Integrative Catchment Modelling of Land Use, Turbidity, Flow and Geology

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<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>catchment area [m$^2$]</td>
</tr>
<tr>
<td>BE</td>
<td>rates of sediment delivery and sediment loading from riverbank erosion [t/yr]</td>
</tr>
<tr>
<td>C</td>
<td>ground cover factor [ ]</td>
</tr>
<tr>
<td>D</td>
<td>drainage density [ ]</td>
</tr>
<tr>
<td>Dv</td>
<td>particle size diameter [mm]</td>
</tr>
<tr>
<td>Ds</td>
<td>index of flow duration variability [ ]</td>
</tr>
<tr>
<td>Fs</td>
<td>stream frequency [ ]</td>
</tr>
<tr>
<td>g</td>
<td>acceleration due to gravity [9.81 m/s$^2$]</td>
</tr>
<tr>
<td>GCx</td>
<td>rates of sediment delivery and sediment loading from gully erosion [t/yr]</td>
</tr>
<tr>
<td>GDj</td>
<td>gully density [km/km$^2$]</td>
</tr>
<tr>
<td>K</td>
<td>soil erodibility factor [ ]</td>
</tr>
<tr>
<td>k$_1$</td>
<td>constant (that includes hydraulic roughness) [ ]</td>
</tr>
<tr>
<td>L</td>
<td>hillslope length factor [ ]</td>
</tr>
<tr>
<td>l</td>
<td>length of overland flow [km]</td>
</tr>
<tr>
<td>Lx</td>
<td>length of the riverbank [m]</td>
</tr>
<tr>
<td>P</td>
<td>land use practice factor [ ]</td>
</tr>
<tr>
<td>PGj</td>
<td>proportion of gully material that contributes to bedload [ ]</td>
</tr>
<tr>
<td>PR</td>
<td>proportion of riparian vegetation [ ]</td>
</tr>
<tr>
<td>Q</td>
<td>flow/discharge [m$^3$/s]</td>
</tr>
<tr>
<td>Q$_{1.58}$</td>
<td>bankfull discharge as the 1.58 year recurrence interval event flow [m$^3$/s]</td>
</tr>
<tr>
<td>Q$_{10}$</td>
<td>10th percentile flow [m$^3$/s]</td>
</tr>
<tr>
<td>Q$_{50}$</td>
<td>median flow [m$^3$/s]</td>
</tr>
<tr>
<td>Q$_{90}$</td>
<td>90th percentile flow [m$^3$/s]</td>
</tr>
<tr>
<td>Q$_s$</td>
<td>sediment transport capacity [t/year]</td>
</tr>
<tr>
<td>R</td>
<td>rainfall erosivity factor [ ]</td>
</tr>
<tr>
<td>Re</td>
<td>Reynolds number [ ]</td>
</tr>
<tr>
<td>S</td>
<td>energy slope approximated by channel slope [tan $\theta$]</td>
</tr>
<tr>
<td>S$_s$</td>
<td>hillslope gradient factor [ ]</td>
</tr>
<tr>
<td>s</td>
<td>particle density and fluid density ratio [ ]</td>
</tr>
<tr>
<td>$v_{cr}$</td>
<td>entrapment velocity [m/s]</td>
</tr>
<tr>
<td>$v_{cr}^*$</td>
<td>entrapment velocity factor [ ]</td>
</tr>
<tr>
<td>V$_{flow}$</td>
<td>flow velocity [m/s]</td>
</tr>
<tr>
<td>w</td>
<td>river width [m]</td>
</tr>
<tr>
<td>Y</td>
<td>rates of sediment delivery and sediment loading from hillslopes [t/ha/yr]</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>mean cross sectional area of a gully [m$^2$]</td>
</tr>
<tr>
<td>$\beta$</td>
<td>correction factor [ ]</td>
</tr>
<tr>
<td>$\theta$</td>
<td>shields parameter [ ]</td>
</tr>
<tr>
<td>v</td>
<td>fluid viscosity [m$^2$/s]</td>
</tr>
</tbody>
</table>
\( \rho \) density of the sediment \([\text{t/m}^3]\) used to calculate gully density (Prosser et al. 2001)
\( \rho \) fluid density \([\text{kg/m}^3]\)
\( \sigma \) particle density \([\text{kg/m}^3]\)
\( \tau \) age of the gully \([\text{y}]\)
\( \tau_{cr} \) shear force stress \([\text{kPa}]\)
Abstract

This document outlines and demonstrates the various aspects that contribute towards water quality systems and management, and the important use of storage/water quality models. The formulation of catchment and water quality models are outlined through the demonstration of three important components including the generation of pollutants produced in the catchment, delivery of pollutant loads into a stream and transport of pollutants through the catchment area and stream or lake. The formulation of models is discussed through site assessments of the Lower Derwent River catchment located in Tasmania, and the Mary River catchment in Queensland.

This document also presents the development of a suspended sediment transport model. This model can be applied as a tool for the assessment of river ecosystems in relation to upstream erosion patterns resulting from land use practices or catchment improvement activities.

The application and contribution of other models is demonstrated through the functions that modelling components have on sustainable regional development which assist stakeholder consultation and the decision-making process for water quality management systems.

Further integration of modelling tools is ensured through linkage with water quality management systems, such as Hazard Analysis Critical Control Point (HACCP), and other risk management systems.

The material presented in this document has been collated over the last three years during my employment with water quality corporations including Hobart Water and SEQWater.
Introduction

Purpose of Thesis

This document outlines and demonstrates all aspects that contribute towards the formulation, application and contribution of modelling catchment and storage/water quality as part requirement for the award of Doctor of Technology, in the Faculty of Sciences and Technology, at Deakin University. The function of this document is to detail the requirements of a Doctor of Technology by presenting my contribution to organisational improvements in practices and processes in relation to modelling tools developed herein and their integration with water quality management and management support systems. The material presented in this document has been collated over the past three years during my employment with water quality corporations including Hobart Water and SEQ Water.

General Introduction

The formulation of catchment and water quality models are outlined through demonstration of three important components including the generation of pollutants produced within a catchment, delivery of pollutant loads into a stream and transport of pollutants through the catchment and stream or lake. The formulation of models is discussed through a number of site assessments carried out while employed by Hobart Water on Lower Derwent River catchment located in Tasmania, and an independent study with the assistance of the Queensland Department of Natural Resources on the Mary River in Queensland. The characteristics of pollutants are presented through a pragmatic suspended sediment transport model developed here specifically for use by water managers and catchment authorities.

This thesis presents the formulation of a suspended sediment transport model and its partial application demonstrated on part of the Mary River in Queensland. The capacity of the model to classify the suspended sediment load into fractions that correspond to different particle size diameter present in a stream is also demonstrated. The model can be applied as a tool for the assessment of river ecosystems in relation to upstream erosion patterns resulting from land use practices or catchment improvement activities. Additionally, it will also contribute towards better planning and appropriate response to different suspended sediment loads for water treatment operations.
Aims and Significance

This research demonstrates the modelling tools and the processes implemented, that together with stakeholder consultation, assist current water corporations with the management of surface water and regional strategic planning of drinking water catchments.

This document discusses the scientific uncertainty of catchment and water quality model outputs which introduce scientific complexities in predicting pollutant generation, delivery and transport, coupled with available computational resources.

The purpose of the document is to inform model developers, water corporations and governments of modelling applications within Hobart Water and SEQWater. These demonstrate the techniques of available modelling tools to understand cause-effect relationships, forecast the impact of management changes, and support and promote the sustainable management of water resources.

Chapter Summaries

The first chapter outlines the relevant company profiles providing background on catchment water quality management practices that relate to this thesis.

The second chapter discusses water quality management support systems including database, geographic information systems (GIS), and catchment/water quality modelling tools, and demonstrates their application to the above mentioned corporations.

The third chapter outlines important aspects of theory, and the formulation of catchment and water quality models, for example, the generation and delivery of pollutants from a catchment to a stream, by the use of site based assessment studies. Transport of pollutants through water storage is demonstrated through the application of one dimensional hydrodynamic and zero dimensional water quality models. Aspects relating pollutant transport through rivers is discussed in the fourth chapter using the proposed suspended sediment transport model.

The fifth chapter discusses in particular the governmental methodology employed by the Queensland EPA and adopted by SEQWater and relevant stakeholders. The methodology uses catchment and water quality modelling information to assess future catchment improvement against defined water quality requirements or objectives.
The sixth chapter discusses different applications and contributions of catchment and water quality models. The chapter demonstrates development and application of the Hazard Analysis Critical Control Point (HACCP) water quality system, which manages and minimises water quality hazards in drinking water supply systems. The modified HACCP system is based on water quality and modelling information that ensures a better understanding of hazards and their behaviour in catchments.
1 Water Corporations

1.1 Hobart Water

Hobart Water is the principle supplier of bulk water to the eight councils of greater Hobart including the Derwent Valley Council, Brighton Council, Southern Midlands Council, Glenorchy City Council, Hobart City Council, Kingborough Council, Clarence City Council and Sorell Council in Tasmania, Australia.

Hobart Water’s major roles are catchment management, water collection, treatment, asset management including bulk water transport and storage, and bulk water supply to councils and other customers.

The past and prospective practices in catchment management of Hobart Water Regional Water Authority are quite unique. In accordance with the Framework for the Management of Drinking Water Quality (Australian Drinking Water Guidelines, 2004), catchments are now recognised as valuable sources of water and appropriate catchment management is regarded essential for best practice in ensuring long-term sustainable resources.

Hobart Water has three major catchment areas that supply water to its customers. They are (Figure 1):

- Wellington Park
- Lake Fenton and Lady Barron Creek
- Derwent River (Lower Derwent River)
This figure (Figure 1. Hobart Water Drinking Water Catchments) incorporates data, which is sourced from the Hobart Water (2003)

**Figure 1.** Hobart Water Drinking Water Catchments
Wellington Park supplies about 20% of drinking water to the Hobart regional area, and occupies 3,651 ha of Wellington Park. “Hobart has relied on drinking water from Mt Wellington catchments since its establishment in 1804… until water was sourced from Lake Fenton 1939, and the Derwent River in 1961” (Hobart Water, 2003, p. 2).

Lake Fenton contributes also about 20% of drinking water to the Hobart regional area, and occupies 1,530 ha. The catchment is located in Mt. Field National Park.

Hobart Water’s largest catchment is the Derwent River catchment, which supplies about 60% of the community’s water via the Bryn Estyn Water Treatment Plant (WTP) at New Norfolk. However, this catchment also supports a range of other activities, including forestry, agriculture, aquaculture, hydro-electricity generation, and recreational pursuits.

The Derwent River catchment upstream of the Bryn Estyn WTP covers a large area of central Tasmania, approximately 7,800 km². The total Derwent River catchment including that downstream Bryn Estyn WTP occupies a total of 8,900 km² or one-fifth of Tasmania.

Hydro Tasmania utilises water from the Derwent River Catchment upstream of the Bryn Estyn WTP. It includes the area between the Great Lake/Lake St Clair and Meadowbank Dam.

However, to ensure that natural supplies of quality drinking water can be sustained, Hobart Water has recognised the importance of implementing a strategic approach to the management of these areas. The strategic management of drinking water catchments uses a collaborative approach with relevant agencies to the practical application of environmental best practice for long-term resource sustainability. Senior Management is committed to ensuring this resource is sustained for the benefit of current and future generations. (www.hobartwater.com.au ,10-Jul-2003)

In the State that does not have any jurisdiction for the protection of drinking water catchments, Hobart Water won the Environmental Excellence Award 2003 for the Lake Fenton/Lady Barron Catchment Management Plan (2000) implementation and the Award for Planning Excellence 2004 for the Wellington Park Drinking Water Catchment Management Strategy, demonstrating a collaborative approach to the practical application of environmental best practice for long-term resource sustainability.

The Lake Fenton/Lady Barron Catchment Management Plan was prepared in consultation with steering committee that included relevant government agencies,
landowners and industries, and it outlines catchment characteristics and management actions that have a potential to improve catchment conditions and water quality.

The Wellington Park Drinking Water Catchment Management Strategy (2004), enclosed in Appendix A, is a key component that ensures sustainable management of Wellington Park drinking water catchment. It is based on a water quality risk assessment where risks identified within catchments are prioritised accordingly, and management actions defined and implemented in consultation with stakeholders. The activities that I have mainly carried out include the following:

- orchestrated steering committee
- carried out public review processes
- coordinated and prepared the final draft
- achieved final agency signoff.

The copy of the final document is enclosed in Appendix A.

Initially, catchment management involves a committed senior management who undertake strategic planning that ensures that the resource planning is in accordance with the company’s corporate strategy. Catchment management projects then undergo project planning phases, including assessment of the project against economic, service, and business objectives. Catchment projects also have to provide for an effective allocation of resources, and effective communication practices that result in the acceptance of project proposal by staff.
1.2 SEQWater

The South East Queensland Water Corporation Limited, trading as SEQWater, is the major supplier of bulk untreated water to local governments and industries in the south-east Queensland region (Figure 2). Primarily, its function is to provide a safe raw water supply to the people of the region. Its product is mainly catchment surface and ground water stored in dams. SEQWater owns and operates three water supply dams which are Somerset Dam, Wivenhoe Dam and North Pine Dam. An insert from the SEQWater Internet web page provides more background on SEQWater dams and is shown in Figure 3.

The Somerset/Wivenhoe Dams provide 86% while 14% of the region’s water comes from North Pine Dam. SEQWater’s major customers include Brisbane Water, Pine Rivers Shire Council, Esk Shire Council and Kilcoy Shire Council. The catchments for these dams are used for cattle grazing, plantation forestry, dairy farms and cropping.
This figure (Figure 2. SEQWater Storage Catchments Locality Map) incorporates data, which is sourced from the SEQWater (2005)

**Figure 2. SEQWater Storage Catchments Locality Map**
Wivenhoe Dam

Lake Wivenhoe is located on the Brisbane River in Esk Shire. Storage capacity for water supply (full supply level) is 1,165,000 megalitres, with a further capacity of 1,450,000 megalitres above full supply level (flood storage), for the temporary storage of flood waters.

Wivenhoe Dam is an earth and rock fill dam, with a centrally located, steel gated, concrete spillway. Lake Wivenhoe, which is the body of water formed by the dam, is also the lower storage for a 500 megawatt hydro-electric power station, owned by Tarong Energy Corporation.

Somerset Dam

Lake Somerset is located on the Stanley River, in Esk and Kilcoy Shires, at the upstream limit of Wivenhoe Dam storage. Storage capacity for water supply is 380,000 megalitres, with a further storage of 524,000 megalitres above the full supply level for the temporary storage of flood waters. The dam is a concrete gravity type, with a central, steel gated spillway. contractor.

North Pine Dam

Lake Samsonvale is located on the North Pine River in Pine Rivers Shire. Storage capacity for water supply is 215,000 megalitres. North Pine Dam has no provision above its Full Supply Level for the storage of flood waters. The dam is a concrete gravity type, with a steel gated spillway, and earth and rock fill abutments.

Figure 3. SEQWater Dams (inserts taken from the SEQWater web page 28 March 2005).
Potential activities affecting water quality include point sources of sewage treatment plants, septic tanks and industry discharges; runoff from landfills including weed control around dams; grazing, cropped land, and forestry operations; urban stormwater runoff; domestic and feral animals within a catchment; human access and potential sabotage; and recreational activities.

Consequently, SEQWater is undertaking initiatives to minimise and manage the risks to water quality in its storages. A key component of these initiatives is developing an understanding of water quality through monitoring and research efforts (SEQWater web page, 28 Feb. 05). SEQWater is also complying with the NHMRC/NRMMC Framework for Management of Drinking Water Quality (NHMRC/NRMMC, 2004) to ensure a good water quality supply to customers through application of the HACCP risk management system, and its integration with management tools including catchment and water quality models.

In the south-east Queensland catchments, water quality modelling has become an accepted tool to support the stakeholder consultation and management of surface water. Modelling techniques are carried out to understand cause-effect relationships and to assess and forecast the impact of management changes.
2 Water Quality Management Support System

The water quality management support system includes application of modelling tools, ensures improved strategic planning and development, and an effective water quality management system. A water quality management support system includes database, GIS, and catchment/water quality modelling tools. SEQWater has based its water quality management system on *TimeStudio*, a water quality database, along with the GIS and catchment/water quality modelling tools. I will further discuss each component of the support system starting with the *TimeStudio* database at SEQWater.

### 2.1 Modelling Tools

A modelling tool primarily assists in predicting spatial representation of pollutant loads in relation to associated water quality hazards, and water supply infrastructure. Therefore, it contributes towards better planned and implemented operational and management improvements to minimise water quality hazards. It is also a useful for validation and verification of the water quality management, and a significant reference point during stakeholder consultations.

Modelling tools are useful for evaluating physical, chemical and biological processes affecting the water quality. Physical, chemical and biological data is collected for modelling input (forcing) data, and general water quality compliance testing. Data collection and analysis are carried out in accordance with scheduled water quality monitoring.

Modelling tools also provide a unique understanding of a water source, and allow the assessment of “what-if” scenarios. Modelling tools will be discussed in more detail in the Section 3.

### 2.2 Time Studio Database

The quality of a modelling outcome is subject to the quality and availability of the monitored data. SEQWater’s *TimeStudio* database includes data sets collected from their water quality monitoring program, and on-line (telemetry) collection of data sets through weather stations, thermistors, and event gauging stations.

SEQWater has established a comprehensive program to monitor raw water quality. The program consists of campaign, field and event data samples; where campaign and field data are collected on a fortnightly, monthly, quarterly, six monthly or
annual bases. Campaign water quality monitoring includes bacterial, nutrient, and inorganic data sets, while field data includes physical and chemical data sets, such as turbidity, dissolved oxygen (DO), and conductivity to name a few. Event samples are triggered by a heavy rainfall event and sampling data sets may include bacterial, nutrient, inorganic, physical/chemical, or protozoa data sets. A series of monitoring locations include dam raw water off-takes, lake monitoring sites and catchment inflow sites. Water quality procedures have been developed for the collection, transmission, distribution and reporting of water quality monitoring results. SEQWater water quality data is used for compliance of water quality monitoring, and water quality modelling.

SEQWater also uses the TimeStudio database to store environmental data, such as meteorological, water quality and creek/river flow data. Weather stations record meteorological data that includes rainfall, wind speed and direction, and solar radiation. On-line water quality data is recorded automatically at TimeStudio’s database through thermistors located in storages that measure Dissolved Oxygen (DO) and temperature water profiles. Lastly, creek/river flow data is recorded through gauging stations located at storage inflow tributaries, where remote sensing of events producing water-flow triggers event sampling. This environmental data is mainly used for water quality modelling, and event sampling.

“TimeStudio database is a Windows application that provides integrated time series data archiving and processing. It has been developed by the Water Resources Department of the Hydro-Electric Corporation of Tasmania (Australia) to help store and analyse time series data. Originally it was developed for work with hydrological, climatic, and environmental data, but it can be used to store and analyse anytime series data. The application is available either for a stand alone PC or in a network version. TimeStudio supports connection to any mainframe hosted database that supports the Open Database Connectivity (ODBC) specification. ODBC is the predominantly standard database interface for the Windows environment, and is supported by most major suppliers of relational database packages” (Hydro Tasmania, 2000, p.1.1).

SEQWater has been using the following TimeStudio design features (Table 1).

**Table 1.** TimeStudio design features (adopted from Hydro Tasmania, 2000, p.1.3).
SEQWater can utilise this feature by entering a data source specification as a formula in Microsoft Excel, and have the data loaded into the Time Series database automatically. DDE is also an effective means of interfacing with GIS. An example of this will be presented later in this section through an application of TimeStudio Modelling software applied to Hobart Water.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exchange (DDE)</td>
<td>from any DDE client application that provides a suitable exchange format. DDE is also an effective means of interfacing with GIS. An example of this will be presented later in this section through an application of TimeStudio Modelling software applied to Hobart Water.</td>
</tr>
<tr>
<td>Open Database Connectivity (ODBC)</td>
<td>ODBC is a specification adopted by most of the major vendors of database packages for Windows. It enables a customer to choose which database TimeStudio manager uses (e.g. Access, Oracle, and so forth). It also means that query tools that support DDE can be used to produce special reports.</td>
</tr>
<tr>
<td>Multiple Document Interface (MDI)</td>
<td>MDI enables multiple tasks display so that a customer can easily switch from entering data to producing a report.</td>
</tr>
<tr>
<td>Context Sensitive Help</td>
<td>A context sensitive help button displays relevant Help text for any item on any window. The on-line Help includes hyper-text links for navigating to related topics.</td>
</tr>
</tbody>
</table>

SEQWater also uses the Time Studio reporting function to generate updated water charts when required. An example of a chart generated by TimeStudio showing a DO profile recorded by an on-line thermistor in the storage area is shown in Figure 4.
Figure 4. DO profile recorded by an on-line thermistor and generated by *TimeStudio* database.

The *TimeStudio* database can be extended to include the *TimeStudio* modelling feature. This feature is not utilised by SEQWater, however, I have completed a project that demonstrated its application to produce a yield and forecast model for the catchment area of Lake Fenton/Lady Barron Creek for Hobart Water.

Hydro Tasmania was engaged to develop a Hydrological Yield and Forecast model that had to meet Hobart Water’s objectives including application of the new operational procedures in managing catchment’s water resources.

### 2.2.1 Demonstration of *TimeStudio* Modelling Feature

A *Hydrological Yield and Forecast* model was developed to provide Hobart water with an objective means of optimising water releases from Lake Fenton, and to make the most efficient use of runoff from the Lady Barron Creek catchment downstream from Lake Fenton.
The hydrological yield model uses real-time data to model the flow through the catchment including inflows into Lake Fenton and releases from Lake Fenton off-take on Lady Barron Creek. The model also uses the rainfall data recorded at Lake Fenton.

The hydrological forecast model uses the same framework as hydrological yield model but as the name implies uses a forecast rainfall to provide forecast catchment flows for two days into the future. This model is dependant on Bureau of Meteorology (BoM) forecast rainfall.

For a conceptual rainfall/runoff model, the catchment was subdivided into five subcatchments of roughly equal area and within which hydrometeorological conditions were similar. Subcatchments were connected in a mathematical network which simulated the actual stream network with excess rainfall as the input and stream flow as the output. The following schematic outlines the model (Figure 5).

![Figure 5. Schematic of Yield Model](image-url)
In conjunction with catchment modelling, a graphic user interface (GUI) was developed that displays the real time and forecast catchment flows. This interface was developed in Excel and allows the user to update catchment values by clicking an update button, view data in graphical form and view a site picture by clicking on the site headings. The models and the interface were installed and are functional at Hobart Water offices. Figure 6 outlines the essential elements of the GUI showing the hydrological model as displayed in Excel format. It also shows on-line monitoring equipment located at Lady Barron Creek.

![Figure 6. Hydrological yield model as displayed in Excel format.](image)

The main outcomes of this project were the following:

- Establishment of permanent monitoring sites and the development of hydrological yield and forecast models to provide Hobart Water with an objective means of optimising water releases from Lake Fenton and to make the most efficient use of runoff from the catchment, and
- Better understanding of water quality yield that emanates from the catchment

I presented this application of the TimeStudio modelling feature at the AWA Integrated Catchment Management Conference 26-27 November 2003 University of Western Sydney.
2.3 GIS

GIS is used to assemble data and to present, analyse and interpret the results.

“Geographical information systems allow the georeferencing of data, analysis and display of multiple layers of geographically referenced information and have proven their value in many aspects of water pollution control” (Adriaanse et al. 1997, p.263).

Adriaanse et al. (1997) list other features of GIS as:

- location, spatial distribution and area of source pollution and affected area
- correlation of various GIS layers (e.g. land cover, land use with drainage and so forth)
- presentation of modelling outcomes, and other GIS layers

Some GIS software provides features that allow hydrological assessment of water catchment. At Hobart Water I undertook the hydrological assessment of the Wellington Park catchment to present opportunities for the upgrade and relocation of some water supply intakes.

