including physical, chemical and biological indicators; and
- The provision of improved information for the NRCMA to make better decisions about funding allocation and management priorities.

Great Barrier Reef, QLD

A variety of modelling projects have been undertaken on the Great Barrier Reef (GBR) catchments. In one of the more recent studies Cogle, Carrol & Sherman (2006) used SedNet and ANNEX (see *Appendix A* for descriptions) to aid the creation of water quality targets for the Great Barrier Reef catchments. Their work was an update of previous modelling undertaken in the GBR catchments. They used improved and more recent input data sets and were able to show that the vast majority of sediment and nutrient pollution delivered to the GBR came from agricultural lands located on steep slopes in high rainfall areas within 70 to 90km of the coast. Their study highlights the utility of a modelling approach to maximise the benefit of limited, costly data collected in the field. In their report they stress that the results of the model are dependent upon the quality of the input data and also the level of understanding of the system processes. They suggest that transparency of process is of major importance to gain acceptance of the modelled output and also note that uncertainty analysis is of utmost importance to obtain the maximum understanding from model results. It should be noted here that the intended use of modelled information must be considered in its analysis. For example, they were seeking an absolute value from their models, for use in guiding nutrient budget levels. When using models to produce figures for comparison between subcatchments, the factors of uncertainty in the actual numbers may be of less importance than the knowledge of catchment characteristics and behaviour.

A later review of all previous GBR catchment export modelling activities (Post *et al*. 2007) describes the following lessons learnt;

- Communication frameworks are important as a support for projects;
- The appropriate level of model complexity depends on the decision to be made;
- Data set utility is greatly variable with respect to validity and comprehensiveness of data;

- Catchment behaviour is often poorly understood, limiting the accuracy of models; and
- The quantification of uncertainty and the ability to translate understanding across different scales pose large challenges.

Great Lakes Coastal Catchment, NSW

The Great Lakes Coastal Catchment Initiative project is a multi-faceted effort at creating a water quality improvement plan for the Great Lakes of NSW. One aspect of the project is an integrated water quality monitoring and catchment export modelling effort, with the aims of accurately predicting a nutrient budget for the Great Lakes system using a model known as AnnAGNPS (see *Appendix A*). Water Quality samples (>500 individual samples) were collected and analysed from across the Great Lakes catchments in order to develop catchment export and estuarine response models. The models were used to estimate nutrient and sediment loads and also to test the potential effectiveness of some of the management strategies that were developed as part of the overall plan. The models were also able to imply the spatial variation in pollutant generation, ie., which areas are likely to contribute most to poor water quality in the lakes.

The Great Lakes Project represents best practice in a number of aspects. Specifically, best practice is represented by the large scale sampling effort conducted to calibrate the models, the division of the land into functional units based on both soil and land use information and the integration of modelled outputs into a decision making tool to inform future management of the lakes and their catchments.

Gippsland Lakes and Lake Burragorang catchments

A project undertaken in the Gippsland Lakes (Hancock *et al*. 2007) integrated catchment export modelling, using SedNet and ANNEX (see *Appendix A*), with sediment tracing with the aim of identifying the major land use and erosion sources for sediment and nutrient pollution in the lakes. A similar project was undertaken in the Lake Burragorang catchment (Rustomji 2006). Rustomji *et al*. (2006) constructed 5 models using different parameters to test their fit to three independently collected sets of data (representing sediment loads in rivers, sediment tracing from river confluences and sediment tracing of surface versus subsurface contributions) from the catchment. These studies were able to give an excellent spatial representation of sediment and nutrient generation in addition to identifying the processes contributing most heavily to water quality problems in the relevant waterways. In general, the concurrences between gathered data and the outputs of calibrated models were good.

A number of poignant lessons were learnt from the studies, including;

- different model parameterisations can lead to vastly different outputs; and
- increased levels of local data used in the calibration phase of modelling clearly improved the accuracy of the results.

Currency Creek, NSW

Baginska *et al*. (2003b) measured nutrient and sediment export from Currency Creek in a bid to test the applicability of foreign models to Australian conditions. They describe how catchment export modelling is particularly useful in combination with rainfall, runoff and water quality data collected from the field, noting that limited data sets can be deceiving as individual runoff events are unpredictable and specific runoff behaviour is dependent on soil attributes and antecedent climatic conditions. Baginska *et al*. (2003b) used 3 years of rainfall, runoff and water quality data to assess the accuracy of the model. They found that major contributions to the accuracy of the model were dependent upon sound choice of runoff coefficients for calibration of flow. They also found that parameter estimation optimisation software, such as PEST, can save a great deal of time. Their study indicates that neither direct observation nor modelling create a perfect image of catchment contributions to water pollution. It is implied that an approach integrating the two methods can be used to advantage.

Tweed River, NSW

Baginska *et al*. (2005) discuss using L-THIA to model changes in nutrient contributions over time from the Tweed River catchment using historical, current and proposed land use arrangements. Their study demonstrated that, due to the general inadequacy of monitoring data in Australian catchments, modelling is often the only way to generate meaningful catchment loads. They also mention that monitoring in coastal catchments is further complicated by the effects of the tide and that the focus of development in coastal areas heightens the importance of improved modelling approaches.

Assessing Catchment Loads

Anthropogenic changes to land use and modern land management practices have resulted in gross changes to the export of pollutants from catchments to waterways. The most widely considered of these pollutants, also referred to as constituents, are sediments, nutrients and pathogens.

Predicting catchment export loads of these pollutants is an important part of the management of soil reserves and waterways. With particular respect to waterways, accurate assessment of runoff loads can help natural resource managers understand the processes behind eutrophication or poor water quality in general and to develop strategies to mitigate problems. Methods of assessing catchment export loads range from direct measurement, empirical methods using existing, discontinuous water quality and flow data and computer modelling. As with any predictive process, each group of methods and each individual method have their own advantages and disadvantages.

Assessing pollutant loads from direct observation and data collection is a time consuming and costly process that is rarely a feasible option (Baginska *et al*. 2003). Where some water quality and flow data is available a variety of averaging, ratio and regression methods can be used. Letcher *et al*. (1999b) provides an excellent review of these methods. There are, however, a number of fundamental flaws with these methods of assessing catchment loads from existing data (following Baginska *et* al. 2003);

- routinely collected water quality data rarely includes samples taken under storm or high flow conditions. This can lead to vast underestimates of total loads because large volumes of pollutants (more than 60%) can be moved in storm events;
- water quality and flow data are rarely collected in conjunction. Letcher *et al*. (2002) found that even the information available from the most comprehensively surveyed Australian catchments was inadequate; and
- assessing pollutant loads in this way limits the understanding of the role of specific subcatchments, land use types or land management practices in generating or attenuating pollution.

Where very little or no data exists, a number of non-computational empirical methods for the estimation of nutrient loads can be used. These methods tend to link nutrient export to sediment export, land use, population information or some other environmental variable in a fixed manner. In general these models tend to be overly simplistic though a multifactorial method developed by Moss *et* al. (1993) was found to be relatively robust (Letcher *et al*. 1999b).

An alternative method for the assessment of pollutant loads from catchment is the development of catchment runoff models. This area has received considerable attention in recent years and there are now a variety of models available to catchment managers that cover most required uses. The field of catchment export modelling is developing and with appropriate care given to model choice, calibration data and required output information can have a key role in supporting catchment management decisions. In particular (following Newham & Drewry 2006);

- They can assist with the prioritisation of investment in catchment remediation on a variety of scales;
- They can evaluate management practices *a priori*;
- They can make potential cost benefit comparisons *a priori*;

Despite the obvious benefits, the use and interpretation of modelled outputs need to be carefully considered. In particular;

- There has been a recent focus on the difficulties modelling the export of nutrients from catchments into waterways. Specifically, it seems that problems with the incorporation of the process defining transport of dissolved nutrients and aspects of riparian mitigation need attention. (Newham & Drewry 2006, Drewry *et al*. 2006);
- The representation of nutrient generation and assimilation processes in local models is limited by the scarce understanding of these processes in Australian catchments (Newham & Drewry 2006). The main effect of this has been limited confidence in model outputs;
- Overseas studies, data and models are generally considered inappropriate for use in the assessment of Australian conditions due to the generally lower levels of N and P export observed here. This is most likely due to the lower population densities, lower fertiliser application rates and lower atmospheric deposition (Newham & Drewry 2006)
- Newham & Drewry (2006) note that rainfall and hydrology are important factors to include in Australian models due to the ways that nutrient runoff is affected by specific rainfall events. In effect, in dry years a high proportion of nutrient transport is subsurface and in wet years the majority of nutrient transport is in overland flow;
- Scale is an important aspect in the choice of models, due to the fact that nutrient generation processes are widely divergent at the scales of plot, paddock, hillslope and catchment (for example) (Newham & Drewry, 2006).

The Effects of Acid Exports on Estuary Health and Aquaculture

Acid Sulfate Soils (ASS) are commonly found on coastal lowlands of the east coast of Australia. These soils contain iron pyrite which, when disturbed, can oxidise and form sulphuric acid. The effects of ASS exports on estuarine systems have been widely reported and include acidification and deoxygenation of estuarine waters, mobilisation of toxic levels of iron and aluminium from the soil into the water column and deleterious impacts on aquatic biota and habitats. The transport of acidic and toxic materials from the site of ASS disturbance has been enhanced in many cases by the extensive drainage and flood mitigation systems that characterise much of the agricultural lands located on the coastal floodplains of northern New South Wales. The Gumma Gumma backswamp in the lower Nambucca catchment has been identified as an area where ASS have been exposed to oxidation from the existence of acid scalds and iron flocculates in runoff.

Sammut *et al*. (1996) showed that runoff from active ASS contributed to estuarine acidification that persisted for over 7 weeks. They also noted that acid could leach from disturbed ASS for up to 1000 years. They estimated that sulfuric acid discharge for a single flood water recession in a medium sized tidal reach could be up to 950t, almost 200 times what would be considered a disastrous industrial spill.

Disturbance of ASS have been linked to a variety of negative impacts on estuary ecology and aquaculture enterprises. Dove and Sammut (2007a) describe shell degradation, increased mortality and reduced growth in oysters farmed in estuarine parts of the Manning River system affected by ASS disturbance. In laboratory experiments they showed that oysters exposed to lower pH waters and elevated levels of Iron and Aluminium had reduced feeding opportunities and showed deleterious effects on soft tissues (Dove and Sammut 2007b). Fish kills in the Richmond, Clarence and Macleay Rivers in 2001 were proven to be caused primarily by low dissolved oxygen levels that were, in turn, largely caused by mobilisation of mono-sulfidic black ooze, a product of ASS disturbance (Walsh, Copeland & Westlake, 2004). Sammut *et al*. (1996) observed extensive mortality of crustaceans and polychaetes in a tributary of the Richmond River affected by ASS runoff.

The Gumma Gumma swamp makes up approximately 20% of the lower Nambucca floodplain. In the early part of the 20th century the area was drained and floodgated, most likely resulting in a lowering of the surface and groundwater levels, invasion of the swamp by *Casuarina spp*. and oxidation of ASS, in turn causing mobilisation of toxic metals, export of acidic waters and deleterious effects on the fauna of Gumma Gumma Creek and possibly the greater Nambucca estuary (Wetland Care Australia, 2004).

Implications for the Lower Nambucca Water Quality Study

The projects reviewed in this section provide a number of invaluable lessons which give useful direction for the development of a water quality monitoring and improvement strategy on the Nambucca estuary.

- Firstly, Baginska *et al.* (2003) has shown that water sampling must sample storm or high flow conditions as large volumes of pollutants (more than 60%) move in storm events. In addition, in order to quantify the total volume of pollutants, a measure of flow volume of storm water must be included. This allows comparisons to be made between subcatchments and improves the understanding of the role of specific subcatchments, land use types, or land use management practices to overall water quality. However, Baginska et al. (2003b) qualifies these statements by asserting that relying only on data gathered from event sampling can be misleading due to variations in catchment exports associated with antecedent conditions (ie. whether it has been wet or dry prior to the event) and variation between individual runoff events. The implications for this study are that water quality sampling in the tributary subcatchments should be event based; that where possible multiple events should be sampled in each system; an attempt should be made to determine total discharge for the sampled events to allow comparisons of total pollutant loads; and that up to date land use mapping and a knowledge of land management practices may assist subcatchment comparisons of water quality.

- Secondly, from the review of the SEQ EHMP, it is apparent that a system wide approach to water quality sampling is desirable. A water quality dataset that has a long-term focus will allow any specific sampling programs to be put in the context of longer-term water quality trends. As this study is only short-term in nature (one year sampling followed by two years implementation), the implications for this study are that the sampling method and parameters analysed should be able to repeated where further funding becomes available, or should be able to be utilised in other programs with a longer term focus.

- Thirdly, the Great Lakes project showed the value of a large scale sampling effort when trying to understand catchment and water quality processes. In addition, the use of high-resolution land use and soil type information also greatly assisted the accuracy of their modelling and allowed greater confidence in management recommendations. As seen in the Great Barrier Reef project, a thorough understanding of catchment processes is required if the determination of catchment exports is to be attempted. The implications for this study are that where resources allow the number of sampling sites should be maximised and, if a modelling approach is to be used, it should be based on recent high resolution land use and soil mapping.

- Fourthly, in terms of modelling catchment exports and loads, several of the projects made recommendations with respect to how to achieve meaningful modelling results, including understanding catchment behaviour (GBR project) and calibrating models with local data (Lake Burragarong). Baginska *et al.* (2005) notes that in catchments where monitoring data is generally inadequate modelling might be the only way to generate meaningful information about the sources and behaviour of pollutants in a catchment. However, Newham and Drewry (2006) offer a realistic assessment of the difficulties of modelling catchment loads including requiring a detailed understanding of the hydrology, rainfall distribution, and runoff coefficients of the focus catchment. The implications for this study are that due to limited data availability (particularly land surface elevation, hydrological connections on low relief floodplains, and local data relating to rainfall distribution and runoff coeficients) a modelling approach will at best provide a ball-park estimate of catchment exports and loads.

- Lastly, it is clear from the body of literature briefly summarised in the section on ASS export that disturbance of ASS can have major deleterious effects on estuarine water quality, habitats, and environments. Determining the pathway of acid export (ie. surface water or groundwater) is an important consideration when designing a sampling strategy where the intention is to determine the extent of ASS impacts on estuary water quality as, depending on the pathway, sampling at the time of a runoff event may not detect acid export. The implications for this study are that in term of ASS disturbance and the export of acid waters and associated heavy metals, an attempt should be made to determine the pathways of acid export before determining the most appropriate sampling regime.

The sampling methodology outlined in *Parts 4* and *5* of this Study have wherever possible incorporated the lessons learnt from this review.

PART 2 Existing Water Quality Assessment on the Nambucca River Estuary

Water quality monitoring and assessment programs that have been or are currently being undertaken on the Lower Nambucca estuary include water quality sampling associated with the NSW Shellfish Quality Assurance Program (NSWSQUAP), water quality sampling on Newee Creek (TUNRA 2008) and a hotspot mapping project undertaken state wide. Nambucca Shire council also undertake some water quality sampling as part of their licensing requirements for the operation of the Macksville sewage treatment works, which dispose of treated effluent into the Nambucca estuary downstream of Macksville township.

NSW Shellfish Quality Assurance Program 2006-2008

Water quality sampling on the lower Nambucca estuary for the NSWSQUAP involves fortnightly analyses of bacteria concentrations in the waterway. To date, analyses have not resulted in an unconditional closure of the river to harvest of shellfish.

The NSW Food Authority (2007) completed a Sanitary Survey of the harvest areas, locating 99 actual or potential sources of pollution and assessing bacterial and microalgal aspects of water quality. They suggested that the most likely threats to the safety of shellfish harvest would come from the Macksville STP or failing on site sewage management systems. Additional high risk sources include stormwater drains and agricultural runoff. They found that the Nambucca River harvest areas are subject to 'low to moderate levels of pollution in dry weather which is greatly exacerbated by rainfall'.

The survey report resulted in the classification of all harvest areas as 'Conditionally Restricted', meaning oyster harvesting must stop when salinity in the harvest area drops below 18 ppt on the ebb tide. The survey also resulted in a no harvest protection zone located around the Macksville STP outlet. The survey found that when salinity is greater than 19 ppt and less than 30mm of rain has been recorded in any 24hr period or less than 70mm in any week at Macksville or Nambucca BOM stations that ‘low to moderate levels of pollution’ are generally the case. The subsequent recommendation is that, when the harvest area is open, oysters harvested from the Nambucca River must be depurated for a period of not less than 36hrs. In addition, the bacterial water quality of all sample sites must meet the following criteria;

- Membrane filtration method – the faecal coliform median or geometric mean of at least 15 samples must not exceed 70 per 100mL and not more than 10% of samples can exceed 85 per 100mL; or
- Most probable number method – the faecal coliform median or geometric mean of at least 15 samples must not exceed 88 per 100mL and and not more than 10% of samples can exceed 260 per 100mL for a five tube decimal dilution or 300 per 100mL for a three tube decimal dilution test.

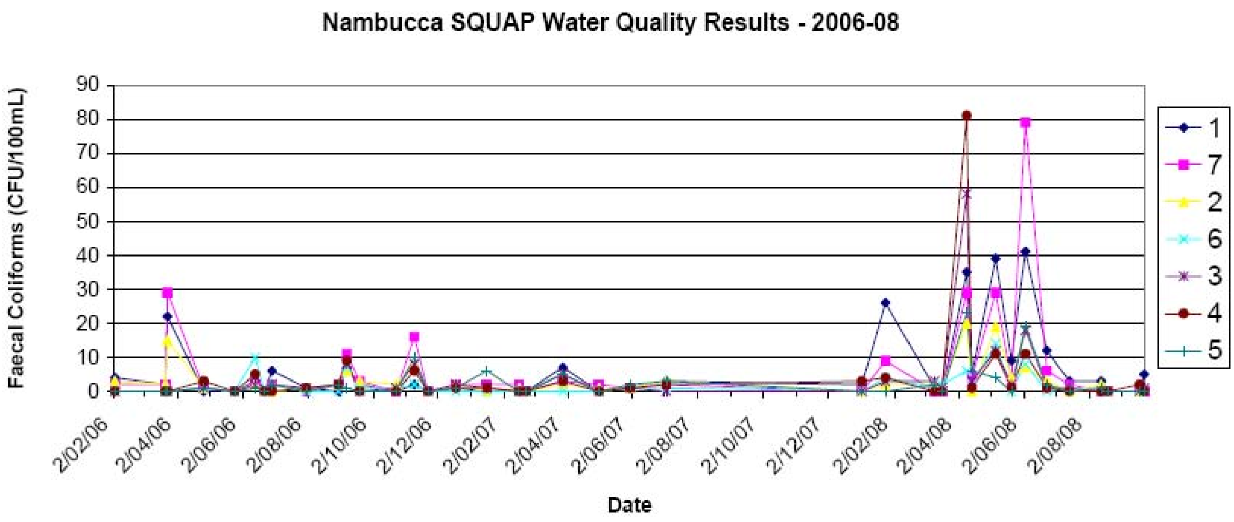


Figure 2 *Results of the Nambucca SQAP water quality investigations from 2006 – 2008.*

Figure 2 shows the results of the Nambucca SQAP testing between February 2006 and September 2008. The results for that period comply with the requirements of the conditionally restricted classification.

Newee Creek Water Quality Study 2007-2009

The first phase of the Newee Creek water Quality Study (TUNRA 2008) was undertaken on behalf of Nambucca Shire Council to try and understand the major contributors to observed poor water quality in Newee Creek. The study sampled event based concentrations of contaminants and physicochemical parameters at 9 sites spread along the length of the creek. The results were somewhat inconclusive, however, water quality was found at some sites to be outside of guideline ranges (ANZECC 2000) for all variables tested during both dry and wet weather sampling periods. The authors were able to say that cow and other animal manure was a significant contributor to bacterial contamination and that wet weather water quality in general was worst at sites downstream of developed areas, including a dairy farm, an area of rural residential development and a cold storage facility. Their results strongly suggested that faecal contamination in the Newee Creek catchment is likely to impact upon the Nambucca River, particularly after rainfall. Further event based monitoring was recommended to occur as part of Phase 2 of the project.

Phase 2 of the project was completed in 2009 (Newcastle Innovation 2009).The second phase of water quality monitoring shows that almost all of the faecal contamination in Newee Creek is derived from herbivorous sources (93-100%). Faecal matter derived from human sources (up to a maximum of 6% of total faecal matter) was most likely to have been from leaking/overflowing septic tanks but contaminated runoff forced in from the greater Nambucca by tidal movements was not ruled out as a potential source. The conclusion that followed from this is that the dairy is the major contributor of faecal material in the catchment. Other conclusions derived from the results were that dissolved oxygen levels in Newee Creek are heavily dependent on rainfall and that high levels of variability exist in other physicochemical parameters. Recommendations from the study include the installation of retainment ponds to reduce stormwater flow and first flush effects, better management of stock access to streams, improved management of runoff from roads, an audit of septic systems in the Newee Creek catchment and promotion of adequate riparian vegetation and ground cover.

Nambucca Shire Council Water Quality Monitoring 1992-2007

Nambucca Shire Council measured Biological Oxygen Demand, Total Suspended Solids, Total Phosphorus, Nitrate, Nitrite, faecal coliforms and physicochemical parameters at 3 sites on the Nambucca River and 1 site on Newee Creek monthly between 1992 and 2007. The assembled data represents an excellent base from which to draw comparisons. A brief summary of the most relevant results is in *Table 1*. Site 4 was located 200m upstream of the Macksville STP effluent discharge pipe, Site 7 was located 200m downstream of the effluent discharge pipe, Site 15 was located at Wrights Corner and Site 16 was located in Newee Creek, immediately downstream from the Midco processing plant.

Table 1 *Summary results of the Nambucca Shire Council water quality monitoring program from 1992 - 2007.Highlighted cells indicate exceedences of ANZECC (2000) default trigger values referred to in the text.*

Site		TSS (NFR) (mg/L)	Total P (mg/L)	NO3 (Nitrate) (mg/L)	NO2 (Nitrite) (mg/L)	Faecal Coliforms (CFU/100mL)	pH
Site 4	*mean*	28.032	0.059	0.346	0.017	29.177	7.732
	median	8.000	0.030	0.080	0.006	10.000	7.760
	st dev	39.415	0.059	0.696	0.026	57.476	0.564
	90th %	85.798	0.150	0.800	0.050	80.900	8.258
	10th %	2.000	0.012	0.010	0.001	1.000	7.334
	count	177	177	177	177	172	153
Site 7	*mean*	32.198	0.063	0.290	0.017	28.567	7.888
	median	9.000	0.032	0.058	0.005	10.000	7.840
	st dev	48.639	0.083	0.359	0.023	63.998	0.484
	90th %	100.075	0.147	0.865	0.050	79.000	8.377
	10th %	1.000	0.010	0.010	0.001	0.000	7.440
	count	178	178	178	178	171	152
Site 15	*mean*	32.617	0.055	0.265	0.016	20.953	7.975
	median	9.000	0.030	0.050	0.005	10.000	7.930
	st dev	48.044	0.054	0.337	0.022	41.840	0.590
	90th %	91.594	0.130	0.800	0.050	50.900	8.480
	10th %	1.500	0.010	0.006	0.001	0.000	7.525
	count	174	174	174	173	172	146
Site 16	*mean*	24.829	0.108	0.259	0.025	149.264	7.484
	median	8.000	0.070	0.050	0.010	24.000	7.390
	st dev	40.948	0.108	0.331	0.056	479.956	0.604
	90th %	76.971	0.237	0.800	0.050	228.200	8.234
	10th %	3.000	0.025	0.010	0.001	5.800	6.880
	count	160	160	160	160	159	137

Table 1 shows that nutrient levels in the Nambucca estuary are frequently above default trigger levels for further investigation set by ANZECC (2000) (median values highlighted). The relevant ANZECC (2000) default trigger values for the protection of aquatic ecosystems in SE Australian estuaries of a moderately disturbed condition are;

- The median value of the sum of the oxides of nitrogen (Nitrate + Nitrite) should not exceed 0.015mg/L; and
- The median value of Total Phosphorus should not exceed 0.03mg/L.

Across the four sites levels of nitrate are frequently very high and Total Phosphorus levels are regularly very high in Newee Creek and occasionally high in the rest of the sampled sites. The collated data indicates that the Nambucca River estuary is likely to be subject to elevated levels of nutrients in runoff. However, if the results collected prior to 1999 are excluded from the analysis the median levels fall well below the ANZECC 2000 trigger values.

The impact of the elevated nutrient levels in the water column depends on a number of factors. These include physiological factors of resident biota, and the extent to which hydrodynamic factors (tidal volumes, flushing times) and turbidity levels moderate the effects of nutrients on the growth of plants and algae. The Nambucca River does not have a history of regular algal blooms. It is possible that the high nitrate levels recorded frequently prior to 1999 could have been a source of stress to some aquatic organisms. It is suggested that as the most recently collected samples have shown acceptable nutrient levels that this is not a source of concern.

The Nambucca Shire Council data also indicates that the river does not meet the ANZECC 2000 water quality guidelines for aquaculture. This warrants mentioning despite the fact that the ANZECC guidelines have been superseded by the NSW SQUAP in defining acceptable water quality for oyster aquaculture. The relevant ANZECC (2000) guideline for the protection of human consumers of aquatic foods is that the median faecal coliform concentration of the water should not exceed 14/100mL and no more than 10% of samples should exceed 43/100mL.

The aquaculture industry of the Nambucca River would benefit from reduced bacterial loads in urban and agricultural runoff and treated effluent.

PART 3 Community Views of the estuary, its health and management

Lower Nambucca River Health Resident's Survey 2009

The 2009 resident's survey was directed at collecting local community opinion on a range of estuary related values, uses, threats, activities and management programs applying to the Nambucca River estuary between Macksville and Nambucca Heads. The survey was general in nature and was not intended to test the resident's knowledge of facts relating to the estuary. Rather it was an attempt to gather information on how resident's perceive the issues affecting the estuary, their views on existing arrangements for estuary management, and to determine the most effective ways to communicate with resident's about estuary management issues, programs and activities.

The survey ran from 10 July 2009 to 14 August 2009. Three thousand and thirty-nine surveys were direct mailed to residents in the study area. Three hundred and thirty-nine (339) surveys were returned marked "insufficiently addressed" or "no mailbox". Of the remaining 2700 surveys that were delivered, 511 were returned completed, representing a 18.9% return rate. This return rate indicates that a direct mail approach using a reply paid service is an effective method to seek community opinion. It also indicates that there is a high degree of interest in the estuary within the local community.

Survey Results

The Sample

Those responding to the survey were inclined to be slightly older than the mean NSW population distributions and the Nambucca Valley community profile population distributions from 2006 (*Figure 3*). Just under half the sample (47%) was aged between 41 and 65 years and just over a third (35%) were over the age of 65 years. 10% of the sample was between the ages of 21 and 40 years old. Slightly more than a third of the respondents had lived in the Nambucca Valley for more than 25 years while a further third had lived in the valley for between 10 and 25 years. Just under half the sample listed their highest formal education as secondary school. A quarter of the respondents were working full-time, with 17% working part-time, 45% retired, and 11% not working.

