COOPERATIVE RESEARCH CENTRE FOR **CATCHMENT HYDROLOGY**

# UPPER-MID GOULBURN EMSS : A PRELIMINARY REPORT ON CATCHMENT SURFACE WATER QUALITY INVESTIGATIONS

**TECHNICAL REPORT**
**Report 05/12**

September 2005

**Shane Papworth**

COOPERATIVE RESEARCH CENTRE FOR
CATCHMENT HYDROLOGY

GOULBURN-MURRAY
WATER

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# Upper-Mid Goulburn EMSS: A Preliminary Report on Catchment Surface Water Quality Investigations

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## Preface

The Cooperative Research Centre (CRC) for Catchment Hydrology's central goal of producing a decision support system able to predict the movement of water, particulates, and solutes from land to rivers, linking the impact of climate variability, vegetation, soil, and water management together in an integrated package is very attractive to regionally based land and water resource managers.

These resource managers are constantly addressing questions about the impacts of land management on river and storage water quality.

The CRC for Catchment Hydrology's research activities have been targeted on five focus catchments, selected to:

- cover a spectrum of spatial scales and catchment characteristics
- span the range of issue-based problems confronting catchment managers
- build upon existing catchment management initiatives at those sites
- link to research networks outside the bounds of the Centre
- satisfy the specific interests of each of the participating industry Parties.

One way of delivering the CRC for Catchment Hydrology's goal has been by the implementation of a series of development projects implemented in each of the CRC for Catchment Hydrology's focus catchments.

In the Goulburn Broken focus catchment a development project was devised by Goulburn-Murray Water to utilize and develop the CRC for Catchment Hydrology's capabilities and to address a number of management issues and concerns around managing land use impacts in and around water storages in northern Victoria. This was a true test of the capabilities of the CRC for Catchment Hydrology and its tools.

**Development Projects aim to:**

(i) build capacity within our Industry Parties to apply the CRC for Catchment Hydrology's modelling tools,

(ii) demonstrate the utility of the tools by applying them to a range of problems at the whole-of-catchment scale, and

(iii) provide our researchers with feedback from end users on the suitability of the models for operational use.

The Development Projects have been undertaken in parallel with the rapid development of the Catchment Modelling Toolkit and all its associated features including training, user e-groups, and documentation.

As documented in this report a successful application of the CRC for Catchment Hydrology's EMSS model was implemented in the Upper–Mid Goulburn River Catchment. The support provided by the CRC for Catchment Hydrology's Catchment Modelling Toolkit team is gratefully acknowledged.

For catchment and water managers, the outcomes of this project will enable them to better evaluate the short- and long-term outcomes of policy and land use decisions at regional scales.

If you wish to find out more about the CRC for Catchment Hydrology's Modelling Toolkit I invite you to visit our web site at http://www.toolkit.net.au

David Perry
Program Leader – Communication and Adoption
CRC for Catchment Hydrology

## Executive Summary


This report provides an introduction to the Goulburn Murray Water (Goulburn-Murray Water) Major Storages Water Quality Study. More specifically, it documents the development and preliminary application of a new surface water quality software model (EMSS-Goulburn) built for the Upper-Mid Goulburn Catchment.

This report:

- outlines the aims and objectives of the Major Storages Water Quality Study;
- documents the construction of a catchment surface water quality model for the Upper-Mid Goulburn Catchment (above Goulburn Weir);
- reports preliminary model outputs (predictions of sediment and nutrient yields and loads);
- acknowledges the uncertainties and limitations of the EMSS modelling process;
- illustrates the potential of EMSS-Goulburn to be used as a tool to predict likely impacts of catchment management actions on water quality; and
- outlines possible future developments of the EMSS-Goulburn model.

### Major Findings

Key findings of this preliminary investigation that should be considered by managers of the Upper-Mid Goulburn Catchment are as follows.