*ArcHydro* tool, which is based on *ArcGIS* including *ArcView* and *Spatial Analyst* software was used. *ArcHydro* tool provides catchment analysis and hydrological modelling capabilities that have been applied to carry out the following:

- understand the catchment hydrology and network drainage
- delineate the catchment above the water supply intake
- provide information to maximise catchment yield
- identify areas that need greater attention.

As input data I have used 10m contours and drainage (1:25 000) files to convert to a raster file (42 x 42) metres (Figure 7).
ArcHydro basic processing tools include estimate of flow direction, water accumulation, stream definition, catchment delineation, calculation of slope and drainage processing. Figure 8 shows some initial results including improved drainage files (or GIS data), and calculation slope that proved to be essential when investigating gully erosion patterns.
However, the most important processing result was the batch watershed delineation that estimated catchment delineation based on the location of 13 water supply intakes. Use of the *ArcHydro* tool also provided recommendations to relocating some water supply intakes to increase water supply yield and reduce gully erosion. The figures showing recommendations and new catchment delineation are not shown in this document.

*ArcHydro* also has the potential to provide estimates of catchment yields by linking batch nodes to TimeSeries data mainly meteorological data such as rainfall. However, this was not implemented at Hobart water due to lack of *ArcEditor* or *ArcInfo* licences.
3 Integrated Catchment Modelling

Currently in Australia, and worldwide, there are a great number of models aimed at contributing to management and improvement of water quality resources. Generally, any approved model would assist water managers, land owners or catchment associations during decision making process. However, the responsibility for catchment and water quality modeling improvement lies equally with research groups to develop accurate scientifically sound models, and with government for ongoing commitment to support research groups and to encourage the industry to applying those models.

3.1 Modelling Theory

There are different types of models applied to water quality and catchment modelling, and they may be conceptual, process based or empirical, dynamic or stationary, and deterministic or probabilistic models.

Larsen et al. (1997) sets out different types of modelling according to the complexity of their outputs, and they include the following:

- **Loadings** – where the management decision to minimise pollution is based on the localised modelled loadings to water body.

- **Mass balances** – where mass balance represents a combination of loadings, inflow variables and residence time. The significance of water quality pollution is determined based on resultant loading and concentration in the receiving waters.

- **Effect evaluations** – where the pollution source is evaluated based on the concentration in the receiving waters.

- **Advanced ecological models** – where the model is capable of refined levels of prediction. These are used to investigate concentrations or loads in the receiving waters.

Some predictive water quality models may be zero dimensional, one dimensional (1D), two dimensional (2D) or three dimensional (3D) with or without integration with GIS. The hydrodynamics driver is a component that provides a 1D, 2D or 3D modelling capacity. It is generally coupled with zero dimensional aquatic ecological models. Certain modelling scenarios would require different hydrodynamics modelling capacities. An example of the suitability of a hydrodynamics modelling capacity to different modelling requirements is listed below.

- For a shallow wetland exposed to strong winds, having a single inflow stream and high source of nutrients, a zero dimensional model would be used as the water column is unlikely to be stratified due to strong winds.
• For a small, deep water storage experiencing stratification related to water quality issues during summer, a 1D (in the vertical) model would be more appropriate.
• For a long, narrow, shallow lake experiencing problems due to lake inflow, a 1D (in the horizontal) would be appropriate.
• For a large reservoir with multiple inflows experiencing higher pollutant loads, a 3D would be the best option.

Other possible water quality issues such as total suspended solids (TSS) transport may also be investigated using water quality models, and the above mentioned scenarios present some examples of most appropriate applications of water quality models.

Adriaanse et al. (1997) states that importance of water quality models is due to their ability to:
• Forecast impacts of new developments in and around a water body.
• Link in with other (catchment) models that provide pollutant loads data.
• Produce sufficient information for policy analysis and testing.
• Provide early warning to downstream water users of increased pollution.
• Provide information complementing better network design upgrade.
• Ensure a better understanding of complex water quality processes and parameters that mostly impact overall water quality.

Currently in Australia, major institutions that focus on developing catchment and water quality models include the Cooperative Research Centre (CRC) for Catchment Hydrology based in Melbourne and the CWR for Water Quality and Treatment based in Perth. The CRC for Catchment Hydrology has produced a modelling toolkit that includes models such as SedNet, MUSIC, Environmental Management Support System (EMSS) recently modified to E2, Adaptive Environmental Assessment and Management (AEAM) and Integrated Quality and Quantity Model (IQQM). The CWR has produced storage models that include DYRESM-CAEDYM and ELCOM to name a few. In Table 2 the main characteristic of the models developed by these two organisations have been summarised.
<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SedNet</td>
<td>“SedNet is a model that constructs sediment budgets for river networks to identify patterns in the long term erosion and deposition throughout a catchment. The model represents sediment generation from hillslope, gully and stream bank erosion. It constructs separate budgets for sediment and bedload. Complete delivery to the stream network of sediment from gully and bank erosion is assumed (net generation), and a delivery ratio is used for sediment from hillslope erosion. SedNet incorporates a transport capacity for long-term bedload, and bedload deposition within streams and reservoirs. The generation, delivery, transport and transformation terms in the sediment budgets are mean-annual averages for the conditions defined. Depending on the erosion and hydrology data used, the averages are valid over 20 years, and longer. SedNet is a spatially explicit model. It uses a link-node structure to construct separate sediment budgets for many (hundreds) of subcatchments” (CRC for Catchment Hydrology, 2005, p.20).</td>
</tr>
<tr>
<td>MUSIC</td>
<td>MUSIC is a tool to assist in the design of urban storm water drainage systems. It simulates runoff, sediment and nutrient generation, movement and treatment through typical components of an urban system such as swale drains, biofiltration trenches, gross pollutant traps, infiltration systems, detention ponds and wetlands. MUSIC operates at a range of temporal and spatial scales; catchment from 0.01 km² to 100 km² and modelling time steps ranging from 6 minutes to 24 hours to match the catchment scale. MUSIC is designed for urban stormwater engineers, planners, policy staff and managers in consultancies and State, regional and local government agencies” (CRC for Catchment Hydrology, 2005, p.20).</td>
</tr>
<tr>
<td>EMSS</td>
<td>EMSS was developed from a catchment scale sediment and nutrient modelling project in South East Queensland and has now been applied in several catchments around Australia. It is a link node based model that separates a catchment into many (perhaps hundreds) of subcatchments. Sediment and nutrient generation is based on average concentration (EMC) and dry weather concentration (DWC) and the model is generally run at a daily time step. Point sources can be represented, as can dams/storages where simple model of transformations to sediment and nutrient are available. Runoff and contaminant routing is included, as is the ability to present management actions such as land use change, land management change and riparian buffer management. It does not include complex water management, although simple release from dams is possible” (CRC for Catchment Hydrology, 2005, p.20).</td>
</tr>
<tr>
<td>Name</td>
<td>Description</td>
</tr>
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<td>------------</td>
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</tr>
<tr>
<td>AEAM</td>
<td>“AEAM is actually a process that is broader than just water quality models and often does not include computer models at all (Holling, 1978; Walters, 1986; Walters 1997). The water quality AEAM type models have been based on average concentration in runoff from a particular land use using monthly data, summed over periods of 10-20 years to give long term averages, but statistics on shorter temporal scales. The models are spatially explicit, using a cell-based approach with cells of the order of 1-16 km². Representation of surface erosion hazard, stream bank erosion, point sources and water management is generally incorporated (CRC for Catchment Hydrology, 2005, p.20).”</td>
</tr>
<tr>
<td>IQQM</td>
<td>IQQM is a hydrologic network model used in planning and evaluating water resource management policies. It is a generalised hydrologic simulation package, which is capable of application to regulated and unregulated streams, and is designed to be capable of addressing water quality and environmental issues as well as water quantity issues. The model is structured for investigating and resolving water sharing issues at the interstate or international level, and between competing group of users, including the environment. The model operates on a continuous basis and can be used to simulate river system behaviour for periods ranging up to hundreds of years. It is designed to operate at a daily time step, but some processes can be simulated at time steps down to one hour. IQQM uses the Sacramento rainfall-runoff model for the generation of subcatchment runoff and uses regression based relationships for the generation of load. However, it is capable of using time series flow and load inputs from other models such as E2 or EMSS.</td>
</tr>
<tr>
<td>DYRESM</td>
<td>DYnamic REServoir Simulation Model (DYRESM) is a one-dimensional hydrodynamics model that predicts the vertical distribution of temperature, salinity and density in lakes and reservoirs. It is assumed that the water bodies comply with the one-dimensional approximation in that the destabilising forcing variables (wind, surface cooling, and plunging inflows) do not act over prolonged periods of time. DYRESM has been used for simulation periods extending from weeks to decades. Thus the model provides a means of predicting seasonal and inter-annual variation in lakes and reservoirs, as well as sensitivity testing to long-term changes in environmental factors or watershed properties (Antenucci and Imerito, 2003).</td>
</tr>
<tr>
<td>Name</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>DYRESM</td>
<td>DYRESM and ELCOM to provide a complete description of reservoir hydrodynamic and biogeochemical behaviour.</td>
</tr>
<tr>
<td>ELCOM</td>
<td>Estuary and Lake Computer Model (ELCOM) is a three-dimensional hydrodynamics model used for predicting the velocity, temperature and salinity distribution in natural water bodies subjected to external environmental forcing such as wind stress, surface heating or cooling (Hipsey et al. 2003).</td>
</tr>
<tr>
<td>RMA</td>
<td>Resource Management Associates (RMA) suite of hydrodynamic and water quality models may be used for coastal, estuarine and river simulation in steady state or dynamic model. The RMA finite element models were originally developed with the support of the U.S. Army Corps of Engineers Waterways Experimental Station (WES) for simulation of 1, 2, and 3-dimensional hydrodynamics, water quality and sediment transport in rivers, bays and estuaries. These models form the basis of the Corps of Engineers’ TABS modelling system.</td>
</tr>
</tbody>
</table>
The current Australian Water Quality Guidelines (2004), and Australian and New Zealand Environment and Conservation Council (ANZECC) (2000) guidelines support application of catchment and water quality models in managing water resources. The ANZECC guidelines state that information provided by a predictive water quality model “improves our conceptual understanding of the ecosystem being managed and in particular the pathways that underpin predictive models” (pp. 2-19).

The CRC for Catchment Hydrology (2005) has outlined three basic components of most water quality models as follows:

- generation of pollutants produced in a catchment.
- delivery of pollutant loads into a stream.
- transport including the way pollutant loads are transported through a catchment.

These modelling components fit into a natural movement progression of any pollutant. Hence, the generation, delivery and transport of suspended sediment in rivers has been investigated here within these modelling components.

Two site assessment studies to assess the theory behind generation and delivery of suspended sediment as a pollutant is reported here. The first site assessment case study was undertaken in south-east Tasmania while working for Hobart Water on the Lower Derwent River. The second case study was carried out on part of the Mary River catchment in Queensland.

The case studies assess catchment characteristics that affect suspended sediment generation and delivery to streams. Those characteristics include land use, hydrometeorology, geomorphology, floodplain and floodplain history, soil properties, land movement, erosion and sediment yield.

### 3.2 Lower Derwent River Case Study

This study discusses generation and delivery of suspended solids in the Lower Derwent River catchment located in Tasmania. The study also outlines the potential contribution of the suspended transport model towards assisting reliable supply of raw water, and optimising the value and treatment of water through the Bryn Estyn WTP.
3.2.1 Derwent River Catchment

The Derwent River flows from Lake St Clair (central Tasmania) through a World Heritage Wilderness region, terminating in south-eastern Tasmania where it becomes the Derwent Estuary.

The Derwent River catchment is divided into two catchments; the Upper Derwent River characterised by power generation infrastructure and controlled river flows, and the Lower Derwent River that receives flow released from the Meadowbank Dam, and runs uncontrolled for 46 km where it becomes the Derwent Estuary.

Figure 9 shows the Derwent River catchment.

![Derwent River catchment map](image)

**Figure 9.** Derwent River catchment

The Derwent River catchment occupies the area between Lake Sorell and the Shannon River in the east; northern edge of the Central Plateau in the north; Lake St Clair, Lake King William and the Florentine River in the west; and in the south by the small township of New Norfolk (Department of Primary Industries Water and Environment)
[DPIWE], Tasmania (2001). The Derwent River catchment is one of the largest river basins in Tasmania covering an area of approximately 7,800 km² upstream of New Norfolk. There are a multitude of land uses within the catchment including hydro power generation, forestry, agriculture, wood processing, National Parks, rural settlements, fish farming and coal mining.

Hydro Tasmania utilises the Upper Derwent River Catchment for hydro-generation occupying the area between the Great Lake/Lake St Clair and Meadowbank Dam. The Lower Derwent River is defined by a controlled flow regime through the Meadowbank Dam with 69 ML/day median flow (20 percentile equating to 49 ML/day and 80 percentile ML/day 105ML/day) (Hydro Tasmania, 2001).

The catchment consists of two different regions distinguished by their rainfall capacities into areas of high and low rainfall. High rainfall areas are located in the north-west with mean annual rainfall at Lake St. Clair of 1,511 mm and at Bronte Park of 943 mm. Areas of low rainfall occur in the south-east with mean annual rainfall at Bothwell of 545 mm and at Bushy Park of 579 mm (DPIWE, 2001).

As reported by the DPIWE (August 2001), the geology of the catchment is dominated by Jurassic dolerite, with other rock types such as tertiary basalt sediments in the Parmeneer Supergroups and Pleistocene glacial deposits near Lake William and Lake Augusta. The DPIWE (2001) also state that the Junee-Florentine karst is the most extensive underground drainage system in Tasmania (over 23,500 ha) and contains the deepest caves known in Australia.

Hydro Tasmania operates the upper catchment of the Derwent River that covers an area of 7,765 km². Grant et al. (2001) states that the Derwent River and a number of its main tributaries have been dammed to form 21 storages for the generation of hydro-electricity. Hydro Tasmania’s Meadowbank Dam is the last storage in a chain of dams and power stations with inter-basin transfers. The water discharged from the Meadowbank Dam affects the condition of the Derwent River downstream particularly its flow and related sediment load. The Meadowbank Dam, being the upper boundary of the Lower Derwent River catchment, will be considered as the reference point for this site assessment.

The Lower Derwent River has a catchment area of 128 571 ha or 1,285.7 km², and includes subcatchments from Meadowbank Dam (latitude -42.62, and longitude 146.84) in the north-west to New Norfolk in the south-east. This study recognises the Bryn Estyn WTP (latitude -42.61, and longitude 147) as the final receiving point being located 4 km upstream from New Norfolk. Flows that reach the Bryn Estyn WTP are significantly
modified by the controlled flow regime produced by the Meadowbank Dam owned and operated by Hydro Tasmania.

The catchment consists of five major tributaries which are the Tyenna River, Styx River, and Plenty River on the south-western side, and the Allenvale Rivulet, and Belmont Rivulet on the north-eastern side.

This figure incorporates data, which is sourced from the Hobart Water (2003)

Figure 10 shows the Lower Derwent River catchment and related sub-catchments.
This figure incorporates data, which is sourced from the Hobart Water (2003)

**Figure 10.** Lower Derwent River catchment
Tyenna River has a catchment area of 38 367 ha or 384 km$^2$, and has the following tributaries: Kallista Creek, Junee Creek, Humbolt River, Lady Barron Creek, and Boyces Creek (Figure 11).

Those tributaries are mainly uncontrolled and have a natural flow, the exception being Boyces Creek that is dammed for agricultural use (DPIWE, 2001).

There are four minor settlements in the area – they are Maydena, Mt. Field National Park, Westerway, and Fentonbury.

Forestry Tasmania occupies the majority of the catchment. The second largest catchment area is managed by the Parks and Wildlife Services, mainly situated within the Mt. Field National Park.

This figure incorporates data, which is sourced from the Hobart Water (2003)

**Figure 11. Tyenna River subcatchment**

The lower catchment (below Westerway and Bushy Park) is mainly used for agriculture. Agricultural disciplines vary from grazing of sheep and cattle to harvesting of crops, mainly currants.
There is also Nortas Karanja fish farm adjacent to Tyenna River, about 2 km east of the township of Westerway, and Nortas hatchery at the Mt. Field National Park.

**Styx River** (Figure 12) has a catchment of 40 242 ha or 402 km², including adjoining smaller catchments of Park Creek (5 421 ha), and Kinvarra Creek (999 ha). It has a sole tributary called the South Styx River. The major settlements are Bushy Park and Glenora.

Those settlements are located in the lower catchment near the junction with the Derwent River. Lower parts of the catchment are privately owned and used for agriculture, mainly for the cultivation of hops.

The Upper and middle catchment is used by Forestry Tasmania, and the south-west part of the catchment is situated within the National Park. The Styx River receives runoff from forestry operations.

Grazing predominates over agricultural practices.
This figure incorporates data, which is sourced from the Hobart Water (2003)

**Figure 12.** Styx River subcatchment
**Plenty River** has a catchment of 26,915 ha or 269 km², including the adjoining smaller catchments of Glenfern Creek (2,980 ha), Charlies Hope Creek (432 ha), and Mike’s Creek (847 ha). It consists of two major tributaries, Stoney Creek, and Puzzle River. The two minor settlements are Plenty and Feilton (Figure 13).

Forestry Tasmania uses two thirds of the catchment. The rest is privately owned and used for agriculture, mostly for the cultivation of poppies. There is also Saltas Salmon Ponds fish farm located 2 km upstream from the Derwent River.

This figure incorporates data, which is sourced from the Hobart Water (2003)

**Figure 13.** Plenty River subcatchment
Allenvale Rivulet has a catchment of 14,498 ha or 145 km$^2$, including the adjoining smaller catchments of Glenelg Creek (1,321 ha), and Kelly Dam Creek (1,566 ha).

The catchment consists mainly of pasture land used for grazing of sheep and cattle (Figure 14).

Belmont Rivulet has a catchment of 8,549 ha or 86 km$^2$, including the adjoining smaller catchments of Springs Creek (1,419 ha), Puzzle Gate (795 ha), Hayes Creek (597 ha), and Johnnys Creek (1,874 ha).

The catchment is mainly used for agriculture. Agricultural disciplines vary from grazing of sheep and cattle to harvesting of potatoes, cereal, onions, and poppies (Figure 15).

This figure incorporates data, which is sourced from the Hobart Water (2003)

**Figure 14. Allenvale Rivulet subcatchment**

**Figure 15. Belmont Rivulet subcatchment**
Morphometric relationships are used to estimate runoff behaviour during rainfall. According to Ritter et al. (2002) drainage density manifests the relationship between geology and climate. In addition, Ritter et al. (2002) note that “resistant surface material and those with high infiltration capacity exhibit highly spaced streams yielding low drainage density” (p.151). They add that if the soil permeability decreases, the runoff is distributed through a higher number of closely spaced channels.

The morphometric relationships are also linked to erosion potential through the existence of vegetation cover in the catchment. The vegetation cover increases soil resistance and infiltration resulting in low drainage density.

Table 3 shows morphometric relationships calculated for the main Lower Derwent River subcatchment.

**Table 3.** Lower Derwent River subcatchment morphometric relationships

<table>
<thead>
<tr>
<th></th>
<th>Tyenna*</th>
<th>Styx*</th>
<th>Plenty*</th>
<th>Allenvale*</th>
<th>Belmont*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (km²)</td>
<td>383</td>
<td>338</td>
<td>227</td>
<td>116</td>
<td>38</td>
</tr>
<tr>
<td>River Length (km)</td>
<td>40</td>
<td>47</td>
<td>41</td>
<td>21</td>
<td>10</td>
</tr>
<tr>
<td>Drainage Density</td>
<td>0.55</td>
<td>0.65</td>
<td>0.50</td>
<td>1.50</td>
<td>0.44</td>
</tr>
<tr>
<td>Stream Frequency</td>
<td>0.17</td>
<td>0.22</td>
<td>0.14</td>
<td>0.18</td>
<td>0.08</td>
</tr>
<tr>
<td>Overland Flow</td>
<td>0.91</td>
<td>0.77</td>
<td>1.00</td>
<td>0.33</td>
<td>1.13</td>
</tr>
</tbody>
</table>

* Excluding the adjoining smaller catchment areas.

Figure 16 illustrates the correlation between drainage density, stream frequency, and length of overland flow for each Lower Derwent River subcatchment.
Figure 16. Lower Derwent River subcatchment morphometric relationships

Figure 16 shows that Allenvale Rivulet subcatchment has a high drainage density, and is likely to contribute the majority of sediment runoff per unit area.

3.2.2 Land Use

The majority of agricultural land in the Lower Derwent River catchment was cleared approximately 150 years ago to allow for cropping and grazing practices. Today, the land is recurrently used for cultivation of various crops such as poppies, cereal, potato, hops and currants. Cultivated land is also used as pasture and the two land practices usually replace each other every 5 years. Currently, the majority of cleared land is used as pasture for the grazing of sheep and cattle.

The percentage of land use types in the Lower Derwent Catchment is as follows:

- Conservation and Natural Environments – including national parks and nature conservation areas (24%).
- Production from dryland agriculture and plantations – including plantation forestry, grazing modified pastures, cropping, perennial horticulture (25%).
- Production from irrigated agriculture and plantations (1%).
- Production from relatively natural environments – including livestock grazing, and commercial production from native forests (50%).

Figure 17 shows land use practices in the Lower Derwent River catchment.
This figure incorporates data, which is sourced from the Hobart Water (2003) and Department of Primary Industries Water and Environment (DPIWE) – Tasmania (2000)

**Figure 17.** Lower Derwent River Land-use
Runoff from the forestry and agricultural practices is diffuse and has an impact on the sediment loads discharged through the process of erosion and runoff. Other industrial/commercial practices which affect sediment loads include aquaculture, waste water treatment plants/lagoons and a few quarries.

The effect that forestry operations have on sediment loads are linked to changes in hydrology, soil disturbance and runoff. The particular features or operations relevant to sediment runoff are forest harvesting and regrowth, and unsealed forest roads.

Riparian buffer strips are included in the Forest Practice Code of Tasmania to minimise impact on rivers and streams in catchments owned by Forestry Tasmania. The Forest Practice Code is a collection of guidelines and standards used in planning forest operations to ensure environmental protection. This code is required under the Forest Practices Act 1985 (Tasmania).

It has been observed in the Lower Derwent catchment that some agricultural (cropping) practices, which follow harvesting, are not undertaken in an appropriate manner to prevent release of sediment, and are usually a source of sediment due to hillslope erosion. The majority of crop fields are located near the riverbank, which exacerbates hill slope and riverbank erosion, causing an increased sediment supply to the river.

Agriculture has the potential to affect the sediment loads in the river via its runoff from the pastures or crop fields which would be reduced with distance from the river and its tributaries. A number of fish farms are located in the Lower Derwent River catchment as mentioned above. Sediment emissions caused by erosion do not occur in areas where fish farms are located.

A sewage treatment plant is located at Maydena that treats a wastewater load equivalent to 100 residences. There is also a double lagoon system, which services the Mt. Field National Park that has registered on average 131,000 registered visitors per year. The Maydena sewage treatment plant discharges into the Tyenna River, and the Mt. Field National Park lagoons effluent enters the ground water system. Other townships are not sewered and dwellings are served by septic tanks.

### 3.2.3 Catchment Reference Points

Reference points represent the start and end of the Lower Derwent River catchment. The catchment starts below the Meadowbank Dam and finishes near the New Norfolk...
township (Figure 10). For the purposes of this study the Bryn Estyn WTP located 4 km upstream from New Norfolk will be regarded as the end of the catchment.

Meadowbank Dam releases regulated flow discharges into the Lower Derwent River. The majority of sediment received into Meadowbank Dam settles as “reservoirs trap up to 95% of the bed load and suspended sediment carried by the river” (Brookes, 1996, p. 229). However, the major impact of regulated flow comes from the reduction in flood peaks, which triggers changes in geometry of the bed to adjust to a new set of flow variables and sediment load (Bravard, 1996).

Davies et al., (2002) states that “the Lower Derwent is characterised by a highly modified flow regime due to the influence of Hydro storages and power stations upstream in the Derwent catchment, and particularly of the Meadowbank dam and power station” (p.15). Flows released from the Meadowbank Dam range from 30 to 180 m$^3$/s.