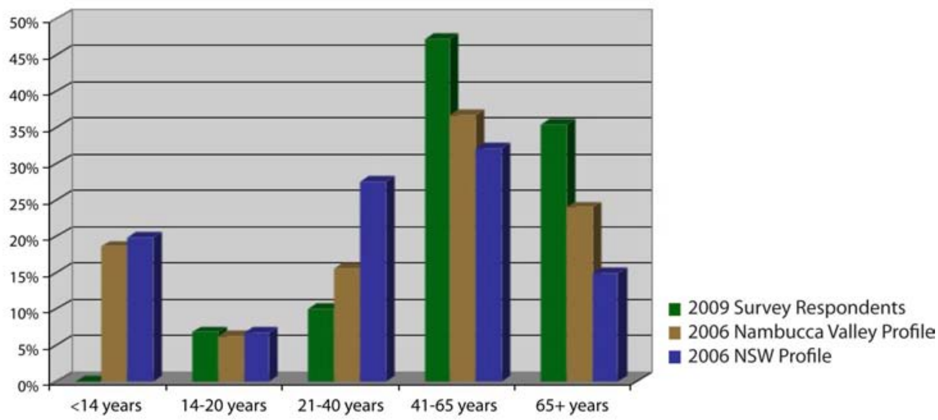


Figure 3 *Comparison of age class distributions between respondents to the 2009 survey and the 2006 Nambucca Valley community profile and 2006 NSW profile.*

Almost two thirds of the sample had accessed the internet in the last week, although surprisingly one quarter of the respondents had never accessed the internet. The most popular publications (*Figure 4*) that the survey group either always or often read were the *Hibiscus Happynings* (92%), *Mid-coast Observer* (82%), *Guardian News* (73%), and the Council newsletter (53%). More than 70% of respondents had either not heard of or rarely or never read the Landcare newsletter.

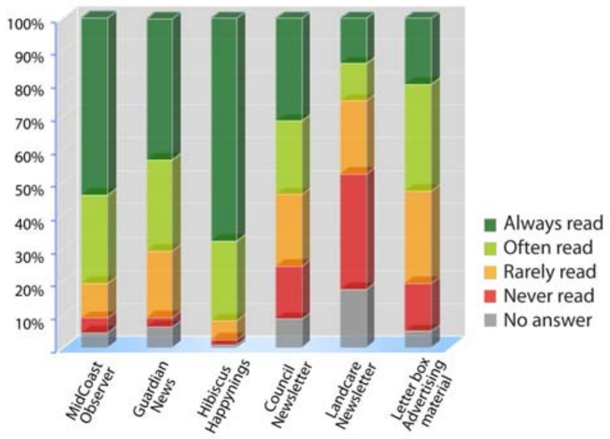


Figure 4 *Collated responses to the question: "How often do you read the following publications".*

Features and Threats

Almost two thirds of the respondents correctly identified an estuary as "the tidal section of a river, or small coastal lakes or creeks that connect to the sea but which may at times be closed by sand at their entrance". However, only 13% of respondents correctly identified that Nambucca Heads, Macksville, Bowraville, and Scotts Head all were located on the estuary. Less than a quarter of the sample knew that Bowraville was on the estuary.

When asked what they liked about the Nambucca River estuary (*Figure 5*) respondents either liked or strongly liked the beautiful scenic and visually pleasing places (94%), the peacefulness and tranquillity (91%), the fact that the estuary attracts tourists and contributes to the local economy (87%), and fishing and recreational boating (84%). Water-skiing, wakeboarding and jet-skiing was the least liked attribute with 40% either disliking or strongly disliking these activities.

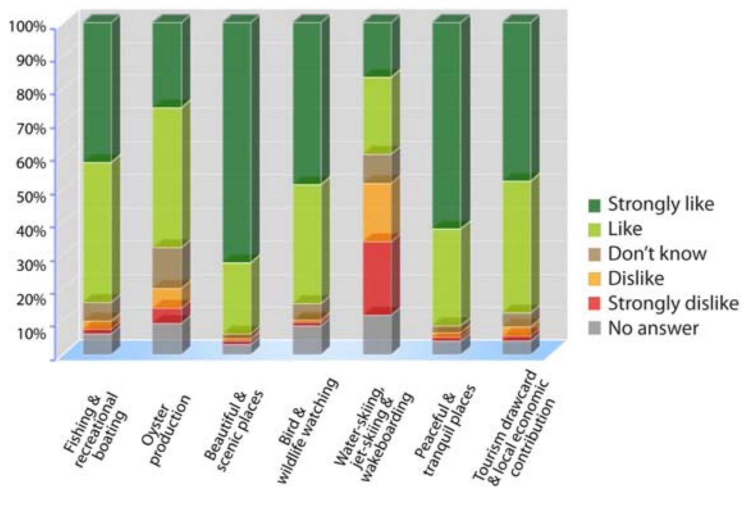


Figure 5 *Collated responses to the question: "What do you like about the Nambucca River estuary".*

Approximately 90% of respondents identified the bird life, the quality/flow/health of the water, and the natural habitat/environment/ecosystem as the most important environmental features of the estuary.

When asked to identify from a list of possible issues affecting the area of the estuary between Macksville and the river mouth at Nambucca Heads, the two most commonly identified issues that respondents either agreed or strongly agreed with were the amount of rubbish and litter in the estuary area and the impacts of tourism on the estuary (*Figure 6*). In terms of skiing, jet-skiing and wakeboarding, just over half the respondents agreed or strongly agreed that it was an important issue in this reach of the estuary, while a quarter of respondents either disagreed or strongly disagreed that these activities were an issue. Similarly, in terms of stock or grazing impacts on the estuary foreshore 57% of respondents either agreed or strongly agreed that this was an important issue while 15% either disagreed or strongly disagreed that this was an issue in the part of the estuary between Macksville and Nambucca Heads.

The most commonly recorded additional comments added to the survey forms by respondents related to either negative perceptions of the professional fishing industry in the estuary (particularly in relation to netting and the perceived effects such practices have on recreational fishing) or to perceived issues related to skiing, wakeboarding, or jetskiing. Negative perceptions relating to the degree of shoaling in the lower estuary and the perceived need to dredge the channel to improve navigability were also common comments added to the survey.

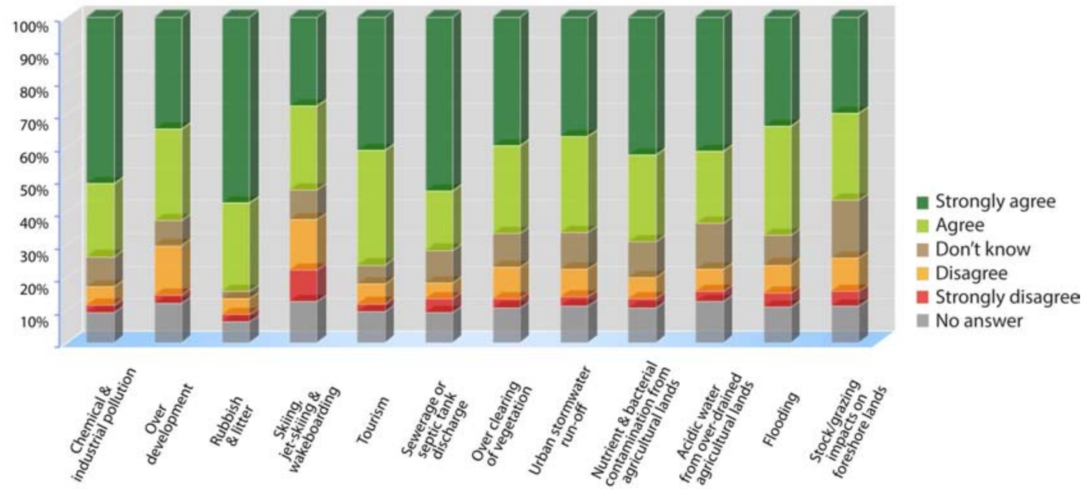


Figure 6 *Collated responses to the question: "In terms of the area of the Nambucca River estuary between Macksville and the river mouth, which of the following (issues listed) do you consider to be important issues".*

Organisations Responsible

When asked to identify from a list provided which organisations have responsibility for the health and management of the estuary (*Figure 7*) the most commonly chosen organisations were the Nambucca Shire Council (87%), the Estuary Management Committee (81%), and Nambucca Valley Landcare (61%). Both the Northern Rivers Catchment Management Authority and "private landholders" were selected by 59% of those who returned surveys. Less than half of all respondents correctly identified the Department of Environment and Climate Change as an organisation responsible for the estuary's health and management, despite DECC being the lead State Government Agency with estuary management responsibilities.

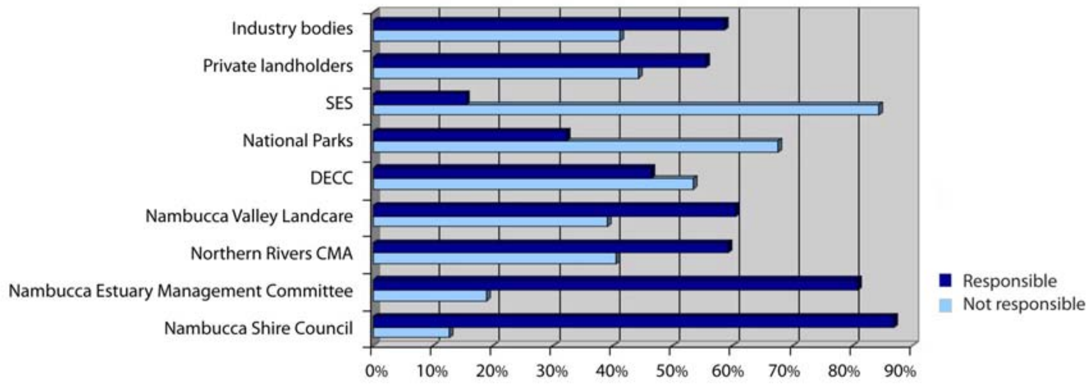


Figure 7 *Collated responses to the question: "Which of the following organisations are responsible for the health and management of the Nambucca River estuary?".*

In response to the statement "Whoever is responsible for managing the estuary, they are doing a good job", just over a quarter of respondents (29%) agreed or strongly agreed while 39% disagreed or strongly disagreed with the statement. With regard to the level of awareness of the Council's Estuary Management Plan, one third of respondents said they were aware of the plan and the studies that support it, while 44% indicated they had not heard of the plan.

When directed to consider the reach of the estuary between Macksville and the river mouth, more than 80% of respondents either agreed or strongly agreed that responsible organisations should be focussing more upon the following four issues (*Figure 8*);

- Riverbank erosion
- The problem of the silting up of the estuary
- Protecting the estuary environment and biodiversity
- Improving riverbank vegetation

Almost 70% of respondents either agreed or strongly agreed that management efforts should be directed as improving water quality in the estuary between Macksville and Nambucca Heads.

The four issues that were considered least important in terms of requiring more attention from the responsible organisations were (*Figure 8*);

- Supporting commercial fisheries such as oyster production
- Improving boating facilities
- Regulating skiing, jet-skis and wakeboarding
- Increasing river based tourism

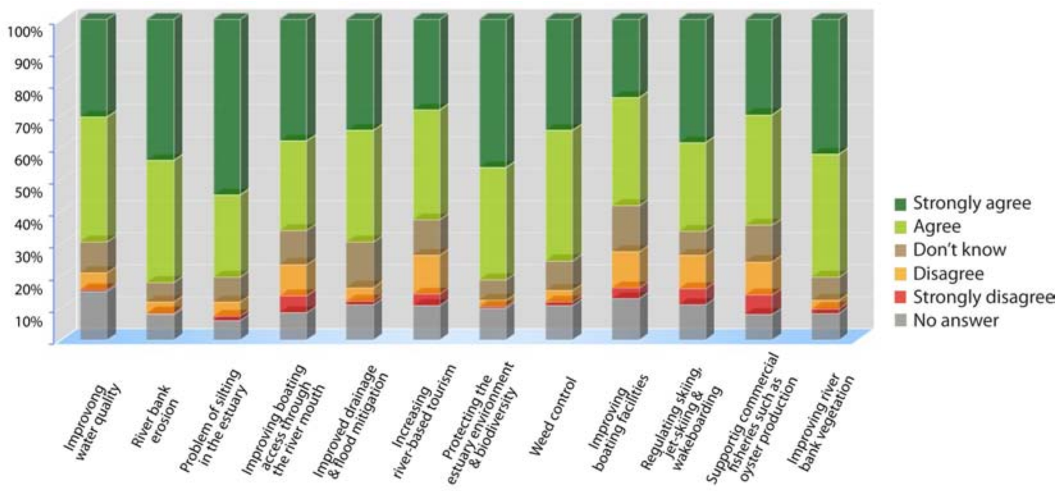


Figure 8 *Collated responses to the question: "In terms of the area of the Nambucca River estuary between Macksville and the river mouth, the responsible organisations should be focussing more on the following (actions listed)"*

Estuary Activities and Programs

The results of the survey indicate that there is generally a low to moderate level of awareness of the estuary management activities currently occurring in the estuary (*Figure 9*). About half of the respondents were aware of erosion control works occurring on the estuary and the involvement of aboriginal *GreenTeam* work crews in estuary management. However, there was very little awareness of activities relating to acid sulfate soil remediation (12%), weed control (22%), wildlife surveys including fish/birds/animals (23%), and tree planting on riverbanks (27%).

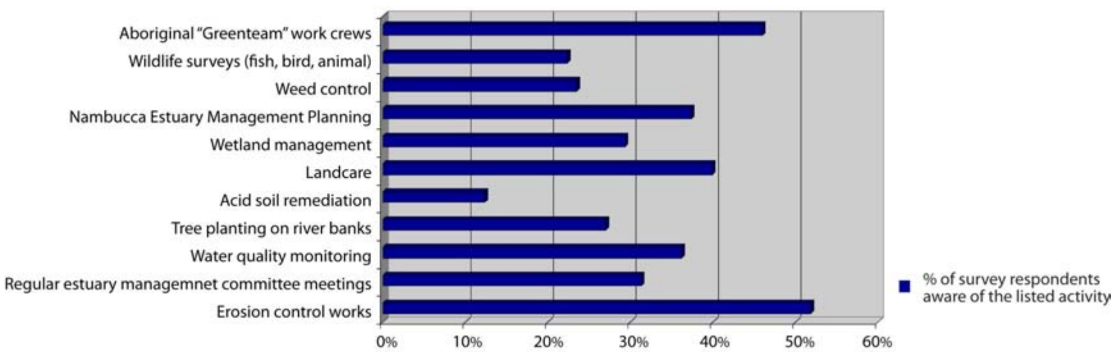


Figure 9 *Collated responses to the question: "Are you aware of any of the following estuary management activities occurring in the Nambucca River estuary?".*

Only 8% of respondents say that they are actively participating in estuary management actions or programs at present, 15% had participated in the past, but 34% said they would like to participate in the future but don't know how. 29% of respondents thought that any problems caused by industry should be fixed by those industries and 19% thought it should be left to "the government".

In order to encourage residents to become more actively involved in estuary management, more than three quarters of respondents thought that more information about specific issues affecting the Nambucca estuary and more information about immediate threats to the estuary would help.

Information about actions that impact upon the estuary's many values was also identified by almost two thirds of respondents as useful information to help motivate residents to become more involved. In order to inform local residents, respondents said they would be more likely to read an advertisement in a local paper (75%) or letterbox drop (66%) than from a website (21%), a landcare source (39%), or local television advertising (53%).

Lastly, there was strong support for the use of funds from a local government environmental levy to address environmental issues in the Nambucca River estuary with 72% of respondents either agreeing or strongly agreeing with such a proposal (*Figure 10*).

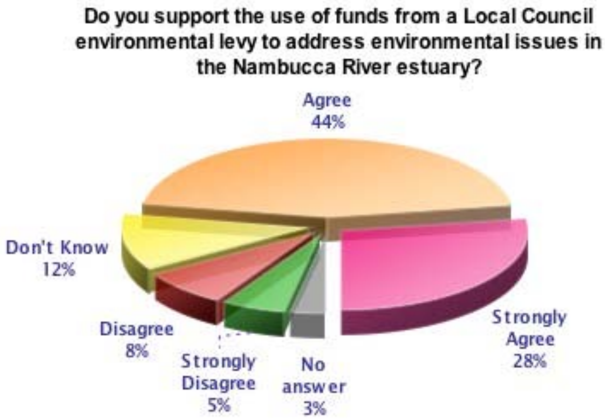


Figure 10 *Collated responses to the question: "Do you support the use of funds from a Local Council environmental levy to address environmental issues in the Nambucca River estuary?".*

Conclusion

Findings from this survey indicate that residents have a fair understanding of the extent of the Nambucca River estuary and of its many values. Most residents value the estuary's natural environment, the opportunities it provides for recreation such as fishing and boating, and its contribution to the local economy through tourism. Wake-boarding/skiing/jet-skiing and the impact of professional fishing on the estuary attracted the most negative feedback in the comments sections of the survey forms.

Although most residents correctly identified the Council as having responsibilities in regard to the estuary, less than half the residents identified DECC has having responsibilities for estuary management. This indicates that there is a degree of confusion in the local community over who is responsible for management decisions in a formal sense. Several comments were received on survey forms that "everyone is responsible for the health and management of the estuary".

The community generally had a low level of awareness of currently occurring estuary management activities. People were most aware of bank erosion works, Aboriginal *GreenTeam* work crews, and Landcare works. From the community's point of view the main issues requiring further attention from responsible organisations are bank erosion, solving the problem of estuary siltation, protecting the estuary environment, and improving bank vegetation. The least supported areas of concern were supporting commercial fisheries such as oyster production, improving boating facilities, regulating skiing, jet-skis and wakeboarding, and increasing river based tourism. Almost three quarters of respondents supported the use of funds from a local government environmental levy to address environmental issues in the estuary.

A third of respondents suggested that they would like to be more involved in estuary programs and activities. To encourage more involvement, residents suggested that advertisements in local free newspapers such as the *Hibiscus happynings* and *Mid Coast Observer* would be the best method (identified as the most read sources of information). Generally residents wanted more information about specific issues affecting the Nambucca estuary, more information about immediate threats to the estuary, and information about actions that impact upon the estuary's many values.

These findings have important implications for future implementation phases of strategies based on this study, particularly in regard to engaging the local community and putting in place effective communication methods to ensure resident's are kept informed of activities to improve water quality and estuary health.

PART 4 Lower Nambucca Estuary Water Quality Study Sampling Program 2008-2009

The sampling methods described below (ie. *Parts 4* and *5* of this Study) were developed after a review of water quality and ecosystem health management projects that have been undertaken over recent years in both NSW and in other eastern States of Australia (see *Part 1*). In summary, the lessons learnt from that review provided the following points which were considered in the design of the sampling program;

- Water quality sampling in the tributary subcatchments should be event based;
- Where possible multiple events should be sampled in each system;
- An attempt should be made to determine total discharge for the sampled events to allow comparisons of total pollutant loads;
- Where resources allow the number of sampling sites should be maximised
- The sampling method and parameters analysed should be able to repeated where further funding becomes available, or should be able to be utilised in other programs with a longer term focus;
- Up to date land use mapping and a knowledge of land management practices may assist subcatchment comparisons of water quality;
- If a modelling approach is to be used, it should be based on recent high resolution land use and soil mapping
- Where data availability is limited a modelling approach will at best provide a ball-park estimate of catchment exports and loads (limiting data includes appropriately scaled land surface elevation information, knowledge of the hydrological connections on low relief floodplains, and local data relating to rainfall distribution and runoff coeficients), and
- In term of ASS disturbance and the export of acid waters and associated heavy metals, an attempt should be made to determine the pathways of acid export before determining the most appropriate sampling regime (particularly relevant to the Gumma Gumma creek subcatchment).

Some of the reviewed programs relied heavily on computer-based models to estimate catchment loads and then to test catchment and subsequent water quality responses to changes in, for example, land use or land management practices. Catchment modelling is an emerging field with likely applications in the Nambucca. However, the field is very complicated with outcomes highly dependent upon the availability of specific datasets that underpin the models. In the Nambucca, due to the lack of specific knowledge and datasets covering the study area (eg. accurate high resolution land surface elevation information that would help determine hydrological pathways and connections on the low relief floodplains and a lack of local runoff coefficient information) a modelling approach was considered to be only useful to provide broad ballpark estimates of nutrients and sediment exports. Apart from a review of the available models in *Appendix A* and the preliminary results of the application of the *WaterCast* model to the study area provided in *Appendix B*, no further consideration of modelling is given in this Study.

Consequently, the 2008-2009 sampling program has focused heavily on event based sampling in all major tributaries feeding into the lower Nambucca estuary except Newee Creek (see *Figure 1 Study Area*). Additionally, due to resource constraints and difficulties associated with gauging discharge in tidal creeks, multiple sampling and estimates of event discharge were limited to a single sampling site on Beer Creek.

Sampling Methods

Water Quality samples were collected using ISCO 6712 automated water sampler units with ISCO 730 bubbler modules installed. The sampling units were installed on concrete slabs placed on creek foreshores and covered with lockable steel cases to discourage vandalism. In the tidal reaches of Teagues, Watt and Bellwood creeks and Lumsdens Drain the pump head was attached to a moveable floating rig (see *Figure 11* and *Plates 1 & 2*) after early tests showed that the creeks were subject to salt wedge stratification, even in the case of medium intensity rainfall events. Bubbler unit sensors were placed at or near the deepest point of the creek attached to a concrete pad to resist movement. The bubbler unit allows the continuous logging of water level. In non-tidal waters this allows an estimation of flow and discharge to be calculated. Additionally, recording flow level allows an analysis of how each waterway behaves in a rainfall event (ie. a hydrograph to be generated) and streamlines the process of choosing samples for analysis.

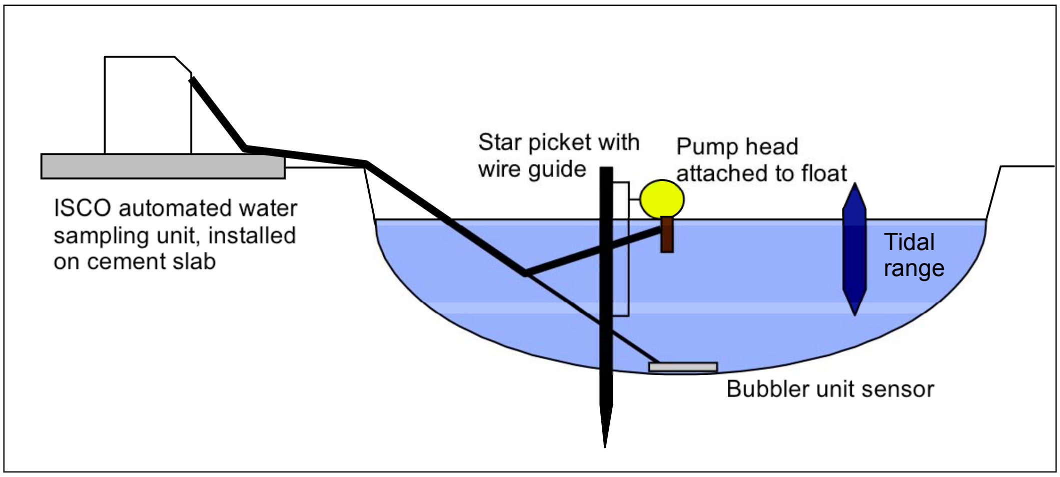


Figure 11 *Typical installation of the ISCO Automated Water Sampler to ensure surface water collection in stratified tidal conditions.*

Plate 1 *ISCO automated stormwater sampling*

Plate 2 *Suction line for sampling estuarine*

Prior to sampling the bottles were thoroughly rinsed with water, then rinsed with approximately 200mL of 100% ethanol, and then allowed to dry completely. Sampling was either automatically initiated at a preset water level (in non-tidal waters eg. Beer Creek) or activated manually when medium to heavy rainfall was either expected or under way. Potential sampling events were identified using short-term weather forecasting reports and the Manly Hydraulics real-time rainfall gauge at Stuarts Island (accessed remotely via modem). Upon activation twenty-four samples of 900ml were collected, at intervals specific to each creek and the type of expected event.

From the 24 collected samples 3 were chosen for constituent analysis. In the case of Beer Creek, the three samples were chosen after a brief analysis of the water level log allowed choice of a sample from the first flush of the event, a sample from the height of the event and a sample from the tail of the event. In the case of the tidal creeks, each of the 24 samples were analysed for salt content using a salinity refractometer allowing the selection of samples that represented stormwater run-off with minimal or no tidal mixing. Upon selection, samples were agitated to remix settled materials and separated into two portions for analysis. 200mL was transferred into a sterile container for bacterial analysis and the rest was transferred into a clean bottle for analysis of nutrient, pH, sediment, and other physical parameters, depending on the system being sampled. Samples were then delivered immediately in an esky to the NATA certified Coffs Harbour Environmental Laboratory for analysis. Samples were analysed for Total Nitrogen (TN), Total Phosphorus (TP), Total Suspended Solids (TSS), Enterococci, pH and turbidity, Faecal Coliforms in some cases (including Lumsdens Lane, Wrights Corner, and Gumma Gumma Creek), Gumma Gumma Creek samples were also analysed for titratable acidity, chloride, sulphate, iron, and aluminium.

Rainfall over the sampling period

A greater proportion of pollutants are transported from catchments during more intense rainfall events (Fletcher *et al*. 2004). This is an important consideration during a water-quality monitoring program. It means not only that specific rainfall event affects the type of runoff collected, but also that the antecedent rainfall patterns affect the 'store' of pollutants available to be exported from the catchment during a given rainfall event. In effect, prolonged dry or drought conditions followed by intense rainfall are likely to produce the highest concentrations of pollutants in runoff.

The sampling was undertaken between December 2008 and June 2009. *Figure 12* is a summary of daily rainfall for the sampling period and the 5 months prior to it. In the five months before commencement of sampling, rainfall was relatively infrequent and only a few events of significant intensity (>30mm/day) were observed. Rain for the months of July to December 2008 was mostly within 10-20% of long term averages with August the only real exception, being much drier than average.

During the sampling period there were an unusual number of intense and sustained rainfall events. These were associated with a pattern of east coast lows that developed over the period and brought widespread flooding to the North Coast and Mid-north Coast region. Rainfall for the months of February, April, May and June far exceeded (25-150% greater) local long term averages. This factor provided an excellent background for event based runoff sampling. With due consideration to the timeframe for the project an effort was made to avoid sampling rainfall events occurring directly after (within two to three weeks) a previous and large event. It was hoped that this would avoid 'falsely positive' results where low concentrations of pollutants were detected because they had been washed into the river in previous events.

In general, the use of automated samplers and access to up to the hour rainfall information via the Bureau of Meteorology and Manly Hydraulics Lab websites meant that 'first flush' runoff conditions were captured for each of the events sampled.