- On a 'whole catchment' scale, average long-term (1980 – 1999) pollutant generation rates from the catchment upstream of Goulburn Weir are approximately 75,000 t/yr Total Suspended Solids (TSS), 1,800 t/yr Total Nitrogen (TN) and 250 t/yr Total Phosphorous(TP). These predictions do not include pollutants trapped within the 'in-line' storages Lake Eildon and Goulburn Weir, or deposited in rivers, streams and floodplains in transit. *Estimated long-term average pollutant loads actually exported to the Lower Goulburn Catchment (i.e. below Goulburn Weir) are approximately 19,900 t/yr (TSS), 480 t/yr (TN) and 70 t/yr (TP).*
- Pollutant generation rates vary considerably both in space and time, and are highly dependent upon climatic conditions in the Upper-Mid Goulburn Catchment.
- Contrary to expectations, many of the catchments and sub-catchments with the highest nutrient production rates appear to be the heavily vegetated, largely undisturbed catchments in the south-eastern parts of the Upper-Mid Goulburn Catchment. This is most likely because these are steeper areas of high rainfall and runoff.
- Lake Eildon and Goulburn Weir act as sediment and nutrient traps, trapping most of the pollutant loads entering from upper catchment rivers and streams. *Lake Eildon is particularly efficient, trapping approximately 96-97% of pollutants entering the storage.*
- EMSS-Goulburn can be used to help identify catchments and sub-catchments which, in a relative sense, should be the focus of future catchment management activities for water quality improvements (erosion control, revegetation, riparian works etc.) and/or further investigation in the Upper-Mid Goulburn Catchment.

  Most pollutant load is generated during wetter climatic periods as high flow events over short duration flow periods. As a general rule, EMSS-Goulburn predicts that *pollutant loads generated during drier years are of the order of 5-30 % of those generated during the wetter years*. Any water quality monitoring program which does not capture 'event' data will not be representative of actual pollutant loads exported, and conclusions drawn from this data alone will be misleading.
- Mean pollutant loads exported from the catchment in pre-European times are estimated at approximately 27,080 t/yr (TSS), 1,100 t/yr (TN) and 140 t/yr (TP). Pollutant loads generated under current land use conditions have increased by approximately 180% (TSS), 67% (TN) and 88% (TP), from loads that would have been generated under pre-European conditions. However, since pre-European times, mean pollutant loads exported to the lower Goulburn system below Goulburn Weir have, on average, *actually decreased by approximately 30% (TSS), 58% (TN) and 51% (TP)*, respectively, due to pollutant trapping within Lake Eildon and Goulburn Weir.

- Likewise, *pre-European TSS, TN and TP yields were typically much lower than current rates, in many cases less than 50% of current rates*. The distribution of sub-catchments with relatively high and relatively low contributions has also changed substantially.
- Under a hypothetical 'Forest Plantations' future land use scenario where all land with 'high' potential for hardwood (bluegum) plantation forestry and some of the 'moderate' potential land is converted to plantations, *average pollutant yields are predicted to decrease by 5-20 %*, though this varies between catchments and sub-catchments, depending on the spatial distribution of forestry activities. Predicted mean pollutant loads exported to the lower Goulburn system (below Goulburn Weir) would decrease by approximately 11% (TSS), 10% (TN) and 10% (TP), respectively.

This report does not attempt to document all of the water quality problems, issues and management actions that could be investigated by EMSS-Goulburn. These are many and varied and a comprehensive analysis of all is beyond the scope of this preliminary document. Also, catchment managers will not just be concerned with water quality issues, but will have to consider the multiple benefits and costs of management actions and programs, and weigh up the priorities of the Upper-Mid Goulburn Catchment against those of other catchments.

**Recommendations**

Time and budget constraints permitting, it is desirable that as additional data becomes available it should be progressively added to this model, to improve and refine model predictions. Of highest priority for managers should be the establishment of surface water quality monitoring programs for the catchment.

Similarly, the EMSS modelling system has been replaced with E2 and so upgrading the current EMSS-Goulburn model would provide enhanced functionality and greater confidence in model outputs.