Davies et al., (2002) suggests that “reduction in flood frequency and intensity has occurred largely due to the combined effects of flow regulation through the Meadowbank power station and attenuation of flood peaks through the series of storages upstream of Meadowbank dam” (p. 16). Hydro generation has resulted in the loss of floods in excess of 150 m$^3$/s and a reduction of flood frequency from 2.1 per year to 0.3 per year (Davies et al., 2002).

A photo of the Meadowbank Dam taken from below the Dam is shown in Figure 18.

![Figure 18. Meadowbank Dam](image-url)
Water quality and flow measured at the outflow of the Meadowbank Dam is shown in Table 4.

**Table 4.** Water quality and flow measured at the outflow of the Meadowbank Dam

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>Water Temp</th>
<th>Turbidity</th>
<th>Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>°C</td>
<td>NTU</td>
<td>m³/s</td>
</tr>
<tr>
<td>median</td>
<td>7.2</td>
<td>13.5</td>
<td>3.7</td>
<td>89.6</td>
</tr>
<tr>
<td>80%</td>
<td>7.4</td>
<td>18.1</td>
<td>9.5</td>
<td>128.4</td>
</tr>
<tr>
<td>20%</td>
<td>6.8</td>
<td>7.6</td>
<td>1.5</td>
<td>67.7</td>
</tr>
<tr>
<td>maximum</td>
<td>7.8</td>
<td>21.7</td>
<td>26.5</td>
<td>596.5</td>
</tr>
<tr>
<td>minimum</td>
<td>6.2</td>
<td>4.7</td>
<td>0.1</td>
<td>19.9</td>
</tr>
</tbody>
</table>

Raw data sourced from Hydro Tasmania (2003)

**Raw data sourced from Hydro Tasmania (2003)**

Figure 19 shows the relationship between the Meadowbank discharge flows and turbidity values, revealing a weak correlation. On-line telemetry equipment monitors water quality and flow measured at the outflow of the Meadowbank Dam. Data has been manipulated as mean daily flows and turbidity.

**Figure 19.** Meadowbank Dam discharge flows and turbidity values
Figure 20 sourced from Davies et al., (2002) shows a flow regime “characterised by very high variation on an hourly basis” (p. 16) based on flow data from September to December 2001 (reported as mean daily flows taken at 2 hourly intervals).

**Figure 20.** Daily flow variations at Lower Derwent River below Meadowbank Dam (sourced from Davies et al., 2002, p.16)

Median monthly flow recorded at the Lower Derwent River below Meadowbank Dam from 1981 to 2001 (Davies et al., 2002) is shown in Table 5.

**Table 5.** Median Monthly Flow at the Lower Derwent River below Meadowbank Dam (Davies et al., 2002, p. 175)

<table>
<thead>
<tr>
<th>Month</th>
<th>Median Flow (m$^3$/s)</th>
<th>20 % Flow (m$^3$/s)</th>
<th>80 % Flow (m$^3$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>61.28</td>
<td>44.25</td>
<td>86.08</td>
</tr>
<tr>
<td>February</td>
<td>56.50</td>
<td>35.11</td>
<td>77.44</td>
</tr>
<tr>
<td>March</td>
<td>56.85</td>
<td>39.87</td>
<td>74.04</td>
</tr>
<tr>
<td>April</td>
<td>67.87</td>
<td>48.65</td>
<td>103.63</td>
</tr>
<tr>
<td>May</td>
<td>84.54</td>
<td>63.90</td>
<td>119.51</td>
</tr>
<tr>
<td>June</td>
<td>101.36</td>
<td>76.32</td>
<td>144.79</td>
</tr>
<tr>
<td>July</td>
<td>127.08</td>
<td>88.30</td>
<td>183.12</td>
</tr>
<tr>
<td>August</td>
<td>133.90</td>
<td>97.23</td>
<td>236.02</td>
</tr>
<tr>
<td>September</td>
<td>134.55</td>
<td>97.99</td>
<td>205.56</td>
</tr>
<tr>
<td>October</td>
<td>124.44</td>
<td>86.05</td>
<td>205.16</td>
</tr>
<tr>
<td>November</td>
<td>94.60</td>
<td>70.24</td>
<td>137.42</td>
</tr>
<tr>
<td>December</td>
<td>74.30</td>
<td>54.19</td>
<td>103.44</td>
</tr>
</tbody>
</table>
Sediment deposition downstream from the reservoir occurs due to the regulation of high-magnitude floods that slows sediment transport, whilst the sediment supplied by tributaries is unaffected or possibly increased (Brookes, 1996).

Davies et al., (2002) suggest that sediment emissions as a consequence of the regulated flow from the Meadowbank Dam may result from the:

- bank slumping due to rapidly fluctuating water levels.
- bed degradation due to armouring.

The complete ecological adjustment below the reservoirs can take up to hundreds of years. Brookes (1996) lists three orders of impact:

- First order – occur at the time of closure, affects transfer of energy and material.
- Second order – channel changes and floodplain dynamics changes resulting from first order changes.
- Third order – impacts on benthic invertebrates, fish, and floodplain fauna resulting from the first and second order change.

The raw water source for the Bryn Estyn WTP is the Derwent River. Bryn Estyn WTP is the downstream reference point and is located on the western bank of the river, approximately 3.5 km north of New Norfolk (Figure 9). The Derwent River catchment via Bryn Estyn WTP is a reliable water supply source, especially during the summer when dry conditions can limit the use of Hobart Water’s other catchment areas.

The river level at the Bryn Estyn intake is influenced by both flow rate and estuarine tidal movements. The location of the WTP is positioned to be above the salt wedge of the Derwent River estuary, that under low median flows, penetrates all the way up the estuary to the New Norfolk township.

The intake at the river is across the road from the WTP site. The raw water is coarse screened at the river and fine screened at the pump station.
The Bryn Estyn WTP has been developed in stages. Stage 1 was a conventional treatment process with 6 filters. The plant was later augmented in Stage 2, by the addition of a clarifier and 6 filters, to increase the capacity of the plant. This is now referred to as Plant 1. In the 1990s a direct filtration process, Stage 3, was added to supply treated water to meet the increasing summer demands on the system. This is now referred to as Plant 2. A diagrammatic overview of the treatment processes of the Bryn Estyn WTP is shown in Figure 21 sourced from the Hobart Water information booklet (2004).

![Figure 21. Bryn Estyn WTP Overall Process (sourced from Hobart Water information booklet (2003).)](image)

Plant 1 is a conventional treatment process, incorporating the unit processes of coagulation, flocculation, clarification, filtration, pH adjustment, fluoridation and disinfection (chlorination). Plant 2 is a direct filtration treatment process, incorporating the same unit processes as Plant 1.

The Bryn Estyn WTP’s average capacity of 150 ML/day is drawn from the Derwent River. During summer months and when customer demands exceed 150ML/day, untreated water is pumped from the river and shandied with treated water to supply the maximum supply of partially treated water to the maximum short-term capacity of 200 ML/day.

The maximum flow rate capacity of the treatment process is affected by the quality of the incoming raw water. During very poor raw water quality periods, the rate of the treatment processes may need to be reduced to achieve a suitable, treated water quality.

The Derwent River is fed by surface water runoff from numerous mountainous catchments and lakes. Seasonal variations and the effects of storms and snow melts lead to a range of water qualities experienced at the intake of the Bryn Estyn WTP.
Figure 22 shows turbidity variations between Meadowbank Dam and Bryn Estyn WTP over the period from 6 December 1999 to 6 October 2003.

Raw data sourced from Hydro Tasmania (2003) and Hobart Water (2003)

Figure 22. Turbidity variations between Meadowbank Dam and Bryn Estyn WTP

Figure 22 shows that the Meadowbank Dam affects turbidity levels recorded at the Bryn Estyn WTP intake. However, it also shows that there are other sources that have an effect on turbidity variations in the river before it reaches the intake.

3.2.4 Climate

Climate averages for three locations within the Lower Derwent Catchment were obtained from the BoM web site in July 2003. The BoM has weather stations located in the lower Derwent River catchment are Bushy Park (station no. 095003), Maydena (095011), and New Norfolk (095015) (Figure 10). Climatic characteristics are shown in Table 6.
Table 6. Climate Characteristics recorded by the Bureau of Meteorology

<table>
<thead>
<tr>
<th>Description</th>
<th>BUSHY PARK 095003</th>
<th>MAYDENA 095011</th>
<th>NEW NORFOLK 095015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean daily maximum temperature (°C)</td>
<td>17.6</td>
<td>16.2</td>
<td>17.4</td>
</tr>
<tr>
<td>Mean no. of days where Max Temp ≥ 30.0 (°C)</td>
<td>11.6</td>
<td>6.5</td>
<td>10.4</td>
</tr>
<tr>
<td>Highest daily Max Temp - deg C</td>
<td>39.5</td>
<td>37.5</td>
<td>39.4</td>
</tr>
<tr>
<td>Mean daily minimum temperature (°C)</td>
<td>6</td>
<td>5.2</td>
<td>6.7</td>
</tr>
<tr>
<td>Mean no. of days where Min Temp ≤ 2.0 (°C)</td>
<td>80</td>
<td>94</td>
<td>64.8</td>
</tr>
<tr>
<td>Lowest daily Min Temp (°C)</td>
<td>-6.7</td>
<td>-6.3</td>
<td>-5.7</td>
</tr>
<tr>
<td>Mean 9am dew point (°C)</td>
<td>6.4</td>
<td>6.8</td>
<td>6.1</td>
</tr>
<tr>
<td>Mean 9am relative humidity (%)</td>
<td>77</td>
<td>81</td>
<td>75</td>
</tr>
<tr>
<td>Mean 9am wind speed (km/h)</td>
<td>5.9</td>
<td>5</td>
<td>6.7</td>
</tr>
<tr>
<td>Mean 3pm dew point (°C)</td>
<td>6.9</td>
<td>7.3</td>
<td>6.3</td>
</tr>
<tr>
<td>Mean 3pm relative humidity (%)</td>
<td>58</td>
<td>62</td>
<td>54</td>
</tr>
<tr>
<td>Mean 3pm wind speed (km/h)</td>
<td>12.3</td>
<td>9</td>
<td>11.2</td>
</tr>
<tr>
<td>Mean monthly rainfall (mm)</td>
<td>578.5</td>
<td>1214.5</td>
<td>549.7</td>
</tr>
<tr>
<td>Mean no. of raindays</td>
<td>150</td>
<td>207.7</td>
<td>133.5</td>
</tr>
<tr>
<td>Highest recorded daily rainfall (mm)</td>
<td>71.9</td>
<td>86</td>
<td>111</td>
</tr>
<tr>
<td>Mean no. of clear days</td>
<td>39.7</td>
<td>24.3</td>
<td>30.2</td>
</tr>
<tr>
<td>Mean daily evaporation (mm)</td>
<td>2.6</td>
<td>not recorded</td>
<td>not recorded</td>
</tr>
</tbody>
</table>

Note: Statistics and length of record
All rainfall observations for a site that have been quality controlled were used, regardless of how many years of data there are. Users should remember that a period of less than 30 years of rainfall data may not produce reliable statistics and such information should be used with caution. As a comparison some 5-10 years of temperature data will provide a reasonable estimate of the mean, (although probably not of the extremes). (BoM WebSite, 2003)

Evapotranspiration maps for Tasmania sourced from the BoM web site (2003) show monthly variations for the Lower Derwent River catchment ranging from 10 mm during winter to 90mm during summer.
3.2.5 Soil Properties

The DPIWE completed a Reconnaissance Soil Map Series of Tasmania in 2000. The area surveyed covers 45 % of the Lower Derwent Catchment. Figure 23 shows the reconnaissance soil map series of Tasmania for Hobart, Ellendale, and Brighton.

This figure (Figure 23. Soil orders for the Lower Derwent River catchment.) incorporates data, which is sourced from the DPIWE – Tasmania (2000)

Figure 23. Soil orders for the Lower Derwent River catchment.

Properties of soil present in the catchment are further described in Table 7.

Table 7. Lower Derwent River soils description based on the Reconnaissance Soil Map Series of Tasmania in 2000 (Spanswick, 2000)

<table>
<thead>
<tr>
<th>Map Unit</th>
<th>CSIRO Code (Old)</th>
<th>Description</th>
<th>Aust. Soil Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>YBs</td>
<td>Well drained stony yellow brown soils developed on Jurassic dolerite bedrock and colluvium on rolling to very steep land.</td>
<td>Ferrosol</td>
</tr>
<tr>
<td>Bd1</td>
<td>Bd</td>
<td>Moderately well drained brown soil developed on Jurassic dolerite bedrock and colluvium on rolling to steep land (10-65%).</td>
<td>Dermosol</td>
</tr>
</tbody>
</table>

Brown Soils on Dolerite
<table>
<thead>
<tr>
<th>Map Unit</th>
<th>CSIRO Code (Old)</th>
<th>Description</th>
<th>Aust. Soil Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pm1 Podzolic Soils on Mudstone</td>
<td>Pm</td>
<td>Poor to imperfectly drained grey brown texture contrast soils developed on Permian mudstone bedrock and colluvium on undulating to rolling land.</td>
<td>Kurosol</td>
</tr>
<tr>
<td>Pss1 Podzol and Podzolic Soils on Sandstone 1</td>
<td>Pss</td>
<td>Imperfectly drained texture contrast soils and well drained deep sands developed on Triassic sandstone bedrock and colluvium on undulating to rolling land.</td>
<td>Kurosol with codominant Podosol</td>
</tr>
<tr>
<td>Bfs1 Brown Soils on Feldspathic Sandstone 1</td>
<td>Bfs</td>
<td>Imperfectly drained grey-brown soils developed on Triassic feldspathic sandstone bedrock and colluvium on undulating to rolling land (3-32%)</td>
<td>Chromosol</td>
</tr>
<tr>
<td>M7</td>
<td>M</td>
<td>Miscellaneous soils on Ordovician and Precambrian rocks.</td>
<td>/</td>
</tr>
<tr>
<td>Bp</td>
<td>A1</td>
<td>Soils developed on flat to gently undulating (0-3%) river terraces.</td>
<td>Chromosol</td>
</tr>
<tr>
<td>Ro</td>
<td>A2</td>
<td>Soils developed on flat to gently undulating (0-3%) river terraces.</td>
<td>Hydrosol</td>
</tr>
<tr>
<td>Ro-Pss1 Podzol and Podzolic Soils on Sandstone 1 Complex</td>
<td>A2-Pss</td>
<td>As for Ro with Pss1 soils on undulating to rolling sandstone slopes.</td>
<td>Hydrosol</td>
</tr>
<tr>
<td>Pss Podzol and Podzolic Soils on Sandstone</td>
<td>Pss</td>
<td>Unidentified soils developed on Triassic sandstone bedrock and colluvium on undulating to rolling land.</td>
<td>/</td>
</tr>
<tr>
<td>A</td>
<td>A</td>
<td>Undifferentiated soils developed on Quaternary alluvium.</td>
<td>/</td>
</tr>
</tbody>
</table>

3.2.6 Hydrological and Morphological Characteristics

The Lower Derwent River has uniform to gradually varied flow properties. Uniform flow is characterised by a constant depth where streamlines and bed profile are parallel and pressure distribution constant (Carling, 1996). Gradually varied flow is typified by gradual changes in cross-section and depth, and the pressure distribution varies (Carling, 1996).

Parsons et al. (2002) have identified that the discharge regime has a significant influence on the morphology and dynamics of a river system, as it influences many 'response level' stream characteristics such as channel slope, width, depth, bedform geometry, meander wavelength, sinuosity and sediment transport.
The Ecosystem Health section of the National Land and Water Resources Audit (2003) has devised a set of four indices that indicate change in flow from 'natural' conditions:

- index of mean annual flow
- index of flow duration curve difference
- index of flow duration variability and
- index of seasonal differences

These indices provide a measure of the deviation in flow volume, duration and seasonal pattern.

The Lower Derwent River natural flow data are inaccessible due to regulated flow released from the Meadowbank Dam. The only hydrological index based on the current flow conditions is the index of flow variability (Dv). It provides a measure of the flow regime variability at a daily/monthly time scale. Dv ranges between 0 and 1, where 0 is the most altered flow duration variability and 1 is no change from natural conditions in flow duration variability.

The equation developed by National Land and Water Resource Audit (NLWRA) to equate the index is shown below, where $Q_{90}$ is the 90th percentile flow, $Q_{50}$ is the median flow, and $Q_{10}$ is the 10th percentile flow.

\[ D_v = \frac{Q_{90} - Q_{10}}{Q_{50}} \]

The equation was used to calculate Dv for the Lower Derwent River. Flow percentiles based on daily flow data measured below Meadowbank Dam from 1-Jan-99 to 31-Aug-03 are listed below:

$Q_{90} = 141.35 \text{ m}^3/\text{s}$
$Q_{10} = 41.20 \text{ m}^3/\text{s}$
$Q_{50} = 89.6 \text{ m}^3/\text{s}$

Index of flow duration variability for the Lower Derwent River is 1.1, which exceeds the value 1 that characterises no change in flow duration variability from natural conditions. One possible explanation for this index value is that the majority of the Lower Derwent River flow is released from Meadowbank Dam and is exceptionally modified.
A floodplain is defined as “the largely horizontally-bedded alluvial landform adjacent to a channel, separated from the channel by banks, and built of sediment transported by the present flow regime” (Ritter et al., 2002, pp.233). A floodplain acts as a buffer for sediment transport from hillslopes, and consequently acts as a storage reserve of sediments. It also maintains the equilibrium of sediment concentration in a river by retaining and releasing sediment (Ritter et al., 2002, Phillips 2003).

Lewin (1996) states that fluvial deposition involves sedimentation of finer material that has been suspended in flowing water along, at or near the river bed. It is important to note that the floodplains of rivers cease acting as one “once the thickness of the valley deposits exceeds the limits of scouring depth” (Ritter et al., 2002 pp.242).

Phillips, J. (2003) notes that sediment delivered to rivers is either deposited an alluvium on the floodplain, or reaches the river as the sediment yield. Phillips, J. (2003) also suggests that sediment is sourced from the floodplain when sediment supply from upstream is limited. Based on Phillips, J. (2003), Ritter et al., (2003), Lewin (1996) and Bravard (1996) the floodplain will be considered a potential sediment source in the Lower Derwent River.

Lewin (1996) has summarised three principles behind the floodplain and its development in relation to sediment transport in a river:

- At high flows, floodplains become part of the surface flow, and during low flow, groundwater discharges through the floodplain into a river system.
- A high proportion of river sediments originate from the floodplain.
- Floodplains preserve a record of hydrological and morphological changes including changes caused by human activities.

The designated geomorphological zones are shown in Figure 26. Based on a study carried out by Davies et al., (2002) the floodplain deposits occur in Zones 4, 6, and 8. Zone 6 was also found to be flooded during the 1960 flood.

The impact that floods have on sediment transport is modified by flood flows that overtop the riverbanks as they spread onto the floodplain because a proportion of suspended sediment goes with that overbank flow. The amount of sediment that settles on the flood plain can be predicted as a function of the mean sediment concentration, and the ratio of the floodplain area and the overbank discharge (Pickup and Marks, 2001).
The River Derwent Flood Data Book (DPIWE, 2000) contains a history of rural floods and their extent, and it states that flooding of the Derwent River was first reported in September 1828. Five major flood events have occurred since then. The Flood Data Book also states that the 1960 flood is considered the largest event in Tasmania since European settlement. It resulted in an inundation near the entry of tributaries and creeks into the Derwent River. Figure 24 illustrates the extent of the Lower Derwent River floodplain after the 1960 flood.
Carling (1996) suggests that “larger floods have greater potential to erode and transport sediment but occur infrequently; and small floods occur frequently but sediment transport is limited and are generally geomorphologically ineffective” (p.75)
Church (1996) and Bravard (1996) found that river geometry represented consistent relationships between flow, and the width, depth, and velocity, as channel size increased systematically through a river system, the additional catchments contributed larger flows to the trunk channel.

Figure 25 shows a photo taken in October 2003 demonstrating a common occurrence in the Derwent River catchment, where cropped land near the river got flooded, potentially contributing to an increased sediment load in Derwent River.

Figure 25. Flooded cropped land near the Lower Derwent River bank.
### 3.2.7 Geomorphological Assessment

The Lower Derwent River’s landscape has been modified based on its geological evolution shown in Table 8.

**Table 8.** Geomorphological history of the Lower Derwent River based on Davies et al., 2002

<table>
<thead>
<tr>
<th>Period</th>
<th>Geologic Era</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>190-136 million years</td>
<td>Jurassic</td>
<td>Triassic sandstone sheets and underlying Permian metamorphics led to the subsequent intrusion of erosion resistant dolerite into the landscape.</td>
</tr>
<tr>
<td>65-2.5 million years</td>
<td>Tertiary</td>
<td>Creation of the Derwent graben(^1), combined with the resistant dolerite, has controlled the Derwent drainage system.</td>
</tr>
<tr>
<td>Last 730,000 years</td>
<td>Quaternary</td>
<td>The basalt flows partially filled Lake Glenora(^2) overlying lake sediments. The basalt flows forced the river to flow as a lateral stream.</td>
</tr>
<tr>
<td></td>
<td>(marked by</td>
<td>In an area abundant in dolerite, the river was forced to cut through the basalt being less resistant to erosion (compared to dolerite).</td>
</tr>
<tr>
<td></td>
<td>climatic</td>
<td>Sediment supply increased as periglacial(^3) processes in the highlands made more material available, resulting in deposition in the lowland areas.</td>
</tr>
<tr>
<td></td>
<td>changes</td>
<td>During interglacial periods vegetation stabilised slopes and sediment supply was reduced and erosion of lowland deposits occurred.</td>
</tr>
<tr>
<td></td>
<td>between</td>
<td>Alternating periods of deposition in incision have left the landscape characterized by numerous elevated terraces(^4).</td>
</tr>
<tr>
<td></td>
<td>glacial(^1) and interglacial periods</td>
<td>The finer sediments found in floodplain deposits along the river are generally a function of a new regime and are of Holocene (recent) origin.</td>
</tr>
<tr>
<td></td>
<td>Glacial</td>
<td>Davies <em>et al.</em>, (2002) has divided the Lower Derwent River into 9 geomorphological zones based on characteristics that include geological structure, channel gradient, valley width and degree of floodplain, the presence and composition of terraces, the degree and</td>
</tr>
<tr>
<td></td>
<td>influences</td>
<td></td>
</tr>
<tr>
<td></td>
<td>have ended</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12,000 years</td>
<td></td>
</tr>
</tbody>
</table>

1. The Derwent Graben was complex with an uneven surface and as a result numerous lakes formed along its length, separated by rapids and cascades. (Davies *et al.* 2002)
2. An ancestral lake which covered an area from Meadowbank Road north of Tyenna River to Plenty (Davies *et al.* 2002).
3. Glacial change – changes of climate with change of altitude due to the degradation, meant that glacial erosion would be carried to its completion, truncating all the higher mountains at the snow line, and causing snowfall to replace rainfall, and normal erosion to replace glacial erosion.
4. Flat, horizontal, or gently inclined surfaces, sometimes long and narrow, which are bounded by a steeper ascending slope, on one side and by a steeper descending slope on the opposite side. Both forms are step like in character.
type of bedrock intrusion into the channel, the channel morphology and features, and dominant erosion processes. This study will exempt zone 9, as it is located downstream from the Bryn Estyn WTP. The zones are illustrated in Figure 26.