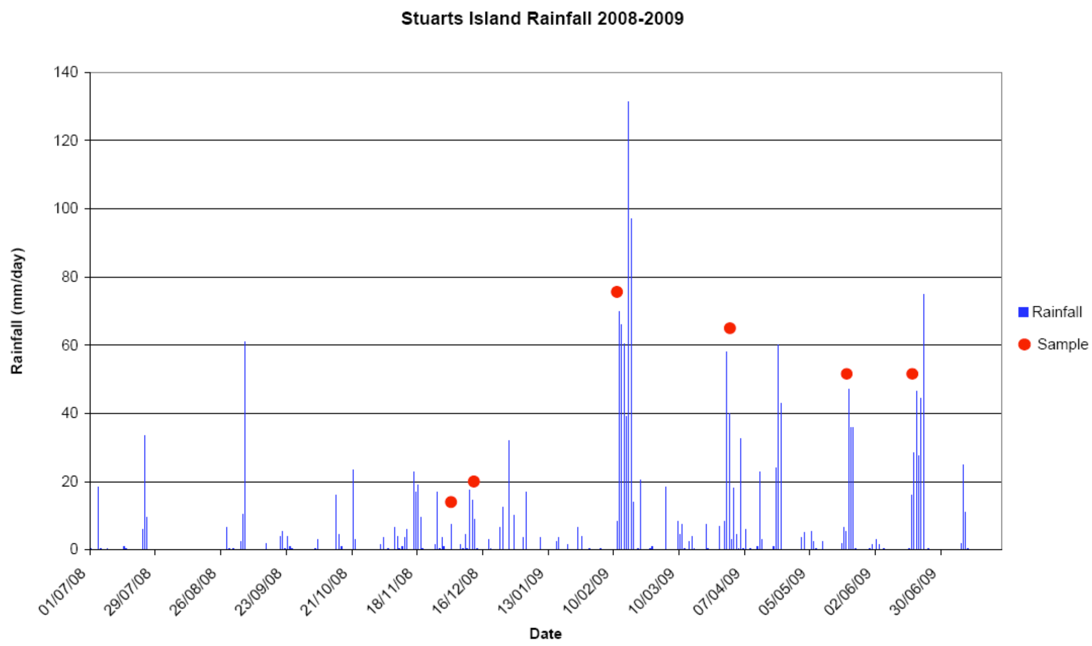


Figure 12 *Stuarts Island daily rainfall during the sampling period.*

Summary of Event-based Sampling Results and Subcatchment Comparisons

Event based stormwater results aim to provide a 'worst case' picture of pollutant transport from catchment to river. However, the results are as much reflective of the specific event that generated them and the antecedent weather patters as they are of catchment condition. This makes drawing definitive conclusions from limited samples collected over a range of events difficult. In attempting to use the collected data for generating management decisions two benchmarks have been chosen for comparison. For each creek sampled during this study the benchmarks for comparison have been the mean and median event based results reported in Fletcher *et al*. (2004) and all the results for the other creeks sampled in this study.

Sampled Water was analysed for pH, turbidity, Total Nitrogen (TN), Total Phosphorus (TP), Total Suspended Solids (TSS) and *Enterococcus*. In the case of the Lumsdens Lane drain and Wrights Corner drain, faecal coliforms were also analysed. In the case of the Gumma Swamp extra parameters were analysed to investigate acid export, being, titratable acidity (Acidity as $CaCO_3$), chloride-sulphate ratio ($Cl:SO_4$) and aluminum (Al) and iron (Fe) concentrations. *Table 2* includes a brief description of the analytes used in this study.

In the summary of results that follows, indications of the ANZECC guidelines for aquatic ecosystems are depicted on the graphs. However, it must be remembered that the guideline values represent values that relate to open estuarine waters and not stormwater flows from tributaries. The ANZECC values are provided as extra information only and are not intended to infer target values for the measured parameters in the stormwater samples.

Table 2 *A list of the analytes used throughout this study.*

pH	A measure of the Hydrogen ion concentration $[H^+]$. The pH scale is between 0 and 14 with 0 being the most acid and 14 being the most basic. A pH of 7 is neutral.
Turbidity	A measure of the capacity of the water to transmit light. Light transmission is in turn related to the health and distribution of aquatic plants and the overall productivity of the estuary. Turbidity is related to Total Suspended Sediment though they are not equivalent.
Total Nitrogen	A measure of the sum of the organic (amino and nucleic acid derived) and inorganic (NO_x, NH_3, N_2) nitrogen in the water sample. Organic and inorganic nitrogen is found naturally in waterways but elevated levels can lead to problems with nuisance plant growth and detrimental effects on stream ecology. Elevated concentrations of nitrogen containing substances in estuaries are generally derived from processes in the greater catchment.
Total Phosphorus	A measure of the total phosphorus in water samples. Phosphorus is found naturally in waterways but elevated levels can lead to problems with nuisance plant growth and detrimental effects on stream ecology. Elevated concentrations of phosphorus containing substances are generally derived from processes in the greater catchment.
Total Suspended Solids	A measure of the particulate matter suspended within the water column. Elevated levels are generally associated with erosion of river and creek banks within the catchment or other soil disturbances. High suspended solid levels can cause poor health by interfering with light transmission.
Enterococcus	A genus of bacteria, formerly known as type-D *Streptococcus*, whose presence is commonly used as a general indicator for the faecal contamination of water. *Enterococcus* is widely regarded as the most reliable indicator of faecal pollution in estuarine ecosystems.
Faecal Coliforms	A suite of bacteria whose presence is commonly used as an indicator for the faecal contamination of water.
Acidity as $CaCO_3$	This is an alternate way of measuring the acidity of water. It refers to the potential for water to release acidic material and is used primarily to assess acid runoff from suspected acid sulfate soil disturbances.
$Cl:SO_4$	The ratio of chloride to sulfate in runoff can provide an indication of the derivation of the soil and thus the potential for the presence of acid sulfate soils. Ratios >4 generally indicate marine derived soils and thus a high likelihood of potential ASS material.
Aluminium and Iron	These two metals are commonly found in elevated concentrations in water running off of active acid sulfate soils. At high concentrations, and especially in acidic (pH<7) waters, these elements are toxic to aquatic life.

pH summary and subcatchment comparisons

Figure 13 shows that whilst pH levels were largely outside of the ANZECC (2000) default guideline range for estuarine waters no samples were found to have extremely low pH values. None of the samples analysed could be considered dangerous for the majority of aquatic organisms. For storm runoff, the results fall within the 'normal' range. The majority of the samples taken in the dry period showed increased pH associated with reduced freshwater runoff. The notable exception is East Street Drain, which drains a disturbed coastal floodplain area and appears to be subject to lower levels of tidal penetration.

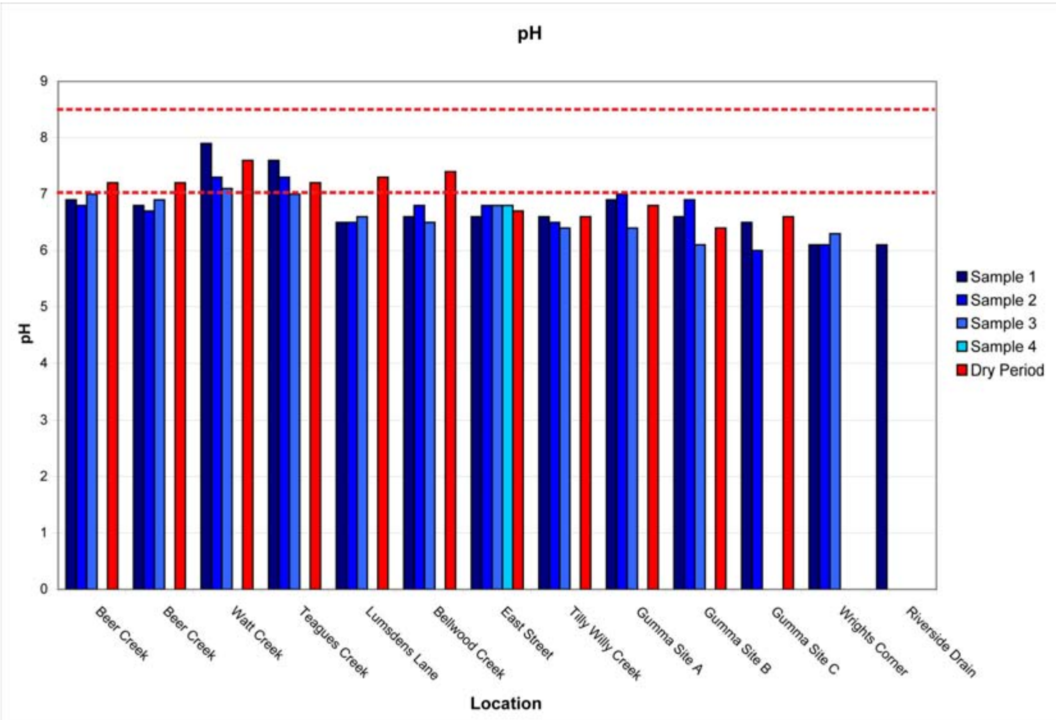


Figure 13 *pH levels of all samples collected to date plotted against ANZECC (2000) default trigger values for slightly disturbed estuarine ecosystems.*

Turbidity summary and subcatchment comparisons

Figure 14 shows that almost all samples exceeded ANZECC (2000) guideline values for estuarine waters with respect to turbidity. The second round of samples collected from Beer Creek was exceptionally turbid water. This is reflective of the increased sediment carrying capacity of waters moving at a higher velocity and is typical of urbanised catchments where water is encouraged to exit the catchment quickly due to the high proportion of hard (paved) surfaces. This effect is enhanced in the case of Beer Creek due to the steepness of the catchment and, potentially, recent soil disturbances in the upper catchment area. Samples taken from East Street show a similar but much less pronounced effect. The samples taken during the dry period were all found to be below the ANZECC default guideline value for turbidity.

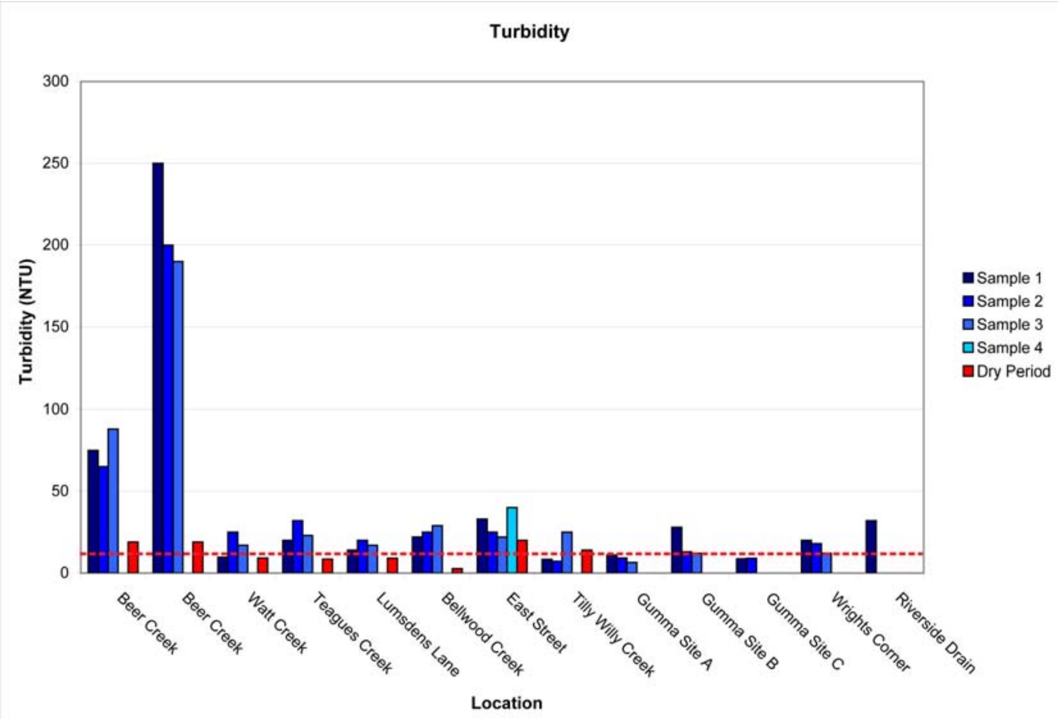
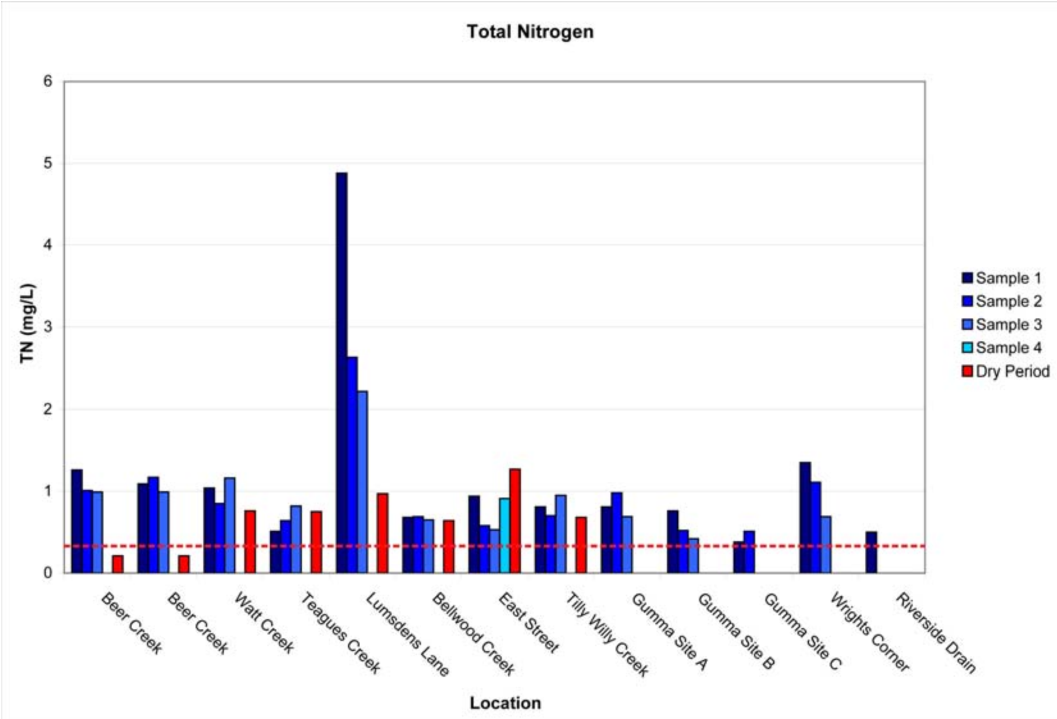


Figure 14 *Turbidity levels of all samples collected to date plotted against ANZECC (2000) default trigger values for slightly disturbed estuarine ecosystems.*

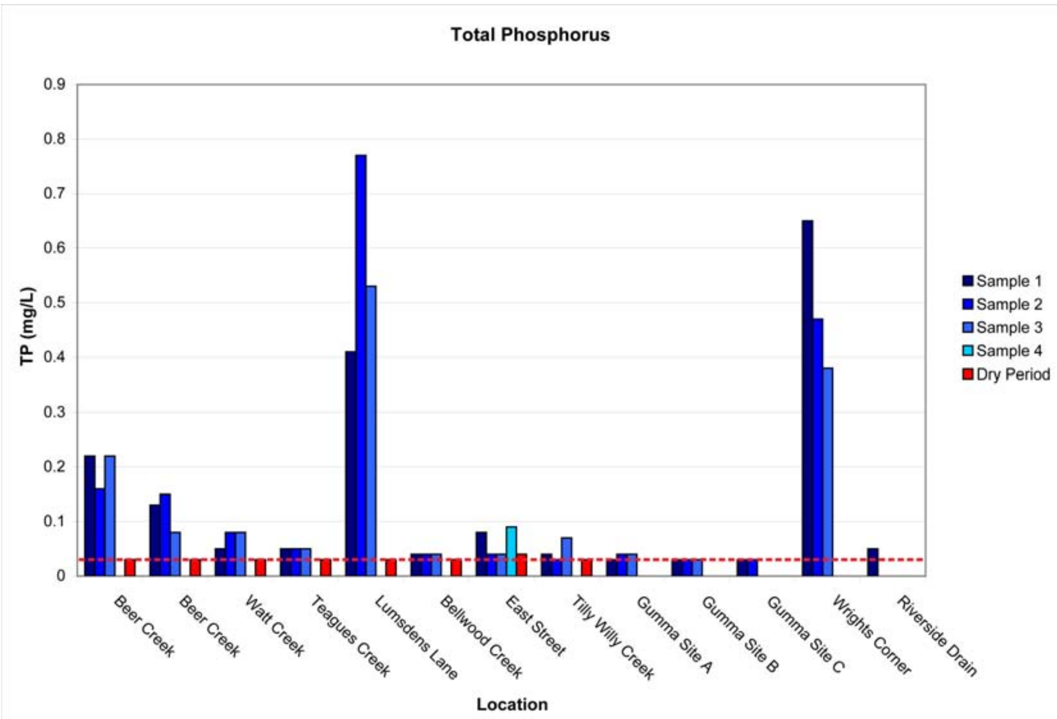
Nutrient summary and subcatchment comparisons

Figures 15 and 1*6* show the concentrations of Total Nitrogen and Total Phosphorous in samples collected throughout the study area. The figures show that very high concentrations of nutrients were exported from the Lumsdens Lane Drain and Wrights Corner during the sampled rainfall events. Lumsdens Lane and Wrights Corner drains are adjacent and transport water from agricultural land that is likely to be under similar land management regimes. The high nutrient levels observed are likely to be a result of recent fertilizer application and/or high levels of manure reaching the waterways. Total Phosphorus levels measured from Beer Creek were also notably high. This may also be indicative of household fertilizer use. Event-based samples from all other locations were also above ANZECC default guideline levels for Total Nitrogen. However, with due consideration to the fact that the sampling was event based, nutrient export levels from all of the waterways except Lumsdens Lane and Wrights Corner are within expected levels.

Figure 5 also shows that Total Nitrogen levels remained elevated during the dry period at all sites with the exception of Beer Creek. There are a number of sources of nitrogen in waterways, including the natural breakdown of vegetable and animal material, bacterial nitrogen fixation, urban stormwater, agricultural runoff including faecal material entering the water and fertiliser use, effluent disposal, and erosion. The pathways of nitrogen delivery, transformation and removal are complex. A brief analysis of land uses indicates that the elevated concentrations of nitrogen in all of the dry weather samples (with the exception of Beer Creek) are most likely to be associated with natural causes such as the breakdown of vegetative matter. The influence of faecal matter washed into creeks from grazing areas during wet weather may also be a factor.



Figures 15 *Total Nitrogen levels of all samples collected to date plotted against ANZECC (2000) default trigger values for slightly disturbed estuarine ecosystems.*



Figures 16 *Total Phosphorus levels of all samples collected to date plotted against ANZECC (2000) default trigger values for slightly disturbed estuarine ecosystems.*

Total Suspended Solids summary and subcatchment comparisons

Figure 17 shows that Total Suspended Solid concentrations are highest from the urban catchment drained by Beer Creek. In the same vein as the results for turbidity, this is indicative of the increased sediment carrying capacity of rainfall runoff from urban areas with a greater proportion of paved surfaces and reflects catchment specific issues such as soil disturbance, steepness, and soil type.

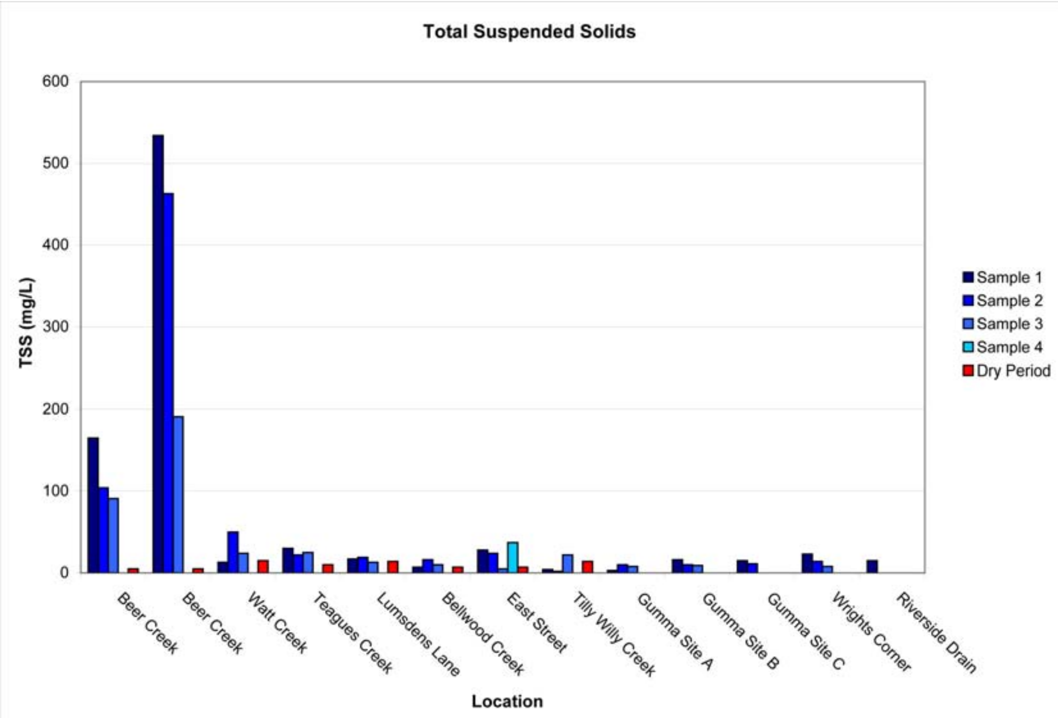


Figure 17 *Total Suspended Solids levels of all samples collected to date.*

Bacterial summary and subcatchment comparisons

Enterococcus levels were very high in all samples collected and extremely high in samples from Lumsdens Lane and from the second sample collected from Beer Creek. In both cases, the results are indicative of leaking sewage mains and or malfunctioning on-site sewage management systems or some similar source of faecal pollution. The numbers from Lumsdens Lane in *Figure 8* are indicative only. The staff of Coffs Harbour Environmental Laboratory communicated that they were too numerous to count and therefore in excess of 50000 colony forming units per 100mL.

The elevated levels of *Enterococcus* in the samples taken from Lumsdens Lane could indicate high levels of cattle faeces entering the drain or possibly a leaking on-site sewage management system in the catchment area. Elevated levels of *Enterococcus* from the Beer Creek catchment may also be linked to animal faeces from household pets or possibly from a leaking sewage main. Sterol testing would be required to differentiate between sources.

In order to further clarify the picture of bacterial export from Lumdens Lane and the drain at Wrights Corner, faecal coliform concentrations were also measured in samples collected at these locations (*Figure 19*). The results show that high levels of faecal coliforms were present in the runoff from Lumdens Lane and that the concentrations of faecal coliforms in runoff collected from Wright's Corner were well within those expected from agricultural land. The lower levels of faecal coliforms relative to *Enterococcus* could possibly relate to the reduced persistence of faecal coliforms in the environment.

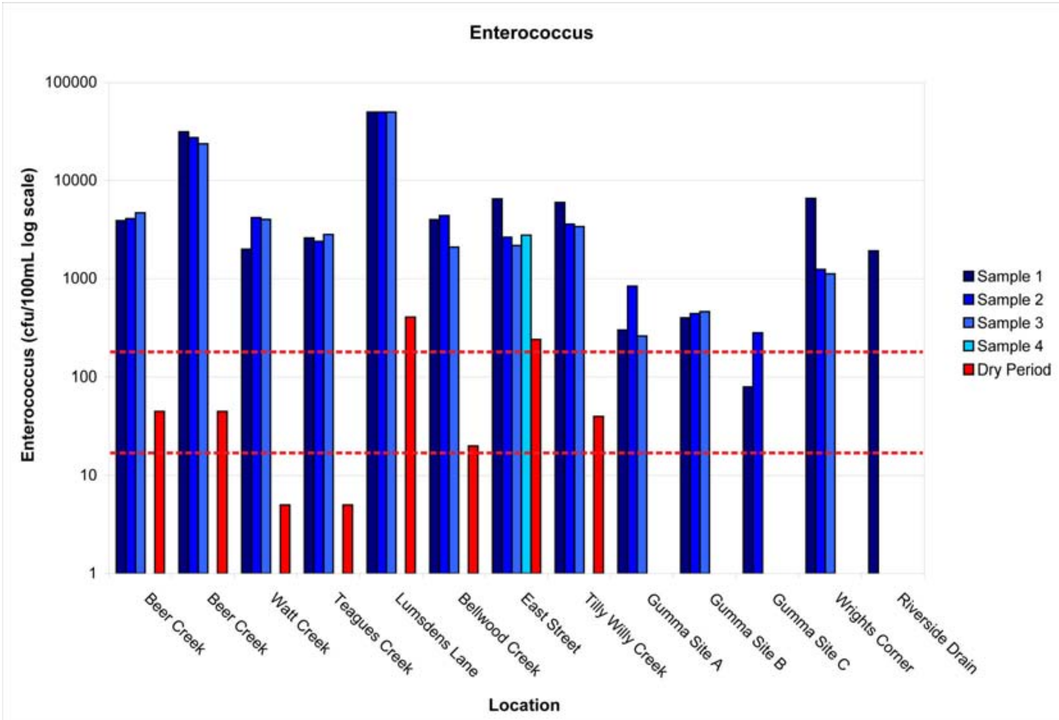


Figure 18 *Enterococcus levels of all samples collected to date plotted against ANZECC (2000) default guidelines for primary contact and secondary contact recreation.*

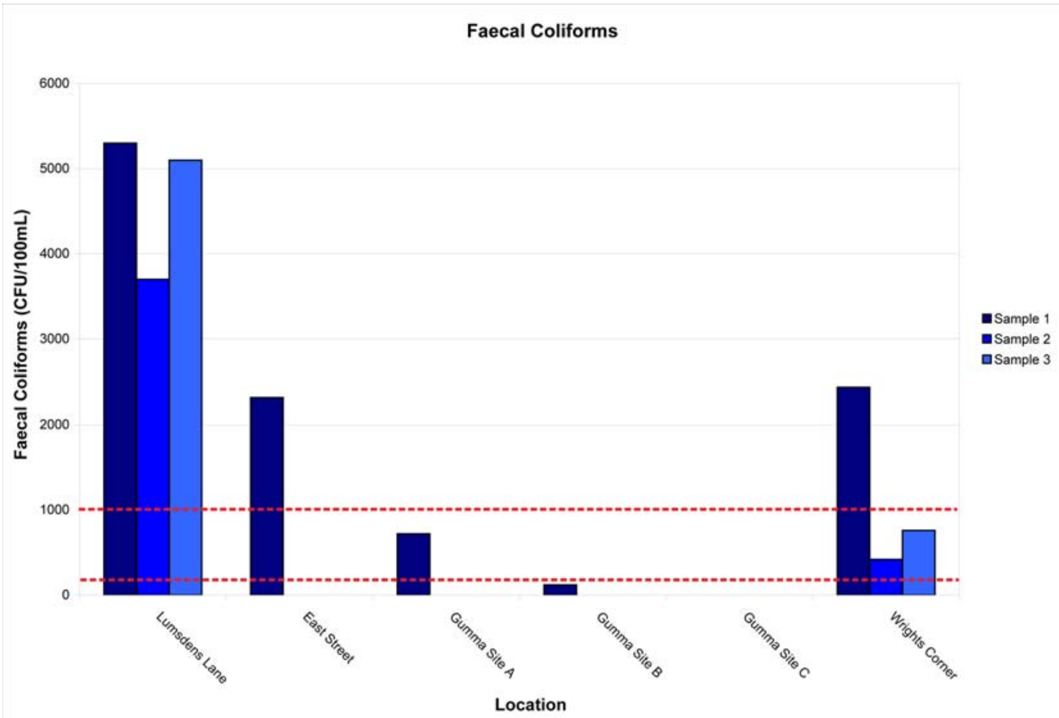


Figure 19 *Faecal coliform levels of all samples collected to date plotted against ANZECC (2000) default guidelines for primary contact and secondary contact recreation.*

PART 5 Subcatchment Water Quality Reports

The following water quality reports provide subcatchment specific sampling information, water quality results, and discussions of results for each sampling site within the study area.

As with *Part 4* above, ANZECC guideline values for the protection of aquatic ecosystems are referred to in the tables. These guidelines are provided for reference only and are not intended to indicate target values for stormwater flowing from tributaries entering the estuary.

A summary of management recommendations for all subcatchments is provided in *Part 6* of the Study.

Beer Creek Subcatchment

Beer Creek is a highly modified drainage line that flows out of a steep, urbanised catchment in central Nambucca Heads (see *Figure 20*). There are traces of scattered remnant vegetation throughout the catchment. A high proportion of the water drained through Beer Creek passes through Nambucca Heads stormwater infrastructure. The downstream 200m of Beer Creek have a formed concrete bed. Immediately prior to its confluence with the Nambucca River, Beer Creek flows through a three-pipe culvert, which provided an ideal place to install the automatic water sampler. Immediately upstream of the culvert is a trash rack.