EMSS-Goulburn (and E2) has the potential to be of great assistance to partner organisations such as the Goulburn-Broken Catchment Management Authority in reviewing, setting and evaluating performance against catchment and water quality strategy management action targets. Local area planning processes, Landcare program planning and other related activities could also benefit from EMSS-Goulburn outputs. EMSS-Goulburn may also prove to be useful for planning and evaluating water quality monitoring programs, and partner organisations such as Central Highlands Water will have an interest in EMSS-Goulburn as a tool to aid risk ranking/prioritization processes. Goulburn-Murray Water also sees EMSS-Goulburn being used as a tool to assist local government. The predictive capability of the model can be used to provide scientifically based input to large scale planning processes, such as relevant planning scheme reviews and amendments.

Ultimately, Goulburn-Murray Water envisages linking EMSS-Goulburn with other models from the Cooperative Research Centre for Catchment Hydrology's Catchment Modelling Toolkit to better predict the impacts of management scenarios on downstream storage water quality, water allocations, environmental flows and end of valley targets.

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## Glossary

| **Term/Acronym** | Description |
|---|---|
| **AEAM** | Adaptive Environmental Assessment and Management |
| **CAEDYM** | Computational Aquatic Ecosystem Dynamics Model |
| **CMA** | Catchment Management Authority |
| **CMSS** | Catchment Management Support System |
| **CRCCH** | Cooperative Research Centre for Catchment Hydrology |
| **DEM** | Digital Elevation Model |
| **DPI** | Department of Primary Industries |
| **DYRESM** | Dynamic Reservoir Simulation Model |
| **DWC** | Dry Weather Concentration |
| **EMC** | Event Mean Concentration |
| **EMSS** | Environmental Management Support System |
| **EPA** | Environment Protection Authority |
| **ER** | Enrichment Ratio |
| **EVC** | Ecological Vegetation Communities |
| **E2** | An enhanced integrated catchment modelling tool, currently under development by the CRC for Catchment Hydrology, which will be an extension of the concepts built into the EMSS and SedNet modelling tools |
| **GIS** | Geographical Information System |
| **GBCMA** | Goulburn Broken Catchment Management Authority |
| **G-MW** | Goulburn Murray Water |
| **kT** | Kilotonnes |
| **MDBC** | Murray Darling Basin Commission |
| **ML** | Megalitres |
| **MSWQS** | Major Storages Water Quality Study |
| **NLRWA** | National Land and Water Resource Audit. |
| **PIRVIC** | Primary Industries Research Victoria |
| **SILO** | Comprehensive national rainfall dataset managed by the Queensland Department of Natural Resources and Mines. |
| **TN** | Total Nitrogen |
| **TP** | Total Phosphorous |
| **TSS** | Total Suspended Solids |
| **USLE** | Universal Soil Loss Equation |
| **VWQMN** | Victorian Water Quality Monitoring Network |

# 1. Introduction

### The Purpose of This Report

This is a report from the Major Storages Water Quality Study (MSWQS) project currently being implemented by Goulburn-Murray Water (Goulburn-Murray Water) in conjunction with the Cooperative Research Centre (CRC) for Catchment Hydrology and Primary Industries Research Victoria (PIRVIC). This document:

- reports issues associated with the construction and application of a regional catchment surface water quality model to the Upper-Mid Goulburn Catchment in northern Victoria;
- reports preliminary findings of the model;
- demonstrates a range of potential applications of the model;
- illustrates its potential as a tool to provide a scientific basis for management decisions; and
- provides a preliminary indication of management directions for the Upper-Mid Goulburn Catchment.

This report is not intended to be a comprehensive evaluation of every potential application of the model built for the Upper-Mid Goulburn Catchment. Rather, it is intended to illustrate, with examples, the practicality and usefulness of the Goulburn model for evaluating management options to improve water quality in the Upper-Mid Goulburn Catchment.

### Report Overview

**In summary:**

Sections 2 and 3 of this report give an overview of the MSWQS, and more particularly the catchment modelling component, including the construction of an Environmental Management Support System (EMSS) modelling system.