**Figure 26.** Geomorphological Zones of the Lower Derwent Study Area (sourced from Davies *et al.* (2002) p.19.

Table 9 outlines each zone, its geomorphology, susceptibility to change or its natural durability, and nature of change are sourced from Davies *et al.* (2002).
Table 9. Characteristics of the Lower Derwent River Geomorphic Zones based on Davies et al., 2002

<table>
<thead>
<tr>
<th>ZONE</th>
<th>GEOMORPHOLOGY</th>
<th>RIPARIAN VEGETATION</th>
<th>SUSCEPTIBILITY AND NATURE OF CHANGE</th>
</tr>
</thead>
</table>
| 1    | **Confined Zone** – narrow steep sided valley  
No major tributaries.  
Hydrology controlled by flows released from Meadowbank Dam.  
The river is entrenched within Triassic sandstone, and is stable and highly resistant to change.  
A small floodplain\(^5\) pockets\(^6\) occur where small gullies and tributaries enter the river. | Predominately natives with *Eucalyptus* spp. and mixed understorey of acacias, tea tree, and assorted macrophytes.  
Willows have colonized the water’s edge where small alluvial pockets occur. | **LOW** |

\(^5\) Land which is covered by water when a river overflows its banks during flooding. The extent of the floodplain will normally be greater than the area covered in a 1 in 100 flood event.  
\(^6\) Alluvial benches and sidebars that generally consist of gravels to cobble sized materials but often draped with fine sand/silts.
<table>
<thead>
<tr>
<th>ZONE</th>
<th>GEOMORPHOLOGY</th>
<th>RIPARIAN VEGETATION</th>
<th>SUSCEPTIBILITY AND NATURE OF CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td><strong>Partially Confined Zone</strong> – valley widens</td>
<td>Tea tree and willows are dominant stream bank species,</td>
<td>MODERATE</td>
</tr>
<tr>
<td></td>
<td>Hydrology controlled by flows released from Meadowbank Dam.</td>
<td>with the most intact vegetation communities associated with bedrock areas where floodplain development is limited and land use has been restricted.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No major tributaries.</td>
<td>Large woody debris loads are currently low, but most probably have been high.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The banks are a mix of alluvial floodplains bounded by higher terrace features, of quaternary (lower) and tertiary (higher) origin, and bedrock (sandstone), where the channel runs against the valley margins.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The bed is controlled by shallow flat-bedded sandstone rapids. Gravel/cobble bars are also present, often on the side of bends below rapids.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7 The shingling or overlapping effect of stream flow upon flat pebbles in the stream bed. The pebbles are inclined so that the upper edge of each individual is inclined in the direction of the current.
<table>
<thead>
<tr>
<th>ZONE</th>
<th>GEOMORPHOLOGY</th>
<th>RIPARIAN VEGETATION</th>
<th>SUSCEPTIBILITY AND NATURE OF CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Controlled Lake Sediments and Terraces – wider valley</td>
<td>The vegetation in this zone is highly modified. Willows are very prominent throughout this zone, thickly colonising the lower banks of most alluvial surfaces. Large woody debris loads are low but would most probably have been high before riparian clearance removed the source.</td>
<td>MODERATE</td>
</tr>
<tr>
<td></td>
<td>Tributaries: Tyenna River</td>
<td>Greater level of floodplain development. Channel is controlled by sandstone outcropping at its upstream extent and basalt towards the downstream end. This zone is characteristically flanked by low floodplains and terraces for most of its length. Bed forms include cobble/small boulder rapids and riffles, and long, moderately deep pools. As the riffles and rapids are composed of bed load they are less geomorphically stable than upstream sandstone rapids.</td>
<td>The alluvial banks in this zone are susceptible to erosion processes particularly when disturbed through vegetation clearance or grazing pressure. Drawdown effects resulting in slumping (related to fluctuating flow levels) are more likely to be active in this zone, although the extensive colonisation of lower banks by willows has mitigated these processes. Mass movement including slumping and small landslips are commonly observed erosion processes affecting terraces.</td>
</tr>
<tr>
<td>ZONE</td>
<td>GEOMORPHOLOGY</td>
<td>RIPARIAN VEGETATION</td>
<td>SUSCEPTIBILITY AND NATURE OF CHANGE</td>
</tr>
<tr>
<td>------</td>
<td>---------------</td>
<td>---------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>4</td>
<td>Confined Basalt – narrow valley</td>
<td>Vegetation is less impacted than in other zones as landuse development has been limited. <em>Eucalyptus spp.</em> are the dominant canopy species, with acacias, dogwood, and tea tree dominant understorey species. Willows, gorse, and blackberries occur sporadically along the lower and middle bank areas but are less prolific than in alluvial reaches. Large woody debris loads are higher in this zone, due to the relatively higher local sources.</td>
<td>LOW Small floodplain pockets, consolidated and slightly imbricated cobble bars, and armoured and cemented cobble riffles also occur in this zone. Although this zone can be considered relatively stable geomorphically (due to the degree of basalt intrusion into the channel), some active bank erosion is evident in the upstream reaches.</td>
</tr>
</tbody>
</table>

Tributaries: Styx River

Associated with underlying basalt geology with some dolerite outcropping at the upstream area.
<table>
<thead>
<tr>
<th>ZONE</th>
<th>GEOMORPHOLOGY</th>
<th>RIPARIAN VEGETATION</th>
<th>SUSCEPTIBILITY AND NATURE OF CHANGE</th>
</tr>
</thead>
</table>
| 5    | Partially Confined Sandstone and Quaternary Terraces – wider valley  
Tributaries: Allenvale Rivulet and Belmont Rivulet  
Sandstone outcropping in the bed is prominent with most riffles and rapids being at least partly controlled by bedrock.  
On the inside of the bend and right bank, the channel is bounded by stepped quaternary alluvium terraces with some less prominent bedrock outcrops. Long runs and pools separated by shallow cobble/bedrock rapids are characteristic. | The vegetation of this zone is again highly modified.  
Sporadic acacias and eucalypts occur.  
Most of the banks are colonised by willows, hawthorn, and gorse. *Phragmites* is common in slack water areas within the channel.  
Large woody debris loadings are low. | LOW  
The level of bedrock control on the channel in this zone means that it is likely to be relatively stable.
<table>
<thead>
<tr>
<th>ZONE</th>
<th>GEOMORPHOLOGY</th>
<th>RIPARIAN VEGETATION</th>
<th>SUSCEPTIBILITY AND NATURE OF CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Partially confined Dolerite and Quaternary Terraces</td>
<td>The vegetation is highly modified and willows have invaded most alluvial banks. Willows appear to thrive on lower banks as they are tolerant of fluctuations in water level. Where bedrock occurs, small remnant pockets of tea tree remain. Large woody debris loads are generally low, although more was observed in the vicinity and upstream of the Styx confluence.</td>
<td>HIGH The terraces are susceptible to erosion and there are some signs of active slumping. Low floodplains are common and show signs of minor slumping in some reaches, most likely associated with land management practices and also potentially with variation in river flow level (drawdown). Some small backwaters occur at the downstream end of low floodplains often where flood channels re-enter the river.</td>
</tr>
</tbody>
</table>

Tributaries: Plenty River

There is variation in the hydrology within this zone due to the influence of flow from the Styx and Plenty Rivers.

The river in this zone predominantly runs through quaternary terraces bounded by dolerite (and sandstone and a small pocket of Basalt near the Plenty River), although some reaches are bounded by high tertiary terraces.

This zone is highly alluvial and is probably a source of sediment for the river.

Large pools separated by fairly regularly spaced riffles characterise this zone. Riffles are mostly composed of cobble/gravel sized sediments, which appear less consolidated than upstream reaches and would probably be mobile during larger floods.

---

8 The point where two streams meet.
ZONE 7

**GEOMORPHOLOGY**

**Sandstone Confined with Basalt Bed Control** – mostly confined within a narrow valley

Sandstone is again the dominant geology controlling the character of the river in this zone, although there are outcrops of both dolerite and basalt in downstream reaches and quaternary terraces also occur along the right bank.

Sandstone ledges\(^9\) are also a common feature, jutting out into the channel, as are small vegetated mid-channel basalt outcrops.

**RIPARIAN VEGETATION**

Riverbanks are again dominated by willows particularly along the water line. Remnant populations of native species including tea tree and dogwood occur on the small rock islands and cumbungi (*Typha*) and *Phragmites* emerge along the water’s edge in the slower flowing areas.

**SUSCEPTIBILITY AND NATURE OF CHANGE**

**LOW**

Although some small floodplain surfaces do occur, this zone is far less alluvial than Zone 6 and the level of bedrock control of the river channel means that this zone is more geomorphically stable.

---

\(^9\) A bed of several beds as in a quarry or natural outcrop, particularly those projecting in a steplike manner.
<table>
<thead>
<tr>
<th>ZONE</th>
<th>GEOMORPHOLOGY</th>
<th>RIPARIAN VEGETATION</th>
<th>SUSCEPTIBILITY AND NATURE OF CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Alluvial River with Quaternary Terraces</td>
<td>Over most of the river native vegetation is much reduced, with willows again very prominent. Large woody debris is sparse.</td>
<td>MODERATE</td>
</tr>
<tr>
<td></td>
<td>Tributaries: Johnny’s Creek, Mike’s Creek</td>
<td></td>
<td>A few cobble/gravel riffles separate what would otherwise be a long pool. Some of the tributaries have mouth bars.</td>
</tr>
</tbody>
</table>
River channels change through processes affected by the catchment characteristics of erosion and deposition (Brookes, 1996). Church (1996) states that “river morphology reflects the concentration and calibre of sediment moving down the channel” (p. 185).

Davies et al. (2002) also stipulates that flow regime and sediment load are two primary determinants of river form and behaviour, and assumes that fine sediment deposition in the Lower Derwent River especially on lower riverbanks and sidebars, tends to result in changes to the river’s morphology and affects other morphological behaviour.
3.2.8 Geomorphological Change and Sediment Yield

Geomorphological changes that may affect sediment transport in the Lower Derwent River include land movement near or on the riverbank (i.e. debris flow, earth fall), erosion and armouring.

Land movement involves the movement of material with high water content from banks to streams, so that they transport large quantities of sediment (Summerfield, 1991). Summerfield (1991) states that “response of slope material to stress is determined by their strength”, which is defined as the “ability to resist deformation and fracture without significant failure” (p. 164). The soil shear strength $\tau$ is the main contributing factor for slope failure (Summerfield, 1991). The shear strength components are shown in Figure 27 below:

- [V] Vertical Stress – that usually presents effects of gravity on a slope or certain load.
- [$\beta$] Angle of Shear Plane – surface or along movement occurs.
- [$\sigma$] Normal Stress – acts at right angle to shear plane, and contributes towards frictional resistance.

![Figure 27. Shear Stress components based on the Summerfield (1991 p. 164).](image)

Summerfield (1991) states that “the maximum angle attained when failure of slope materials occurs is known as the threshold angle of stability” (p. 164).

Slope stability is subject to the relationship between shear strength acting as the resisting force and shear stress acting as the driving force. It is represented through the safety factor. Summerfield (1991) suggests that slope movement will occur when shear stress exceeds shear strength.

This maybe expressed using a safety factor (SF) (Summerfield 1991, p.167) and if

- SF > 1.3 then the slope is stable, or if
- SF <1 : the slope is “actively unstable”
- 1<SF<1.3 : the slope is “conditionally stable”, subject to changes in shear strength.
Factors that influence land movement are: soil cohesion, pore-water pressure, and soil compaction (Summerfield, 1991 and Ritter et al., 2002).

Cohesion\textsuperscript{10} is other factor that affects the shear strength. Moist soils, such as soils present on the riverbanks, that consist of high silt or clay content, demonstrate capillary cohesion\textsuperscript{11}. Summerfield (1991) suggests that capillary cohesion improves the soils ability to withstand much higher angles.

Normal stress is effective only if there is a surface contact between particulates. “Below the water table the voids between particles are filled by water and this gives rise to a positive (greater than atmospheric) pore water pressure, which has a buoyancy effect on the overlying material and thus acts in opposition to the normal stress” (Summerfield, 1991, p. 164). Pore-water pressure introduces a concept of the effective normal stress. Therefore, particulates located below the water table are under the pore-water pressure effect and have effective normal stress that is in this case less than normal stress.

Pore-water pressure is the cause of land movement after heavy rain – “pore-water pressures in slope materials are high and effective normal stress low” (Summerfield 1991, p. 164). Summerfield (1991) also states that the soil compaction is also an important factor, since densely packed soils are more stable than loosely packed soils.

The term “landslide” is generally used to describe a rapid land mass movement; however, landslide in technical terms is a “pure slide along the well defined shear plane” (Summerfield, 1991, p. 172). A landslide includes translational slides having planar shear surfaces, and rotational slides where shear planar surface is concave-up (Summerfield, 1992).

The pure slide does not involve other types of land movement, such as fall or flow. Summerfield (1991) has identified six types of movement: creep, flow, slide, heave, fall, and subsidence. Table 10 further subdivides each type into more specific categories.

\textsuperscript{10} “Chemical bonding of rocks and soil particles and the adhesion of clay-sized material as a result of electromagnetic and electrostatic forces” (Summerfield et al. 1991, p. 164).

\textsuperscript{11} “Water is drawn over particle surfaces by capillary forces … thin water films on particles contribute to adhesion by creating capillary cohesion” (Summerfield et al. 1991, p. 164).

<table>
<thead>
<tr>
<th>PRIMARY MECHANISM</th>
<th>MASS MOVEMENT TYPE</th>
<th>MATERIALS IN MOTION</th>
<th>MOISTURE CONTENT</th>
<th>TYPE OF STRAIN AND NATURE OF MOVEMENT</th>
<th>RATE OF MOVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractional</td>
<td>Rock slide</td>
<td>Unfractured rock mass</td>
<td>Low</td>
<td>Shallow slide approximately parallel to ground surface of coherent rock mass along single fracture</td>
<td>Very slow to extremely rapid</td>
</tr>
<tr>
<td>Rock block slide</td>
<td>Fractured rock</td>
<td>Low</td>
<td>Slides approximately parallel to ground surface of fractured rock</td>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>Debris/earth slide</td>
<td>Rock debris or soil</td>
<td>Low to moderate</td>
<td>Shallow slide of deformed masses of soil</td>
<td>Very slow to rapid</td>
<td></td>
</tr>
<tr>
<td>Debris/earth block slide</td>
<td>Rock debris or soil</td>
<td>Low to moderate</td>
<td>Shallow slide of largely undeformed masses of soil</td>
<td>Slow</td>
<td></td>
</tr>
<tr>
<td>Positional</td>
<td>Rock slump</td>
<td>Rock</td>
<td>Low</td>
<td>Rotational movement along concave failure plane</td>
<td>Extremely slow to moderate</td>
</tr>
<tr>
<td>Debris/earth slump</td>
<td>Rock debris or soil</td>
<td>Moderate</td>
<td>Rotational movement along concave failure plane</td>
<td>Slow</td>
<td></td>
</tr>
<tr>
<td>Soil creep</td>
<td>Soil</td>
<td>Moderate</td>
<td>Widespread incremental downshepe movement of soil or rock particles</td>
<td>Extremely slow</td>
<td></td>
</tr>
<tr>
<td>Talus creep</td>
<td>Rock debris</td>
<td>Low</td>
<td>Widespread incremental downslope movement of soil or rock particles</td>
<td>Extremely slow</td>
<td></td>
</tr>
</tbody>
</table>

| Fall | Rock fall | Detached rock joint blocks | Low | Fall of individual blocks from vertical faces | Extremely rapid |
| Debris/earth fall (topple) | Detached cohesive units of soil | Low | Toppling of cohesive units of soil from near-vertical faces such as river banks | Very rapid |
| Cavity collapse | Rock or soil | Low | Collapse of rock or soil into underground cavities such as limestone caves or lava tubes | Very rapid |
| Settlement | Soil | Low | Lowering of surface due to ground compaction usually resulting from withdrawal of ground water | Slow |

Human impact has had an increasing influence on catchments and their water courses (Brookes, 1996). Brookes (1996) states that "the most extensive changes affecting streams are land use changes attributable to agriculture, forestry, grazing, mining,
and urbanization” (p. 225). Land clearing has a major effect of triggering land instability resulting in accelerated hillslope and gully erosion, and increased sediment supply to rivers.

Table 11 prepared by Marston et al. (2001) presents a summary of erosion by land use for river basins in Australia containing intensive agriculture – the data was based on an assessment carried out as part of the National Land and Water Resources Audit (NLWRA) by CSIRO (2001).


<table>
<thead>
<tr>
<th>Landuse</th>
<th>Area (km²)</th>
<th>Total Erosion (t/y)</th>
<th>Erosion Rate (t/ha/y)</th>
<th>Rate of Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed Forest</td>
<td>22,000</td>
<td>2,552,000</td>
<td>1.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Open Forest</td>
<td>228,000</td>
<td>6,900,000</td>
<td>&lt;1</td>
<td>1.0</td>
</tr>
<tr>
<td>Woodland (unmanaged lands)</td>
<td>220,000</td>
<td>103,400,000</td>
<td>5.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Commercial native forest production</td>
<td>153,000</td>
<td>5,800,000</td>
<td>&lt;1</td>
<td>1.1</td>
</tr>
<tr>
<td>National Parks</td>
<td>86,000</td>
<td>76,200,000</td>
<td>9.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Cereals excluding rice</td>
<td>180,000</td>
<td>38,933,000</td>
<td>2.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Legumes</td>
<td>22,000</td>
<td>740,000</td>
<td>0.0</td>
<td>3.2</td>
</tr>
<tr>
<td>Oilseeds</td>
<td>6,000</td>
<td>2,382,000</td>
<td>4.0</td>
<td>9.6</td>
</tr>
<tr>
<td>Rice</td>
<td>1,500</td>
<td>115,000</td>
<td>1.0</td>
<td>5.9</td>
</tr>
<tr>
<td>Cotton</td>
<td>4,000</td>
<td>2,784,000</td>
<td>7.0</td>
<td>11.0</td>
</tr>
<tr>
<td>Sugar Cane</td>
<td>5,000</td>
<td>18,623,000</td>
<td>40.0</td>
<td>57.0</td>
</tr>
<tr>
<td>Other agriculture land use</td>
<td>2,000</td>
<td>2,329,000</td>
<td>54.0</td>
<td>34.0</td>
</tr>
<tr>
<td>Improved pastures</td>
<td>190,000</td>
<td>41,429,000</td>
<td>2.0</td>
<td>5.3</td>
</tr>
<tr>
<td>Residual/Native pastures</td>
<td>1,673,500</td>
<td>957,939,000</td>
<td>6.0</td>
<td>3.2</td>
</tr>
<tr>
<td>Total Assessment Area</td>
<td>2,793,000</td>
<td>1,260,126,000</td>
<td>5.0</td>
<td></td>
</tr>
</tbody>
</table>

Accelerated soil erosion has economic, ecological and social costs to society (Scott et al., 2001). In the Lower Derwent River catchment an increase in turbidity can add substantially to the cost of water treatment.
Erosional patterns are divided into three categories, hillslope erosion including sheet and rill erosion, riverbank erosion, and gully erosion. The following sections discussing these types of erosion include theory and methodology to calculate sediment loading in streams from different erosion patterns. The Mary River catchment study will take the theory further and include an estimate of erosion developed in the catchment.

**Hillslope Erosion**

Hillslope erosion is directly related to vegetation composition and patterns, soil and soil surface characteristics, and topographical factors (Lane et al., undated). The main factors that contribute to the hillslope erosion process are raindrop impact and flowing water. Hillslope erosion by water involves detachment, transportation, and deposition of soil particles (Lane et al., undated).

Hillslope erosion includes sheet and rill erosion as they generally occur together. Sheet erosion occurs during high rainfall intensity due to raindrop effects and runoff particularly when the soil is bare. The most intensive crop land uses have the greatest potential to result in increased sheet erosion patterns. Rill erosion occurs when the soil is detached by concentrated runoff (Scott et al., 2001). Rills commonly develop along tillage lines and on the edges of roads and tracks where the soil has been disturbed and runoff concentrated (Lu et al., 2001).

Rates of sediment delivery and sediment loading from hillslopes to water streams may be calculated using the Universal Revised Soil Loss Equation (URSLE), that was customised to the Australian environment by Rosewell (1993), and Lu et al. (2001). The URSLE equation is outlined below, where the various factors are represented. R is rainfall erosivity, K is soil erodibility, L is hillslope length, S is hillslope gradient, C is ground cover and P is land use practice.

\[ Y = R \times K \times L \times S \times C \times P \ \text{[t/ha/yr]} \]  

**Riverbank Erosion**

“Streambank erosion often involves the loss of valuable agricultural and recreational land” (Askey –Doran et al., 2002, p.2). Human activities have an enormous effect on bank stability. Askey–Doran et al. (2002) note that the increase of stream bank erosion is due to:
• extensive clearing of deep-rooted vegetation, resulting in rainfall moving over land at a much faster rate, and
• removal of native riparian vegetation, resulting in streambanks becoming unstable.

Askey–Doran et al., (2002) discuss the two major factors impacting the rate of erosion:

• Scour – “this occurs when the force applied to a streambank by flowing water exceeds the resistance of the bank surface to withstand those forces” (p. 2). Scour is initiated by changes in the streamflow, and “is the most destructive process” (p. 3).

• Slumping - bank falls usually occur in the river as result of bank. Once soil loses its support it rapidly falls down into the river contributing sediment load. (Summerfield, 1991).

Prosser et al. (2001) suggest that activities such as the clearing of riparian vegetation, increased flood magnitudes and an increase in water velocities through the removal of large woody debris are the main triggers of riverbank erosion. Furthermore, Prosser et al. (2001) suggests that riverbanks become susceptible to erosion if either the resistance to erosion is reduced or the erosive power of flows increases (p. 87).

Channel geometry usually indicates when the riverbank erosion occurs; usually identifying the size of channel network (Prosser et al., 2001). Catastrophic channel erosion (a high magnitude erosion) usually takes place on confined floodplains of relatively high gradient where stream power is high (Prosser et al., 2001).

Prosser et al. (2001) also suggests that channels that have widened catastrophically are due to high flow variability, where the channels are constantly adjusting to changes in flow regime.

Riparian tree roots provide sufficient strength to stabilise the majority of riverbanks, and consequently the loss of riparian vegetation exacerbates riverbank erosion. Overhanging and emergent vegetation has the effect of reducing flow velocities and the ability to scour the bank.

Riverbank erosion is calculated using the following empirically derived equation sourced from Prosser et al., (2001). The equation is outlined below, where PR is the proportion of riparian vegetation, Q_{1.58} is bankfull discharge as the 1.58 year recurrence interval event and Lx is the length of riverbank.
“Clearing of vegetation, and other European modifications, have greatly increased the power of our streams” (Rutherford et al., 2000, p. 337)

Riparian zones facilitate the direct interaction between terrestrial and aquatic ecosystems. Phillips, C. (2003) states that the riparian zone is probably the most important place in the catchment for enhancing stream habitat and water quality. “Any change that eliminates or reduces vegetative cover is likely to increase sediment discharge proportionately more than water discharge” (Brooks 1996, p. 225).

Large et al. (1996) have identified the major roles of riparian vegetation and they include the following:

- production of organic matter.
- absorption of dissolved matter including phosphates and nitrates.
- formation of physical structures that reduce kinetic energy of flowing waters.
- creation of a range of habitats (for flora and fauna).

reduction of available solar energy. (pp.117-136)

Figure 28 illustrates riparian vegetation and processes that occur to stabilise the riverbank.

![Figure 28. Riparian vegetation and processes that occur to stabilise the riverbank based on Askey–Doran et al., 2002, p.4.](Image)
Tabacchi *et al.* (1998) states that vegetation dynamics within the riparian zone are substantially influenced by hydrological disturbance regimes. “The ability of riparian vegetation to control and recycle allochthonous\(^{12}\) inputs from the upland drainage basin and the river itself is a fundamental aspect of river geology” (Tabacchi *et al.*, 1998, p. 498).

Based on Askey–Doran *et al.* (2002) the role of riparian vegetation in controlling channel and bank stability is as follows:

- Root reinforcement is the most important factor preventing bank collapse. Figure 29 illustrates riparian vegetation root structure.

![Figure 29. Root structure based on the StreamScapes Aquatic Education and Information web site (December 2003)](image)

- Ability to use much of the water present and improve drainage – prevent collapse due to soil saturation.
- Holds in place large vegetation (trees).
- Channel flow velocity is reduced by riparian vegetation – reduces scour and related undercutting and bank collapse.

Some plant species have been recognised as potential indicators of the disturbance level and the landscape connectivity (Tabacchi *et al.*, 1998). Exotic species have tended to form the predominant vegetation in areas disturbed by human activities. Together certain human activities and types of land use, including vegetation clearing, grazing and flow manipulation, threaten the integrity of riparian vegetation in Australian catchments. Tabacchi *et al.* (1998) also state that flow regulation by dams and diversions may allow the encroachment of riparian vegetation into the channel, increasing erosion potential.