Figure 20 *Map of the Beer Creek subcatchment showing landuse classes and location of the sampling site.*

Beer Creek subcatchment sampling results

The location of the units at Beer Creek meant that the samplers could be triggered automatically by the water level in the culvert. In order to capture the first flush of a runoff event the unit was set to begin sampling with a water level of 100mL. For the same reason a two-part sampling program was chosen, with the first 4 samples being collected at 5 minute intervals and subsequent samples being collected at 30 minute intervals.

Beer Creek was sampled twice, first on the night of December 2nd 2008 and then on the morning of December the 11th 2008. The results of testing of the samples and a comparison to the ANZECC guidelines for the protection of aquatic ecosystems are provided in *Table 3*. The water level log (see *Figures 21* & *22*) shows that Beer Creek reacted quickly to the rainfall events, with water level spiking and largely receding within two hours. This is to be expected for an urbanised catchment with an abundance of hard surfaces. Samples were taken to coincide with the times that the water was rising, peaking and trailing off.

Table 3 *Results of event based water quality sampling at Beer Creek*

Sample	Date	pH	Turbidity *(NTU)*	TN *(mg/L)*	TP *(mg/L)*	TSS *(mg/L)*	Enterococcus *(cfu/100mL)*
1st Beer (a)	02.12.08	6.9	75	1.26	0.22	165	3900
1st Beer (b)	02.12.08	6.8	65	1.01	0.16	104	4100
1st Beer (c)	02.12.08	7	88	0.99	0.22	91	4700
2nd Beer (a)	12.12.08	6.8	250	1.09	0.13	534	31400
2nd Beer (b)	12.12.08	6.7	200	1.17	0.15	463	27400
2nd Beer (c)	12.12.08	6.9	190	0.99	0.08	191	23800
Dry weather sample	18.05.09	7.2	19	0.21	0.03	5	45
ANZECC Guidelines	(protection of aquatic ecosystems)	7 - 8.5	0.5 - 10	0.3	0.03	n/a	35 (primary) 230 (secondary)

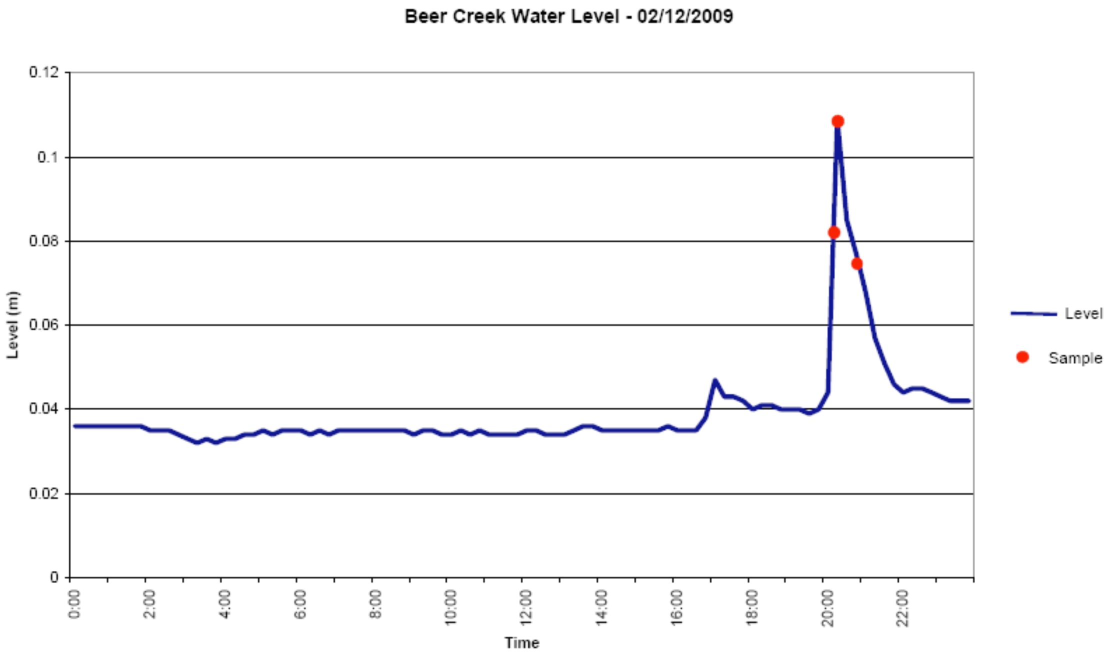


Figure 21 *Beer Creek water level and sampling times for first sampling event, 2 December 2008.*

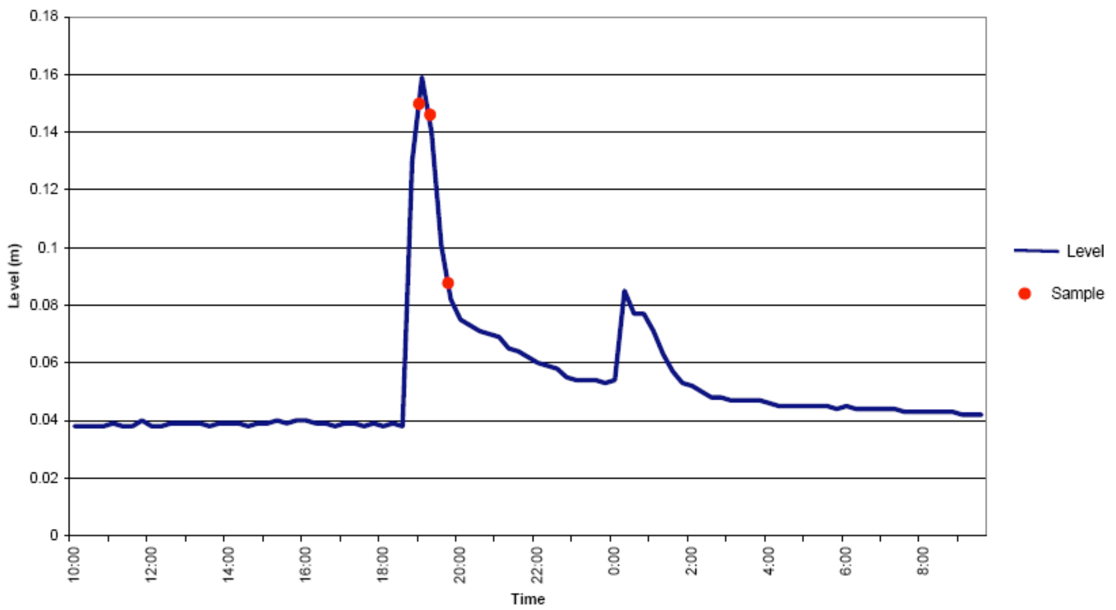


Figure 22 *Beer Creek water level and sampling times for second sampling event, 10-11 December 2008*

Discussion of Beer Creek Results

Samples were collected from Beer Creek over two separate rainfall events. The recorded data shows that water moves very quickly through the Beer Creek catchment, with levels spiking and receding rapidly. This is due to the urbanised nature of the catchment, the steepness of the terrain and the creek is fed by hydraulically efficient stormwater infrastructure. The high velocity of stormwater runoff from Beer Creek increases its capacity to transport sediment, and associated nutrient and bacterial pollutants, from the catchment to the Nambucca River. These factors are evident in the high levels of turbidity, Total Suspended Solids, Total Phosphorus and *Enterococcus* in the samples from Beer Creek, particularly those collected during the higher rainfall event on the 10^{th} and 11^{th} of December 2008.

Whilst the levels of pollutants in runoff from the Beer Creek catchment are within the bounds of those commonly encountered from residential areas (Fletcher *et al*. 2004) over the course of a storm they still represent the delivery of a significant volume of pollutants. In particular;

- The Beer Creek catchment is a source of high levels of faecal pollution, a concern to the oyster growing industry and for people using the river recreationally. Whilst the origin of the faecal material is uncertain at this stage the most likely explanations are droppings from pets and wild fauna, or a leaking sewer rising main. However, the proximity of the Beer Creek confluence to the estuary mouth means that residence times for pollutants in the water column are likely to be comparatively short.
- The Beer Creek catchment delivers higher concentrations of sediments than any of the other subcatchments in the lower Nambucca. High suspended sediment loads can cause negative ecological impacts. These include smothering seagrasses, reduced primary productivity and interference with the respiration of aquatic fauna. In addition to this, suspended sediments act as a vector for the delivery of other forms of pollution such as nutrients and faecal matter. The level of suspended sediment in the runoff is most likely linked to poor onsite sediment controls in areas where soil disturbance is high.
- Relatively high concentrations of phosphorus were detected in runoff from the Beer Creek Catchment. This is most likely linked to fertilizer use in backyards.

Teagues Creek Subcatchment

Teagues Creek drains a mostly forested catchment before entering into a small tidal marsh/mangrove forest prior to its confluence with the Nambucca River (see *Figure 23*). There is a small area of grazing land in the upper catchment, an old waste disposal site, a quarry and a small urban residential area in the lower catchment. The sampling station was located approximately 20 metres downstream of the Pacific Highway bridge adjacent to a public walkway.

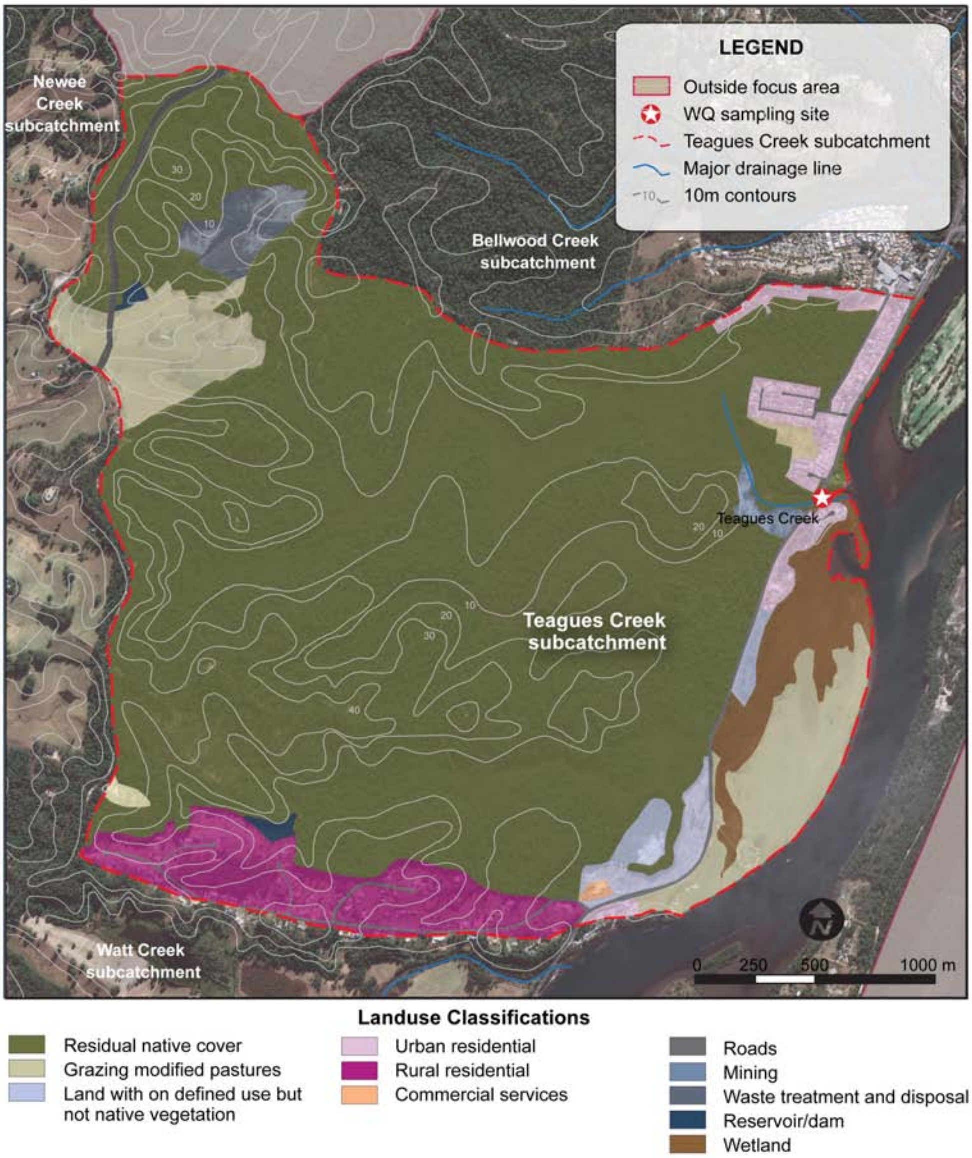


Figure 23 *Map of the Teagues Creek subcatchment showing landuse classes and location of the sampling site.*

Sampling results

The location of the sampler on Teagues Creek proved to be problematic, with constant vandalism causing problems with the sampling unit. Consequently, the bubbler unit was not operational at the time that sampling was undertaken and precise water level data was not obtained over the sampling period. The water level shown in *Figure 24* is therefore indicative only. Samples from Teagues Creek were collected at 30 minute intervals to capture runoff across an entire tidal cycle. Commencement of sampling was triggered manually after observations of rainfall at the Stuarts Island gauge confirmed a likely run-off event.

The water level and salinity graph of Teagues Creek shows that freshwater runoff was attenuated by tidal activity. Shortly after the peak of high tide, however, the freshwater began to flow quickly, the salinity dropping rapidly. The graph also shows that relatively little mixing of runoff and tidal water occurred upstream of the sampling gauge, ie., salinity values in the runoff samples were low across the low tide.

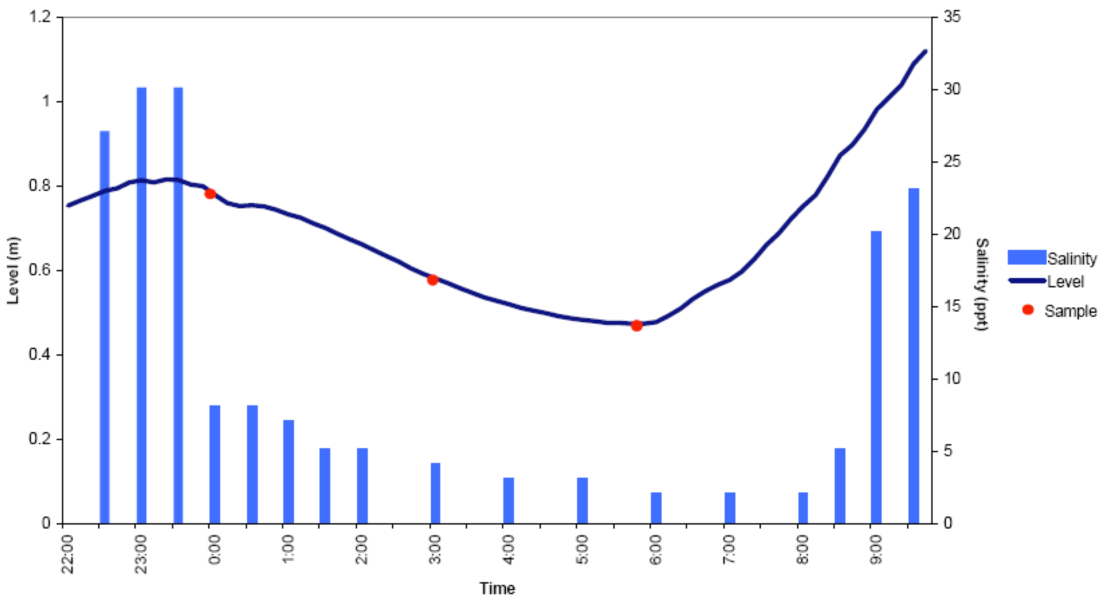


Figure 24 *Teagues Creek water level (indicative), salinity and sampling times.*

In the case of Teagues Creek the samples were chosen to represent both the different stages of the flow event and the freshest runoff available. The results are provided in *Table 4*.

Table 4 *Results of event based water quality sampling at Teagues Creek, Nambucca Valley*

Sample	Date	pH	Turbidity *(NTU)*	TN *(mg/L)*	TP *(mg/L)*	TSS *(mg/L)*	Enterococcus *(cfu/100mL)*
Teagues (a)	13.02.09	7.6	20	0.51	0.05	30	2600
Teagues (b)	13.02.09	7.3	32	0.64	0.05	22	2400
Teagues (c)	13.02.09	7	23	0.82	0.05	25	2820
Dry weather sample	18.05.09	7.2	8.5	0.75	0.03	10	5
ANZECC Guidelines	(protection of aquatic ecosystems)	7 - 8.5	0.5 - 10	0.3	0.03	n/a	35 (primary) 230 (secondary)

Discussion of Teagues Creek Sampling Results

The concentrations of all measured parameters in samples taken from Teagues Creek are in line with expected normal values in stormwater from a mostly forested catchment (Fletcher et al., 2004). The limited extent and location of development within the catchment is most likely the primary factor keeping the sampled water quality parameters within a “normal” range for stormwater run-off. Other factors include the mostly forested nature of the catchment and the positive impacts that the wetland systems have on filtering and processing pollutants and attenuating stormwater discharges.

Watt Creek Subcatchment

Watt Creek is a tidal creek that flows out of a mixed cleared and forested catchment (*Figure 25*). More than 50% of the catchment area consists of grazing lands and the drainage of the floodplain has been significantly modified through the construction of drainage swales and drainage channels to assist production. In the past the main arm of Watt Creek has also been highly modified in its lower reaches, with channelisation works and a floodgate installed on the main channel. However, the floodgate is now defunct and the creek currently functions as a relatively typical small tidal creek.

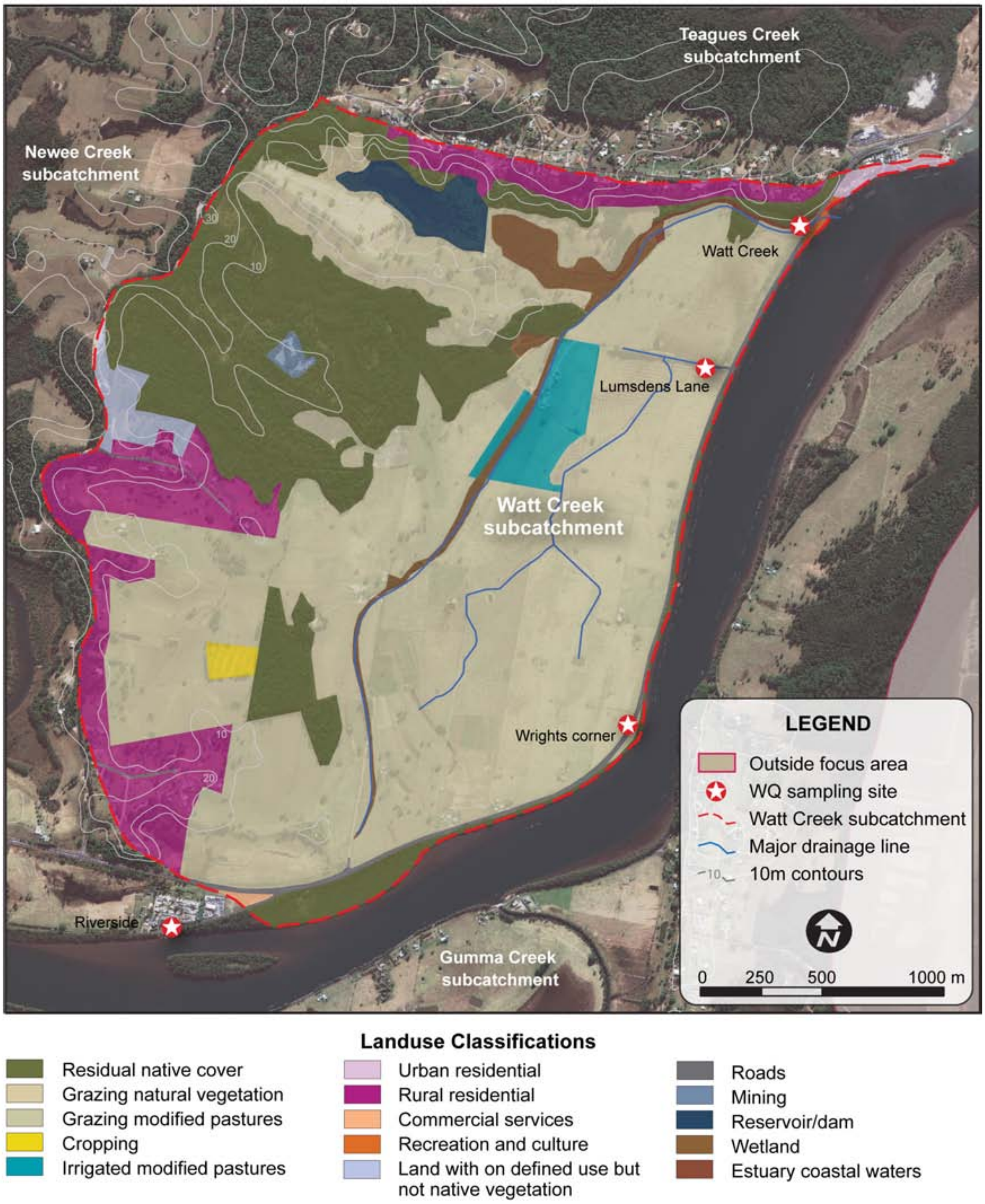


Figure 25 *Map of the Watt Creek subcatchment showing landuse classes and location of sampling sites.*

The most prominent drain now functioning in the catchment runs adjacent to Lumsden Lane. The Lumsden Lane drain is floodgated although some leakage of the gate occurs as evidenced by the growth of mangroves throughout the lower sections of the drain. This drains intercepts a large portion of the runoff from the low relief floodplain areas south east of the main creek through a system of drainage swales and shallow channels. The majority of the runoff flows over modified pastures used for cattle grazing with a relatively smaller area of irrigated pastures also occurring within the potential catchment for the drain. Consequently, pollutants occurring on the floodplain from whatever sources are intercepted by the drain and very efficiently transported to the Nambucca River.

Other drains (eg. Wrights Corner) drain floodplain lands through cuts in the river levee and then through culverts under the Pacific Highway and are not floodgated. These drains generally operate on a smaller scale than the Lumsden Lane drain but have similar landuse characteristics.

Sampling results

Watt Creek

The sampling site on Watt Creek was located immediately upstream of the confluence with the Nambucca River. The water level and salinity graph (*Figure 26*) shows that freshwater flows from Watt Creek are attenuated by the tidal cycle but that freshwater flows arrive quickly on the run-out tide. The results, specifically the salinity profile, also indicate that some mixing occurs between runoff and tidal waters upstream of the sampling site (ie. salinity remains in the vicinity of 10ppt almost until the low tide).

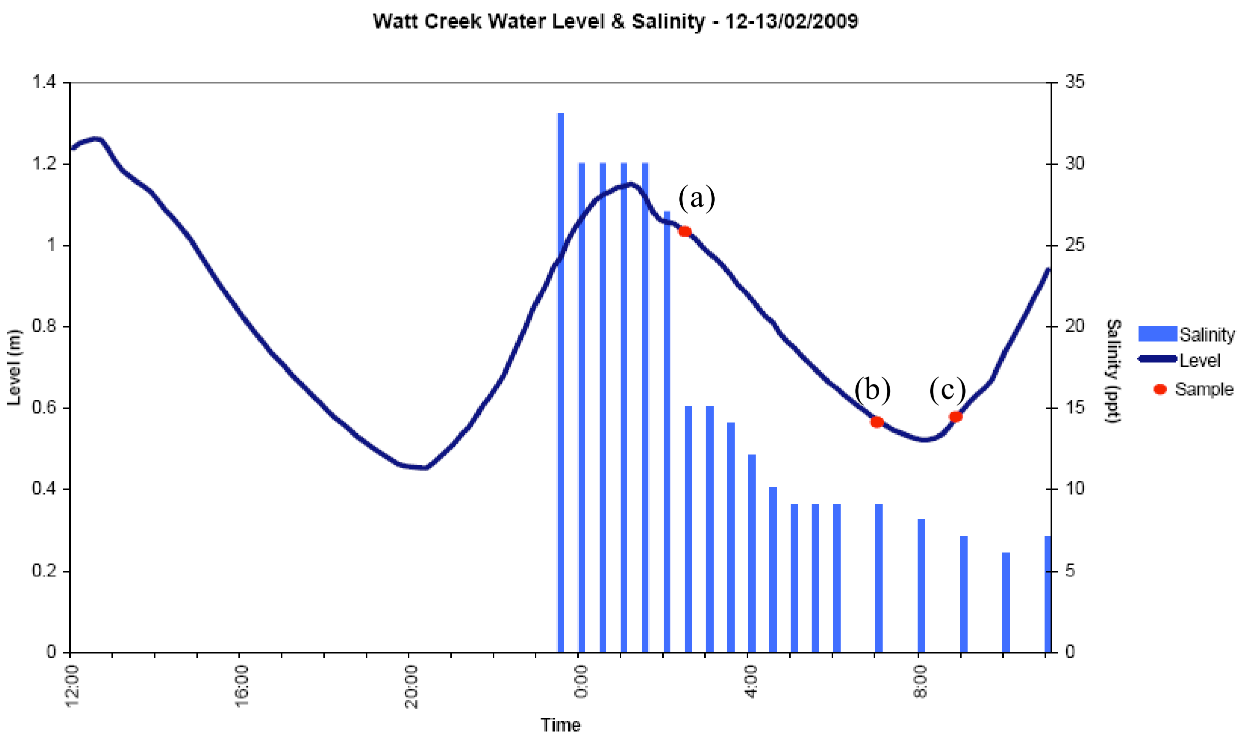


Figure 26 *Watt Creek water level, salinity and sampling times.*

The sampling unit on was set to collect samples at 30 minute intervals in order to capture runoff over an entire tidal cycle. The results of testing of the samples are presented in *Table 5*.

Table 5 *Results of event based water quality sampling at Watt Creek, Nambucca Valley*

Sample	Date	pH	Turbidity (NTU)	TN (mg/L)	TP (mg/L)	TSS (mg/L)	Enterococcus (cfu/100mL)
Watt (a)	13.02.09	7.9	9.7	1.04	0.05	13	2000
Watt (b)	13.02.09	7.3	25	0.85	0.08	50	4200
Watt (c)	13.02.09	7.1	17	1.16	0.08	24	4020
Dry weather sample	18.05.09	7.6	9.2	0.76	0.03	15	5
ANZECC Guidelines	(protection of aquatic ecosystems)	7 - 8.5	0.5 - 10	0.3	0.03	n/a	35 (primary) 230 (secondary)

Lumsdens Lane

The automated sampler was set to collect water from the Lumsdens Lane Drain at 45 minute intervals in order to sample two consecutive low tides. The data shows that the drain reacts relatively quickly to rainfall events but that a sustained runoff is the result (*Figure 27*). Some mixing of incoming tidal waters with the freshwater flows occurs towards high tide due to the leaking floodgate. The sample results are presented in *Table 6*.