Section 4 provides an introduction to the EMSS-Goulburn model; its background, its potential uses, how it was constructed, data requirements, as well as model assumptions and uncertainties.

Section 5 reports predicted water quality impacts (estimated pollutant loads and generation rates) under Section 6 reports estimated pollutant loadings into Lake Eildon and Goulburn Weir.

Sections 7 reports predicted water quality impacts, (pollutant loads and generation rates) historical and future land use conditions.

Section 8 compares EMSS-Goulburn predictions of sediment and nutrient loads with other relevant studies and modelling projects.

Section 9 demonstrates the usefulness of EMSS-Goulburn for investigating the effects of different management scenarios (land use change, riparian zone management, point source management).

Section 10 reports potential future developments for the Major Storages Water Quality Study project and EMSS-Goulburn.

## 2. What is the Major Storages Water Quality Study (MSWQS)?

Goulburn-Murray Water initiated the MSWQS in order to obtain the necessary information and decision support tools needed to meet its responsibilities as a manager of key water resources. This information is required of Goulburn-Murray Water by Government, is expected by the community and forms a key part of our role as a large resource manager.

The MSWQS is being conducted as a multi-phase project, including:

1. water quality trend analysis in major storages (completed, see 'Major Storages Operational Monitoring Program Water Quality Review' (Water Ecoscience 2002));
2. development of comprehensive catchment surface water quality models (in progress);
3. development of hydrodynamic and ecological water quality models for major Goulburn-Murray Water storages (commencing 2004); and
4. communication and extension of model outputs to develop and influence policies, strategies and works programs to manage and improve water quality in catchments and storages.

In essence, what Goulburn-Murray Water is trying to do is develop the tools and knowledge required to better manage the quality of its key 'product' (i.e. water). The construction and application of comprehensive water quality models for Goulburn-Murray Water storages and their catchments, will enable Goulburn-Murray Water and other natural resource managers and stakeholders to make informed, scientifically and evidence grounded management decisions.

More specifically, Goulburn-Murray Water has commissioned the construction of predictive software water quality models for the Upper-Mid Goulburn Catchment, and the major storages within this catchment.

At present (July 2004), the construction and application of storage models for Lake Eildon and Goulburn Weir are still at an early, data collation phase. Methods and results of this component of the MSWQS are not discussed further in this document.

Instead, this report documents the preliminary findings of the construction and application of a whole of catchment surface water quality model to the Upper-Mid Goulburn Catchment. **Goulburn-Murray Water has applied an Environmental Management Support System (EMSS)** to the Upper-Mid Goulburn Catchment. EMSS was developed over a period of several years by the Cooperative Research Centre for Catchment Hydrology. Vertessy *et al.* (2002) provides further information about the development of the EMSS and the philosophy underpinning it.

The EMSS model built for the Upper-Mid Goulburn Catchment (EMSS-Goulburn) will be used as a decision support tool by Goulburn-Murray Water and also, hopefully, by other agencies and other stakeholders to help investigate the likely effect of changing land use and management actions to improve water quality. Ultimately, this will assist us to achieve our long-term goals. That is, the protection and improvement of water quality to the extent practicable in the most efficient and cost-effective manner.

# 3. Catchment Surface Water Quality Modelling

## 3.1 Different Options

A variety of modelling approaches are available for estimating surface water runoff and pollutant loads at a catchment scale.

*Time Scale*

Temporally, models may be run at a discrete time step, such as daily or weekly, or run using long-term average inputs. The former approach, which includes models such as AWBM, Sacramento and SimHyd, simulates the temporal distribution of runoff (and pollutants) and enables the analysis of individual events and trends. The latter approach, used by models such as ICMS, SedNet and FILTER, estimates long-term pollutant rates using land use and corresponding areal pollutant loading rates, and is computationally less intensive (Chiew *et al.*, 2002).