---

\(^{12}\) Pertaining to materials, particularly rock masses, that formed somewhere other than their present location, and were transported by fault movements, large-scale gravity sliding, or similar processes. Autochthonous material, in contrast, formed in its present location. Landslides can result in large masses of allochthonous rock, which typically can be distinguished from autochthonous rocks on the basis of their difference in composition. Faults and folds can also separate allochthons from autochthons.
Native vegetation in the Lower Derwent River catchment has been predominantly cleared for agricultural use, and much of its native riparian vegetation has been replaced by exotic species such as willow, gorse, blackberry, hawthorn, and introduced pasture grasses. Native vegetation has been maintained where floodplain development is limited and it includes dry sclerophyll plants such as *Eucalyptus spp*, *Acacia spp*, dogwood, and tea tree. Willows have been effective in colonising the alluvial riverbanks where native vegetation has been removed, or riverbank slumping has occurred (Davies et al., 2002).

Davies et al. (2002) observed that riverbank slumping is most common in the geomorphological zones 2, 3, and 6 (Figure 26), where susceptible alluvial banks have collapsed due to a rapid decrease in high water level, which leaves the riverbanks saturated and unsupported. A change of channel width occurs as a result of bank slumping, and flow regulation.

Gully Erosion

Gully erosion refers to the removal of soil by running water as a direct response to rainfall. Gully erosion channels are at least 50 cm deep, and are usually initiated by land use practices such as agriculture, forestry, and so forth. Other factors including geology, soil texture, rainfall and seasonal climate extremes will further influence the extent of gully erosion.

Gully initiation is more sensitive to the local degradation of the valley floors, rather than to an increase of catchment runoff. Hence, gully erosion occurs when valley floor vegetation is disturbed or cleared (Prosser et al., 2001). Once the protective ground cover is removed, gullies spread rapidly up through the valleys towards surrounding ridges and spurs where they stop due to insufficient runoff to continue the erosion (Prosser et al., 2001).

A Land Degradation Survey carried out by the Department of Land and Water Conservation (New South Wales) during 1987-1988 recommended that the best management practice to treat extreme gully erosion was to change the land use of the area. One example of preventative measures is listed in the Zund (2002) information sheet and is available to farmers or developers. Other states have similar information sheets.

Gully shape depends on the type of topsoil and subsoil.

Figure 30 shows two types of gully erosion that commonly occur, depending on soil texture.
Figure 30. Gully erosion types subject to soil texture based on Boucher (2002) Department of Primary Industries (Victoria) web site.

Gully erosion is calculated using the following equation sourced from Prosser et al., (2001) where $GC_x$ [t/yr] is the sediment load due to gully erosion, $[m^2]$ is the catchment area, $\rho$ [t/m$^3$] is the density of the sediment, $\alpha$ [m$^2$] is mean cross sectional area of the gully, $\tau$ [y] is age of the gully, $PG_j$ [] is the proportion of gully material that contributes to bedload, and $GD_j$ [km/km$^2$] is the gully density.

$$GC_x = \frac{1000 \rho \alpha \sum_{j=1}^{n} PG_j GD_j}{\tau}$$ (3)

Gullies measured from aerial photographs are converted into gully density by dividing the sum of the total length of mapped gullies [km] by the total aerial of the aerial photograph [km$^2$] (Hughes et. al. 2001). Each of the environmental attributes, such as land use, mean annual rainfall, geology are summarised for each gully density polygon selected in a map (Hughes et. al. 2001).

Soil erosion causes increased turbidity in rivers and a resultant sedimentation of estuaries. The sediment released by the erosion process that enters the water stream also transports nitrogen and phosphorus that may lead to increased growth of algae, which in turn may interfere with aquatic organisms. It is worth to mention that organic and mineral components generated through soil erosion also affect the turbidity readings, and consequently the health and aesthetic drinking water requirements.

Ritter et al. (2002) suggest that human activities that include undercutting and erosion introduces changes to slope angle, reduces shear strength by changes in cohesion, pore-pressure and related normal stress. Factors that contribute to the occurrence of land movement are listed in Table 12.

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Factors contributing to increased shear stress</strong></td>
<td></td>
</tr>
<tr>
<td>Removal of lateral support through undercutting</td>
<td>Erosion by rivers and glaciers, wave action, faulting, previous rock falls or slides.</td>
</tr>
<tr>
<td>or slope steepening</td>
<td>Undercutting by rivers and waves, subsurface solution, loss of strength by extrusion of underlying sediments.</td>
</tr>
<tr>
<td>Removal of underlying support</td>
<td></td>
</tr>
<tr>
<td>Loading of slope</td>
<td>Weight of water, vegetation, accumulation of debris.</td>
</tr>
<tr>
<td>Lateral pressure</td>
<td>Water in cracks, swelling (especially through hydration of clays), pressure release.</td>
</tr>
<tr>
<td>Transient stresses</td>
<td>Earthquake, wind movement of trees.</td>
</tr>
<tr>
<td><strong>Factors contributing to reduced shear strength</strong></td>
<td></td>
</tr>
<tr>
<td>Weathering effects</td>
<td>Disintegration of granular rocks, hydration of clay minerals, dissolution of cementing minerals in rock or soil.</td>
</tr>
<tr>
<td>Changes in pore-water pressure</td>
<td>Saturation, softening of material.</td>
</tr>
<tr>
<td>Changes of structure</td>
<td>Creation of fissures in shales and clays, remolding of sands and sensitive clays.</td>
</tr>
<tr>
<td>Organic effect</td>
<td>Burrowing of animals, decay of tree roots.</td>
</tr>
</tbody>
</table>

The factors listed are just a guide to earth movements, since real life situations vary due to different intensities and frequencies applied by the various factors. As already mentioned, human activities have greatly increased the supply of sediment from agricultural hillslopes due to the rapid extension of gully networks (Prosser et al., 2001), and flow regulation by dams and diversions (Tabacchi et al., 1998). Prosser et al., (2001) state that increased sediment loads can result in substantial changes to a river’s physical form, chemical processes and ecological health. Hillslope, gully, and bank erosion are often only activated during high flow precipitation events, and therefore suspended loads increase during higher river flows (Carling, 1996).

Various types of land movement can occur in a catchment and this was observed during my visit to the Lower Derwent River catchment site on the 15 October 2003.
The majority of land movement in the catchment is initiated as a result of land clearing, particularly on steep slopes – some hillslopes used for grazing have signs of earth creep that may exacerbate the formation of gullies that would serve as debris flow channels during rain events. Figure 31 demonstrates such an example and Figure 32 shows the combined effects of earth creep and overgrazed pasture.

**Figure 31.** Example of earth creep located in the Lower Derwent River catchment

**Figure 32.** Example of the combined effect of earth creep and overgrazed pasture located in the Lower Derwent River catchment.
Landslides in the Lower Derwent River catchments usually occur above riverbanks or agricultural dams. Figure 33 shows an example of the failure of an agricultural dam situated on a creek that feeds the Lower Derwent River.

**Figure 33.** Example of rotational landslide pasture located in Lower Derwent River catchment

An example of a landslide above the Lower Derwent riverbank is illustrated in Figure 34.

**Figure 34.** Example of landslide above the riverbank located in Lower Derwent River catchment.
It was observed during the site visit that apart from earth creeps and landslides, there were also signs of debris earth channels. These channels were supported by formed gullies to transport debris during rain events. Such an example is illustrated in Figure 35.

![Image](image.png)

**Figure 35.** Example of debris flow located in the Lower Derwent River catchment.

### 3.2.9 Conclusion – Lower Derwent River Catchment Study

The CSIRO Land and Water (2001) has published river budget data for all Australia’s catchments. The results for the Derwent River sediment loading is as follows:

- Hillslope erosion as a % input to river  13.13
- Gully erosion as a % input to river  21.89
- Streambank erosion as a % input to river  64.95
- Total sediment supply to rivers (t/yr)  351,478

It is necessary to determine the sources of turbidity for the purposes of long-term management of water resource, and the ability of the WTP to meet specific health and aesthetic requirements. Using the Lower Derwent River as an example, areas, events, and land use practices that are found to release significant sediment loads are:

- Sediment loading from the Meadowbank Dam and associated flow fluctuations that cause erosion due to riverbank slumping.
- Sediment loading from major tributary catchments mainly due to land use related erosion patterns from agriculture and forestry.
- Sediment loadings due to hillslope, gully, and riverbank erosion resulting mainly from agricultural and forestry operations.
3.2.10 Recommendations - Lower Derwent River Catchment Study

The ability to effectively manage and respond to the variations in suspended solids is essential for maintaining process control, adequate compliance with health targets (Dept of Health, Tasmania) and consumer confidence in a treatment plant under its current operating arrangements. Severe restrictions would be required should the supply be unavailable for an extended period, particularly in summer.

The predictive modelling would provide system design that would allow:
- Catchment condition assessment re: turbidity and sediment supply.
- Identifying catchment variables/mediators that affect water quality.
- Demand planning.
- Optimised water treatment and production, and process control at the WTP.

Catchment and water quality modelling would also provide a benchmark for the Lower Derwent River catchment for the long-term assessment and improvement of catchment conditions. The benchmark can be also transposed to assist Tasmanian councils that manage source waters. In addition, it would allow a coordinated approach to strategic demand planning for the future management of all Hobart Water drinking water catchments.

Hobart Water needs to set in place a short-term solution to managing its treatment process as a response to variation in raw water turbidity, while the long-term solution would involve understanding the sources of water quality variation that would enable the development of an effective catchment management plan. This project would also provide baseline data and information to further investigate, and contribute towards preparing the Derwent River Catchment Management Plan.

Benefits of modelling short-term response would mainly relate to the Bryn Estyn WTP operations, whilst the long-term responses would benefit Derwent River catchment management. Long term catchment management plan for the Derwent River catchment should include the following:
- contributing towards preparing the plant for emergencies (petrol, pesticide spills and so forth).
- improving the efficiency of water treatment process.
- reliability of supply.
- sustainability of supply.
- contributing to water quality, data, information, and knowledge - benefits identified by the Water Quality Coordinator are related to suspended solids loading and its potential for correlating identified loads with nutrient and microbiological levels.
It is envisaged that the project will align the catchment management plan with the HACCP system – since the project will be based on identifying the risk associated with sediment sources/hazards.

HACCP system ensures quality assurance management of the water resource and provides a basis for improvement through application and control of standardising methods, and ensures pollution prevention management. Using the HACCP approach, Hobart Water would be able to assess all hazards and associated risks to water quality and cover the full water supply system from “catchment to tap”.

Modelling would also assist in improving water licensing associated with the Derwent River, which would have a considerable economic impact on Hobart Water, and sustainability of natural resources. Other benefits related to sustainable development are linked to social, environmental, Occupational Health and Safety (OH&S), and knowledge transfer aspects.

The long-term benefits are related to factors that may be of high strategic importance including:
- probability of technical success.
- probability of commercial success.
- profitability for the organisation, considering the cost of the project,
- strategic fit.
- consistency with technological threats and opportunities.

The proposed suspended sediment transport model is discussed in more detail in Section 4. This project did not eventuate with Hobart Water.
3.3 Mary River Catchment Study

This study discusses generation and delivery of suspended solids in part of the Mary River catchment in Queensland that is somewhat different to the scenario of the Lower Derwent River catchment. The study also outlines the potential contribution of the suspended load transport model towards predicting sediment yield in water suspension that affects river ecosystems by reducing water clarity, declining respiration in a fresh water environment, and minimising available light necessary for plant photosynthesis.

The study area is a section of Mary River catchment bounded by Kilkivan and Gympie townships (Figure 36).
Figure 36. Mary River Catchment including the study area.
3.3.1 Mary River catchment

The Mary River has a catchment area of approximately 9,400 km$^2$, and occupies the area between Blackall, Conondale, Jimna, the Burnett Ranges and the south-east Queensland coast (South East Regional Water Planning (SERWP), DNRM, 2002). The catchment consists of six major tributaries including Munna, Tinana, WideBay, Yabba, Obi Obi and Six Mile Creeks.

The Mary River consists of three broad geological regions as follows (SERWP, DNRM, 2002, p.14):

- the Maryborough Basin located in the north-west and ranges from the headwaters (Conondale-Jimna) through Glastonbury and Kilkivan towards Biggenden. The geology is characterised by sandstones, shales and volcanics.
- the Gympie Group located east and parallel to the first region, and ranges from Cooroy. The geology is characterised by slates, shales, limestones and volcanics.
- the Neranleigh-Fernvale Group located on the eastern edge and partly submerged by the Pacific Ocean. The geology is characterised by slates, graywackers and phyllites.

The catchment is mostly privately owned and utilised for dairy, sugar and other horticultural production. The Mary River is also an important water source to the towns of Gympie, Noosa, Tiaro and Imbil. Additionally, since 1959 it supplies water for irrigation to agricultural land administered by the Irrigation and Water Supply Commission Queensland. The Mary River mean annual flow discharge is approximately 2,514,000 ML, with allocated annual flow for agriculture of approximately 86,374 ML, and 59,901 ML for urban and industrial use (SERWP, DNRM, 2002).

The catchment consists of two different regions distinguished by their rainfall characteristics of high and low rainfall. Low rainfall areas are located in the north-west with mean annual rainfall at Kilkivan of 860 millimetres. Areas of high rainfall occur in the hinterland areas of the south-east with mean annual rainfall of 2,000 millimetres (SERWP, DNRM, 2002).

The Mary River catchment geology map is enclosed in Appendix B.
3.3.2 Study Area – Mary River Section

The study area has a catchment of 1,880 km\(^2\), and includes the Mary River main trunk situated upstream from Gympie and between Fishermans Pocket (latitude -26.19, and longitude 152.59) and Miva (latitude -25.87, and longitude 152.49) gauging stations. It receives water from the following tributaries:

- Wide Bay Creek,
- Widgee Creek,
- Glastonbury Creek and
- Scrubby Creek.

Figure 37 shows a map of the study area.
This product (Figure 37. Mary River Study Area) incorporating data from: © Commonwealth of Australia (National Land and Water Resources Audit) 2004.

Figure 37. Mary River Study Area
The study area is dominated by open forest and woodland, crops or improved pastures and small areas of grassland (Johnson, 1996). Figure 38 shows the majority of the study area has less than 10 percent vegetation cover.
This product (Figure 38: Vegetation Density in the Mary River Study Area) incorporating data from: © Commonwealth of Australia (National Land and Water Resources Audit) 2004.

**Figure 38:** Vegetation Density in the Mary River Study Area
The attributes of streams within the study area that relate to suspended solid loadings are outlined in Table 13. The attributes are based on *An Ecological and Physical Assessment of the Condition of Streams in the Mary River Catchment – State of the Rivers, Department of Natural Resources* (Johnson, 1996).
Table 13. Mary River - Study Area attributes are based on Johnson (1996)

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Length (km²)</th>
<th>Geomorphology</th>
<th>Riparian Vegetation</th>
<th>Aquatic Vegetation</th>
<th>Aquatic Habitat</th>
<th>Overall Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mary River</td>
<td>Poor</td>
<td>Moderate</td>
<td>Moderate – Poor</td>
<td>Very Poor</td>
<td>Very Poor</td>
<td>Moderate</td>
</tr>
<tr>
<td>Wide Bay Creek</td>
<td>Poor - Moderate</td>
<td>Very Stable – Very Unstable</td>
<td>Very Poor – Moderate</td>
<td>Moderate – Very Poor</td>
<td>Good – Very Poor</td>
<td>Good – Moderate</td>
</tr>
<tr>
<td>Widgee Creek</td>
<td>Poor - Moderate</td>
<td>Unstable – Very Stable</td>
<td>Very Low – High</td>
<td>Stable</td>
<td>Poor – Very Poor</td>
<td>Good – Very Poor</td>
</tr>
<tr>
<td>Glastonbury Creek</td>
<td>Moderate</td>
<td>Moderate – Stable</td>
<td>Moderate – High</td>
<td>Stable</td>
<td>Very Poor</td>
<td>Very Poor</td>
</tr>
<tr>
<td>Scrubby Creek</td>
<td>Poor</td>
<td>Very Stable</td>
<td>Very Low</td>
<td>Stable</td>
<td>Very Poor</td>
<td>Good</td>
</tr>
</tbody>
</table>

Definition*

- **Reach Environs**: Land immediately bordering the stream (including vegetation cover, land use and land tenure), and on the floodplain.
- **Bed and Bar Stability**: Proportion of the bed forming a bar (for aggrading beds) and the overall bed stability ratio (for eroding beds).
- **Channel Diversity**: Variability of stream channel types (fast flowing rocky beds, pools and riffles, slow deep meandering channels, wetlands within subcatchment).
- **Bank Stability**: Percentages of the banks on each side of the reach that are rated as stable.
- **Riparian Vegetation**: Width, structural form and species, composition of the remnant riparian vegetation along the stream banks.
- **Aquatic Vegetation**: Aquatic vegetation (submerged, floating, and emergent) and of the species composition.
- **Aquatic Habitat**: Organic debris (branches, logs, etc.) and substrate character (vegetation, roots, bank overhang) in the stream bed and canopy cover along the stream banks.

* Attribute definitions are sourced from the correlating maps (Johnson, 1996, Map Section under Legend)
3.3.3 Land Use

DeRose (2002) identified that the Mary River catchment land uses have a considerable effect on erosion and subsequent suspended solids loads.

The study area is mainly used for livestock grazing, followed by conservation areas, and production and plantation forestry. Other less dominant activities such as cropping and dairy industries are mainly situated in proximity to the Mary River trunk (Figure 39).
This product (Figure 39. Land Use within Mary River Study Area) incorporating data from: © Commonwealth of Australia (National Land and Water Resources Audit) 2004.

**Figure 39.** Land Use within Mary River Study Area
The increased gully erosion seen is linked to extensive grazing practices particularly in the western part of the study area.
### 3.3.4 Climate

The Mary River study area catchment has a subtropical climate with mean daily minimum and maximum temperatures being 13.4 and 27.1°C respectively – based on the BoM weather station located at Gympie (No. 040093) (Table 14).

**Table 14. Climate Characteristics of the Study Area**

<table>
<thead>
<tr>
<th>Gympie</th>
<th>Temperature (°C)</th>
<th>Rainfall (mm)</th>
<th>Evaporation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Daily Max.</td>
<td>Mean Monthly</td>
<td>Mean Monthly</td>
</tr>
<tr>
<td>January</td>
<td>31.3</td>
<td>165.1</td>
<td>5.5</td>
</tr>
<tr>
<td>February</td>
<td>30.2</td>
<td>169.2</td>
<td>4.8</td>
</tr>
<tr>
<td>March</td>
<td>29.4</td>
<td>146.2</td>
<td>4.2</td>
</tr>
<tr>
<td>April</td>
<td>27.3</td>
<td>84.9</td>
<td>3.3</td>
</tr>
<tr>
<td>May</td>
<td>24.5</td>
<td>73.4</td>
<td>2.3</td>
</tr>
<tr>
<td>June</td>
<td>22.1</td>
<td>61.2</td>
<td>2</td>
</tr>
<tr>
<td>July</td>
<td>21.9</td>
<td>54.9</td>
<td>2.1</td>
</tr>
<tr>
<td>August</td>
<td>23.4</td>
<td>39.5</td>
<td>2.8</td>
</tr>
<tr>
<td>September</td>
<td>26.0</td>
<td>47.2</td>
<td>4.1</td>
</tr>
<tr>
<td>October</td>
<td>28.4</td>
<td>72.1</td>
<td>4.8</td>
</tr>
<tr>
<td>November</td>
<td>30.3</td>
<td>89.1</td>
<td>5.6</td>
</tr>
<tr>
<td>December</td>
<td>31.3</td>
<td>135.5</td>
<td>5.8</td>
</tr>
<tr>
<td>Annual</td>
<td>27.1</td>
<td>79.15</td>
<td>3.9</td>
</tr>
</tbody>
</table>

### 3.3.5 Floodplain History

Heavy rainfall in the Mary River headwaters located in areas around Maleny and Mapleton usually causes major flooding at Gympie during the period between December and April (BoM, 2004). However, it can also cause flooding in the lower Mary River catchment.

Gympie and Maryborough are recognised as two locations within the catchment with a long history of flooding. Figure 40 illustrates the highest annual flood peaks at the Gympie gauging station since 1860 (BoM, 2004). The Gympie gauging station is located 10 km upstream from the Fishermans Pocket gauging station, which is the study area’s starting point.
Rainfall in excess of either 200 mm or 300 mm in 48 hours, will cause significant moderate to major flooding and significant major flooding respectively. Table 15 shows flood gauge heights of the highest flood, and records of recent floods in the study area.

Table 15. Study Area Flood History based on Bureau of Meteorology (2004) data.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gympie*</td>
<td>Feb 1893 - 25.45</td>
<td>21.44</td>
<td>18.75</td>
<td>20.73</td>
<td>19.65</td>
<td>21.40</td>
<td>21.95</td>
</tr>
<tr>
<td>Woolooga</td>
<td>Mar 1890 - 12.50</td>
<td>9.75</td>
<td>4.95</td>
<td>7.54</td>
<td>9.00</td>
<td>5.28</td>
<td>7.40</td>
</tr>
<tr>
<td>Miva</td>
<td>Feb 1893 - 23.08</td>
<td>21.84</td>
<td>18.92</td>
<td>20.80</td>
<td>18.30</td>
<td>20.45</td>
<td>20.65</td>
</tr>
</tbody>
</table>

*Gympie is located 10 km upstream from the study area.

Therefore, according to the BoM (2004) records, the study area is likely to endure some flooding between December and April.

### 3.3.6 Geomorphology

River channels change through processes affected by the catchment characteristics of erosion and deposition (Brookes, 1996). The upper reach of the study area has two distinct terrace systems which include upper and lower alluvium (SERWP, DNRM Qld). However, “from the Widgee Creek junction, the Mary River enters the sandstone of the Mesozoic sequence where the upper alluvium becomes sandy and less defined against sandstone bedrock” (SERWP, DNRM Qld, p.14).

Generally, the Mary River “lower banks consisted of fine gravel, while the upper banks ranged from fines to boulders and head a mean particle size of fine sand”
The geomorphological characteristics of the study area including reach environs, bed and bar stability, channel diversity, and bank stability are ranked in Table 13.

### 3.3.7 Soil Properties

Australian soils are mostly ancient, infertile and weathered have been subject to extensive degradation due to unsustainable agricultural practices in more recent times (NLWRA – Soils, 2002). Ritter et al. (2002) has identified the most important criteria concerning soils, including:

- Colour – assists in identifying horizons within the soil profile.
- Texture – particle size distribution for particles less than 2 mm in diameter (including clay, silt, and sand).
- Structure – shape developed when particulates cluster into pedes\(^{13}\).
- Organic matter content – includes decomposed litter and humus.
- Moisture retention – water content in soil.

This soil classification system was adopted by the CSIRO in the 1960s and is currently the preferred soil classification standard. The Australian Soil Classification orders are illustrated in Figure 41.

\(^{13}\) Soil aggregates.
Figure 41. Soil orders based on Ritter et al. (2002, p. 65).

Information concerning the soils present in the study area is based on the Mary River (Gundiah-Curra) soils map supplied by the DNRM (Qld) and the NLWRA – Soils web page (2002). The Mary River – Study Area soil map and a summary of description of the soils present in the study area is enclosed in Appendix B.