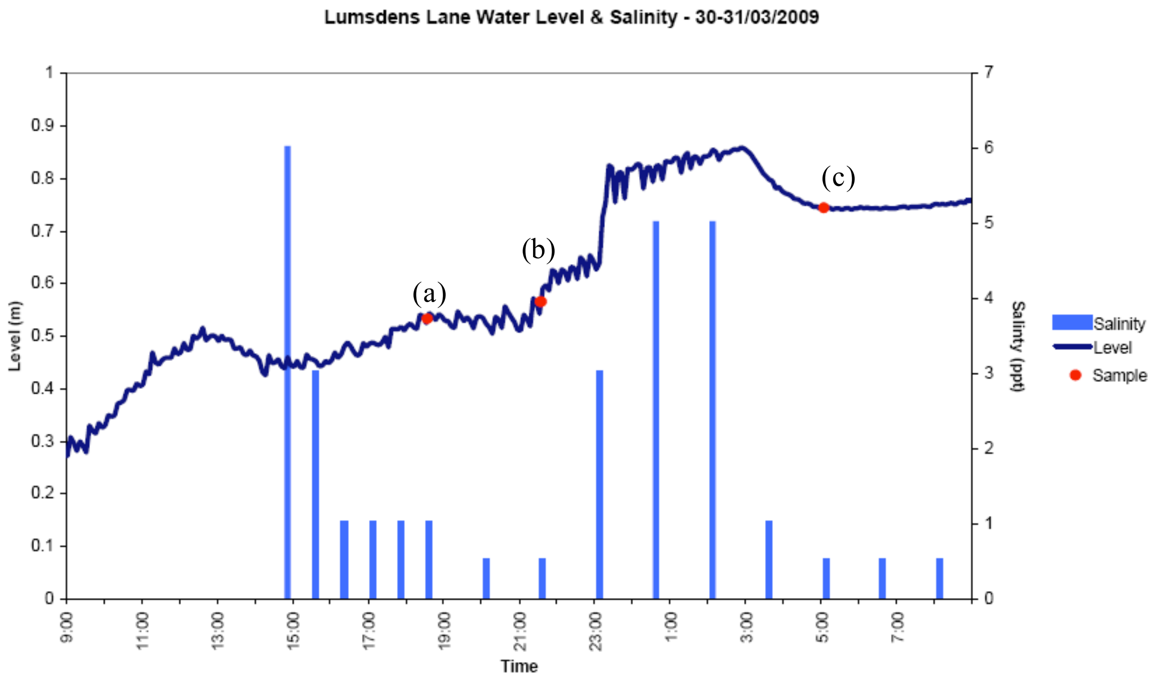


Figure 27 *Lumsdens Lane water level, salinity and sampling times.*

Table 6 *Results of event based water quality sampling at Lumsdens Lane, Nambucca Valley*

Sample	Date	pH	Turbidity (NTU)	TN (mg/L)	TP (mg/L)	TSS (mg/L)	Enterococcus (cfu/100mL)	Faecal Coliforms (cfu/100mL)
Lumsdens (a)	31.03.09	6.5	14	4.88	0.41	17	>50,000	5300
Lumsdens (b)	31.03.09	6.5	20	2.63	0.77	19	>50,000	3700
Lumsdens (c)	31.03.09	6.6	17	2.22	0.53	13	>50,000	5100
Dry weather sample	18.05.09	7.3	9.1	0.97	0.03	14	405	Not sampled
ANZECC Guidelines	(protection of aquatic ecosystems)	7 - 8.5	0.5 - 10	0.3	0.03	n/a	35 (primary) 230 (secondary)	150 (primary) 1000 (secondary)

Wrights Corner

The drain at Wrights Corner carries water from agricultural land similar in nature to the land drained at Lumsdens Lane. It was sampled on the 21st and 22nd of May 2009. Due to a failure with the ISCO pump, the samples were collected manually, however, water levels at the culvert were still accurately recorded. *Figure 28* shows that the drain responds relatively quickly to a rainfall event, probably as a result of the rapid drainage of rainfall off the Pacific Highway (which is fed to the culvert through spoon drains on the highway verge). All samples collected were freshwater samples with tests using a salinity refractometer showing no mixing with tidal waters (ie. zero salinity).

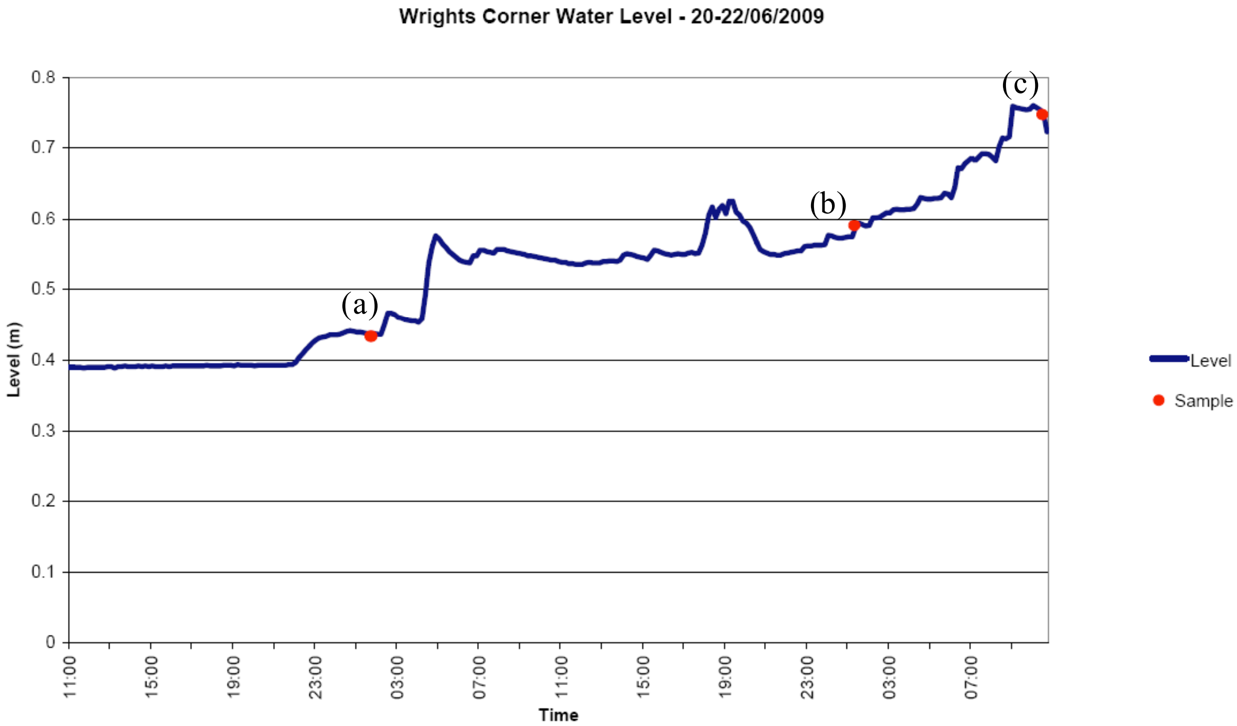


Figure 28 *Wrights Corner Drain water level and sampling times.*

Table 7 *Results of event based water quality sampling at Wrights Corner culvert, Nambucca Valley*

Location	Date	pH	Turbidity (NTU)	TN (mg/L)	TP (mg/L)	TSS (mg/L)	Enterococcus (cfu/100mL)	Faecal Coliforms (cfu/100mL)
Wrights Corner (a)	21.5.09	6.1	20	1.35	0.65	23	6600	2440
Wrights Corner (b)	22.05.09	6.1	18	1.11	0.47	14	1240	420
Wrights Corner (c)	22.05.09	6.3	12	0.69	0.38	8	1120	760
ANZECC Guidelines	(protection of aquatic ecosystems)	7 - 8.5	0.5 - 10	0.3	0.03	n/a	35 (primary) 230 (secondary)	150 (primary) 1000 (secondary)

Discussion of the Watt Creek subcatchment results

The sampling results show that water quality within the catchment is variable, depending upon the source of receiving waters. Whilst most parameters for the Watt Creek sampling site were within the range of what would be expected for stormwater discharge from a predominantly rural/agricultural catchment, concentrations of Total Nitrogen (TN) and Total Phosphorous (TP) were elevated. This is most likely the result of fertiliser use in areas of pasture improved grazing lands.

In contrast, the Lumsdens Lane results showed very high bacterial and nutrient concentrations. The concentrations of *Enterococcus* in all three wet weather samples were in excess of 50,000 cfu/100ml, TN was almost 4 times higher at its maximum than any other site on the Nambucca, and TP was also significantly elevated. Levels of TN and *Enterococcus* remained very high even in the dry weather sample indicating that these two parameters remained a problem even in dry weather situations. More investigation is required to determine the causes and source of such high readings. Potential causes may include recent use or over use of fertilizers on the paddocks, the inflow of faecal matter from cattle or other animals, or inflow from leaking or faulty onsite sewerage management systems (OSMS) within the Lumsdens Lane drainage catchment.

Samples from the drain at Wrights corner showed similarly elevated levels of TN, TP and *Enterococcus*, however, the levels were substantially less elevated than Lumsdens Lane and reduced over the period of sampling. The most likely source of elevated levels at this site relate to agricultural practices and the export of pollutants through the drainage system with the first flush of runoff. Antecedent conditions, specifically the frequency of heavy and sustained rainfall events in the months prior to the sampling, may also account for lower readings from this site.

Bellwood Creek Subcatchment

Bellwood Creek is a tidal creek that drains a mixed urban, agricultural and forested catchment (*Figure 29*). It is the closest of the tidal tributaries to the mouth of the Nambucca sampled in this study and therefore subject to the greatest variation in water level as a result of tidal movements. The upper catchment is mostly forested but also contains significant urban residential areas in the east and north. The middle section of the catchment is made up of a rural residential subdivision and some mixed grazing land. There is a large, densely populated retirement village in the lower catchment, a commercial area, and a recreation reserve. The two main arms of the creek converge in a mangrove forests before entering the Nambucca River estuary.

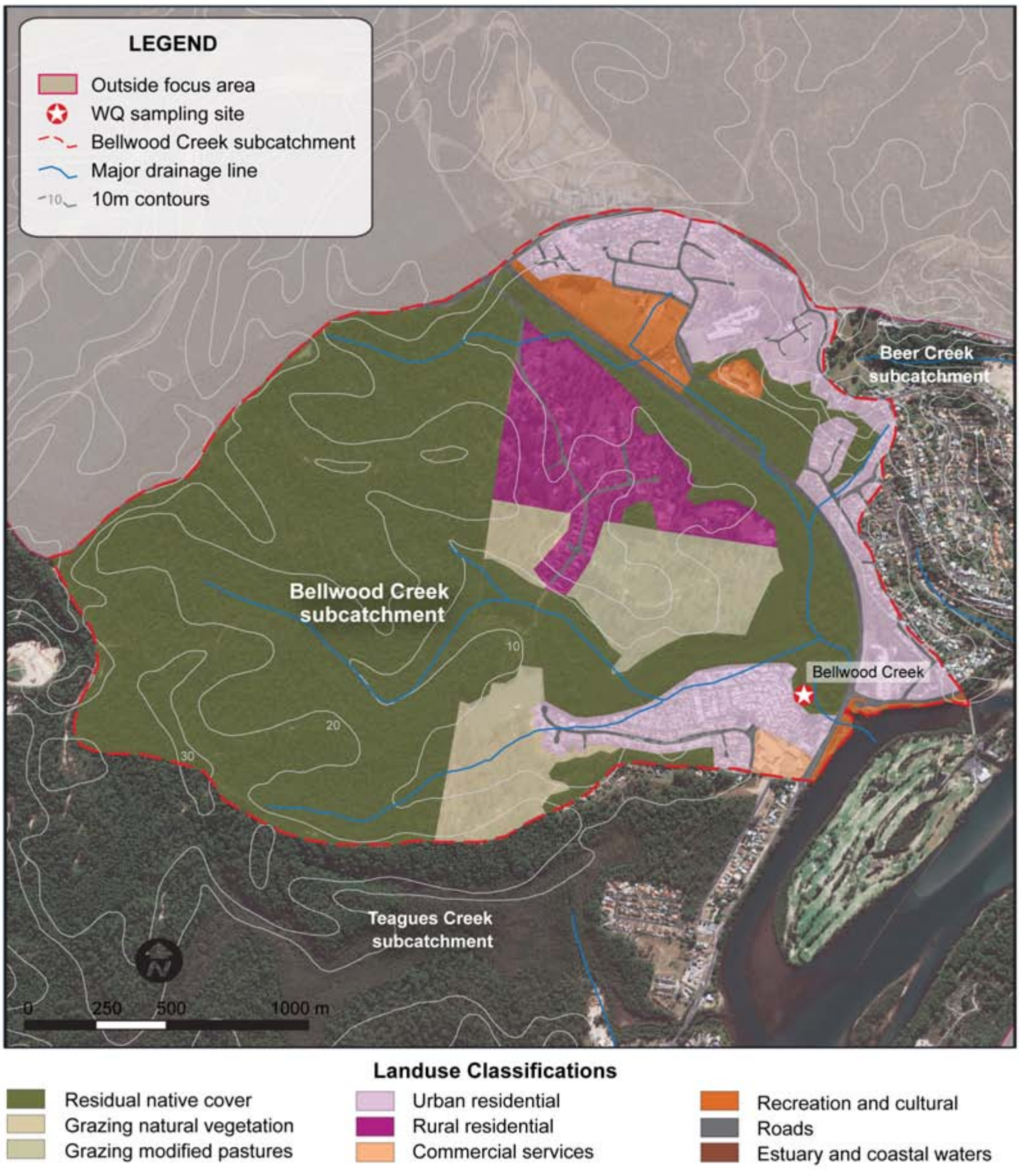


Figure 29 *Map of the Bellwood Creek subcatchment showing landuse classes and location of the sampling site.*

Sampling results

The sampling unit on Bellwood Creek was located approximately 150m upstream of the confluence with the Nambucca River. It was set to collect water at 45 minute intervals in order to capture runoff over two consecutive low tides.

Figure 30 shows that freshwater flows out of the Bellwood Creek catchment are attenuated by tidal movements but that little mixing of tidal and fresh waters occurs upstream of the sampling site. The large variation over the tidal cycle shown in the level of Bellwood Creek shown in *Figure 30* (c.f. 3m) and the corresponding moderate level salinity recording is an indication that freshwater runoff comprised a large part of the water level at the high tide during the sampling period. Results of sampling are presented in *Table 8*.

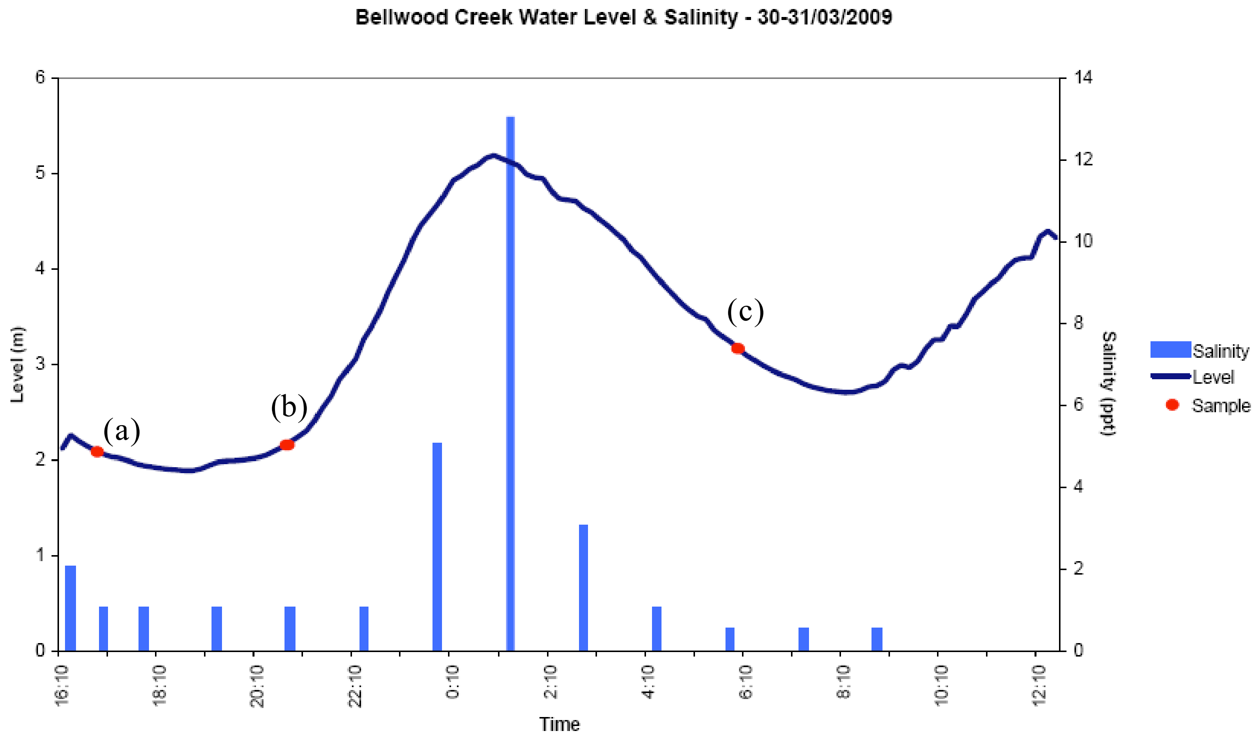


Figure 30 *Bellwood Creek water level, salinity and sampling times.*

Table 8 *Results of event based water quality sampling at Bellwood Creek, Nambucca Valley*

Sample	Date	pH	Turbidity *(NTU)*	TN *(mg/L)*	TP *(mg/L)*	TSS *(mg/L)*	Enterococcus *(cfu/100mL)*
Bellwood (a)	31.03.09	6.6	22	0.68	0.04	7	4000
Bellwood (b)	31.03.09	6.8	25	0.69	0.04	16	4400
Bellwood (c)	31.03.09	6.5	29	0.65	0.04	10	2100
Dry weather sample	18.05.09	7.4	2.7	0.64	0.03	7	20
ANZECC Guidelines	(protection of aquatic ecosystems)	7 - 8.5	0.5 - 10	0.3	0.03	n/a	35 (primary) 230 (secondary)

Discussion of the Bellwood Creek subcatchment results

The concentration of pollutants in the samples collected from Bellwood Creek were at the lower end of the range expected for event based runoff. The limited extent and location of development within the catchment is most likely the primary factor keeping the sampled water quality parameters within a “normal” range for stormwater run-off. Other factors may include the extensive natural bushland in the upper catchment and the positive impacts that the wetland systems have on filtering and processing pollutants and attenuating stormwater discharges.

One issue of concern that was not picked up during sampling was the potential for illegal connections of stormwater to the sewer infrastructure to create problems with overflows during rain events. Anecdotal reports suggest that during the event prior to the one sampled, an overflow occurred through a service cover adjacent to the sampling site with untreated sewerage flowing over the bank surface directly into the creek.

Tilly Willy Creek Subcatchment

Tilly Willy Creek enters the Nambucca River upstream of Macksville. Just over half the catchment area is grazing country. Other landuses within the catchment include an industrial estate (12% of the catchment area), rural residential areas (11%), and urban residential along the catchment divide in the east and in the lower catchment around Macksville (see *Figure 31*). Extensive areas of wetland and associated swamp forests (13% of the catchment area) also occur in the mid reaches of the catchment, however the wetlands appear to have been extensively drained by cut channels. The sampling site was located immediately upstream of the Taylors Arm bridge as this site was considered the most accessible and to be near the limit of tidal influence. Consequently, urban residential and commercial areas around Macksville and downstream of the sampling site can not be considered part of this assessment.

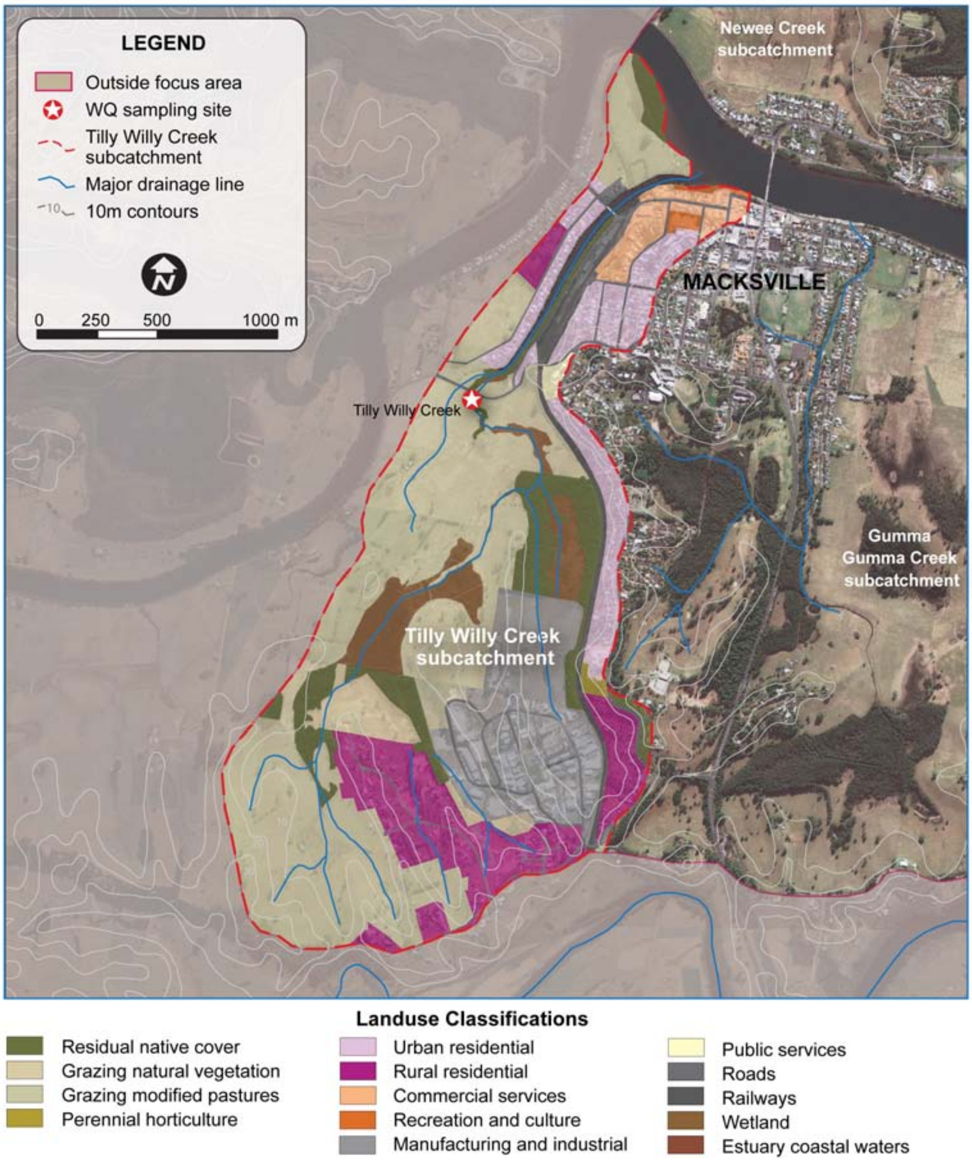


Figure 31 *Map of the Tilly Willy Creek subcatchment showing landuse classes and location of the sampling site.*

Sampling results

Water quality samples were collected from Tilly Willy Creek on the 18th and 19th of June 2009. Due to a malfunctioning pump on the ISCO water sampler all three samples were collected by hand. Samples were timed to correspond with low tides to ensure that they were representative of runoff from the Tilly Willy catchment as opposed to tidal waters from the Nambucca River. *Figure 32* shows the level of Tilly Willy Creek during the time it was sampled. It indicates that the sampling site chosen for Tilly Willy Creek is subject to tidal influences during high tides and that the base flow level of the creek increased over the course of the rainfall event. The results of sampling are presented in *Table 9*.

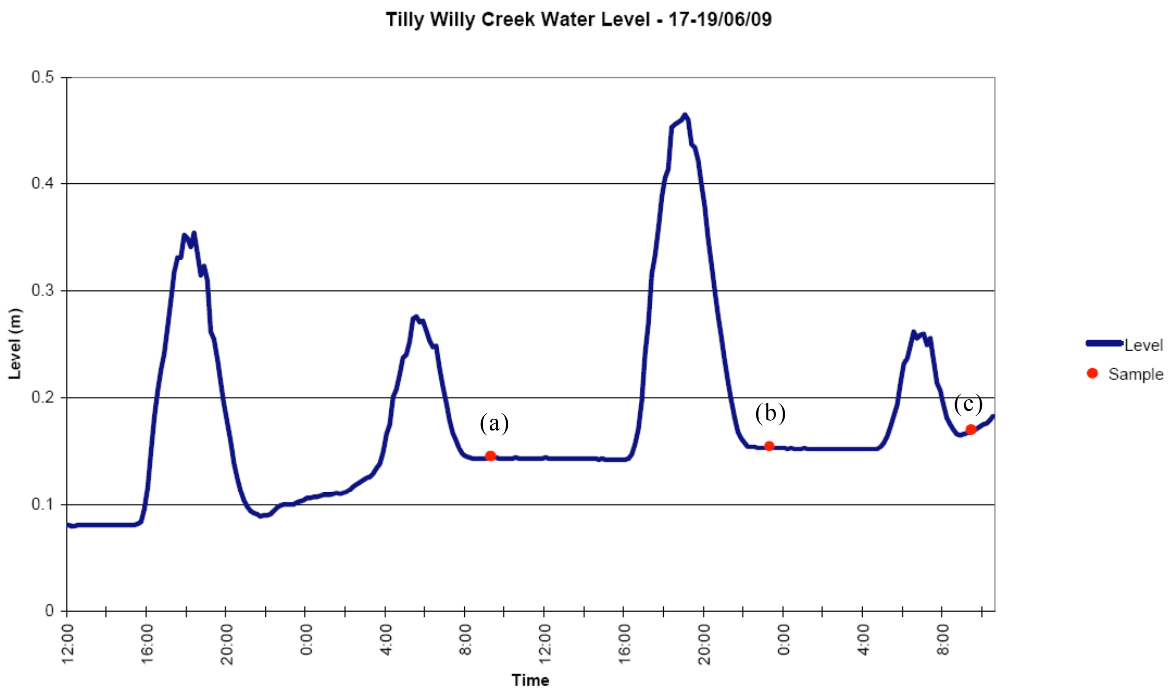


Figure 32 *Tilly Willy Creek water level and sampling times.*

Table 9 *Results of event based water quality sampling at Tilly Willy Creek, Nambucca Valley*

Sample	**Date**	**pH**	**Turbidity** *(NTU)*	**TN** *(mg/L)*	**TP** *(mg/L)*	**TSS** *(mg/L)*	**Enterococcus** *(cfu/100mL)*
Tilly Willy (a)	18.06.09	6.6	8.4	0.81	0.04	4	6000
Tilly Willy (b)	19.06.09	6.5	7.2	0.7	0.03	2	3600
Tilly Willy (c)	19.06.09	6.4	25	0.95	0.07	22	3400
Dry weather sample	18.05.09	6.6	14	0.68	0.03	14	40
ANZECC Guidelines	(protection of aquatic ecosystems)	7 - 8.5	0.5 - 10	0.3	0.03	n/a	35 (primary) 230 (secondary)

Discussion of the Tilly Willy Creek subcatchment results

All measurements taken were within the bounds of expected rainfall runoff from a catchment with predominantly agricultural land. The extensive areas of wetland in the mid-catchment may be partly responsible for the low levels of pollution in the runoff from Tilly Willy catchment. However, the wetlands have been significantly drained and so their ecosystem functions and ability to attenuate flows and reduce the flow of contaminants to the estuary are likely to have been diminished.

In recent years there has been anecdotal reports from local stakeholders that Tilly Willy Creek delivered particularly turbid waters to the estuary during storm events. The lack of strong data to support these reports should not be considered conclusive as Tilly Willy Creek was the last waterway to be sampled during this study and therefore was subject to the most antecedent rainfall conditions of all the waterways. Whether or not this factor has had an effect upon results is uncertain.

Interestingly, dry weather sample results exceeded the ANZECC guidelines for turbidity, TN, and *Enterococcus*. The high levels of turbidity require further investigation before an explanation can be provided but possible causes include damage to banks and the bed by stock, soil disturbances associated with the expanding industrial estate in the headwaters, soil characteristics, or other factors associated with agricultural landuses. The exceedence of ANZECC guidelines in dry weather readings for TN and *Enterococcus* may be linked either to agricultural practices or ineffective OSMSs.