*Spatial Scale*

Spatially, models may be generally categorised as either lumped or distributed. Lumped models use catchments or sub-catchments as the fundamental modelling unit, and estimate catchment runoff and pollutant loads based on catchment-average climate data and model parameters. Distributed models simulate runoff at a finer scale and use physically based algorithms to transport runoff and pollutant loads to the drainage system. While distributed models are notionally more accurate than lumped models, they are computationally more intensive and require considerably more input data (Chiew *et al.*, 2002). This can be a problem in areas with limited data availability, or where the conceptual understanding of catchment processes is poor. Where this is the case, errors and uncertainties associated with more complex distributed models are likely to be more pronounced than with simpler lumped models.

## 3.2 So What is EMSS?

The Environmental Management Support System (EMSS) is a daily runoff and pollutant load model that was originally developed for the South East Queensland region by the Cooperative Research Centre for Catchment Hydrology (CRCCH). EMSS was developed to enable catchment managers to estimate current runoff and pollutant loads and to assess the impact of changes in land use and land management practices on runoff and pollutant export loads (Chiew *et al.* 2002).

The current version of EMSS is a spatially semi-discrete, temporally discrete (daily time step) model that predicts runoff, and daily loads of water quality pollutants. At present, EMSS only models three priority water quality pollutants, namely **Total Suspended Solids (TSS), Total Nitrogen (TN) and Total Phosphorous (TP)**.

EMSS predicts daily runoff volume, TSS, TN and TP loads at a catchment and sub-catchment scale, and routes these through a representation of the existing stream network. Storages and their effect on flows and water quality are also considered via simple storage models. Pollutant point sources are also included as appropriate.

Predictions of pollutant loads are responsive to changes in land use, diffuse management treatments, riparian management and point source management. The effect of each of these management actions on original load predictions can be assessed in both a spatial and temporal context.

In designing the EMSS, the CRC for Catchment Hydrology envisaged that it should be as flexible as possible, to cater to the changing and evolving requirements of catchment managers and other stakeholders (Vertessy *et al.*, 2002). One of the design criteria fundamental to the EMSS is that it should be able to incorporate other water quality 'modules' as they become available. A number of other modules are actively being developed by the CRC for Catchment Hydrology as a part of its 'Catchment Modelling Toolkit' program. Of particular interest to this project is the ongoing development of salt balance model, and a pathogen model fate and transport model, which are scheduled to be ready for incorporation into the EMSS system within the next 2-3 years.

Other design requirements of EMSS were:

- that it should have modest data input requirements;
- that it should have an easy to use graphical user interface, in a GIS-type environment; and

- that it could be run quickly and efficiently on a standard desktop computer.

Specific details of the EMSS system applied to the Upper-Mid Goulburn Catchment are discussed in greater depth in Section 4.

### 3.3 Components of the EMSS System

EMSS consists of three linked models, illustrated conceptually in Figure 1.

Runoff and pollutant loads are simulated for each sub-catchment using the Colobus model, which comprises the rainfall-runoff model SimHyd, and a pollutant export model. Colobus provides daily estimates of runoff, TSS, TP and TN.

The river network connecting sub-catchments is represented using a node-link network. Flows and pollutant loads are conveyed down the river network using the routing model Marmoset.

Large storages on the river network are modelled using the Mandrill storage model, which simulates the regulation of river flow and accounts for within-storage pollutant trapping (Chiew *et al.* 2002).

#### 3.3.1 Catchment Runoff & Pollutant Export Model (Colobus)

Colobus, the lumped conceptual catchment scale model used to simulate runoff and daily pollutant loads in the EMSS, comprises a hydrologic model and pollutant export model. The hydrologic model considers each catchment in three parts: a forest pervious land use model, another pervious land use model, and an impervious land use model. The two pervious land uses are modelled using the rainfall-runoff model SimHyd, while the impervious land use is modelled using a simple loss model. The pervious land use and other land use SimHyd models each have seven parameters (a total of fourteen parameters for each sub-catchment), while the impervious model has a single loss parameter (Chiew *et al.* 2002). A conceptual diagram of SimHyd is provided in Figure 2.