A list and descriptions of soils located in the catchment based on Zund (2004) are as follows:

- **Podosols** (infertile soils with organic material and alluvium)
• located in hillslopes on moderately weathered coarse grained sedimentary rocks
• **Vertosols** (shrink and swell clay soils)
  • located in plains and swamps
• **Hydrosols** (seasonally wet or permanently wet soils)
  • located in lower slopes on deeply weathered coarse grained sedimentary rocks
• **Kurosol**s (acidic soils with an abrupt increase in clay)
  • located in hillslopes on moderately weathered sedimentary rocks
• **Sodosols** (soils high in sodium and with an abrupt increase in clay)
  • located in hillslopes on microdiorite rocks
  • located in hillslopes on moderately weathered andesite and microdiorite rocks
  • located in hillslopes on moderately weathered sedimentary rocks
  • located in alluvial plains of the Mary River
• **Chromosols** (soils with an abrupt increase in clay)
  • located in hillslopes on phyllite rocks
  • located in hillslopes and plains on deeply weathered coarse grained sedimentary rocks
• **Ferrosols** (Iron rich soils)
  • located in hillcrests and plains on deeply weathered andesite rocks
• **Dermosols** (structured soils)
  • located in on hillslopes on moderately weathered andesite or microdiorite rocks
  • located in hillslopes on deeply weathered andesite rocks
  • located in hillslopes on phyllite rocks
  • located in hillslopes on moderately weathered sedimentary rocks
  • located in hillcrests on deeply weathered fine grained sedimentary rocks
  • located in alluvial plains of the Mary River
  • located in alluvial plains of local creeks
• **Kandosols** (structureless soils)
  • located in hillcrests on deeply weathered coarse grained sedimentary rocks
  • located in alluvial plains of local creeks
• **Rudosols** (minimal soil development)
  • located in alluvial plains of the Mary River
• **Tenosols** (weakly developed soils)
  • located in hillslopes on deeply weathered fine grained sedimentary rocks.
3.3.8 Land Movement in the Study Area

Johnson (1996) has identified various types of land movement that occur in the Mary River catchment. The majority of land movement is initiated as a result of land clearing, particularly on steep slopes – some hillslopes used for grazing have signs of earth creep that usually exacerbate to form gullies that serve as debris flow channels during rain events.

An example of a slumping bank at Mary River trunk is shown in Figure 42.

![Figure 42. Slumping Bank at the Mary River (Johnson, 1996, p. 52).](image)

The Scrubby Creek tributary, also within the study area, was observed by Johnson (1996) and is an example of good geomorphological conditions (Figure 43).

![Figure 43. Scrubby Creek: an example of good geomorphological conditions (Johnson, 1996, p. 57).](image)
3.3.9 Hillslope Erosion

Table 16 demonstrates a link between hillslope erosion and land use categories in the Mary river catchment.

**Table 16.** Hillslope Erosion and Land Use Categories in the Mary River Catchment based on DeRose (2002, p.22)

<table>
<thead>
<tr>
<th>Land use category</th>
<th>Area (km²)</th>
<th>Proportion of total area (%)</th>
<th>Predicted total soil loss (t y⁻¹)</th>
<th>Proportion of total catchment erosion (%)</th>
<th>Average predicted soil loss rate (t ha⁻¹ y⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native pastures</td>
<td>3144</td>
<td>34</td>
<td>252</td>
<td>29</td>
<td>0.8</td>
</tr>
<tr>
<td>Improved pastures</td>
<td>201</td>
<td>2.2</td>
<td>28</td>
<td>3</td>
<td>1.4</td>
</tr>
<tr>
<td>Sugar cane</td>
<td>120</td>
<td>1.3</td>
<td>76</td>
<td>8</td>
<td>6.3</td>
</tr>
<tr>
<td>Other crops</td>
<td>528</td>
<td>5.6</td>
<td>158</td>
<td>18</td>
<td>3.0</td>
</tr>
<tr>
<td>Forest and reserves</td>
<td>5128</td>
<td>54</td>
<td>359</td>
<td>41</td>
<td>0.7</td>
</tr>
</tbody>
</table>

It was identified that cropping land occupied only 7% of the Mary River catchment, but contributes 26% of the total erosion (DeRose, 2002). An estimate of the hillslope erosion for the Mary River catchment study area was sourced from the Australian Natural Atlas web site and based on the URSLE attributes for the study area (Figure 44). The annual hillslope erosion URSLE equation is outlined in section 3.2.8.
This product (Figure 44: Hillslope Erosion within the Mary River Study Area) incorporating data from: © Commonwealth of Australia (National Land and Water Resources Audit) 2004.

**Figure 44:** Hillslope Erosion within the Mary River Study Area.
3.3.10 Riverbank Erosion

The Mary River and its tributaries located within the study area generally have a very poor to moderate riparian zone; the mean riparian width of the Mary River trunk was 30 metres (ranging from 0.5 to 50 metres) and the mean riparian width of its tributaries was 12 metres (ranging from 1 to 50 metres) (Johnson, 1996). Johnson (1996) has also identified that the majority of the Mary River riparian zone consists of various grasses (including native and exotic species), while the riparian zone of its tributaries has high vegetation diversity consisting of native and exotic species of tall trees, shrubs, vines, and grasses.

The riparian zone assessments of the Mary River and its tributaries are ranked in Table 13.

3.3.11 Gully Erosion

The majority of gullies that are within the Mary River catchment occur in the study area and are the result of land use and vegetation characteristics that mainly consist of grazing pastures and bare woodland. The gully density layer was obtained from the Bureau of Agricultural Sciences web site (2003) and is shown in Figure 45. The annual gully erosion equation is outlined in section 3.2.8.
This product (Figure 45: Gully Density within the Study Area) incorporating data from: © Commonwealth of Australia (National Land and Water Resources Audit) 2004.

**Figure 45:** Gully Density within the Study Area.
3.3.12 Mary River and SedNet Model

“SedNet was used in a national assessment of the movement of sediment and nutrients across Australia for the National Land and Water Resources Audit” (Prosser, 2002), and to identify “the major processes involved in the delivery of sediment and nutrients to rivers within the Mary Catchment” (DeRosa et al., 2002 p. 4). The SedNet model assisted in quantifying the sediment load produced by hillslope, gully and riverbank erosion.

In addition, DeRosa et al., (2002) noted that SedNet also calculated “reservoir, floodplain, or river sediment load deposit, and related sediment load that reaches estuaries and coast” (p. 4).

The SedNet model has identified that in the Mary River catchment:
- hillslope erosion contributes 5% of total sediment load.
- gully erosion contributes 8% of total sediment load.
- riverbank erosion contributes 87% of total sediment load.

Erosion processes within the Mary River catchment are further discussed later in this section.

The suspended load in a river travels at a velocity slightly lower than the water, and consists of mainly fine grain sediment – coarse sediments are likely to be transported via bedload (Ritter et al., 2002). They also state that “most of the bed material is transported as suspended load”. The suspended load is influenced by stream sediment transport capacity and its rate of supply from the catchment (Carling, 1996).

(Ritter et al., 2002) suggests that the concentration of fine sediment in a stream is subject to sediment supply rather than sediment transport capacity, however, coarse sediment is more affected by depth and velocity, and therefore more subject to transport capacity. Sediment load variations are also subject to climate variations, and geological characteristics.

The methodology used by the SedNet model based on Prosser et al. (2001) and DeRose et al. (2002) stipulates that sediment loading or its transport capacity of flow Qs [m³/s] is a function of discharge per unit width w [m] of channel, hydraulic roughness k₁ [] and hydraulic gradient S [], where β [] is correction factor. Sediment loading is calculated using the formulae below.
\[
\frac{Q_s}{w} = k_1 \left( \frac{Q}{w} \right)^\beta S' \tag{4}
\]

*SedNet* predicts that 95% of suspended sediment in the Mary River and less than 1% of the bedload, which is delivered to the river network in any one year is exported to the coast (DeRose *et al.*, 2002). It is also estimated that of the 445,000 tonne per year of suspended solids, which is exported to the coast, 55% of the total yield is “derived from erosion within basin areas that adjoin the main river catchment” (DeRose *et al.*, 2002, p. 5). Predicted annual suspended sediment loads for each river link using *SedNet* are illustrated in Figure 46.

![Figure 46. Annual suspended sediment loads for each river link (DeRosa *et al.*, 2002, p. 34).](image-url)
SedNet has also identified areas that substantially contribute to increased suspended load exported to the coast (Figure 47) – such an area was the majority of the Mary River trunk.

**Figure 47.** Areas that Substantially Contributed to Increased Suspended Loading (DeRosa *et al.*, 2002, p. 37).

Figure 47 shows that the study area contributes 0.1 - 0.3 t/ha/year suspended sediment load. Figure 47 also shows the spatial suspended solids export variations across the catchment. In addition, a large proportion of the sediment export occurs along the main river channel, which suggests that river bank erosion of the main river channel largely contributes to sediment loading. Also, some of the highest export is concentrated in the lower catchment adjacent to the estuary.
3.3.13 National Land and Water Audit of Mary River and its Catchment

A Natural Heritage Trust government initiative produced “The National Land and Water Resources Audit” (NLWRA), the first Australia-wide assessment of:

- water availability and quality
- dry land salinity
- vegetation
- rangelands
- agricultural productivity and sustainability
- natural resource management
- landscapes, catchments, rivers and estuaries
- biodiversity (NLWRA, 2002, p. 2)

In relation to the Mary River, the audit has evaluated the catchment condition in terms of land, water and biota components, and river condition based on aquatic biota, and environmental indices.

The Catchment Condition index developed by NLWRA was based on a combination of the:

- water condition subindex that further involves the suspended sediment ratio, pesticide hazard, industrial-point source hazard, and impoundment density indices.
- land condition subindex that further involves predicted 2050 salinity, soil degradation hazard, and hillslope erosion ratio.
- biota condition subindex that further involves: native vegetation fragmentation, native vegetation extent, protected areas, road density, feral animal density, and weed density.

The Mary River catchment and the study area within were found to be moderately modified as shown in Figure 48 and Figure 49.
Catchment condition is greatly affected by the suspended solids loading that influences water quality and associated biota. The indicators that are closely related to suspended solids loading are as follows:

- soil erosion hazard
- soil degradation hazard
- hillslope erosion ratio
• suspended sediment load
• native vegetation extent.

The NLWRA also includes an assessment of Australian rivers using two condition indices being the aquatic biota index and the environment index. These river assessment indices including subindicators are illustrated in Figure 50. “The assessment philosophy is based on departure from reference or pre-European settlement conditions” (NLWRA, 2002, p. 8).

**Figure 50.** NLWRA River Assessment Indicators (NLWRA, 2002, p. 8).

The suspended solids loading component acts as an important factor influencing the aquatic and environmental indices, since it is related to several indicators including catchment disturbance, habitat and hydrological disturbance. An environment index has been established for each stream within the Mary River catchment. The NLWRA has identified that the overall environmental index shows that the Mary River is moderately to substantially modified (Figure 51).
Figure 51. Mary River Environment Index based on GIS layers available on NLWRA web site (April 2004).

An index was also established for aquatic biota, which measures a response of macro-invertebrates to environmental conditions (Figure 52).
**Figure 52.** Mary River Aquatic Biota Index based on GIS layers available on NLWRA web site (April 2004).

The Mary River aquatic biota index shown in Figure 52, demonstrates that less than half of the streams within the Mary River catchment are significantly impaired.

CSIRO Land and Water (2001) has listed the erosion and sediment transport data for all Australia’s catchments including the Mary River. The erosion and sediment transport estimates suggested for the Mary River are shown in Table 17.

**Table 17.** Mary River Erosion and Sediment Transport Estimates

<table>
<thead>
<tr>
<th>Description</th>
<th>Australian Agriculture Assessment (2001) Report</th>
<th>SedNet Model (DeRose et al., 2002)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hillslope Erosion (%)</td>
<td>38.54</td>
<td>5</td>
</tr>
<tr>
<td>Gully erosion (%)</td>
<td>17.03</td>
<td>8</td>
</tr>
<tr>
<td>Streambank erosion (%)</td>
<td>44.43</td>
<td>87</td>
</tr>
<tr>
<td>Sediment supply to river (t/year)</td>
<td>266 713</td>
<td>450 000</td>
</tr>
</tbody>
</table>
The estimates listed in that report are different to estimates suggested by the *SedNet* model. This suggests that further data validation and suspended sediment modelling is required in this area.

The areas, events, and land use practices that may be found to release significant sediment loads to the Mary River are:
- Sediment loading from major tributary catchments mainly due to land use related erosion patterns.
- Sediment loadings due to hillslope, gully, and riverbank erosion resulting mainly from agricultural and forestry operations.

### 3.3.14 Conclusion - Mary River Catchment Study

The application of the *SedNet* suspended sediment model aims to predict sediment yield in water suspension that affects river ecosystems by reducing water clarity, declining respiration in a fresh water biota, and minimising available light necessary for plant photosynthesis.

The proposed model, described in Chapter 4, aims to further contribute to ecological assessment processes of natural habitats in a fresh water environment, and a reliable and sustainable potable water supply and optimisation of the value, and treatment of water.

The proposed model will provide information for:
- Identifying concepts that have the potential to improve river health with respect to sediment transport.
- Estimating the potential impact of increased sediment loads on fresh water ecosystems, particularly fish and their related habitats.
- Estimating the effects of river sediment loads on an estuarine ecosystem.
- Estimating the impacts of agricultural activities on sediment loads.
- Estimating the impacts of hydrological changes and related riverbank erosion and sediment transport.
- Ongoing monitoring of river health and the assessment of management and rehabilitation actions.

The predictive model would provide a system design to ensure the following:
- Catchment condition assessment regarding turbidity and sediment supply.
- Identification of catchment variables/mediators that affect water quality.
The model would also assist in the analysis of any modelling inconsistencies predicted by available catchment or sediment transport models. The predictive suspended sediment model is discussed in Chapter 4.

### 3.4 Catchment and Water Quality Modelling

“The modelling system is designed to simulate land and water management activities” (Newham et al., 2002) and to optimise the use of resources to meet company’s strategic and management goals.

In south-east Queensland, catchment and water quality modelling has become an accepted tool to support stakeholder consultation and management of surface waters. Modelling techniques are carried out to understand cause-effect relationships and to assess and forecast the impact of management changes. SEQWater has been using modelling tools through WBM Oceanics’ consultancy before my employment for the Wivenhoe Sustainable Loads Project.

The Wivenhoe Sustainable Loads Project was completed by SEQWater in consultation with relevant stakeholders to investigate sustainable target loads for the Wivenhoe Dam in relation to environmental values and water quality objectives, based on catchment and water quality modelling. Catchment water quality objectives were endorsed through stakeholder consultation in line with the Queensland Government water quality guidelines and Environmental Protection Policy (1997) for water requirements.

Modelling tools used for the Wivenhoe Sustainable Loads Project included EMSS for the catchment modelling component, DYRESM-CAEDYM for the modelling of whole dam issues, and RMA for the localised issues.

Following the Wivenhoe Sustainable Loads Project, the Board of SEQWater requested further modelling to investigate water quality variations at the Wivenhoe water supply off-take. The WBM Oceanics baseline *DYRESM-CAEDYM* model was initially configured to “simulate nitrogen and phosphorus cycles, suspended sediment and one species of phytoplankton” (WBM Oceanics 2004, pp. 5-10), and to assess phosphorus response, measured as chlorophyll-a. The model forcing data was modified to investigate changes of nitrogen, phosphorus, and suspended sediment concentrations at the Wivenhoe Dam off-take across different off-take elevations and withdrawal volumes.
This aspect of the project was under the supervision and input from Dr Michael Barry of WBM Oceanics, and the report was reviewed by Dr Matthew Hipsey of the Centre for Water Research (CWR) University of Western Australia.

This modelling project was carried out to improve operational procedures and actions of the water supply off-take and to reduce pollutant loads. The report is enclosed in Section 3.5.

### 3.5 Wivenhoe Water Quality Off-take Modelling

This aspect of the thesis demonstrates the application of modelling tools to improve operational practices and procedures at Wivenhoe Dam off-take.

As already mentioned, SEQWater is the major supplier of untreated bulk water to Local Governments and industries in the region. The water is primarily surface and ground water stored in various dams. Major customers include Brisbane Water, Pine River Shire Council, Esk Shire Council and Kilcoy Shire Council. Wivenhoe Dam (also know as Lake Wivenhoe) is located on the Brisbane River in the Esk Shire. The storage capacity for water supply (full supply level) is 1,165,000 ML, with a further capacity of 1,450,000 ML above full supply level (flood storage), for the temporary storage of floodwaters (SEQWater web page, 28 Feb. 05). A Wivenhoe catchment locality map is shown in Figure 53.

The primary function of Wivenhoe Dam is to provide a safe water supply to the people of Brisbane through its release into the Brisbane River where the Mt Crosby Water Treatment Plant operated by Brisbane Water is located. This treated water is supplied to the greater Brisbane area.

Potential activities affecting water quality include:
- Point sources: including sewage treatment plants, septic tanks and industry discharges.
- Runoff from landfills, grazing, cropped land, and forestry operations.
- Urban stormwater runoff.
- Weed control around dams.
- Domestic and feral animals within a catchment.
- Human access and potential sabotage.
- Recreational activities.

Consequently, SEQWater is undertaking initiatives to minimise and manage the risks to water quality in its storages. A key component of these initiatives is the
development of an understanding of water quality through monitoring and research efforts (SEQWater web page, 28 Feb. 05).

One such research effort has been the impact of varying withdrawal volumes and off-take elevations on downstream water quality at the Wivenhoe off-take. The motivation for this effort has been to ensure better operational practice and reduction of downstream nutrients and suspended solids concentrations. The outcome of this investigation will assist SEQWater catchment and water supply operations to improve water quality released from Wivenhoe Dam. The following reports on this research.
This figure incorporates data, which is sourced from the SEQWater (2005)

**Figure 53.** Locality Map of Brisbane showing Wivenhoe Dam Catchment.
3.5.1 Methodology

A one-dimensional process based model DYRESM-CAEDYM (DC) has previously been developed as part of the Wivenhoe Sustainable Loads Project study (WBM Oceanics, 2004). The WBM Oceanics DC model was configured to “simulate nitrogen and phosphorus cycles, suspended sediment and one species of phytoplankton” (WBM Oceanics 2004, pp. 5-10). This model was modified as part of this study. These modifications involved altering off-take elevations and water supply withdrawal volumes.

The DYRESM one-dimensional hydrodynamics model, described earlier (see Table 2), was used in this study. CAEDYM simulates biogeochemical cycles and eutrophication processes and is coupled with the hydrodynamic models DYRESM and ELCOM to provide a complete description of reservoir hydrodynamic and biogeochemical behaviour.

3.5.2 Model Setup

In constructing the baseline DC model, WBM Oceanics (2004) undertook a thorough review of the data sets available for forcing the model.

Following this review, forcing data was used from the following sources:

- BoM provided some meteorological data.
- SEQWater provided meteorological, withdrawal volume and initial conditions data sets.
- A purpose built WBM Oceanics EMSS catchment model provided inflows data and bathymetry.

After a brief review, these forcing data sets were adopted for this study.

The baseline DC model was calibrated over a “dry” period (mid 2002 to late 2003) and validated over a “wet” period (mid 1998 to mid 1999). The dry period was selected for use in this for this study, as the wet period included significant flushing of the dam during an inflow event, which corresponded to an Average Recurrence Intervals (ARI) greater than 1 year. As such, the wet period was considered to be not reflective of ambient “business as usual” conditions and was not used as part of this study. Figure 54 is an example of the dry period calibration of the baseline DC model, which shows DC phosphorus predictions against monitoring data collected across Wivenhoe Dam. Monitoring stations are shown as 30001, 30015, 30016 and 30017.
Figure 54. DC total phosphorus calibration against monitoring data sourced from WBM Oceanics (2004).

Figure 55 shows location of the 30001, 30015, 30016 and 30017 monitoring points in the dam.
Figure 55. Location of the monitoring points (30001, 30015, 30016 and 30017) sourced from WBM Oceanics (2004).
Model changes made to address the scope of this study were:

- Off-take elevations (EL) were varied to include 33m, 39m, 45m, and 52m.
- Withdrawal volumes were varied to 0.25, 0.5, 0.75, 1, 1.25, 1.5 and 1.75 times the actual measured off-take volumes. These elevations were selected based on those available at the dam wall. The Wivenhoe Dam off take design is shown in Figure 56.

![Figure 56. Wivenhoe dam off-take design.](image)

To summarise, Table 18 shows the matrix of DC simulations executed in this study. An “x” represents a model scenario.
Table 18. DC simulations matrix.

<table>
<thead>
<tr>
<th>Flow</th>
<th>Off-take Elevations (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>33</td>
</tr>
<tr>
<td>quarterly decrease</td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>x</td>
</tr>
<tr>
<td>0.5</td>
<td>x</td>
</tr>
<tr>
<td>0.75</td>
<td>x</td>
</tr>
<tr>
<td>measured quarterly increase</td>
<td>x</td>
</tr>
<tr>
<td>1.25</td>
<td>x</td>
</tr>
<tr>
<td>1.5</td>
<td>x</td>
</tr>
<tr>
<td>1.75</td>
<td>x</td>
</tr>
</tbody>
</table>

3.5.3 Results

A time series of DC predictions for the off-take water quality were extracted for each modelling scenario.

For the purposes of compliance of water quality monitoring and HACCP water quality management system requirements, these time series were shown as median Total Nitrogen (TN), Total Phosphorus (TP), and Suspended Solids (SS) concentrations in this report. Results are presented below and discussed in Section 3.5.4.

Figure 57 presents the TP median concentrations at the Wivenhoe off-take across off-take elevations and flows.
Figure 57. TP Concentrations at Wivenhoe Off-take.

Median TP concentrations for all simulations are generally similar, being within approximately 10% of each other. The exception is the 33m EL off-take at lower flows, which have higher median TP concentrations.

Figure 58 presents the median TN concentrations at the Wivenhoe off-take for all simulations.

Figure 58. TN Concentrations at Wivenhoe Off-take.
Again, median TN concentrations are similar for nearly all off-takes and flows. The exception is again the 33m EL off-take at lower flows.

Figure 59 presents the median SS simulated concentrations at the Wivenhoe off-take across modelled off-take elevations and flows.

![Figure 59. SS Concentrations at Wivenhoe Off-take](image)

Figure 59 shows a general increase of median SS concentration with increased withdrawal flows. However, there is an apparent grouping of increased SS concentrations for mid level off-takes.

### 3.5.4 Discussion

Modelling of TP at the Wivenhoe Dam off-take suggests that TP concentrations generally do not vary significantly across off-take elevations and flows. This implies that operational changes are unlikely to contribute to minimising the level of TP in raw water. However, the exception is the elevated medium TP concentrations for the 33m EL off-take and lower flows. This may be related to sediment phosphorus release and the subsequent entrainment of bottom waters in the off-take.

The median TN concentrations are reasonably similar for nearly all off-takes and flows, again with the exception of the 33m EL off-take at lower flows. This may again be related to sediment nutrient release providing nitrogen to the relatively confined extraction zone near the sediments, as was suggested for TP.
In order to test this hypothesis, DO concentrations through the off-take were also extracted from the model simulations. Figure 60 shows the time series of DO for all extraction elevations at the lowest flow rate.

![Figure 60. DO timeseries for all extraction elevations at the lowest flow rate](image)

The figure shows that DO concentrations are significantly reduced in the lower elevation off-takes, particularly at 33m. This is consistent with elevated sediment nutrient release, and consequent entrainment of high nutrient waters into the lower off-takes.

In order to further investigate this hypothesis, a small set of supplementary simulations was executed that examined the impact of increased sediment phosphorus release rates and catchment TP concentrations on off-take water quality. In these simulations, both the rate and concentrations were doubled. The corresponding suite of DC runs is shown in Table 19.

### Table 19. Phosphorus cycle DC runs matrix

<table>
<thead>
<tr>
<th>Flow</th>
<th>Off-take Elevations (m)</th>
<th>Increased sed release</th>
<th>Increased inflow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>33m EL</td>
<td>39m EL</td>
<td>45m EL</td>
</tr>
<tr>
<td>quarterly</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>decrease</td>
<td>0.25</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>0.75</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Measured</td>
<td>1</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>quarterly</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>increase</td>
<td>1.25</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>1.75</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>
Figure 61 shows the sediment and catchment TP concentrations across off-take elevations and flows.

\[ \text{Figure 61. TP concentrations at varying sources.} \]

The figure shows that catchment inflows generally dominate the off-take TP loads. This is consistent with previous studies that have shown the importance of catchment loads to water storage health, and the key role that mitigating catchment pollutant loads can have on improving storage water quality (WBM Oceanics, 2004).

The figure also shows, however, that median off-take TP concentrations are again elevated for low flows at the 33m EL off-take. This is consistent with the previous hypothesis that at low off-take elevations, sediment nutrient release is important in determining off-take water quality.