Gumma Gumma Subcatchment

Like many of the subcatchments described in this study, Gumma Gumma subcatchment actually represents numerous creeks, drains and wetland areas that discharge into the estuary. In this case the major tributaries are Gumma Gumma Creek and the highly modified East Street drain. The area drained by these two tributaries probably covers two thirds of the Gumma Gumma subcatchment as defined in *Figure 33*, however the extensive low relief floodplain and a lack of appropriately scaled topographic data makes delineation of the actual catchment areas difficult. Sampling in this subcatchment was restricted to 3 sites on Gumma Gumma Creek and a single site on the East Street drain. As the two sampling areas have marked differences in landuse and potential water quality issues they will be discussed separately.

Gumma Gumma Creek sampling area

The Gumma Gumma Creek subcatchment is primarily low-lying floodplain. Marginally higher lands are used for grazing and lower backswamp areas generally form freshwater wetlands and regenerating swamp forests. Small areas of rural residential development are found in the higher headwater areas in the south and to the east along Gumma Road. Small areas of cropping, perennial horticulture, and irrigated pastures also occur. Gumma Gumma Creek has been significantly modified in the early parts of the last century with extensive drainage works, the installation of floodgates at its mouth (removed in 2006), and an increase in the production expectations of the low lying agricultural lands. Most of the backswamp area is underlain by estuarine derived soils characterised by low wet-bearing strength, high erodibilty, low permeability, potential acid sulfate soils (PASS), strong acidity, sodicity, high aluminium toxicity and salinity, poor drainage, high flood hazard and seasonal water logging (DLWC, 2000). As a consequence the Gumma Gumma Creek drainage area is very susceptible to disturbance, has a high risk of actual acid sulfate soils (AASS) at shallow depths, and is capable of releasing high concentrations of toxic pollutants and acid if the estuarine subsurface soils are exposed.

Documented impacts in similar high risk ASS catchments on the mid-north coast include (Johnson et al., 2003);

- Reduced surface water levels in the backswamp and increased rates of drainage of surface waters.
- Widespread replacement of reed and rush species by swamp oaks and swamp paperbarks in response to lowered water tables
- Gradual loss of seasonal grazing value as the reeds and rushes and native grass species have been replaced by colonizing oaks and paperbarks
- The loss of surface peat layers as a result of altered fire regimes, altered hydrology causing drying and wind erosion, and tidal incursions which have resulted in salt scalds further exposing the surface soil to erosion.
- Increased oxidation of acid sulfate soils (ASS) producing large volumes of sulphuric acid, dissolved iron, and dissolved aluminium available for transport through the drainage system during wet weather events.

Anecdotal evidence and various field observations support the occurrence of all the above impacts in the Gumma Gumma Creek subcatchment, so the sampling strategy for Gumma Gumma Creek was designed to try to determine the concentrations of acidity, metals (Aluminium:Al and Iron:Fe), and other parameters (as per other sampling sites) being exported during storm events.

East Street Drain sampling area

The East Street drain is the main drainage channel for stormwater from the eastern part of Macksville township. The lower half of the channel connects a number of shallow drains and grassed swales within a predominantly urban catchment. Approximately 20% of the drainage area is recreation (including the golf course and open parklands) and sporting fields. The upper half drains a small rural residential area, low relief grazing lands, and some forested swamplands. A narrow and sparsely covered corridor of vegetation exists along most of the length of the drain. The urban areas are differentiated from those in the Beer Creek subcatchment by their relatively low relief.

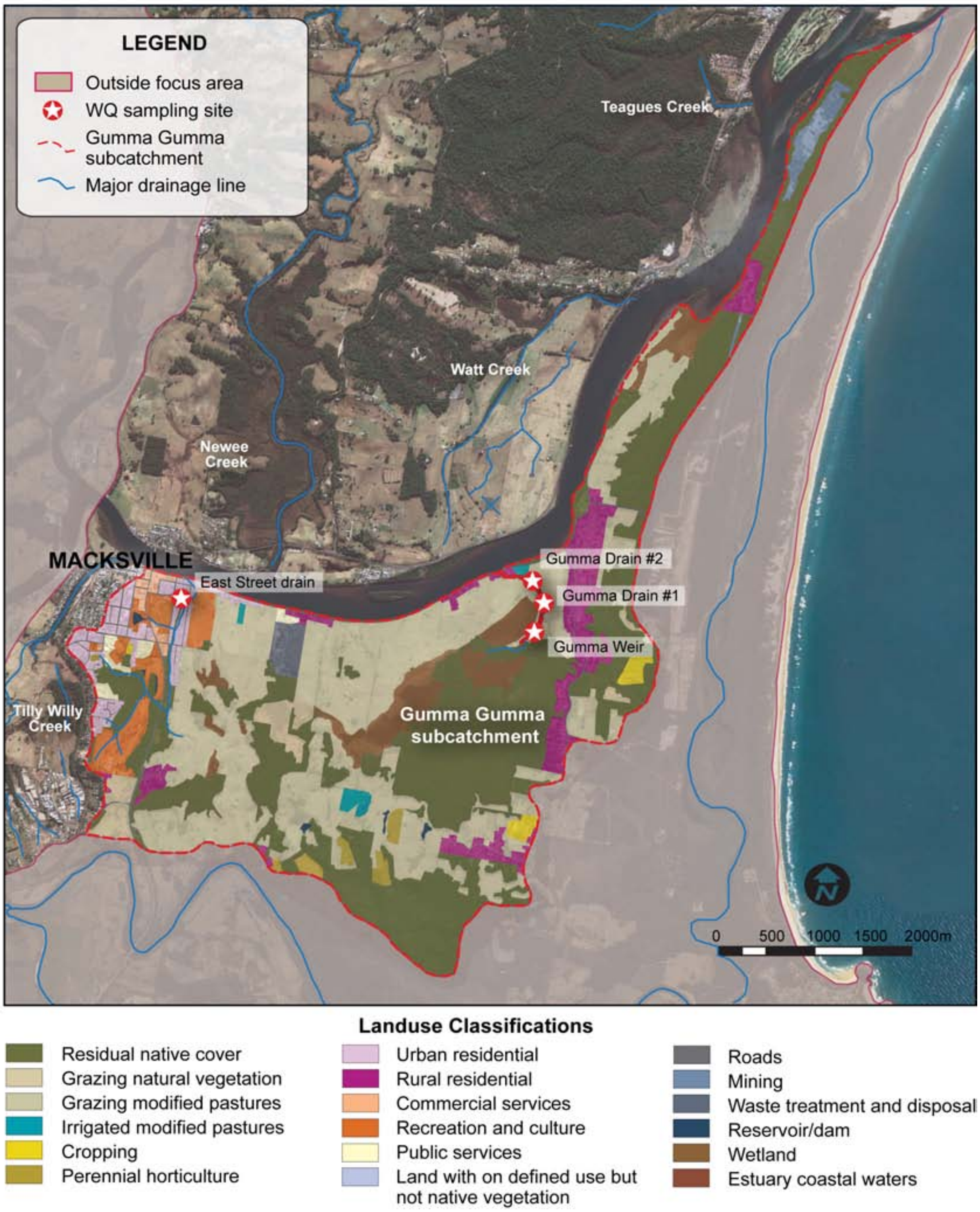


Figure 33 *Map of the Gumma Gumma subcatchment showing landuse classes and location of sampling sites.*

Sampling results

Gumma Gumma Creek

Three different sites were chosen along Gumma Gumma Creek to analyse water quality. The sites were chosen to coincide with areas where major drainage lines from distinct areas of the wetland joined with the creek. In this way it was hoped that any changes in the management and landuse of parts of the backswamp under different ownership might be reflected by variation in the results.

Samples were collected from Gumma Gumma Creek during a heavy rainfall event on the 27th and 28th of May 2009. Due to difficulties with vehicle access and the possibility of inundation, ISCO automated water samplers could not be used and thus no water level information exists for the Gumma sites. However, all samples taken from the Gumma Gumma sites were collected to coincide with low tides to avoid the possibility of sampling tidal waters. The results of sampling of the base set of parameters are presented in *Table 10*.

Table 10 *Results of event based water quality sampling at Gumma Gumma Creek, Nambucca Valley*

Sample	**Date**	**pH**	**Turbidity** *(NTU)*	**TN** *(mg/L)*	**TP** *(mg/L)*	**TSS** *(mg/L)*	**Enterococcus** *(cfu/100mL)*	**Faecal Coliforms** *(cfu/100mL)*
Gumma Weir (a)	21.5.09	6.9	11	0.81	0.03	3	300	Not sampled
Gumma Weir (b)	22.05.09	7	9.2	0.98	0.04	10	840	720
Gumma Weir (c)	28.05.09	6.4	6.5	0.69	0.04	8	260	Not sampled
Gumma Drain #1 (a)	21.5.09	6.6	28	0.76	0.03	16	400	Not sampled
Gumma Drain #1 (b)	22.05.09	6.9	13	0.58	0.03	10	440	120
Gumma Drain #1 (c)	28.05.09	6.1	12	0.42	0.03	9	460	Not sampled
Gumma Drain #2 (a)	22.05.09	6.5	8.7	0.38	0.03	15	80	0
Gumma Drain #2 (b)	28.05.09	6	9	0.51	0.03	11	280	Not sampled
ANZECC Guidelines	(protection of aquatic ecosystems)	7 - 8.5	0.5 - 10	0.3	0.03	n/a	35 (primary) 230 (secondary)	150 (primary) 1000 (secondary)

As discussed above, historical land use and drainage of Gumma Gumma swamp indicate a potential for the disturbance of acid sulfate soils. As a result additional analyses were performed on water samples from Gumma Gumma Creek and Drains #1 and #2. The additional analyses were designed to better determine the extent of any issues related to the export of acid or toxic metals into the estuary and included titratable acidity (a more useful indicator of acidity in drainage waters than pH as it measures acidity associated with dissolved aluminium and iron), the ratio of $Cl:SO_4$, and Aluminium and Iron concentration. The results of the additional parameters are contained within *Table 11*.

Table 11 *Results of acid export analyses from Gumma Gumma Creek.*

Sample	Date	pH	Acidity as $CaCO_3$ *(mg/L)*	Cl:SO4 Ratio	Aluminium *(mg/L)*	Iron *(mg/L)*
Gumma Weir (a)	21.5.09	6.9	8	9.1:1	0.19	1.24
Gumma Weir (b)	22.05.09	7.0	8	7.9:1	0.24	0.91
Gumma Weir (c)	28.05.09	6.4	10	8.25:1	0.036	1.28
Gumma Drain #1 (a)	21.5.09	6.6	8	7.1:1	0.46	2.93
Gumma Drain #1 (b)	22.05.09	6.9	8	7.7:1	0.29	1.47
Gumma Drain #1 (c)	28.05.09	6.1	13	8.99:1	0.098	2.17
Gumma Drain #2 (a)	22.05.09	6.5	14	7.3:1	1.9	0.49
Gumma Drain #2 (b)	28.05.09	6.6	19	7.9:1	0.041	1.48

East Street Drain

Four water quality samples were taken from the drain during a rainfall event on the 21st and 22nd of May 2009. The water level and sampling times are shown in *Figure 8*. Two of the samples (identified as (a) and (d)) were collected by hand and two using the automated ISCO water sampler. When inspected with a refractometer, none of the samples from East Street showed any salt content, including Sample (d), taken at high tide. It is assumed that, owing to the size of the rainfall event, the Nambucca River would have been flowing fresh to the mouth by this time.

Figure 34 shows that marine waters enter East Street Drain at high tides and that low tides are attenuated by freshwater flows during wet periods.

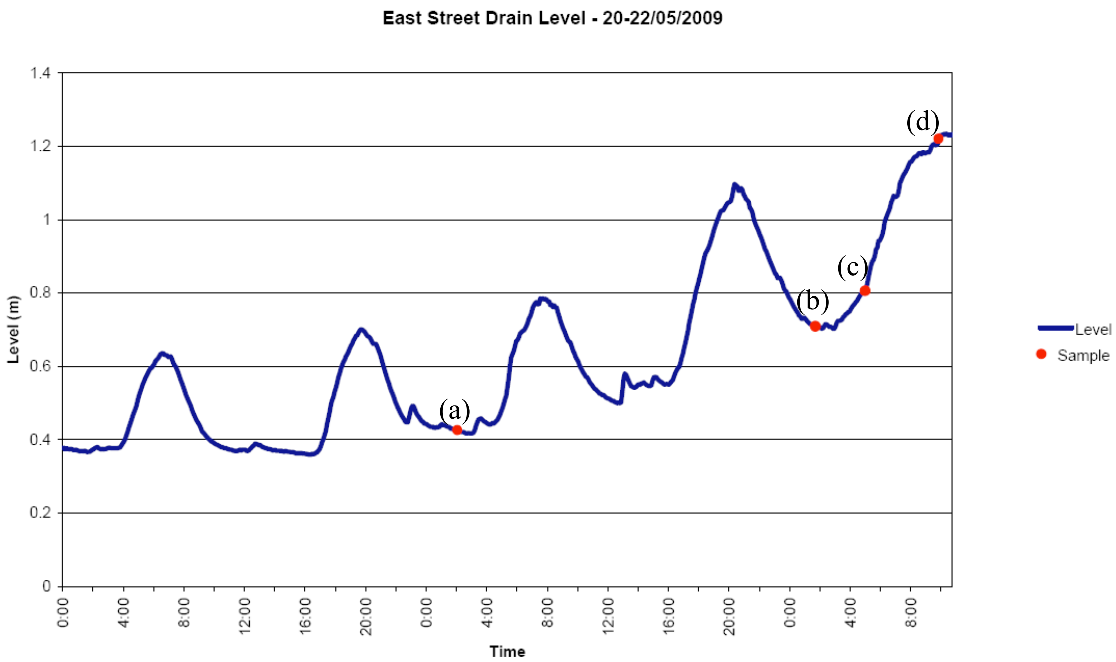


Figure 34 *East Street Drain water level and sampling times.*

Table 12 Results of event based water quality sampling at Tilly Willy Creek, Nambucca Valley

Sample	Date	pH	Turbidity (NTU)	TN (mg/L)	TP (mg/L)	TSS (mg/L)	Enterococcus (cfu/100mL)	Faecal Coliforms (cfu/100mL)
East St (a)	21.5.09	6.6	33	0.94	0.08	28	6500	2320
East St (b)	22.05.09	6.8	25	0.58	0.04	24	2640	Not sampled
East St (c)	22.05.09	6.8	22	0.53	0.04	5	2180	Not sampled
East St (d)	22.05.09	6.8	40	0.91	0.09	37	2780	Not sampled
Dry weather sample	18.05.09	6.7	20	1.27	0.04	7	240	Not sampled
ANZECC Guidelines	(protection of aquatic ecosystems)	7 - 8.5	0.5 - 10	0.3	0.03	n/a	35 (primary) 230 (secondary)	150 (primary) 1000 (secondary)

Discussion of the Gumma Gumma subcatchment results

Gumma Gumma Creek

The pH and titratable acidity results from all Gumma Gumma Creek samples are within normal range. However, this should not be taken to mean that there are not issues with acid export from this system. In particular the very high concentrations of aluminium and iron indicate that acid sulfate processes are prevalent in the subcatchment. It is possible that acid export from Gumma Swamp is occurring but was not detected by this study for three reasons:

- Acid export from oxidized sufidic soils is transported from catchments into receiving water under two main scenarios, either via groundwater seepage or through surface runoff (or both);
- The survey methodology was based around attempting to capture acid export flux associated with groundwater seepage; and,
- Antecedent rainfall (ie. three previous large events in a four month period) meant that the conditions for surface acid production did not exist.

Under the groundwater seepage scenario, export occurs when the groundwater level is higher than the drain water level and acid groundwater is able to seep into the drain to be exported into the estuary. This pathway can lead to frequent, chronic acid discharge and high acid export rates. This pathway is most likely to be the primary cause at sites with high hydraulic conductivity through the soil (Johnston *et al*., 2003a). The export of acid drainage water under this scenario is most likely to be detected from 7-14 days after an event (Thor Aaso, pers.comm., 2009)

In soils with low hydraulic conductivity the major pathway of acid export is through surface runoff. Under this scenario, shallow groundwater and evaporation leads to accumulation of acid salts on the surface which are then exported during runoff events. Alternatively, ASS at the surface (as a result of the loss of overlying peat layers through erosion or burning) may be exposed during dry periods, again resulting in the accumulation of acid salts on the surface which can then be exported by runoff. This pathway generally leads to more infrequent acid discharge events with lower acid export rates (Johnston *et al*., 2003). In order to detect acid runoff under this scenario it is necessary to sample the first flush of surface water runoff after an extended dry period (where surface acid production processes are most likely to have occurred).

The results from this sampling period indicate that acid production in this system is most likely to be under the second scenario, that is, via a surface water runoff. Field investigations including determining the hydraulic conductivity of the subsoils and the proximity of the AASS to the surface in several backswamp areas support this hypothesis. Further monitoring is required to confirm this scenario as the management approach required to address surface production of acid are different to those required to address groundwater seepage issues.

In terms of nutrients, suspended sediment and bacteriological concentrations, all sampled sites were at the lower end of the spectrum for what would be expected under stormwater runoff conditions.

East Street Drain

Apart from moderately high bacteriological concentrations, the East Street drain water quality results are towards the lower end of the spectrum for stormwater runoff from a predominantly urbanised subcatchment.
As described above, the East Street drain catchment is relatively flat and many of the stormwater drains that connect to it are grassed swales. The low relief nature of the catchment does not encourage fast stormwater flows and so the transport of pollutants and contaminants is less efficient. It is therefore not surprising that many of the issues observed in runoff from the Beer Creek catchment do not appear to affect the East St drain (such as elevated turbidity and suspended sediment), despite being urbanized catchments of a similar size and density. In addition, water in the East Street drain is regularly flushed by tidal cycles.

Interestingly, the dry weather sampling results for Total Nitrogen are in excess of the wet weather samples. The source for nitrogen in this catchment may be fertilisers applied to the many sporting fields, golf course, or parklands, or breakdown of vegetative matter or algae within the channel.

PART 6 Lower Nambucca River Estuary Water Quality Strategy

The Lower Nambucca River Estuary Water Quality Strategy is not intended as a comprehensive strategy to resolve all the water quality issues of the lower Nambucca River estuary. Rather, it is a set of management recommendations and actions which are based on a relatively brief period of event-based storm water sampling on major tributaries feeding into the lower estuary.

As such, this Strategy has a narrow focus in so far as it deals predominantly with diffuse sources of pollutants entering directly into the lower Nambucca River estuary through tributary systems such as creeks and drains. Factors including, for example, point source pollution from sewerage treatment plants (including town and recreational facilities such as caravan parks), diffuse pollution from sources upstream of Macksville, and pollutants such as chemical or metal contaminants are outside the scope of this Strategy. Consequently the recommendations below deal only with those subcatchments studied and do not extend to broader recommendations for catchment management or to specific issues such as sewerage treatment and disposal or chemical or heavy metal pollution associated with industrial or agricultural operations.

In some respects the omissions of these sources of poor water quality can rightly be considered to reduce the ability of the Strategy to deliver large scale changes to the water quality of the lower estuary. However, it is based on the premise that identifying specific management actions relevant to individual small catchments is likely to have a more significant affect on water quality in the estuary than generic prescriptions for broader catchment management. It could also be argued that it is a more efficient way to invest scarce resources as it more effectively targets resources to the identified problems. The methodology applied within this study to determine the issues in each subcatchment could also be applied in other focus areas or subcatchments to come up with specific management recommendation for those areas. In this way, the Strategy could be expanded as the need arises and as resources become available.

As outlined in *Objective 3* in the introduction of this Study, the recommendations in this Strategy aim to address the water quality issues identified in the lower Nambucca estuary through the 2008-2009 sampling program. The recommendations broadly fit into four main areas although some integration and overlap is necessary;

- ***Priority Subcatchments***, that is which subcatchments should be considered a priority for management, remediation, and/or further investigation
- ***Subcatchment Management Actions***, that is individually tailored management actions specific to each subcatchment; and,
- ***Proposed Further Monitoring***, that is what further monitoring is required to improve the understanding of the identified water quality issues in the study area.
- ***Communication***, that is how the results of the community survey can be used to raise awareness of water quality issues in the lower Nambucca area.

Priority Subcatchments

The event based water quality sampling revealed a number of subcatchments were exporting very high concentrations of nutrients, suspended sediments and bacterial contaminations during storm events, most notably Lumsdens Lane in the Watt Creek subcatchment and Beer Creek. Unfortunately, the difficulties associated with gauging tidal streams and drains during events prevents total loads being derived for almost all the catchments assessed (see Proposed Future Monitoring Program for recommendations with regard to stream gauging on specific systems). In the absence of event discharge data, subcatchment comparisons of total loads of contaminants are not scientific due to the complexity of factors such as catchment area, rainfall distribution, runoff coefficients, and finer scale hydrological and hydraulic factors.

Despite this, it is clear that concentrations of pollutants in some subcatchments far exceed what could be described as within “normal stormwater values”. Additionally some systems have strong circumstantial evidence which point to water quality issues, for example iron flocculate and oyster bleaching indicating acid export in the Gumma Gumma Creek subcatchment. Therefore, on this basis the following recommendations are made as to which subcatchments should be consider highest priority, medium priority, and lowest priority for management, remediation, and future monitoring. The priorities have been determined on the basis of the parameters sampled and are presented to reflect priorities in terms of achieving improvements in those parameters (*Table 13*).

Table 13 Priority subcatchments for further investigation and management action

Water Quality Issue	Priority	Subcatchments	Justification	Recommendations
Elevated Nutrients	**HIGH**	Watt Creek: (specifically Lumsdens Lane and Wrights Corner).	Lumsdens Lane showed Total Nitrogen concentrations up to four times higher than the average for all subcatchments. Additionally, both Lumsdens Lane and Wrights Corner showed Total Phosphorous concentrations up to five times higher than the average across all subcatchments.	Further investigation should be undertaken in accordance with the recommendations in the Proposed Future Monitoring Framework below to determine total loads being exported and likely sources. Subsequent management actions will be dependent upon the clarification of the sources of contaminants.
	MEDIUM	Beer Creek Tilly Willy Creek East Street Drain	Nutrient results were generally higher than the ANZECC guidelines for the protection of estuarine systems but were within "normal" ranges for storm events.	Typical strategies for further investigation will include long-term periodic dry weather sampling of TN and TP, and event based sampling should any specific issues be identified. Refer to suggested management actions below for subcatchment specific actions to reduce levels of nutrient contaminants being transported to the estuary from these systems.
	LOW	Bellwood Creek Teagues Creek Gumma Gumma Creek	Nutrient levels were generally low across all samples compared to what might be expected for stormwater runoff from these subcatchments.	No action is currently warranted with regard to managing nutrient exports in these subcatchments. However, long-term periodic dry weather sampling of TN and TP would assist in determining trends in nutrient export from these systems.

Water Quality Issue	Priority	Subcatchments	Justification	Recommendations
Bacterial contamination	**HIGH**	Watt Creek (particularly Lumsdens Lane) Beer Creek	Lumsdens Lane and Beer Creek showed *Enterococcus* concentrations in excess of 13 and 9 times the median results respectively compared to other sampled sites in the study area.	Further investigation should be undertaken in accordance with the Subcatchment Management Recommendations and Proposed Future Monitoring Framework detailed below. Subsequent management actions will be dependent upon the clarification of the sources of contaminants.
	MEDIUM	Tilly Willy Creek Bellwood Creek East Street Drain	Bacterial contamination results as measured using *Enterococcus* as the primary indicator were higher than the ANZECC guidelines for the protection of estuarine systems but were considered within "normal" ranges for storm events in these catchments.	Refer to the suggested management actions below for subcatchment specific actions to reduce the levels of bacterial contaminants being transported to the estuary from these systems during storm events.
	LOW	Teagues Creek Gumma Gumma Creek	*Enterococcus* levels were consistently lower than what might be expected for stormwater runoff from these two subcatchments.	No action in regard to managing bacterial contamination is currently warranted, however, long-term periodic dry weather sampling of these parameters is still recommended.

Acid and associated heavy metal export	**HIGH**	Gumma Gumma Creek	Although the sampling regime was unable to determine the extent of the existing issues with regard to acid and associated heavy metal contaminant export, field investigations were able to clarify the likely pathways of export.	Further investigation should be undertaken in accordance with the recommendations in the Proposed Future Monitoring Framework below. Subsequent management actions will be dependent upon confirmation of the acid export pathway and estimated total loads.

Water Quality Issue	Priority	Subcatchments	Justification	Recommendations
	MEDIUM	Watt Creek (specifically Wrights Corner and Lumsdens Lane)	Wrights Corner in particular recorded the lowest readings for pH in the Study Area. However, none of the readings indicated excessive acidity (as measured by pH). It is possible that the sampling regime was not able to determine whether there are existing issues with acid sulfate soils in this subcatchment.	Further investigation should be undertaken in accordance with the recommendations in the Proposed Future Monitoring Framework below specifically in respect to monitoring alternative measures of acidity related to acid sulfate soils. Parameters such as acidity as $CaCO_3$, $Cl:SO_4$ ratio, and Aluminum and Iron concentrations may assist in determining whether low pH readings in these systems result from acid sulfate soil conditions.

Water Quality Issue	Priority	Subcatchments	Justification	Recommendations
Suspended Sediment and turbidity	**HIGH**	Beer Creek	Beer Creek showed the highest levels of suspended sediments and turbidity of all the subcatchments after a comparatively minor storm event.	Appropriate management actions are detailed in the suggested management actions for Beer Creek below.
	MEDIUM	Tilly Willy Creek	Anecdotal reports of high levels of turbidity in Tilly Willy Creek after storm events were not able to be confirmed during the sampling period. This may be related to the fact that Tilly Willy was sampled last of all sites and therefore was subject to the most antecedent rainfall and wet wether conditions.	Further investigations should be undertaken in line with the recommendations in the Proposed Future Monitoring Framework below. Subsequent management actions should be based on the outcomes of further sampling, however, some preliminary recommendations are included in the management recommendations for Tilly Willy Creek.

High Priority subcatchments: Recommended management actions

Gumma Gumma Creek subcatchment

Although the sampling results were inconclusive, the major issue of concern in the Gumma Gumma creek subcatchment is acid export from Gumma Gumma Creek and associated backswamps. To date, the management of the Gumma Gumma Creek and associated wetland areas has been mainly focussed on containment of acid water export under an acid remediation trial, initially proposed by Wetland Care Australia in 2006, and now being implemented largely by Nambucca Shire Council. The containment strategies are predominantly designed to contain groundwater seepage of acidic water and associated contaminants into the creek and estuary. However, analysis of the results of sampling under this program and subsequent field investigation supports the hypothesis that acid production from the Gumma Gumma swamp follows a predominantly surface water pathway. This hypothesis requires further testing as it has significant ramifications for the management approach.