Finally, this study found that median SS concentrations had a notably different behaviour to TP and TN across the modelled scenarios. The SS model results showed that mid-depth off-take elevations consistently displayed higher SS concentrations than at other levels. This may suggest that these depths are subject to high SS loading and one possible explanation is that sediment bearing catchment inflows may typically be inserting at mid-depth in the reservoir, at least over the period modelled in this study. A DC contour plot of SS concentration for the case of the 45m EL off-take scenario supports this hypothesis (Figure 62).
The SS results also showed a discernable increase in concentration with off-take volumes. It is likely that as withdrawal volumes increase, the vertical extent of the extraction zone also increases. This zone increase may result in all extractions progressively taking more and more mid-depth water as extraction volumes increase that may account for the observed increase in SS concentrations with flow, if catchment loads typically insert at mid-depth.

This hypothesis requires further investigation since the inflow temperature values used in the model were estimated (in the absence of measured data) using antecedent ambient air temperatures. This is an untested assumption for this reservoir. Additionally, inflow tracking investigations carried out in March 2004 by SEQWater found that the tracked inflow was an underflow. Clearly more study is needed in this area.

### 3.5.5 Conclusions

The one-dimensional process based model **DYRESM-CAEDYM** was used to investigate water quality variations at the Wivenhoe off-take across differing off-take elevations and flow regimes. The outcomes of this modelling study have improved
our understanding of off-take water quality in relation to different management actions and may be of assistance to dam operations.

The operational recommendations suggested by this study are to:

- Avoid use of the 33m EL off-take, particularly during low flows to minimise pollutant concentration in raw water released from Wivenhoe Dam.
- Be aware of the suspended sediment mid-depth intrusion that may affect water quality at the 39m EL and 45m EL off-takes.
- Use when possible the 52m EL off-take, since it is the least affected by nutrient and suspended solids loading.

3.5.6 Future Work

There is potential for the model to be improved subject to the availability of better forcing data, particularly in relation to modelling and recalibration of SS data. In addition, the comparison between model predictions and SEQWater investigations into tracking of TSS inflow data carried out in March 2004 would be useful in validating some model predictions.

Also, application of two dimensional (laterally averaged) (i.e. CE-QUAL-W2, RMA) or three dimensional (i.e. ELCOM, POM) water quality models could be considered to further investigate the behaviour of the water quality at the Wivenhoe off-take. It is noted that substantially improved forcing and calibration data will be required for any such modelling exercises, none of which are currently available.

Finally, it is noted that this study has, in some ways, provided a ‘worst case scenario’ for the development of extraction rules for Wivenhoe Dam. This is primarily because water from the extractions is allowed to flow approximately 60km downstream through the Brisbane River, prior to being re-extracted, treated and distributed to customers. This riverine path may afford considerable natural treatment of the releases, and improve water quality above and beyond that likely to be characteristic of Wivenhoe Dam releases. As such, it may be worthwhile considering integration of the modelling results/scenarios described in this study with a downstream receiving water quality model that captures the natural treatment processes within the Brisbane River prior to extraction. This will provide a more complete modelling framework that would inform a more robust assessment and potential alteration of the extraction practises at Wivenhoe Dam. It is noted that such a receiving water quality model (RMA) is currently being developed as part of the Water Quality Improvement Plan under the direction of the Moreton Bay Waterways and Catchments Partnership.
3.6 Uncertainty in Water Quality Modelling

McIntyre et al., (2003) state that catchment and water quality models are a central part of the catchment management plans “because they can apply the best available scientific knowledge, conditioned by historical evidence, to predict water quality responses to changing controls” (p. 259).

The expectation of improved modelling tools for ecological events has introduced scientific complexities in predicting pollutant transport of nutrients, suspended sediment micro-organisms, and toxins. These complexities coupled with available computational resources have introduced a degree of uncertainty in catchment and water quality model outputs. McIntyre et al., (2003) argue that this uncertainty is expressed by the following:

- Models frequently fail to predict the most local and basic biological indicators with a reasonable degree of precision (p. 260).
- Even when models are claimed to be reliable following audits, a very significant margin of error is allowed (p. 260).
- The application of modelling to the new era of high ecological standards presents severe challenges, especially given that modelling experience is with relatively stressed ecological systems (p. 260).
- Economic implications of model errors may be relatively serious (p.260).
- Future driving forces such as climate and distributed pollution sources are poorly defined and themselves cannot be modelled with much precision (p. 260).

Working as the Water Quality Modeller, I understand that there is an expectation to produce good quality modelling predictions to service a company’s ongoing operational improvements, planning and implementation of improved catchment management actions, and regional catchment water quality objectives endorsed by the state government.

Therefore, to minimise the level of modelling uncertainty, I have adopted a procedure which includes a thorough understanding of the science behind the model as well as the key factors affecting pollutant transport through the site, assessment of the catchment being investigated, and review of the available water quality data. The quality of data required by a model is crucial to minimising modelling uncertainty. In relation to data quality and related uncertainty McIntyre et al. (2003) adds that “the problem magnifies as both the number of interacting parameters increases and as the precision of the data decreases” (p. 261). If available data is of poor quality, the modelling should be postponed until quality data is available.
SEQWater is controlling some factors influencing quality of data through the application of operational procedures for sampling, collecting and transporting of water quality samples, together with ongoing quality review of the laboratory that analyse samples, and quality assurance of the *TimeStudio* database.
4 Suspended Sediment Transport Model

Recent studies of suspended sediment transport in freshwater have, to an extent, addressed the nature of the suspended solids load. However, the composition and availability of suspended sediment load and its relationship to river velocity have not been investigated entirely. This chapter therefore presents the formulation of a suspended sediment load model and its application to fresh water rivers and creeks. The capacity of the model to classify the suspended solids load into fractions that correspond to different particle size diameter that are present in a stream is also demonstrated. The suspended sediment transport model can be applied as a tool for the assessment of river ecosystems in relation to upstream erosion patterns resulting from land use practices or catchment improvement activities. Additionally, it may also contribute towards better planning and appropriate response to different suspended solids loads for water treatment operations.

Rivers carry large quantities of sediment that contribute to increased levels of turbidity and suspended solids. Land use practices which are linked to an increase of sediment levels in rivers include unsustainable farming practices, forestry operations, earth moving operations and poor catchment management. In addition, the geomorphological reaction of rivers to land use practices also contributes to increased sediment levels through riverbank erosion.

Human activities have greatly increased the supply of sediment from agricultural hillslopes by the rapid extension of gully networks (Prosser et al., 2001) and flow regulation by dams and diversions (Tabacchi et al., 1998). Prosser et al. (2001) and Brookes (1996) state that increased sediment loads can result in substantial changes to river physical form, chemical processes and ecological health.

There are two major concerns relating to increased sediment load in Australian fresh water rivers, including the increased cost of water treatment to “household, industry and infrastructure” (Thomas, 2001, p. 6), and the detrimental effect on fresh water habitat that responds to sediment input changes (Parsons et al., 2002).

This proposed model attempts to provide a benchmark for the long-term assessment and improvement of catchment conditions, and to provide advice to landowners on how to better manage source waters. The proposed model will provide information that can be used to:

- Estimate the effects of sediment loads on river ecosystems, particularly fish related habitats.
- Estimate the impacts of agricultural activities on sediment loads.
• Estimate the impacts of hydrological changes, related riverbank erosion and sediment transport.
• Identify concepts that have the potential to improve river health with respect to sediment transport.
• Monitor river health and the assessment of management and rehabilitation actions.
• Assist in WTP operations.
• Contribute towards a general understanding of sediment transport in rivers.

The value of the model is its capacity to classify suspended solids loads into fractions that correspond to different particle size diameters present in a river.

### 4.1 Theory

The suspended solids load is defined as the total weight of suspended solids transported through a river cross-section over a given period of time (Naden et al., 2002).

Types of movement of solids illustrated by Summerfield (1991) include suspension, rolling, sliding, and saltation (Figure 63). Saltation refers to particles that are too heavy to remain in suspension.

![Figure 63. Suspended load movement in rivers (Adapted from Summerfield, 1991, p. 200).](image)

The continual suspension and re-suspension of solids within river systems affects turbidity and suspended load levels in a fresh water system. Carling (1996), Summerfield (1991), and Ritter et al. (2002) identified their velocity to be of prime importance to sediment transport in a river. Sediment deposition occurs when the sediment settling velocity exceeds the sediment entrapment velocity (Figure 64).
Carling (1996) suggested that particle entrapment depended on its immersed weight, drag and lift forces imposed by the flow, and variation in “particle shape, density and degree of exposure” (Carling, 1996, p. 171).

Lift and drag forces imposed by the flow are expressed through the force balance equilibrium between the “shear stress promoting the entrapment and the particle size, density and gravity resisting entrapment” (Carling, 1996, p. 171).

The lift force promoting the entrapment is expressed by Shields parameter ($\theta$) and includes shear force stress ($\tau_{cr}$) required to move a particle, and particle size diameter ($D$). The drag or gravity force resisting the entrapment includes sediment density ($\sigma$), fluid density ($\rho$), particle diameter, and gravity velocity ($g$).

\[
\frac{\text{Shear Force}}{\text{Gravity Force}} = \frac{\tau_{cr} D^2}{(\sigma - \rho) g D^3} = \theta
\]  

\(5\)
The variation of the Shields parameter with the Reynolds number (Re) produces the Shields function curve (Carling, 1996). An example of the Shields function curve for fine silts is demonstrated in Figure 65.

![Shields function curve](image)

**Figure 65.** Shields function curve plotted as a function of the Reynolds number (Adapted from Carling, 1996, p. 171).

The Shields curve illustrates the threshold for particle movement in a river or stream being subject to variations of Reynolds number and Shields stress.

Suspended load movement was also described by F. Hjulström in 1935 who defined a mean velocity as an important factor in sediment entrapment. Figure 66 illustrates a “mean velocity at which uniformly sorted particles of various size are eroded, transported, and deposited” (Ritter *et al.*, 2002, 197).
However, the Hjulström curve fails to account for channel longitudinal and cross-sectional velocity variations. In addition, it does not identify “unique mean flow velocity at which particles of a particular size are set in motion” (Summerfield, 1991, p. 201).

In the water industry the amount of suspended sediment is usually represented by the TSS concentration (mg/L) or turbidity (NTU). Currently, the turbidity parameter has been adopted to represent the presence of suspended solids because it is easy to collect data and it is cost effective. Gippel (1988), states that a close correlation between turbidity and concentration can be achieved if sediment characteristics are relatively constant. Studies undertaken by Mack (1988), Lewin (1996), and Lewis et al. (2002) have found a strong log-linear correlation between turbidity and concentration. However, the correlation is different for different catchments, as catchments vary in soil composition, mineral content, geomorphology, and vegetation.

4.1.1 Turbidity

Gippel (1989) defines turbidity as a lack of water clarity as perceived by the human eye. Turbidity is measured by various turbidity meters using different methods. A Nephelometer measures the degree of light travelling through a water column that is scattered with suspended organic and inorganic components expressed in NTUs, a
Jackson Turbidity meter uses JTU units and the Secchi disk reads the depth at which a Secchi disk becomes barely visible. However, the Nephelometer is found to be the most sensitive.

Gippel (1989) states that turbidity is affected by:
- Sediment particle size
- Shape and composition
- Water colour

Particle size is a major determinant of turbidity since the turbidity generally follows the suspended solids concentration. Particle size may also distort the turbidity-concentration relationship as a mass of fine material will give a higher turbidity than an equal mass of coarse material.

The shape and composition of particles defined as organic and mineral components, as well as water colour, also tend to distort the relationship between linear turbidity and concentration. Additionally, organic components absorb light, whereas mineral components sometimes do not have uniform optical properties (Gippel, 1988).

### 4.1.2 Particle Size Distribution

The understanding of particle size distribution of a suspended load is very important for successful application of this model. Suspended sediment sampling and analysis across the region/catchment provides input particle sizes required to run the model, and to calculate sediment loading distribution.

According to Blott and Pye (2001) the parameters used to describe a particle size distribution include the following characteristics of the particulate matter:
- The average size
- The sorting of the sizes around the average
- The symmetry to one side of the average
- The degree of concentration of the grains or particles relative to the average
For the purpose of this model the average size would be presented as a frequency histogram expressed as the number or mass of particles as a function of their size, to provide sufficient information to model data input and verification. An example of such information is shown in Figure 67.

**Figure 67.** Sample statistics and particle size distribution analysis (adapted from Blott and Pye, 2001 p.1243).

Frenz et al. (2004) states that “the grain size distribution varies regionally, whereas the grain size of the fine silt peak stays remarkably stable per region and with increasing water depth, the coarse silt peak decreases in grain size with increasing water depth from >20 to <15 \( \mu m \)” (p. 59). The Australian Standard AS 1726-1993
further outlines the description, identification and classification of soils in Appendix C.

The particle size distribution analysis for fine sediment, including silts and clays, is generally determined by hydrometer and pipette analysis (Bardet and Young, 1997), whereas course sediment (i.e. sands, gravels, cobbles and boulders) is determined by sieve analysis.

4.1.3 Velocities at River Cross-Sections

River velocity can be plotted based on the number of isovels (lines of equal velocity) characterised by a river’s cross-section. A skewed riverbed usually triggers a higher number of isovels due to an induced shear stress. Carling (1996) suggests that if the lowest river velocity isovel, which occurs closest to the bank, has a value of 0.1 m/s, then the highest isovel, which occurs closest to the river surface is 0.5 m/s.

Gordon et al., (1992), and Ritter et al., (2002) agree with Carling (1996) stating that river velocity is greatest in mid-channel and decreases towards the banks and riverbed due to frictional resistance.

The transverse variability of velocity pattern is shown in Figure 68.

Figure 68. Flow Velocity at River’s Cross-section based on Gordon et al. (1992) p.269. (a) Relatively straight section, (b) At a bend. In both diagrams, V4>V3>V2>V1.

Gordon et al. (1992) has demonstrated in Table 20 three different cross sectional velocities that vary due to different channel geometry and bed roughness.
Table 20 Three variations on the velocity profile based on the Gordon et al. (1992, p. 268).

<table>
<thead>
<tr>
<th>Diagram</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Diagram" /></td>
<td>Typical velocity profile – where the average velocity occurs at 0.4D.</td>
</tr>
<tr>
<td><img src="image2.png" alt="Diagram" /></td>
<td>Velocity profile that occurs at the centre of rapid broad streams.</td>
</tr>
<tr>
<td><img src="image3.png" alt="Diagram" /></td>
<td>Velocity profile that occurs in the shallow, steep, cobble, and boulder streams.</td>
</tr>
</tbody>
</table>

### 4.1.4 Longitudinal Velocities

The longitudinal velocity profile is important in choosing an appropriate monitoring location. An example of longitudinal velocity variation is shown in Figure 69.
Figure 69. Longitudinal velocity variations sourced from Gordon et al. (1992, p. 270).

Carling (1996) states that the bedload tends to follow the variation of the maximum velocity, and deposition occurs close to the inside of the band where velocity is lowest. Understanding of cross-sectional and longitudinal velocities can further improve the modelling outcome.

4.2 Model Formulation

The transport of particles is subject to their size (Prosser et al., 2001). The model can calculate the suspended load of particles present in a river based on the sediment transport process affected by suspended sediment velocities influenced by their particle size diameter and river flow.

Figure 70 illustrates the predictive model flow chart. It shows the parameters and methodology required to calculate the suspended solids load at a chosen location in the river.
Figure 70. Suspended Solids Load Model Flow Chart.

Other velocity factors may be included at the point such as:
- river cross-sectional velocity
- river longitudinal velocity
These are not included in the proposed model.

Model calibration and verification

Particle Size Distribution

TSS

Particle Load Distribution

Particle not in suspension

Particle in suspension

TSS

Turbidity

Correlation factor
The proposed model is based on the entrapment velocity factor \( (v_{cr}^*) \) that when multiplied with a mean flow velocity \( (v_{flow}) \) computes the entrapment velocity of particles present in suspension.

\[
v_{cr} = v_{cr}^* \cdot v_{flow}
\]  

(6)

The flow velocity is derived from the monitored flow value and cross section area at a chosen site location, and the entrapment velocity factor is calculated based on the particle size distribution, and water temperature affected by water density and viscosity, and suspended particle density.

The entrapment and settling velocities are subject to particle size diameter, particle distribution and soil composition at the given area. Therefore, soil analysis is required to determine the particle size distribution and particle density.

Particle size load distribution is estimated by the suspended sediment particle size distribution and suspended solids load evaluated from river flow and TSS concentration.

The entrapment velocity factor is derived using the Shields curve, where the Shields parameter is a function of the Reynolds number \( 0_{cr} = f(Re) \). Particle density \( (\sigma) \) and fluid density \( (\rho) \) are substituted by their ratio \( (s) \).

\[
s = \frac{\sigma}{\rho}
\]  

(7)

\[
\frac{v_{cr}^2}{(s-1)gD} = f\left(\frac{v_{flow}D}{v}\right)
\]  

(8)

The entrapment velocity constant is derived from the formulas shown above (8) and is as follows:

\[
v_{cr}^* = \frac{(s-1)gD^2}{v}
\]  

(9)

The velocity of a particle coupled to the corresponding TSS value provides the suspended solids loading at the monitoring location.

An example of the suspended sediment transport model template to calculate the suspended solids load at a chosen monitoring location is shown in Figure 71. The
model calculates the suspended solids load if the entrapment velocity of a particle is less than the river velocity.

<table>
<thead>
<tr>
<th>Water Quality Component: Suspended Sediment Velocity and Loading</th>
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<tbody>
<tr>
<td>Location</td>
</tr>
<tr>
<td>GIS Coordinates</td>
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<tr>
<td>Station No.</td>
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</tbody>
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<table>
<thead>
<tr>
<th>particle diameter</th>
<th>particle size distribution</th>
<th>entrapment velocity ($v^*$)</th>
<th>entrapment velocity</th>
<th>particle size load</th>
</tr>
</thead>
<tbody>
<tr>
<td>(mm)</td>
<td>%</td>
<td>factor []</td>
<td>m/s</td>
<td>mg/s</td>
</tr>
<tr>
<td>0.005</td>
<td></td>
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<tr>
<td>0.065</td>
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<td>0.125</td>
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<td>0.5</td>
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<td>Total</td>
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</table>

<table>
<thead>
<tr>
<th>Input</th>
<th>Recorded Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (A)</td>
<td>m²</td>
</tr>
<tr>
<td>Flow (Q)</td>
<td>m³/s</td>
</tr>
<tr>
<td>Velocity (v)</td>
<td>m/s</td>
</tr>
<tr>
<td>Gravity acc. (g)</td>
<td>m/s²</td>
</tr>
<tr>
<td>Water temperature (t)</td>
<td>°C</td>
</tr>
<tr>
<td>Particle and fluid density ratio (S)</td>
<td></td>
</tr>
</tbody>
</table>

Water Temperature

<table>
<thead>
<tr>
<th>True/False temperature function</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment Density ($\sigma$)</td>
<td>kg/m³</td>
</tr>
<tr>
<td>Fluid Density ($\phi$)</td>
<td>kg/m³</td>
</tr>
<tr>
<td>Fluid viscosity ($\nu$)</td>
<td>m²/s</td>
</tr>
<tr>
<td>Particle and fluid density ratio (S)</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 71. Suspended sediment and velocity modelling template.](image)

It is envisaged that the cross sectional area would be calculated using the rating curves measured at river gauging stations. A rating curve flow value correlated to a cross sectional area, most likely would not match the flow value measured at the monitoring site. Therefore, a Microsoft Excel macro was written to calculate the cross sectional area that relates to measured flow based on the rating curve information. The Excel macro is shown in Appendix D.

A correlation between turbidity and concentration would be calculated for each catchment having the same sediment characteristics. This would allow a more user friendly application of the model.
4.3 Discussion

The suspended sediment transport model for freshwater rivers relates to the composition and availability of suspended solids to river velocity. The main advantage of the model is its capacity to classify suspended solids loads into fractions that correspond to different particle size diameters that are present in a river or stream, and therefore provide a better understanding of the suspended solids source and its relation to catchment characteristics. The model has the capacity to support a site-based assessment of suspended solids load in relation to upstream catchment characteristics and related erosion patterns. A site-based assessment supported by the suspended sediment transport model would achieve a good understanding of the suspended solids load in relation to a river ecosystem and water treatment operations.

The factors that impact on suspended sediment transport and are not incorporated in this model include cohesive forces relevant to clay particles, movement of eddies relevant to water turbulence and particle shape, since the model assumes particles to be spherical.

Hunt (2004) states that “cohesive forces including clay particles have electrostatic forces that have a significant range even in water with high turbidity” (p. 81).

Therefore, the model would be most successful for the sortable silts with particle size diameter 10-63 μm, not including cohesive material finer than 10 μm. McCave (2004) supports this by stating that “Above about 10 μm the flocculation factor in flowing water becomes quite small as most aggregates are broken up by flow, particularly strong flow. This means that under strong flows this material can be sorted according to its primary grain size” (p.111).

The model would also be applicable should the friction factor for the Reynolds number be less then 4,000, which excludes the turbulent flow. Aliseda et al. (2002) have demonstrated that the “settling velocity of the particles is enhanced by the turbulence” (p. 103). The effect of turbulence that impact settling velocity is associated with energetic eddies. Yang et al. (1998) discuss the effect that eddies have on velocity and states that eddies in turbulent flow are “primarily responsible for the magnitude of average settling velocity” (p. 204).

Finally, the shape of the particles would impact a level of confidence related to the model output. However, it is possible to overcome this problem since “the shape element is determined by a combination of two other parameters, one which represents the asymmetry/symmetry structure and a second which defines the peakedness” (Hartmann 2004, p. 65). Laboratory sediment analysis would be able to
provide this information and thus could be incorporated in the model as a corrective or confidence factor related to particle shape. Additionally, Bardet and Young (1997) state that particles with a diameter smaller than 5 μm are likely to have an asymmetrical shape, and also to their knowledge, “there is no experimental data on the drag coefficient of spheres for Reynolds’s number in the range 10⁻³ to 10⁻⁶ which corresponds to 1 to 5 μm diameter spheres falling in liquid” (p. 485). This suggests that the model would fail for particles with a diameter smaller than 5 μm.

This model has the potential to analyse the dynamic behaviour of suspended sediments with respect to erosion, since it would relate to a particular upstream catchment/area of concern to stream condition. This information will further contribute and provide information for sediment management strategies.

Catchment management strategies use catchment and water modelling information to assess future catchment improvements against defined water quality requirements or objectives.
5 Water Quality Objectives

“A water quality objective is a numerical concentration limit or descriptive statement to be measured and reported on. It is based on scientific water quality criteria or water quality guidelines but may be modified by other inputs as social, cultural, economic and political constraints” (ANZECC, 2000, pp. 2-11). ANZECC guidelines (2000) have outlined the water quality management framework for long-term management of any water resources including the establishment of environmental values, understanding the relationship between environmental values and human activity, and defining water quality objectives to be achieved by implementing management goals through stakeholder and community involvement.

The Queensland Government has adopted this approach and supports:

the National Water Quality Management Strategy (NWQMS) and Environmental Protection (Water) Policy 1997 (Water EEP) to promote the sustainable management of water resources by determining environmental values (or uses) of waterways and corresponding water quality objectives (also known as targets) for different indicators of water quality such as pH, nutrients and toxicants (QLD EPA, 2005, p. 1).

Figure 72 illustrates this process:

produced to assist water quality managers and stakeholders such as local governments, regional natural resource management (NRM) bodies and other groups to consult and obtain broad agreement on community values and uses for their waterways consistent with the National Water Quality Management Strategy and Water EPP (QLD EPA, 2005, p. 2).
SEQWater has already set environmental values and water quality objectives for the Wivenhoe catchment in consultation with relevant stakeholders, and is now in process of conducting the North Pine Sustainable Loads project that will set environmental values and water quality objectives for the North Pine project. As part of this thesis and in collaboration with SEQWater, I developed the project scope and project plan for the modelling component, and to organise stakeholder involvement in this process. Figure 72 shows the stakeholder brochure outlining the project scope and goals.
North Pine Sustainable Loads

This brochure outlines the North Pine Sustainable Project including its aim, scope and proposed outcomes.

The South East Queensland Water Corporation Limited, trading as SEQWater, is the major supplier of bulk untreated water to Local Governments and industries in the South-East Queensland region. SEQWater owns and operates three water supply dams including Somerset Dam, Wivenhoe Dam and North Pine Dam. Somerset/Wivenhoe Dams provide 86% of our water, and 14% of water comes from North Pine Dam. SEQWater’s major customers include Brisbane Water, Pine Rivers Shire Council, Esk Shire Council and K'gyma Shire Council. SEQWater’s primary function is to provide a safe water supply to the people of South East Queensland.

SEQWater in consultation with stakeholders has previously implemented the Wivenhoe Sustainable Loads project which investigated sustainable target loads for the Wivenhoe Dam in relation to Environmental Values (EVs)* and Water Quality Objectives (WQO)**. Science and modeling tools were used to evaluate and assess target loads and develop Wivenhoe catchments water quality objectives that are in accordance with the Queensland Government draft water quality guidelines and Environmental Protection Policy (1997) for Water.

The aim of the project is to identify and support sound catchment management actions that will ensure sustainability of water quality in North Pine Dam. The project is based on identifying values, objectives and targets using a stakeholder engagement and science-based approach. Catchment and storage modelling will form a key component of the science-based approach. In South-East Queensland, catchment and water quality modelling have become accepted tools to support stakeholder consultation, and to define options for water quality management.

* particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and which require protection from the effects of pollution (ANZECC 2000 and Draft Queensland Water Quality Guidelines 2004).

** a water quality objective was defined above as a numerical concentration limit or descriptive statement recommended for the support and maintenance of a designated water use (ANZECC 2000 and Draft Queensland Water Quality Guidelines 2004).

North Pine Dam

Lake Samsonvale is located on the North Pine River in Pine Rivers Shire. North Pine Dam’s primary function is to provide a safe water supply for Brisbane, Pine Rivers, Redcliffe and parts of Caboolture. The dam has a 348 square kilometres catchment area. Storage capacity for water supply is 215,000 megalitres. (Figures 1 and 2).

Figure 1. North Pine dam

In South East Queensland, catchment and water quality modelling has become accepted tools to support stakeholder consultation and management of surface waters. This project will utilise well recognised modelling tools to inform the setting of WQOs.

Figure 2. North Pine’s catchments and dams/storages

Outcome:

Agree on the process of establishing environmental values (EVs) and water quality objectives (WQOs) in accordance with Water Quality Management Framework (based on NWQMS and Water EPP)

Review EVs for North Pine catchment and storage

Discuss and evaluate current management actions

Identify priority pollutants and area/sub-catchments

Review WQOs for North Pine catchment and storage

Identify modelling scenarios to adjust water quality objectives associated with nutrient and suspended solids load modelling, and to assist implementation of prioritised management actions.

MODELLING: Modelling and Review

Outcome:

Prepare stakeholder consultation presentation including the following:

- Modelling outcomes addressing specific site management actions associated with pollutant load modelling
- Modelling outcomes addressing EVs associated with pollutant load modelling

WORKSHOP 1: Define EVs, WQOs and Management Goals

Feedback loop

WORKSHOP 2: Setting Management Actions

Agenda including the following:

- discussing the modeling outcome in relation to specified EVs in relation to pollutant load modelling
- setting the management actions including their timeline, project team, and budget.

Figure 73. North Pine Sustainable Loads project stakeholder brochure.
Figure 72 demonstrates that the modelling component of water quality management is a crucial contribution towards establishing regional water quality objectives in Queensland. Further management of water quality pollutants in catchments, is specified in the ANZECC guidelines and is achieved by monitoring and assessment programs, and organised procedural management responses. Water quality monitoring and the modelling component are used in conjunction to gauge the health of catchments in relation to specified guidelines.

“Water quality criteria for raw water used for drinking – water treatment and supply usually depend on the potential of different methods of raw water treatment to reduce the concentration of water contaminants to the level set by drinking water criteria” (Enderlein et al., 1997 p.18). In Queensland this criteria is set by the Draft Queensland Water Quality Guidelines (2004), ANZECC Guidelines (2000) and the Australian Water Guidelines (NHMRC & ARMCANZ 2004).

The Australian Water Guidelines (NHMRC & ARMCANZ 2004) deal with an appropriate water quality management system. “It points out that successful management of water quality in a water supply system requires an understanding of the process ad practices which can affect water quality within the system” (ANZECC, 2000, pp. 6-1).

However, in some cases guidelines do not provide sufficient information for a contaminant and encourage a hazard risk assessment approach to identify customised criteria suitable for raw water supply.

The Cooperative Research Centre (CRC) for Water Quality and Treatment, in collaboration with the National Health and Medical Research Council/Natural Resource Management Ministerial Council (NHMRC/NRMMC) and key stakeholders, has developed a Framework for Management of Drinking Water Quality (the Framework) for incorporation into the Australian Drinking Water Guidelines most recent revisions. The Framework promotes increased awareness of a comprehensive preventative strategy for drinking water quality management based on quality and risk management principles (Nadebaum et al., 2004, p. 4).

The Australian Drinking Water Guidelines (2004) now promote a water quality management system. Nadebaum et al., (2004) state that “understanding the entire water supply system, the hazards and events that can compromise drinking water quality, and the preventative measures and operational control necessary for assuring safe and reliable drinking water” (p.4). The information provided by predictive modelling contributes towards a better understanding of hazards and their behaviour.
in the catchment. The water quality management system component then continues from the modelling component to minimise the effect of those identified hazards.

SEQWater has expressed their commitment to the development of a water quality management system in the 2005/06-2007/08 Corporate Strategy based on the Framework and the HACCP water quality management system.

I was employed by SEQWater in August 2004. As part of this thesis and my engagement with SEQWater I undertook the task of developing and implementing the HACCP water quality management system for raw water supply. Consequently, SEQWater achieved the national HACCP accreditation carried out and approved by SIA Global on 18 March 2005. The SEQWater HACCP system will be further discussed in Section 6.1.
6 HACCP Management System

The HACCP system is based on Codex Alimentarius that specifies the HACCP system approach to managing food safety, as follows:

The Codex Alimentarius implements the Joint FAO/WHO Food Standards Programme, the purpose of which is to protect the health of consumers and to ensure fair practices in the food trade. The Codex is a collection of internationally adopted food standards presented in a uniform manner. It also includes provisions of an advisory nature in the form of codes of practice, guidelines and other recommended measures to assist in achieving the purposes of the Codex Alimentarius (SAI Global, 2004, p. 299-i).

HACCP is a standard and certified system that ensures quality assurance management of the product and therefore customer confidence. Additionally, it is a process that reduces the chance of errors and provides a basis for improvement through application and control of standardising methods, and ensures pollution prevention management.

The HACCP approach was modified slightly by me to suit water supply operations and in particular address the requirements specified in the Framework that is incorporated in the Australian Drinking Water Guidelines (2004). The Framework was developed by the CRC for Water Quality and Treatment, in collaboration with the NHMRC/NRMMC, and advocates a “proactive approach for minimising health risk in water supply systems and provides greater attention and better measures of control for system management, extending from the catchment to the consumer” (Nadebaum et al., 2004). The HACCP process consisting of twelve elements is summarised in Table 21.

<table>
<thead>
<tr>
<th>Commitment to Drinking Water Quality Management</th>
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<tbody>
<tr>
<td><strong>ELEMENT 1</strong></td>
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<td><strong>System Analysis and Management</strong></td>
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<td><strong>ELEMENT 2</strong></td>
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<td><strong>ELEMENT 3</strong></td>
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The application of the HACCP system to water treatment operations and in particular to raw water operations is a very new process, and to date I am not aware of any other Australian water corporation to have a certified HACCP system for raw water operations.

6.1 SEQWater Certified HACCP System

The national HACCP certification was granted to SEQWater on 18 March 2005 on the basis of an external audit conducted by SAI Global Assurance Services. SAI Global audits are carried out within the requirements of SAI Global procedures that also reflect the requirements of international standards relating to audit practice such as ISO 19011. SAI Global Auditors are assigned to audits according to industry, standard, or technical competencies appropriate to the organisation being audited.

I will briefly discuss HACCP history, purpose and scope, before demonstrating in more detail the SEQWater HACCP system and my role in particular.

The SEQWater HACCP was prepared in accordance with Codex Alimentarius. The scope of the HACCP plan was the operation and maintenance of SEQWater’s dams for the supply of untreated water to local governments and other customers, and the management of water quality.

The objectives of SEQWater HACCP are defined as:

- A safe raw water supply to customers.
- United stakeholder approach in managing water quality from catchment to tap.
- Identification and management of key water quality hazards thereby assisting daily operations as well as long-term strategic planning.

I conducted the following activities:

- Develop, implement and coordinate the SEQWater HACCP system.
- Liaise with agencies to ensure a sound development of the HACCP system.
- Coordinate internal and external system improvements (eg. audits).
- Carry out internal HACCP competency training.
- Undertake the SEQWater HACCP Annual Review.
- Maintain ongoing communication with the HACCP team.
- Receipt and review selected monitoring data.
- Preparation of selected HACCP reports (e.g. HACCP Plans, Trigger Value reports).
Both catchment and water authorities have had a challenge to prepare the HACCP system for raw water supply. As mentioned in Section 5, the CRC for Water Quality and Treatment has developed *A Guide to Hazard Identification and Risk Assessment for Drinking Water Supplies* to assist these authorities to manage water quality. However, water resources managed by these authorities and their operational and managing priorities are often different to the guide. Therefore, SEQWater HACCP was formulated to suit the SEQWater profile, water quality monitoring program and procedures, operational water supply practices as well as the characteristics of the catchments and storages. An overview of the SEQWater HACCP system is outlined below.

**SEQWATER HACCP SCOPE**

SEQWater HACCP will encompass the operation and maintenance of SEQ Water's dams for the supply of untreated water to local governments and other customers, and the management of water quality.

**SEQWATER HACCP TEAM**

HACCP Team was established to incorporate the extensive knowledge at SEQWater to ensure all available information was incorporated into the HACCP process.

**DESCRIPTION OF SEQWATER CUSTOMERS**

SEQWater major customers include Brisbane Water, Pine River Shire Council, Esk Shire Council and Kilcoy Shire Council. SEQWater consults with these customers on an ongoing basis on relevant issues including review and validation of trigger limits, and incident response. Issues are summarised and documented in a Customer Liaison Register (*Appendix F)*.

**PRODUCT DESCRIPTION AND INTENDED USE**

The South East Queensland Water Corporation Limited (ABN 14 088 729 766), trading as SEQWater, is the major supplier of untreated water in bulk to Local Governments and industries in the south east Queensland region. SEQWater owns Wivenhoe, Somerset and North Pine Dams. The catchments of these dams are used for grazing cattle, plantation forestry, dairy farms and cropping. See *Appendix F* for the SEQWater catchment mapshowing storage intake points and water quality monitoring locations.

**PROCESS FLOW DESCRIPTION**
SEQWater product is primarily catchment surface and ground water stored in dams owned and operated by SEQWater. A description of process flow is illustrated through the use of GIS catchment maps and accompanying HACCP Plans (Appendix F).

POTENTIAL HAZARDS

Potential hazardous events have been identified as part of the SEQWater Risk Assessment process, and include:

- Sewage treatment plant discharges and overflows
- Other point sources releases including industry discharges
- Potential leachate from septic tanks within catchments
- Runoff from landfills and potential leachate
- Runoff from grazing land – in relation to erosion and faecal matter
- Runoff from cropped land
- Runoff from land used for forestry operations
- Urban stormwater runoff
- Weed control around dams – spraying activities
- Domestic and feral animals within a catchment area or dam
- Human access and potential sabotage
- Recreational activities that have potential to affect water quality

For each identified hazardous event a series of parameters have been identified to monitor water quality impact as described in the Hazard-Parameter Table (Appendix F).

Based on the categories specified in the Risk Management Guidelines (AS/NZS HB 436:2004) hazard likelihoods, consequences and risk rankings were determined and summarised in the following Hazard Assessment Ranking Tables (Appendix F):

- North Pine
- Somerset
- Wivenhoe
- Lockyer and Mid Brisbane

CRITICAL CONTROL POINTS

Critical Control Points (CCPs) are locations at which effective control of water quality is achievable, in particular for those parameters with direct or indirect effects on health of consumers. Based on this definition the HACCP team has developed a list of CCP that correspond to customer off-take points.
SEQWater does not have a direct control over some off-takes owned by our customers (e.g. Mt. Crosby Off-take operated by Brisbane Water). However, SEQWater HACCP provides a system to notify customers and ensure appropriate corrective actions are taken when potential water quality issues arise.

A list of SEQWater CCPs are provided in the HACCP Plans (Appendix F).

In consultation with major customers SEQWater has established alert and critical trigger limits for each CCP site. These limits are reviewed on an ongoing basis as part of the HACCP verification process. These trigger limits are summarised in Trigger Limits Table (Appendix F).

**CCP MONITORING SYSTEMS**

SEQWater has established a comprehensive program to monitor raw water quality as detailed in the Program Sample Instruction and 2005 Campaign (Routine) WQ Sample Calendar (Appendix F). A series of monitoring locations include dam raw water off-takes, lake monitoring sites and catchment inflow sites. Depending on location, samples are collected either on a fortnightly, monthly, quarterly, six monthly or annual basis. Samples are either collected as part of campaign or event based monitoring. Water Quality (WQ) Procedures have been developed for the collection, transmission, distribution and reporting of water quality monitoring results. In addition to the Water Quality Monitoring Program, SEQWater has established a Communications Register. This register provides details of any issues or complaints raised by customers, members of the public or SEQWater staff, and details how these issues were addressed.

**INCIDENT REPORTING AND CORRECTIVE ACTIONS**

SEQWater corrective action process comprises of a reporting requirement and an incident investigation requirement. The requirement for incident reporting or corrective actions is identified through the following (Appendix F):

- SEQWater's HACCP water quality monitoring program
- site specific HACCP Plans
- SEQWater's Communications Register
- Incident Reporting System

A framework for identifying and managing incidents has been developed so that:

- incidents are reported to the relevant party in a timely fashion
corrective and preventative action can be taken to improve the quality of service provided by the Corporation to its customers and prevent human and environmental harm.

This framework includes a system to monitor water quality (see CCP Monitoring Systems), identify non-conformances, report non-conformance to customers and SEQWater management in accordance with WQ5 (Appendix F) and undertake corrective actions.

**VERIFICATION PROCESS**

SEQWater has developed a system to verify and review the effectiveness of its HACCP system through a review of the following:

- water quality monitoring data (both results and parameters selection) including two weekly compliance reports and seasonal and annual trend analysis reports
- trigger limits undertaken in consultation with customers
- water quality incidents
- CCPs
- relevant procedures

This verification process is documented in SEQWater’s Management Review Procedure and comprises a three-tiered process. A nominated Water Quality section member initially reviews the relevant HACCP element, and reports his/her findings and recommendations at the following Water Quality section meeting for approval. The Water Quality Manager presents the outcome at the next Managers Meeting for final approval.

A HACCP verification and validation schedule (Appendix F) has also been developed to outline a timetable and status of the system.

**RECORD KEEPING AND NOTIFICATION**

HACCP records are developed and maintained in accordance with SEQWater's IMS procedures.

HACCP records (Appendix F) include the following:

- water quality data
- water quality trigger value reports
- trend analysis of trigger value parameters at CCPs
- agendas and minutes of meetings (e.g. water quality section, and managers meeting)
• customer notification records
• incident reports
• HACCP system review reports (external and internal)

Note that records are kept either as hard copies (uncontrolled), on the Intranet (controlled) or electronic copies. Intranet copies should be accessed in the first instance if possible.

The SEQWater HACCP system allows spatial inclusion of water quality hazards (e.g. point sources, various land uses, and so forth), monitoring locations, and water supply infrastructure. In the SEQWater HACCP process, flow charts have been replaced with catchment maps defined within the Spatial Information System – EasiMaps consisting of GIS layers of sampling and Critical Control Point (CCP) locations, off-takes, hazardous point sources (e.g. waste treatment plants, septic, industry discharges), cropped areas, grazing areas, forestry and so forth. The SEQWater process flowchart is illustrated in Figure 74 showing the CCPs.

CCPs are locations at which effective control of water quality is achievable, in particular for those parameters with direct or indirect effects on the health of consumers. Each CCP has an associated HACCP plan that outlines relevant hazards, parameter water quality monitoring, and response procedure in case of a water quality incident, that is, the safety guidelines are exceeded. Appendix E shows the SEQWater HACCP Plan for the North Pine Dam CCP.
Figure 74. North Pine process flowchart.

The geographical interface system, *EasiMaps*, is used to access more information and customise the process flow chart, in case of a water quality incident. A preliminary desktop investigation includes detecting pollutant sources in relation to the CCP where the monitoring program identifies a water quality excess.

Figure 75 illustrates an example of such an investigation that relates to increased bacterial contamination and suspended sediment levels at North Pine catchment.
**Figure 75.** North Pine catchment map - increased bacterial contamination and suspended sediment levels investigation.

The HACCP system was made available through the SEQWater Intranet to allow broad access by employees across all divisions, and consistency and fit with other SEQWater management systems such as the Integrated Management System (IMS), the Environmental Management System (EMS), and OH&S. A part of the SEQWater HACCP home page is shown in Figure 76 for illustration purposes.
Figure 76. Illustration of SEQWater HCCP home page.
A full CD containing a certified interactive copy of the SEQWater HACCP system dated 23 March 2005 is attached as Appendix F. The information of SEQWater HACCP enclosed in Appendix F is commercial in confidence and public distribution is not permitted. This CD represents a contribution towards the Doctor of Technology program at Deakin University (this thesis).

The SEQWater HACCP water quality management system was designed to allow integration with modelling management tools. This approach has been unique and allows broad and integrated application of both HACCP and modelling tools. The modelling tools, that include catchment and water quality models, were incorporated to increase understanding of the catchment and assist with hazard risk analysis and verification of HACCP elements including hazard assessments, evaluation of CCPs and prioritisation of corrective actions.

Since most of the catchments, which harvest raw water, are owned and managed by other stakeholders, such as various governments, or private citizens; the application of modelling tools increases the likelihood of implementation of site-based corrective actions. This likelihood is due to stakeholder discussion and endorsement of modelling findings related to sources of hazards and their associated corrective actions.
7 Conclusions

In south east Queensland, catchment and water quality modelling has become an important tool to support the stakeholder consultation and management of surface water. Modelling techniques are carried out to understand cause-effect relationships and to assess and forecast the impact of management changes.

Water corporations, industries and government are relying on modeling tools and water quality modellers to ensure the following:

- Identify major pollutant sources and establish a relationship between pollutant loads and land-use patterns.
- Predict pollutant loads in relation to associated hazards and water quality control points.
- Provide spatial representation to enable local and regional assessment of hazards at a water quality control point.
- Provide forecast of future pollutant loadings, and evaluate present and future adequacy of management actions.
- Investigate water quality changes as a result of various catchment management changes.
- Assist in operational and management improvements to minimise hazards at a water quality control point.
- Ensure a reference library useful for validation and verification of the HACCP system.
- Assist during stakeholder consultations to achieve implementation of corrective actions.
- Support and promote the sustainable management of water resources by determining environmental values (or uses) of waterways and corresponding water quality objectives required by ANZECC guidelines (2000), Australian Drinking Water Guidelines (2004), local (Queensland) water quality guidelines (2004).

I have demonstrated my professional contribution to introduce and implement effective modelling to catchment and water quality management during my employment with Hobart Water and SEQWater. This newly created company role, for which I am responsible, of Water Quality Modeller needs further integration within SEQWater. This requires strategic placement and development of future modelling strategies both internally and externally to SEQWater. Further integration of modelling tools is ensured through linkage with water quality management systems, such as HACCP, and other risk management systems.
Figure 77 outlines the water quality modelling strategy overview within SEQWater that is consistent with current corporate and water quality strategies.
Figure 77. Water Quality Modelling Framework developed for SEQWater.
Formulation of the suspended sediment transport model would contribute to the development and application of catchment/water quality models. The aforementioned model has the capacity to support a site-based assessment of a suspended solids load in relation to upstream catchment characteristics and related erosion patterns. The information supplied by the model would improve water habitat investigations allowing integration of different factors affecting transport of suspended sediment. The model would also assist operation of water intakes located in rivers. However, the model requires data collation, analysis and integration, and subsequent model validation, before its application.

The application of the model is likely to be achieved due to its simplicity and applicability. In the future I envisage application or integration of this model with other current catchment/water quality models.

8. Summary of contributions to Doctor of Technology program

The Lower Derwent River site assessment has highlighted important results and implications for the understanding of catchments. The essential elements are the generation and delivery of pollutants to water bodies necessary to identify pollutant sources, and adequate application of water quality management support systems that include modelling tools.

The site assessment has identified that sources of significant sediment loads to the Lower Derwent River are associated with regulated flow releases from the Meadowbank Dam, tributary inflows and agricultural activities located close to the riverbanks. The study has concluded that Hobart Water would benefit from the predictive suspended sediment transport model, which would allow a short-term response in optimising water treatment and production at Bryn Estyn WTP, and long-term responses that would benefit Lower Derwent River catchment management including water resource management, strategic and demand planning, and policy development.

Additionally, discrepancies in relation to the suspended solids loads estimate for the Mary River catchment listed in the Australian Agriculture Assessment (2001) report and the SedNet model (DeRose et al., 2002) have been identified. Both assessments were derived from the current published methodologies that aimed to quantify the sediment load in a river produced by hillslope, gully and river bank erosion based on
the catchment assessment of geomorphology including floodplain history and riparian vegetation, climate, land use and soil properties.

The methodology proposed by the suspended solids transport model has the capacity to support a site based assessment of suspended solids load in relation to upstream catchment characteristics and related erosion patterns, providing a way to validate the current published methodology described above. A site based assessment supported by the proposed model would achieve a good understanding of the suspended solids load in relation to a catchment condition assessment, and identification of catchment pollutant (sediment) sources.

During my employment with Hobart Water, I have demonstrated my contribution to the application of hydrological modelling implemented by Hobart Water to ensure optimised releases from Lake Fenton and the efficient use of runoff from the catchment, as well as hydrological assessment of the Wellington Park catchment to present opportunities for the upgrade and relocation of 13 water supply intakes. I have also briefly mentioned the substantial contribution towards delivery of the Wellington Park Drinking Water Catchment Management Strategy (2004) that included organising the stakeholder and public review processes, and preparing and signoff of the final document by the steering committee.

The Wellington Park Drinking Water Catchment Management Strategy (2004) is based on water quality risk assessment, and demonstrates consistency with the Australian Drinking Water Guidelines (1996). Additionally, SEQWater is committed to the application of a water quality risk management system and its integration with catchment and storage modelling. SEQWater uses catchment and storage modelling information to assess future improvements against defined water quality requirements or objectives, and has already set environmental values and water quality objectives for the Wivenhoe catchment.

My contribution towards the SEQWater project used catchment and storage modelling information to assess future improvements against defined water quality requirements or objectives for the North Pine catchment. It included development of the project plan and scope, coordination of stakeholder involvement and management of the relevant project tasks.

I have also carried out a modelling project that involved application of modelling tools, including TimeStudio database and the one dimensional process based model, DYRESM-CAEDYM, to assess water quality variations for TN, TP and SS at the Wivenhoe off-take across different off-take elevations and flow regimes, and to
consequently improve operational practices and procedures at that off-take. The outcome of this project has the potential to be integrated with other regional modelling projects and incorporated into the SEQWater HACCP system.

I have developed and implemented the HACCP water quality management system in consultation with HACCP team members and have also coordinated internal and external system improvements. On the basis of my work, national HACCP certification was granted to SEQWater by SAI Global Assurance services.

In closing, future management of water resources will depend greatly on the integration and application of modelling tools and water quality management systems, that together with stakeholder consultation and the decision-making process will achieve sustainable regional development. The integration and application of modelling tools and water quality management systems is summarised in Figure 78.

Figure 78. Application of modelling tools and water quality management systems.
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