Before recommending management strategies for Gumma Gumma Creek, the following additional observations from the field investigations are provided;

- Observations over the sampling period showed that the drop board weir structures on the creek and the lateral drain at Drain #1 are not operational. The main weir on the creek itself is not managed and no dropboards were in place over the seven months between December 2008 and June 2009. Interestingly, the maximum weir height should all the drop boards be installed is still less than a natural bed control some 40 meters upstream of the weir site. This means the structure is largely redundant as water level is controlled by the upstream control. The weir on lateral Drain #1 is not functional as the original floodgate is still in operation.
- A lateral drain connecting the freshwater wetland on the western side of the creek with the creek channel has eroded a crossing which if not addressed may result in headward erosion during high flows and potential lowering of the wetland water level.
- Monosulfidic black ooze (MBO) was observed on the freshwater swamp margins, essentially at the surface. MBO has been linked to fish kills in many coastal estuary systems due to its ability to rapidly deplete dissolved oxygen in the water column.
- The hydraulic conductivity, as determined through pit tests, was extremely low.
- Acid sulphate soils were at the surface in the western freshwater wetland area.
- The natural levee on the western side of the creek has several low points which show evidence of salt scalding, consistent with the intrusion of saline water during highest tide events.
- Swamp sheoak and swamp paperbark have invaded extensive areas of what was most likely sedgeland or reed swamp in wetland areas to the south and south east of the creek. The extensive invasion of swamp paperbark into reed swamps and sedgelands as a result of drainage has been shown to significantly increase shallow groundwater and soil acidification (Johnson *et al.*, 2003b)
- Iron precipitates were extensive in shallow lateral drains on the eastern side of the creek.

As a result of the field observations and the hypothesis that acid is most likely being exported under a surface water runoff pathway, the recommendations for Gumma Gumma Creek fall into two main categories;

- *Further Monitoring:* it is recommended that a water quality sampling program be initiated by Nambucca Shire Council to attempt to quantify the extent of issues related to surface water acid export. The sampling program should focus on capturing first flush events after extended dry periods using automated sampling equipment. Details of a suggested monitoring program are contained with the proposed Future Monitoring Framework in the next section of this report.
- *Remedial Works:* to reduce the potential for surface acid export remedial works should

commence including the removal of stock impacts, plugging of lateral drains, prevention as much as possible of any future salt scalding resulting from saline intrusion (which can damage surface vegetation, setting back recovery processes), control of sheoak and paperbark encroachment which would otherwise promote surface acidity, and the slow raising of water levels to drown out surface ASS and to promote regeneration of wetland species such as sedges, couch, rushes, etc.

Watt Creek subcatchment

The levels of *Enterococcus* being exported from the Lumsden Lane drain are the main concern in this catchment. The levels are probably high enough to affect the aquaculture industry and the use of the estuary for water contact recreation after rainfall events. At present it is unclear whether the bacterial indicator material originated from human or animal sources.

Other concerns relate to the high nutrient readings. By considering the concentration of nutrients in the water column and the drain discharge for a known rainfall event it would be possible to estimate the total quantity of nitrogen or phosphorous entering the estuary (for example in kilograms). Unfortunately, to date, no gauging of the Lumsdens Lane drain or any of the other major tidal creeks entering the estuary has been completed. Consequently, it is not possible to derive quantitative information of the amount of nutrients entering the estuary through this drain compared to say one of the larger tidal creeks. For this reason, it is difficult to allocate priorities to particular subcatchments needing remedial treatment. However, suffice to say that the levels of TN and TP in the samples collected warrant further investigation and remedial action where the causes can be determined.

Actions that would assist in improving water quality in the Watt Creek subcatchment include;

- Ruling out failing OSMSs as the source of very high bacterial contamination in Lumsdens Lane drain by checking OSSMs within the drain catchment.
- Undertaking sterol testing to determine the probable source of the faecal material.
- Accurately mapping the drainage system on the floodplain. This action may be assisted once airbourne LiDAR survey data can be acquired over the catchment area. Accurately determining the drain catchment area may assist in locating potential sources of contamination or pollutant generation in both the Lumsden Lane and Wrights Corner drain systems.
- Slowing down the transport of pollutants to allow some processing of nutrients before they enter the estuary by reinstating wetland areas on the floodplain.
- Improving agricultural practices by managing paddocks to reduce the potential for export of nutrient and bacterial contamination

Beer Creek subcatchment

Management of the runoff from the Beer Creek catchment could result in improved stormwater quality. The basic management principals that would apply in this situation are source control, peak flow attenuation and stormwater treatment. A number of specific actions warrant investigation including;

- Source control measures such as education campaigns, encouraging the installation of water tanks and the ongoing careful maintenance of sewerage infrastructure.
- The installation of a series of detention basins may help to attenuate flows somewhat and reduce the transport of sediments. This type of action requires careful investigations as such systems have in some locations been associated with nutrient saturation and associated algal growth.
- Where feasible given current flood planning considerations, the replacement of the paved sections of the creek bed and banks with grassed swales could be beneficial. Grassed swales promote infiltration of stormwater resulting in decreased velocities, increased sediment

trapping efficiency and decreased stormwater volumes. They are particularly effective for the moderation of negative stormwater impacts arising from average rainfall events.

- More effective sediment controls where soil disturbance occurs, for example, during early phases of land development or construction.

Medium Priority subcatchments: Recommended management actions

Bellwood Creek

Management actions that could assist in maintaining the current water quality levels in Bellwood Creek include;

- Ensuring that any future development within the Bellwood Creek catchment does not impact upon the quality of runoff, *ie*., that effective and appropriate Water Sensitive Urban Design principles are employed.
- Testing urban residential areas within the catchment to identify properties with illegal stormwater to sewer connections. This may assist in reducing the potential for overflows from sewer infrastructure to heavy rainfall events.

Tilly Willy Creek

Some management actions that could lead to an improvement of runoff quality from the Tilly Willy Creek Catchment include;

- Fencing the creek and associated wetlands to exclude stock;
- Reinstating wetland functions through modifications to the artificial drainage system; and
- Careful and regular monitoring and maintenance of on site sewage management systems OSMSs located within the catchment.
- Ensuring that any future development within the Tilly Willy Creek catchment does not impact upon the quality of runoff, *ie*. that effective and appropriate Water Sensitive Urban Design principles are employed.
- More effective sediment controls where soil disturbance occurs, for example, during early phases of land development or construction.

East Street Drain subcatchment

In terms of East Street drain, management actions that could assist in improving the current water quality in the drain include;

- Source control measures such as education campaigns, encouraging the installation of water tanks and the ongoing careful maintenance of sewerage infrastructure.
- Ensuring that any future development within the East Street Drain subcatchment does not impact upon the quality of runoff, *ie*., that effective and appropriate Water Sensitive Urban Design principles are employed.

Low Priority subcatchments: Recommended management actions

Teagues Creek

Management actions that could assist in maintaining the current water quality levels in Teagues Creek include;

- Ensuring that appropriate runoff controls are applied to the quarry located immediately upstream of the confluence of Teagues Creek and the Nambucca River. Runoff from the quarry should be subject to sediment control in the form of sediment traps and fences on site; and

- Ensuring that any future development within the Teagues Creek catchment does not impact upon the quality of runoff, *ie*., that effective and appropriate Water Sensitive Urban Design principles are employed.

Proposed Future Monitoring Framework

The review of existing projects undertaken in *Part1* of the Study provided a number of guidelines for the design of water quality sampling programs attempting to determine subcatchment exports of nutrient, bacterial, sediment, and ASS related contaminants to the estuary. However, due to resource constraints, not all the guidelines could not be incorporated into this Study. Additionally, some of the results of the event based sampling raised issues that cannot be adequately resolved on the basis of the collected information.

The proposed future monitoring framework provides details of the next stage of monitoring required to address existing deficiencies in the knowledge base and to allow more certainty in management decision making. The framework is discussed in terms of three main focus areas;

- The collection of additional data to allow quantification of contaminate loads to facilitate subcatchment comparisons;
- Additional sampling programs in Low and Medium Priority subcatchments; and,
- Further sampling programs in High Priority subcatchments

Collection of additional data to allow quantification of contaminant loads to facilitate subcatchment comparisons.

The calculation of total event export loads of contaminants (such as total nutrient load or suspended sediment loads per event) is generally undertaken by determining a flow weighted event mean for the contaminant and then multiplying it by the total event discharge volume. However, the gauging of tidal creeks and drains is a complicated field requiring highly specialised equipment and significant resources. Consequently, with the exception of Beer Creek, which had the sampling unit installed outside the area of tidal influence and in a pipe culvert in a constructed concrete channel, it was not possible to gauge total event discharge data within the study area. As a result, it has not been possible to calculate the total event export loads of contaminants in most subcatchments and so comparisons of total export loads are not currently possible.

Therefore it is recommended that any future monitoring program should attempt to address these fundamental deficiencies in the dataset. Gauging should firstly focus on the current High Priority systems of Gumma Gumma Creek and Lumsdens Lane, and if resource allow be followed up with gauging of Tilly Willy Creek, Watt Creek, Teagues Creek, and Bellwood Creek. Gauging of Beer Creek and East Street Drain are of a lower priority as discharge from these sites can probably be estimated using empirical formulae for discharge through pipe culverts.

Further, it is recommended that a specialist contractor be engaged to undertake the gauging as a high degree of technical knowledge and the use of specialised equipment is required.

Additional sampling programs in Low and Medium Priority subcatchments

Recommendations from the Ecosystem Health Program review (BMT WBM, 2007) suggest that long-term data is the best means for putting event based data into context. It is therefore recommended that a sampling program be initiated within the study area to gain a thorough understanding of trends in water quality. A long-term monitoring program should focus on collecting monthly low-tide samples at all sites and focus on the following parameters: salinity (EC), pH, Total

Nitrogen (TN) broken down into Nitrogen species, Total Phosphorous (TP), filterable reactive phosphorous (FRP), *Enterococcus*, Total Suspended Sediment (TSS), and turbidity.

Additionally, the following subcatchment specific recommendations for event-based sampling are made for Low and Medium Priority subcatchments within the study area.

- *Bellwood Creek*
  The sampling undertaken for this Study is considered adequate for the identification of existing issues in the creek and no further event-based monitoring of water quality is considered necessary unless specific issues arise.
- *Tilly Willy Creek*
  In terms of future monitoring, it is suggested that sampling of another storm event be undertaken to clarify the results of this study. In particular, sampling after an extended dry period may clarify the issues identified in the subcatchment report in *Part 5*. The possibility of testing for metal concentrations and chemical contaminants should also be explored given the extensive industrial area in the headwaters and the potential for the relatively efficient transport of sediments and associated contaminants to the estuary provided by the extensive drainage work undertaken through the mid-catchment wetland areas. In addition, some testing of the direct stormwater inputs from the township of Macksville could be undertaken to determine the extent of any issues associated with this part of the catchment.
- *Teagues Creek*
  The sampling undertaken for this Study is considered adequate for the identification of existing issues in the creek and no further event-based monitoring of water quality is considered necessary unless specific issues arise. However, much of the stormwater from urban areas within the catchment, adjacent to the Pacific Highway, does not enter the creek system and instead discharges directly into the Nambucca estuary. It is suggested that any future water quality monitoring activities could be targeted at identifying issues in stormwater outlets directly discharging into the estuary.
- *East Street Drain*
  The sampling undertaken for this Study is considered adequate for the identification of existing issues in the East Street Drain area and no further event-based monitoring of water quality is considered necessary unless specific issues arise. As with Beer Creek subcatchment, MUSIC modelling of the subcatchment could potentially be of value to determine appropriate strategies for improving stormwater management or for testing the likely benefits of any proposed strategies to address any existing issues such as elevated dry weather Total Nitrogen levels.

Further sampling programs in Highest Priority subcatchments

Gumma Gumma Creek

The purposes of further monitoring in the Gumma Gumma Creek subcatchment are to clarify the mechanisms of export of acid and associated contaminants from the creek and associated wetlands, and to accurately assess the quantity of acid (pH and titratable acidity), aluminium, and iron being exported from the gumma wetlands.

To achieve these aims the following actions are recommended;

- An attempt to gauge discharge through the main creek should be made, focussing on estimating discharge under runoff conditions and linking discharge to water level. The use of an experienced and specialised contractor is recommended as the flow dynamics are complicated by tides and the relatively wide floodplain. A budget of approximately $10,000 is estimated.

- Once gauging information is available, it is recommended that a semi-permanent water quality monitoring station be established adjacent to the upstream weir structure on the main creek. The station should be constructed in such a way that a portable automated sampling unit (eg. ISCO 6712 portable sampling unit) can be easily installed within the permanent station, safe from damage from flood flows and vandalism. Ideally, the unit would be capable of being initiated by a modem allowing remote triggering of the sampling program. The unit will require a water level sensor (such as an ISCO 730 bubbler module). A budget of approximately $25,000 is estimated for the purchase of the portable sampling unit and associated equipment.
- The program should attempt to capture data over a number of storm events, provided they are preceded by extended (4-6 month) dry periods. As the unit is portable, it is not necessary for it to remain on-site at all times, rather the unit should be installed prior to the occurrence of a period of likely stormwater events, or prior to the occurrence of a potential event associated for instance with the development of an East Coast low pressure system. The decision to trigger the unit to collect samples should consider that the purpose of sampling is to collect samples from the first flush of an event occurring after a prolonged dry period. An adequate storm event would equate to more than 50mm of rain in any 12 hour period or in excess of 80mm in a 24 hour period.
- It is recommended that the following parameters be tested by an accredited Water Quality Testing laboratory: salinity (EC), pH, Titratable acidity, oxygen-reduction potential, soluble Fe (iron), and soluble Al (aluminium). A budget of approximately $500 per sample tested is required.

The use of the portable sampling equipment requires training and it is recommended that, if possible, Nambucca Council consider allocating the responsibilities for setup, deployment, and maintenance of the equipment to a Council staff member. Recurrent funding will be required to service the units and to cover the costs of the collection, testing, interpretation, and reporting of the WQ data. A budget of approximately $10,000 per annum is recommended to cover the recurring costs of the sampling program.

In addition to clarifying the export pathways from Gumma Gumma Creek and in quantifying the levels of contaminants entering the estuary from this system, the water quality data collected under this monitoring program will provide a baseline for assessing the success or otherwise of any future remediation strategies.

Watt Creek

Given the significantly elevated levels of contaminants identified in this study's sampling program it is considered judicious to attempt to further quantify the issues. It is suggested that a monitoring program be initiated to;

- Obtain water quality samples at the three monitored sites in the catchment over a further two storm events to ascertain whether the issues with bacterial and nutrient contamination are persistent, and to clarify any issues related to potential acid sulfate soils. An adequate storm event would equate to more than 50mm of rain in any 12 hour period or in excess of 80mm over a 24 hour period. An attempt should be made to sample all sites during the same event and to attempt to capture the initial flush of the event, the estimated peak, and a tail of the flow event. These samples could be collected manually provided adequate occupational health and safety measures are taken.
- The following parameters should be tested at all three sites; salinity (EC), pH, Total Nitrogen (TN) broken down into Nitrogen species, Total Phosphorous (TP), filterable reactive phosphorous (FRP), *Enterococcus*, Total Suspended Sediment (TSS), and turbidity.
- The following additional parameters should be tested at Wrights Corner and Lumsdens Lane;

Titratable acidity, oxygen-reduction potential, soluble Fe (iron), and soluble Al (aluminium).

- If the first set of sampling results are broadly consistent with the initial findings detailed in this report, undertake faecal sterol testing of samples from the second event to attempt to determine the source of faecal contamination.
- If levels at the Lumsdens Lane site are consistently high, obtain flow and discharge data to assist in quantifying the levels of pollutants being exported during events. Again, an experienced contractor should be engaged to undertake this component of the monitoring program as it involves specialist knowledge and equipment.
- If persistent, install a semi-permanent water quality monitoring station at the Lumsdens Lane site which can house a portable automated sampling unit to allow quick and easy monitoring of the site when storm events are anticipated. This will allow a body of data to be built up to support management actions and will also allow future assessment of the effectiveness of any actions implemented.

Beer Creek

Although Beer Creek is considered high priority in terms of addressing the identified existing water quality issues (ie. high bacterial, nutrient and sediment loads during storm events), generally speaking, the sampling undertaken for this Study is considered adequate and no further event-based monitoring of water quality is considered necessary unless specific issues arise.

However, MUSIC modelling of the subcatchment could potentially be of value to determine appropriate strategies for improving stormwater management or for testing the likely benefits of any proposed strategies to address existing issues as identified above.

Communication

It is recommended that a communication strategy be developed to raise local awareness of the water quality issues in the lower estuary and of the management actions being taken to address those issues.

The results of the community survey identified the following issues that are relevant to a communications strategy;

- There is confusion in the local population as to who is responsible for managing the estuary
- There is generally a low level of awareness of current estuary management activities and programs.
- Residents are interested in more information about specific issues affecting the Nambucca estuary and more information about immediate threats to the estuary
- Information about actions that impact upon the estuary’s many values would help motivate residents to become more involved.
- The most effective way to inform local residents is through advertisements in either the *Hibbiscus Happynings* or the *Mid-coast Observer*, or through a letterbox drop.

References

Argent, R. (2006) *PortsE2: A Decision Support System for Water Quality Improvement in Port Phillip and Western Port*.

Baginska, B., Pritchard, T. & Krogh, M. (2003) Roles of land use resolution and unit-area load rates in assessment of diffuse nutrient emissions. *Journal of Environmental Management.* **69** pp 39 – 46.

Baginska, B., Milne-Home, W. & Cornish, P. (2003b) Modelling nutrient transport in Currency Creek, NSW with AnnAGNPS and PEST. *Environmental Modelling and Software*. **18** pp 801 – 808.

Baginska, B., Lu, Y. & Pritchard, T. (2005) *Modellling Nutrient Loads to Better Manage Impacts of Urbanisation in Tweed Catchment, New South Wales, Australia*. Paper delivered at ModSim 2005.

BMT WBM (2007) *Ecosystem Health Monitoring Program and Report Card Scoping Study*. Report compiled for the Northern Rivers Catchment Management Authority.

Cogle, A., Carroll, C. & Sherman, B. (2006) *The use of SedNet and ANNEX models to guide GBR catchment sediment and nutrient target setting.* Department of Natural Resources, Mines and Water. QNRM06138.

Dove, M. & Sammut, J. (2007a) Impacts of estuarine acidification on survival and growth of Sydney rock oysters *Saccostrea glomerata* (Gould 1850). *Journal of Shellfish Research*. **26(2)** pp 519 – 527.

Dove, M. & Sammut, J. (2007b) Histological and feeding response of Sydney rock oysters, *Saccostrea glomerata*, to acid sulfate soil outflows. *Journal of Shellfish Research*. **26(2)** pp 509 – 518.

DLWC (2000) Soil landscapes of the Macksville & Nambucca 1:100 000 sheets. Department of Land and Water Conservation, Sydney.

Fletcher, T., Duncan, H., Poelsma, P. & Lloyd, S. (2004) *Stormwater Flow and Quality and the Effectiveness of Non-Proprietary Stormwater Treatment Measures – A Review and Gap Analysis*. CRC for Catchment Hydrology Report 04/8

Hancock, G., Wilkinison, S. & Read, A. (2007) *Sources of sediment and nutrients to the Gippsland Lakes assessed using catchment modelling and sediment tracers*. CSIRO Land and Water Science Report 70/07.

Harris, G. P. (2001). Biochemistry of nitrogen and phosphorus in Australian catchments, rivers and estuaries: effects of land use and flow regulation and comparisons with global patterns. *Marine and Freshwater Research* **52** pp 139 – 149.

Johnston, S., Kroon, F. Slavich, P., Cibilic, A. and Bruce, A. (2003a) Restoring the balance. Guidelines for managing floodgates and drainage systems on coastal floodplains. NSW Agriculture, Wollongbar, NSW.

Johnston, S., Slavich, P., and Hirst, P. (2003b) Alteration of groundwater and sediment geochemistry in a sulfidic backswamp due to Melaleuca quinqenervia encroachment. *Australian Journal of Soil Research*, 2003, **41**, pp.1343-1367, CSIRO Publishing.

Jordan, P., Argent, P. & Nathan, R. (2007) New generation models for catchment modelling: developments in the eWater CRC. *Proceedings of the 5th Australian Stream Management Conference. Australian rivers: making a difference.*

Letcher, R., Merritt, W., Jakeman, A. & Baginska, B. (1999) Modelling Water Quality in Data Poor Catchments: A Combined Modelling Approach. *Proceedings of the International Congress on Modelling and Simulation (MODSIM99),* 6–9 December, 1999, Hamilton, New Zealand, vol.

1. pp. 203–208.

Letcher, R., Jakeman, A., Merritt, W., McKee, L., Eyre, B. & Baginska, B. (1999b) *Review of Techniques to Estimate Catchment Exports.* Technical Paper for the NSW EPA.

Letcher, R., Jakeman, A., Calfas, M., Linforth, S., Baginska, B. & Lawrence, I, (2002) A comparison of catchment water quality models and direct estimation techniques. *Environmental Modelling and Software*. **17** pp 77 – 85.

Merritt, W. S., Letcher, R. A., and Jakeman, A. J. (2003). A review of erosion and sediment transport models. *Environmental Modelling and Software* **18** pp 761 – 799.

Moss, A., Rayment, G., Reilly, N., and Best, E. (1993). Sediment and Nutrient Exports from Queensland Coastal Catchments. *Unpublished Report*, Department of Environment and Heritage and Department of Primary Industries, Brisbane.

Newcastle Innovation (2009) Water Quality within Newee Creek and its Catchment (Phase 2). Report prepared for Nambucca Shire Council.

Newham, L., Letcher, R., Jakeman, A., Heathwaite, A., Smith, C. & Large, D. (2002) *Integrated Water Quality Modelling: Ben Chifley Dam Catchment, Australia*.

Newham, L. & Drewry J. (2006) *Modelling Catchment Scale Nutrient Generation*. CSIRO Land and Water Technical Report 28/05

New South Wales Food Authority (2008) *Sanitary Survey Report for the Middle Nambucca River at the Nambucca River*.

New South Wales Food Authority (2008) *Sanitary Survey Report for the Upper Nambucca River at the Nambucca River*.

Post, D., Waterhouse, J., Grundy, M. & Cook, F. (2007) *The Past Present and Future of Sediment and Nutrient Modelling in GBR Catchments*. CSIRO: Water for a Healthy Country National Research Flagship.

Rustomji, P. (2006) *Modelling sedimenta and nutrient budgets in the Lake Burragorang catchment*. CSIRO Land and Water Science Report 57/06

Sammut, J., White, I. & Melville, M. (1996) Acidification of an estuarine tributary in Eastern Australia due to drainage of acid sulfate soils. *Marine and Freshwater Research*. **47** pp 669 – 684.

The Universty of Newcastle Research Associates (TUNRA) (2007) *Water Quality Within Newee Creek and its Catchment*. Report 06/06.

Walsh, S., Copeland, C. & Westlake, M. (2004) *Major Fish Kills in the Northern Rivers of NSW in 2001: Causes, Impacts and Responses*. NSW DPI – Fisheries Final Report Series No. 68.

Wetland Care Australia (2004) *Gumma Gumma Wetland Management Issues and Options – Information Bulletin*.

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APPENDIX A
Introduction to Catchment Export Modelling

It is generally accepted that there are three or four basic classes of catchment export models. In practice most models are best described as hybrids of either empirical, conceptual or physical modelling (Letcher *et al*. 1999b, Newham & Drewry 2006). In addition, the categories used to group models are not universally agreed upon. This can make reviewing the literature somewhat confusing. Newham & Drewry (2006) describe a fourth class of index based model.

All model types have their inherent advantages and disadvantages. The 'best' model for any given application will depend on a number of factors, including the intended use of the model, the data and computing resources available and the expertise of the model user (Letcher *et al*. 1999).

Generation Rates Based (or Empirical) Models

These models are characterised by their simplicity, in effect being a small number of spatial and temporal variables contributing to generation and little or no consideration of routing processes or the interaction between rainfall and runoff (Letcher *et al*. 1999b). In many cases they can be just as accurate as more complicated models and are particularly useful as a first step in identifying sources of sediment and nutrient generation. They are, however, often highly catchment specific because the calibration of these models is frequently completed with some *in situ* water quality analysis. Whilst accurate predictions can be obtained from these models, they come with no insight into the processes behind them (Newham & Drewry 2006). In addition to this the most simple of the generation based models (empirical models) can be limited in their ability to predict changes in catchment exports when changes in land use or land management occur (Letcher *et al*. 1999). Empirical models also tend not to be responsive to changes in rainfall event intensity or regularity, ignoring the interaction between rainfall and runoff (Letcher *et al*. 1999).

Process Based (or Conceptual) Models

Particularly suited to long term predictions in large catchments, process based models are typically based upon a series of storages and transfer mechanisms. They are frequently calibrated with locally observed data and are based on an actual knowledge of nutrient generation processes. Some process based models allow the user to define the scale of the model (eg. the size of subcatchments) and thus the volume and spatial distribution of calibration data required. This allows a flexibility of approach that is important in data poor catchments. Well designed process models can give the user an insight to the processes and locations that contribute to pollutant enrichment or degradation. The success of process based models appears to hinge largely on the correct choice of scale and calibration data (see Letcher *et al*. 1999b) and thus on the expertise and knowledge of the user.

Physics Based Models

These models are most often based upon algorithms that describe plot-scale or stream –reach processes. In theory these algorithms can be directly sourced from the catchment but the large heterogeneity in stream and sediment processes within a catchment means that the reality of this is very complicated. They are not considered inappropriate for catchment scale mapping in Australian conditions for the following reasons (following Letcher *et al*. 1999b);

- The spatial and temporal distribution of appropriate data to drive and calibrate these models is too sparse in Australian catchments;
- These models require an expert knowledge to compile, limiting their usability; and
- When run at a catchment scale, the computational requirements of these models are prohibitive.

In addition, the scaling up of these models to catchment wide predictions can lead to an unacceptable accumulation of error (Newham & Drewry 2006).

Index Based Approaches

These models are based upon source and transport information and were originally developed to generate data indicating the risk of nutrient loss from soils. Although designed for field scale applications, they have been used at the catchment scale in Australia for the prioritisation of management practices (Newham *et al*. 2002). In comparison with physics-based approaches, the local application of index-based approaches is less likely to be thwarted by a paucity of input data and the models are capable of adequately representing the spatial distribution of export loads. However, they provide no treatment of nutrient generation processes or movement (Newham & Drewry 2006).

Comparing Model Classes

Merritt *et al*. (2003) make a comparison between the various classes of catchment export models. A summary of their findings follows. Overall it may be concluded that physics-based models and the more complex conceptual models are not particularly appropriate for estimating catchment exports for the following reasons (Following Merritt *et al*. 2003):

- Lack of sufficient spatially distributed input data to drive the models;
- Paucity of calibration data in space and time to define an appropriate parameter set for the models and hence reliable output;
- The over-dependency of model results on the experience of the user; and
- For physics-based models in particular, demanding computational requirements at large catchment scales.

On the other hand, generation based approaches can be combined constructively to provide models without these problems and with the following properties(Following Merritt *et al*. 2003):

- Event responsiveness and sensitivity to climate variability;
- Allow investigation of catchment source strengths; and
- General physical interpretability of modelling results.

Choosing a Catchment Export Model

As a general rule, there is no absolute 'best' model for modelling in all catchments, rather a best approach involves choosing the most appropriate model for the particular situation and outcome required (Letcher *et al* 1999). In assessing the applicability of models to various systems, the following list of factors to be considered was compiled by Newham and Drewry (2006);

- adequate simulation of hydrologic and biogeochemical processes under current management conditions;
- identification of critical source areas that currently, or potentially, contribute high loads of nutrients and other contaminants to streams;
- the potential to simulate the impact of current and future land management practices on spatio-temporal outputs reaching surface waters;
- sensitivity to climate variability;
- modest and readily available input data requirements;
- clearly stated assumptions;
- able to be comprehensively tested;

- possess strong visualisation capabilities to enable results to be effectively communicated to users; and
- short model processing times.

Letcher *et al*. (1999b) added the following comments;

- the suitability of the model to Australian conditions;
- hardware requirements;
- the accuracy and validity of the model; and
- the objectives of the users.

A common misconception is that more complicated models create more accurate predictions (Letcher *et al* 1999). In fact, the increased number of parameters and subsequent increase in data requirements can mean that errors accumulate within the more complex models to the point where confidence limits are unacceptably low.

As a conclusion, for modelling within Australian conditions the following generalisations can be made;

- Generation rates-based models and simple process based models are thought to be more appropriate than complex process based or physics based models;
- Process-based approaches, and some generation rates-based models, are useful because they allow investigation of catchment source strengths and have good general interpretability of results without onerous data requirements;
- A combination of generation based and process based approaches can provide a model that is sensitive to rainfall event and climate variability and indicates to the user the relative contribution of processes and subcatchment areas; and
- A flexible approach where the user defines the scale and sensitivity of the model helps to eliminate error accumulation and tailor the model to the specific availability of data.

Using International Models

A general consensus in recent Australian reviews of catchment export modelling approaches is that there are major differences between Australian catchments and the rest of the world (Letcher *et al* 1999, Newham and Drewry 2006). Specifically;

- Sheet and rill erosion are higher per unit area than the rest of the world;
- Sediment discharge to oceans is lower;
- Sediment delivery ratios from erosive event to waterway are lower;
- Australian N and P exports are much lower due to lower atmospheric deposition, lower fertiliser application and lower population densities (Harris 2001);
- The Australian climate is much drier than the rest of the world with a highly variable rainfall regime and hydrological response (*op cit* Newham & Drewry 2006);
- Many of the processes important in the delivery of constituents to Australian streams are not represented in international models (*op cit* Newham & Drewry 2006); and
- Australian soils are generally poorer quality and more weathered meany that agriculture tends to be less intensive.

These differences potentially effect the applicability of overseas developed models to Australian conditions without extensive modifications being made (Letcher *et al*. 1999b).

Issues with Available Models

A review of recent literature indicates that the current focus for improving catchment export models is to improve the understanding and representation of proceses governing the generation and movement of dissolved nutrients and nutrient uptake in the riparian zone.

The focus for modelling up until now has been on sediment bound N and P, but some studies suggest that dissolved nutrients are equally as important. Land management and land use affect the types and proportions of N and P in runoff and in turn affect the mechanisms by which N and P reach waterways. This means that the effectiveness of mitigating factors such as riparian buffers depends on both the particular land practices and the specific climate, ie. the delivery and abundance of rainfall. The basic concern is that dissolved nutrients may not be adequately represented in Australian models. In addition, both overland and soil flow need to be considered to adequately represent Australian systems (Newham and Drewry 2006). Dissolved nutrients do not respond to overland transport or riparian buffers in the same way as sediment bound nutrients (Newham and Drewry 2006). This transport may be especially important when flow is primarily through groundwater discharge.

Both riparian vegetation and wetlands can be sinks for nutrients but may have a finite lifespan as such. Some research indicates that they may act as sources when saturated (Newham & Drewry 2006). Improved understanding of representation of these processes is required to improve upon the current situation.

Calculating Unit Area Load Rates

Catchment export models often rely on some method of assessing unit area load rates or the amount of constituent generated per area of a particular land use. This presents a number of difficulties, particularly in Australian catchments where the relevant runoff data is often sparse or non-existent. Choosing nutrient generation rates to be used in the calibration of models can be complicated because the factors controlling nutrient, sediment and pathogen generation are often highly specific to a catchment due to their dependency on topography, soil type land use and land management practices. In addition to this, where data does occur it is often too sparse to provide confidence in the distributions represented. This makes it difficult to attribute confidence limits to the modelled catchment load outputs. A number of initiatives to overcome the difficulties of modelling in data poor catchments have been undertaken in recent years. These include;

- An Australian National Pollutant Inventory was established in 1995 and included diffuse sources of TN and TP from catchments around the country;
- Letcher *et al*. (1999, 1999b) described a combined empirical and conceptual approach for modelling in data poor catchments;
- Baginska *et al*. (2003) describe a method of using ‘bootstrap’, or ‘jacknife’, artificially generated data to fill out observed distributions and provide modellers with a more certain method of assessing confidence limits.

Sources of Error

Generally, within a model error with either be systemic or random (Letcher *et al.* 1999b). Systemic error is a problem with the model or algorithms within the model that result in a consistent bias towards over or under prediction of loads. Random error is introduced as a result of the data that is used to calibrate or to drive the model. Different types of models are more or less susceptible to types of error. For example, Generation based models can be prone to overestimation of loads in large catchments when filtration or in stream losses are not appropriately represented. Physics based models applied at catchment scales can lead to large randomly generated errors, as small errors in the input data are compounded during their application across a large catchment (Letcher *et al*. 1999b).

Calibration and Input Data

There are a variety of ways to calibrate catchment export models but all require some form of observed runoff and flow data. As a general rule, historical data from Australian catchments has not been collected with a view to the calibration of runoff models. In many cases his limits the utility of existing data.

It needs to be noted that models should be used with appropriate event-based water-quality data (Letcher *et al*. 2002), because routine water quality monitoring often does not capture large runoff events that may carry a large percentage of the load (Baginska *et al*. 2003)

Currently Available Catchment Export Models

In this section a brief review of some Australian models is undertaken. The list is not meant to be exhaustive. Internationally developed models have been excluded as they are widely viewed as inappropriate for Australian conditions (Newham & Drewry 2006). In addition to this models which are obviously inappropriate for the current project and models which focus only on one aspect of the current project have been excluded.

CMSS

CMSS (Catchment Management Support System) is a unit area generation based model most commonly used to provide an indication of the relative contributions of land uses and individual subcatchments to the total catchment load. It contains four sub modules, a database module for entering information, a policy module for entering information about land management, a predictive module for calculating catchment loads and an interrogation module for retrieving information. Unit area models of this type are most representative of long term load generation and may not accurately reflect mearsured loads in any given year due to high interannual rainfall and runoff variability (Letcher *et al* 2002). CMSS allows the user to define land use types and the generation rates for each land use. It then assumes homogeneity for each land use, ignoring differences in land management and soil fertility at a plot scale (Drewry *et al*. 2006). There is a capacity to add a subcatchment network and to add accumulation and attenuation information throughout the network. There is also allowance for point sources. The data requirements are modest, meaning CMSS is accessible to a wide range of users. CMSS does not have a capacity to model the hydrology of catchments. This is considered a major downfall, given the importance of rainfall and flow in the movement of nutrients (Newham & Drewry 2006). Baginsksa (2003) also notes a tendency for over-estimation of loads from this model when used on large catchment areas.

CatchMODS

CatchMODS (Catchment scale Management Of Diffuse Sources model) gives users the ability to analyse the current effects catchment land use and hydrological conditions on receiving waters and to analyse the effects of management activities. There are hydrologic, sediment and nutrient export models integrated into the CatchMODS system as well as a component that estimates the economic value of works. CatchMODS incorporates information from climate and associated hydrologic factors, catchment topography, land use, riparian management and point source pollution. Although riparian revegetation and gully management is modelled, management simulation of riparian buffer zones is not (Drewry *et al*. 2006). The sediment model incorporated into CatchMODS was built upon the same processes as the SedNet model but includes improved spatial scale modelling. The hydrologic submodel is a popular model known as IHACRES. CatchMODS models N and P inputs based upon the sediment load but also includes provisions from groundwater and point sources for N. Newham and Drewry (2006) suggest that this simplified treatment of P inputs limits the accuracy of CatchMODS when modelling intensively farmed catchments.

EMSS

EMSS is a catchment scale model designed to estimate daily runoff loads to receiving waters. It incorporates pollutant generation and runoff, pollutant routing and streamflow and a reservoir model. EMSS uses daily rainfall and evapotranspiration data alongside user specified pollutant generation rates to calculate daily estimates of flow, sediment concentration, N, P and pathogens from subcatchment areas. The model uses a spatial structure of links (pollutant routing) and nodes (pollutant generation or reservoirs).

In contrast to annual pollutant load reporting in CatchMODS, pollutant loads in EMSS are predicted daily by the hydrological model, but reported monthly to reduce apparent daily errors (Vertessy *et al*. 2001). Loads are predicted using event mean concentration and the baseflow runoff volume by dry weather pollutant concentration (Merritt *et al*. 2003). EMSS allows the user to allocate different event-mean and dry weather concentrations to subcatchments and landuses but the variability in these figures may not be adequately represented by most data sets (Drewry *et al*. 2006).

E2

E2 is a model based on two previous modelling packages EMSS (described above) and the Integrated Quantity and Quality Model (IQQM, see Jordan et al. 2007). E2 uses a subcatchment node and link style of spatial structure where constituents (pollutatnts) are generated and filtered within subcatchments before being passed to a node from which they are routed, potentially being subject to degradation or enrichment along the way. It includes improved flexibility and hydrologic modelling, allowing users to construct a model by choosing from and linking together a variety of sub models to achieve their aims. E2 also allows the user to choose the specific set of algorithms that define how the model responds to input data. Within E2, the user divides a catchment into Functional Units, or areas of common response. Each functional unit is subject to a rainfall-runoff model, a pollutant generation model and a filtering model. The functional units are then grouped into subcatchments, which are connected via links to other subcatchments or point sources. The links represent river reaches which are subject to a routing model, a source/sink model and a decay/enrichment model. E2 allows users to choose between two types of pollutant generation model.

E2 (Argent *et al.,* 2005) can be used to model sediment and nutrient generation rates under alternative land uses.

WaterCAST

The Water and Contaminant Analysis and Simulation Tool (WaterCAST) was designed to assist managers of predominantly rural catchments to make informed decisions as to how changes in catchment management influence the quantity and quality of runoff to receiving waters. WaterCAST includes mechanisms to improve the estimation of flows, loads and constituent concentration given actual, planned or hypothetical changes in land management or climate change. WaterCAST was built upon the flexibility of the E2 model and, like E2, WaterCAST allows the user a flexible approach to choosing specific submodels or algorithms to suit their application. However, a number of improvements have been made including;

- Enhanced and methods for modelling streamflow routing, making the process less time consuming;
- Improved handling of scenarios;
- Improved reporting capabilities; and
- Methods for rapid input of geospatial data.

CREAMS/GLEAMS

These models use a physics based approach to calculate the effects of agricultural practices on nutrient concentration in surface and groundwater runoff. The model considers rainfall runoff, sediment transport capacity and the effects of various types of erosion. They have been used to a limited extent in Australia.

LASCAM

LASCAM was originally developed to analyse the balance of salt and water in catchments but has since been modified to include mechanisms for the analysis of sediment generation, hydrological processes and nutrient mobilisation and transport (Merritt *et al*. 2003). LASCAM incorporates a variety of conceptual model components to achieve this. Whilst the output information generated is quite detailed, the input requirements for LASCAM are relatively demanding for a conceptual type model.

IHACRES

IHACRES is a popular rainfall-runoff model that has been incorporated into a range of sediment and nutrient transport models. IHACRES is a simple model, containing a maximum of 7 parameters (Letcher *et al*. 1999b) which are used to calculate discharge at catchment outlets and insteam routing accounting for evaporation, drainage, antecedent weather and rainfall. IHACRES has also been modified to calculate sediment concentrations based upon stream carrying capacity (Letcher *et al*. 1999b).

ANSWERS

Answers was developed to calculate runoff and erosion but has been extended to include nutrients. It uses four classes of land description as well as channel descriptions and event information to estimate runoff and erosion. It is a physics-based model and the onerous data requirements (Letcher *et al*. 1999b) are considered to render it unsuitable for use in most Australian catchments.

APPENDIX B
Modelling Catchment Exports in the Lower Nambucca Estuary Area

As a further support for investigations into water quality in the lower Nambucca estuary it was decided that a base case modelling exercise should be undertaken. The reasons for doing so were various;

- It was hoped that a modelling exercise would further clarify the picture of the relative contributions of each subcatchment to pollution in the lower Nambucca; and
- The model, once set up, could be used later to investigate potential changes in pollutant export delivered by best management practices throughout the catchment.
- The modelling was not undertaken to provide an accurate sediment or nutrient budget for the lower Nambucca, rather to provide an indication of the relative contribution of particular land uses or subcatchment areas.
- The model may assist the identification of pollutant sources and priority areas for management;
- The model may enable 'scenario testing' of land management practices, management interventions, future land use, climate changes, etc;
- The model might assist the broader understanding of relative contributions by producing maps, figures, and statistics (ie. numerical data such as loads and inferred concentrations) for comparison between subcatchments

It is important to note that the accuracy of the model outputs cannot be verified. In short, 'all models are wrong, some are useful'.

Model Choice

The model chosen for application to this project was WaterCast. WaterCast was chosen primarily for the flexibility it offers. WaterCast is essentially a framework for running a variety of models that generate information about runoff generation and pollutant export from a catchment. The wide variety of models available for choice mean that WaterCast can be applied to both large/complex and small/simple projects whilst retaining an element of reliability. In addition, WaterCast provides users with a choice of outputs, including tables, charts and figures. This was considered important in providing end users with accessible information.

In a data poor catchment, such as the Nambucca, a modelling approach to the analysis of pollutant generation is, by necessity, simple or it will contain too many assumptions. Whilst WaterCast can be made to fit complex modelling applications it was used here in a simplistic way to suit the situation of limited input and calibration information.

Developing a model within the WaterCast framework requires the user to choose from a suite of models that calculate the way rainfall is converted to runoff, the way constituents/pollutants are generated from the land and the way they are routed in the stream network. The specific models chosen for this project are detailed later in the text.

Spatial Representation of the Study Area

The subcatchment unit is used by WaterCast as the primary unit for analysis of catchment export behaviour. In effect, the export of pollutants is analysed primarily between subcatchments. WaterCast has a terrain wizard that will divide a catchment area into subcatchments based upon the import of a digital elevation map (DEM). In the absence of a reliable and accurate DEM a subcatchment map created by GECO Environmental (2008) was entered directly into WaterCast. The subcatchments were then linked individually to the theoretical outlet, being the Nambucca River. A schematic diagram of subcatchment position and flow direction is presented in *Figure A2-1*.

WaterCast then requires the definition of functional units (areas of identical constituent generation capacity) within the spatial network. Each functional unit within WaterCast can be assigned an individual rainfall runoff model, constituent generation models and constituent filtering models. Functional units were defined by importing a recent landuse map (GECO Environmental 2008) directly into WaterCast. The landuse categories of the mapping were chosen to correspond with the Australian Land Use and Management (ALUM) categories. The landuse categories used are listed in *Table A2-1* with constituent generation rates.

Rainfall Runoff

Rainfall and evapotranspiration data was imported from an Australian Bureau of Meteorology SILO data drill. The data was dated from 01/01/1889 to 17/08/2009 and the location of the data drill was approximately centred over Stuarts Island (for latitude 153,00' and longitude 30,39').

For all functional units SimHyd was chosen as the model component for calculating the runoff generated from each given rainfall event. SimHyd was chosen because of its reputation as a stable tool for both small and large scale applications (Chiew and Scanlon 2004). In the absence of local data, SimHyd was parameterised using default data, unchanged for different subcatchments and functional units. This represents an underuse of WaterCast's capacity but also avoids false complexity within the model.

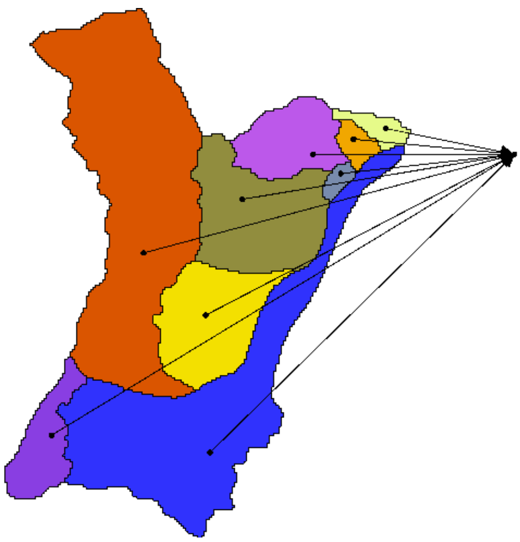

Figure A2-1 *Subcatchment position and flow direction in WaterCast*

Constituent/Pollutant Generation

The constituent generation model chosen for this application was an event mean concentration/dry weather concentration type model.

Three constituents were chosen for analysis in this run of WaterCast. They were total suspended solids, Total Nitrogen and Total Phosphorus. As little information exists about the generation of faecal material from different land use types, faecal indicators were not included as a constituent for analysis.

No locally collected data exists for the concentration of nutrients and sediment exported from the various land uses in the lower Nambucca catchment. The nutrient and sediment concentrations used in the model were adapted from Argent (2006) with only minor changes to improve the relevance to local conditions and the ALUM landuse classification used. A summary of nutrient and sediment generation rates for each functional unit employed in WaterCast is in *Table A2-1*.

Table A2-1 *EMC/DWC values applied to nutrient and sediment generation model in WaterCast.*

ALUM Category	Simplified Category	TN		TP		TSS	
		DWC	EMC	DWC	EMC	DWC	EMC
Residual Native Cover	*Forest*	0.5	1.5	0.05	0.1	6	40
Grazing Natural Veg	*Pasture Non Irrigated*	0.5	2.5	0.06	0.18	15	90
Grazing Improved Pasture	*Pasture Irrigated*	1.5	3.5	0.15	0.6	20	100
Cropping	*Annual Horticulture*	0.7	3	0.08	0.15	20	120
Perrenial Horticulture	*Perrenial Horticulture*	0.5	2.5	0.05	0.15	15	90
Land in Transition	*Pasture Non Irrigated*	0.5	2.5	0.06	0.18	15	90
Irrigated Modified Pastures	*Pasture Irrigated*	1.5	3.5	0.15	0.6	20	100
Dairy	*Industrial*	1.5	4	0.18	0.7	15	120
Manufacturing and Industrial	*Industrial*	1.5	4	0.18	0.7	15	120
Urban Residential	*Urban*	1.5	4	0.18	0.6	15	120
Rural Residential	*Green Space*	0.5	1.5	0.05	0.1	6	40
Commercial Services	*Commercial*	1.5	4	0.18	0.7	15	120
Public Services	*Commercial*	1.5	4	0.18	0.7	15	120
Recreation and Culture	*Green Space*	0.5	1.5	0.05	0.1	6	40
Roads	*Roads*	1.5	4	0.18	0.7	25	160
Railways	*Roads*	1.5	4	0.18	0.7	25	160
Mining	*Industrial*	1.5	4	0.18	0.7	15	120
Waste Treatment and Disposal	*Industrial*	1.5	4	0.18	0.7	15	120
Reservoir	*Water*	0.1	0.1	0.01	0.01	1	1
Wetland	*Water*	0.1	0.1	0.01	0.01	1	1
Estuary Waters	*Water*	0.1	0.1	0.01	0.01	1	1

Filtration

The WaterCast modelling framework offers the user the choice of a number of models for the filtration of sediments and nutrients in the environment. Due to the lack of local information no filtration step was included in this application of WaterCast.

Stream Routing Model

The WaterCast framework offers the user a choice of methods to represent in stream routing of runoff, e.g., storage hold ups and time spent in flow. As per Filtration modelling stream routing was considered excess to the needs of this project.

Results

There are two relevant ways of interpreting results with a view to future management of the catchment. Either the total volume of pollution exported or the concentration of pollutants per unit area from a given catchment can be assessed.

Table A2-2 *Mean daily flow and yearly catchment export rates for subcatchments in the lower Nambucca.*

Subcatchment	Flow ML/d	TSS kg/y	TN kg/y	TP kg/y
Newee Creek	33.8	716000	23500	2340
Gumma Creek	26.8	649000	20200	1800
Teagues Creek	12.2	346000	10100	873
Watt Creek	9.8	198000	6590	586
Bellwood Creek	6.04	183000	5320	480
Tilly Willy Creek	4.73	119000	3980	468
Beer Creek	1.35	43100	1200	92.4
West Nambucca	1.21	41000	1120	80.3
Golf Course	0.679	19400	543	37

Table A2-3 shows the total flow and total mass of constituents exported from each of the subcatchments in the lower Nambucca. In this case, as in many, the flow and export of nutrients and sediment are strongly aligned with catchment size. In the case of flow, this is to be expected as the model was set up with generic rainfall runoff parameters for all sub catchments. In the case of nutrient and sediment loads this result is suggestive of a relatively homogenous catchment.

Table A2-3 *Mean daily flow and yearly catchment export rates for subcatchments in the lower Nambucca*

Subcatchment	TP t/ha/y	TN t/ha/y	TSS t/ha/y
Bellwood Creek	0.001	0.0111	0.381
West Nambucca	0.000833	0.0116	0.425
Newee Creek	0.000874	0.00876	0.267
Teagues Creek	0.000898	0.0104	0.356
Gumma Creek	0.000846	0.00946	0.305
Watt Creek	0.000754	0.00847	0.255
Golf Course	0.000687	0.0101	0.361
Beer Creek	0.000861	0.0112	0.401
Tilly Willy Creek	0.00125	0.0106	0.318

According to the model the mean generation of nutrients and sediment is more concentrated in some subcatchments than others (*Table A2-3*). *Figures A2-2, A2-3* and *A2-4* demonstrate this clearly. The generation of Nitrogen appears to be most concentrated in the subcatchments with a greater proportion of urban development. These are Beer Creek, Bellwood Creek and West Nambucca subcatchments. According to the model the generation of Phosphorus is most concentrated in Tilly Willy Creek and Bellwood Creek catchments. This may be because of the higher ratio of roads to other landuses in those two catchments. The generation of sediment follow a similar pattern then Nitrogen, being mostly generated in urbanised subcatchments.

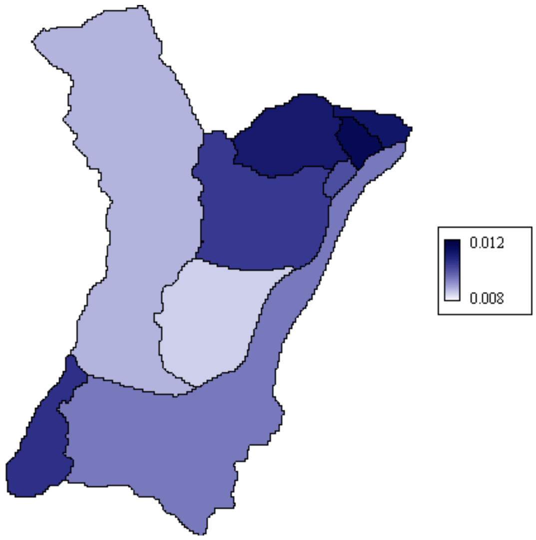

Figure A2-2 *Predicted average Total Nitrogen export from subcatchments in the lower Nambucca Estuary. Units are tonnes/hectare/year.*

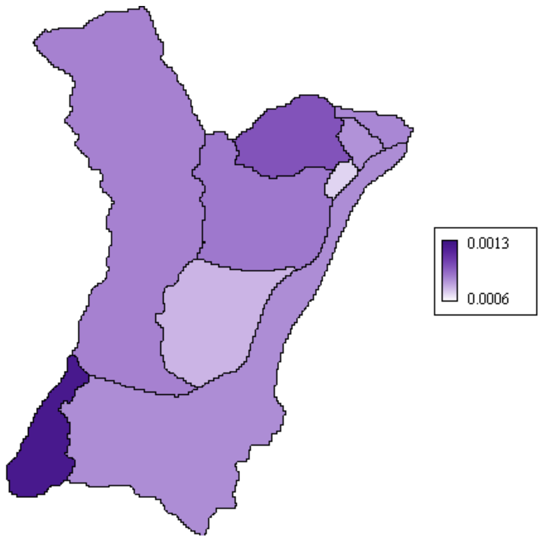

Figure A2-3 *Predicted average Total Phosphorus export from subcatchments in the lower Nambucca Estuary. Units are tonnes/hectare/year.*

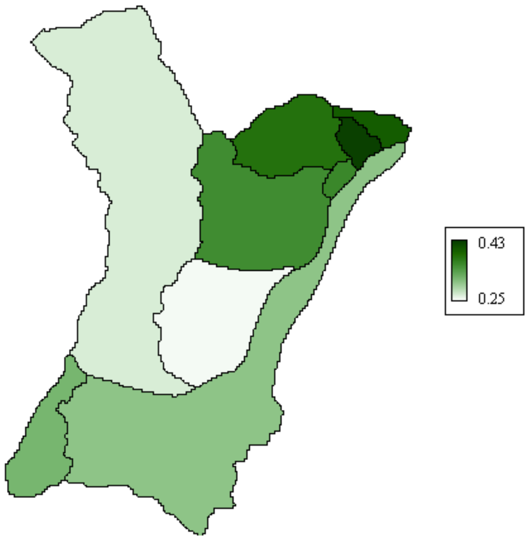

Figure A2-4 *Predicted average Total Suspended Sediment export from subcatchments in the lower Nambucca Estuary. Units are tonnes/hectare/year.*

Discussion

This application of WaterCast has provided some useful insights in nutrient and sediment generation in the lower Nambucca. However, conclusions should be drawn carefully and the model output is best assessed as part of a suite of analyses. The model results suggest that nutrient and sediment generation in the lower Nambucca is more concentrated in urban areas and areas with a higher relative cover of roads. This is largely supported by the results of water quality analyses. Contrary to the results obtained during event based sampling associated with this study (see *Parts 4* and *5* of the Study main document) the model does not find a strong correlation between nutrient export and grazing systems. This anomaly may be partly explained by difficulties with subcatchment resolution in the lower Watt Creek area.

A number of assumptions have been made in the preparation of this information and there are subsequent limitations to its utility. For example,:

- No local data was used to calibrate or parameterise this model. A lack of locally sourced data for model parameterisation is widely considered the biggest obstacle facing model developers. However, the collection of such data could take decades and be extremely expensive;
- The model would have benefited from the inclusion of a filtration step. The results can only be analysed as the ability of each subcatchment to generate nutrients and sediment as opposed to delivering them to a stream network;
- The floodplain is fairly flat, making it difficult to accurately define catchment boundaries. Small errors in catchment area can lead to large errors in the estimation of runoff and nutrient generation;
- The historical data obtained from the data drill is assumed to be relatively accurate. The model outputs are dependent upon this; and
- Point source inputs were not included in this analysis.

A large number of data dependent improvements could be made to this application of WaterCast;

- This application of WaterCast was based upon subcatchments mapped from coarse elevation data. Nambucca Shire Council is awaiting the delivery of digital elevation data created using the LiDAR flyover method. This data, transferred into a digital elevation map would allow

WaterCast to generate an accurate subcatchment and stream network map, greatly improving the modelled understanding of runoff pathways. This especially relates to the Watt Creek subcatchment;

- Inclusion of point source inputs from the Macksville Sewage Treatment Plant. Inputs from the Macksville STP are monitored fortnightly. This data is readily available from Nambucca Shire Council. The inclusion of this information as it exists would require the model to be run over a shorter time period than was done here and at a slower time step. Alternatively, it could be assumed that inputs from the STP are homogenous at a fortnightly time scale and the model could be run using daily rainfall and evapotranspiration data (and stream flow gauging data if it existed);
- Calibration of the rainfall runoff models requires flow data to be collected on a daily basis from as many of the subcatchments as possible. It is preferable that this data covers a period of more than a decade over both wet and dry periods. This factor is complicated by the tidal nature of the lower reaches of the creeks and the ephemeral nature of some of the freshwater reaches;
- Existing soil landscapes information could potentially be merged with landuse data to provide a more comprehensive functional unit map. The soil landscapes information could then be used to improve the rainfall runoff aspect of the model through improved parameterisation of permeability, erodibility, etc. An obvious, related, change would be to adjust the permeability of land in urban settings;
- Almost all modelling projects of this type would benefit from regularly collected local data referring to nutrient generation rates from different land uses during dry and wet times; and
- No filtration model was chosen due to a lack of local data. This limits the application of landuse change scenarios (such as riparian vegetation) to this baseline modelling exercise.