The pollutant export model uses the simulated daily runoff and estimated pollutant concentrations for each land use to estimate daily loads of TSS, TP and TN for each sub-catchment. The daily pollutant load is estimated as:

**Daily pollutant load = surface runoff x EMC + subsurface runoff x DWC**

Where the event mean concentration (EMC) is defined as the flow-weighted average pollutant concentration over a storm event and the dry weather concentration (DWC) is defined as the pollutant concentration measured during dry periods (Chiew *et al.* 2002b). Given the lack of land use-specific EMC and DWC data available for the Upper-Mid Goulburn Catchment, default EMSS values derived from an extensive data mining exercise during the development of an earlier EMSS model (Chiew *et al.* 2002b) were adopted for the Upper-Mid Goulburn model. DWC and EMC values for TSS, TP and TN used are provided in Table 1.

For each sub-catchment, DWC and EMC values are then scaled between the lower and upper values based on a mapped erosion hazard index.

Cross checking of these default values against select data from the Victorian Water Quality Monitoring Network (VWQMN) program indicates that DMC values for ‘vegetated’ land uses (e.g. ‘Managed Forests’, ‘Plantations’, Native Bush’ etc) are in agreement with data from streams in predominantly forested catchments. However water quality data for

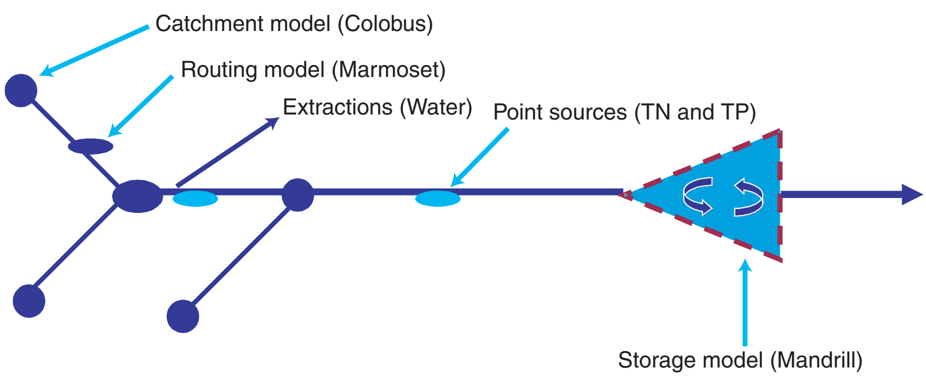



Figure 1. EMSS Conceptual Diagram.

Table 1. DWC and EMC Values for TSS, TP and TN.

| Land Use | | TSS (mg/L) | | TP (mg/L) | | TN (mg/L) | |
|---|---|---|---|---|---|---|---|
| | | DWC | EMC | DWC | EMC | DWC | EMC |
| Dense Urban<br>Suburban | Lower | 5 | 40 | 0.05 | 0.12 | 0.9 | 0.9 |
| | Median | 7 | 130 | 0.11 | 0.28 | 1.5 | 1.6 |
| | Upper | 27 | 380 | 0.28 | 0.72 | 2.8 | 4.6 |
| Native Bush<br>Conservation Area<br>Managed Forest<br>Plantation | Lower | 3 | 8 | 0.02 | 0.05 | 0.3 | 0.4 |
| | Median | 7 | 20 | 0.03 | 0.20 | 0.4 | 0.8 |
| | Upper | 14 | 90 | 0.06 | 0.40 | 0.5 | 2.0 |
| Grazing<br>Rural Residential | Lower | 5 | 40 | 0.03 | 0.12 | 0.5 | 0.9 |
| | Median | 10 | 140 | 0.07 | 0.28 | 0.7 | 1.6 |
| | Upper | 23 | 380 | 0.14 | 0.72 | 0.9 | 4.6 |
| Intensive Agriculture<br>Broadacre Agriculture | Lower | 5 | 40 | 0.03 | 0.12 | 0.5 | 0.9 |
| | Median | 10 | 140 | 0.07 | 0.36 | 0.7 | 2.1 |
| | Upper | 23 | 490 | 0.14 | 1.1 | 0.9 | 5.9 |

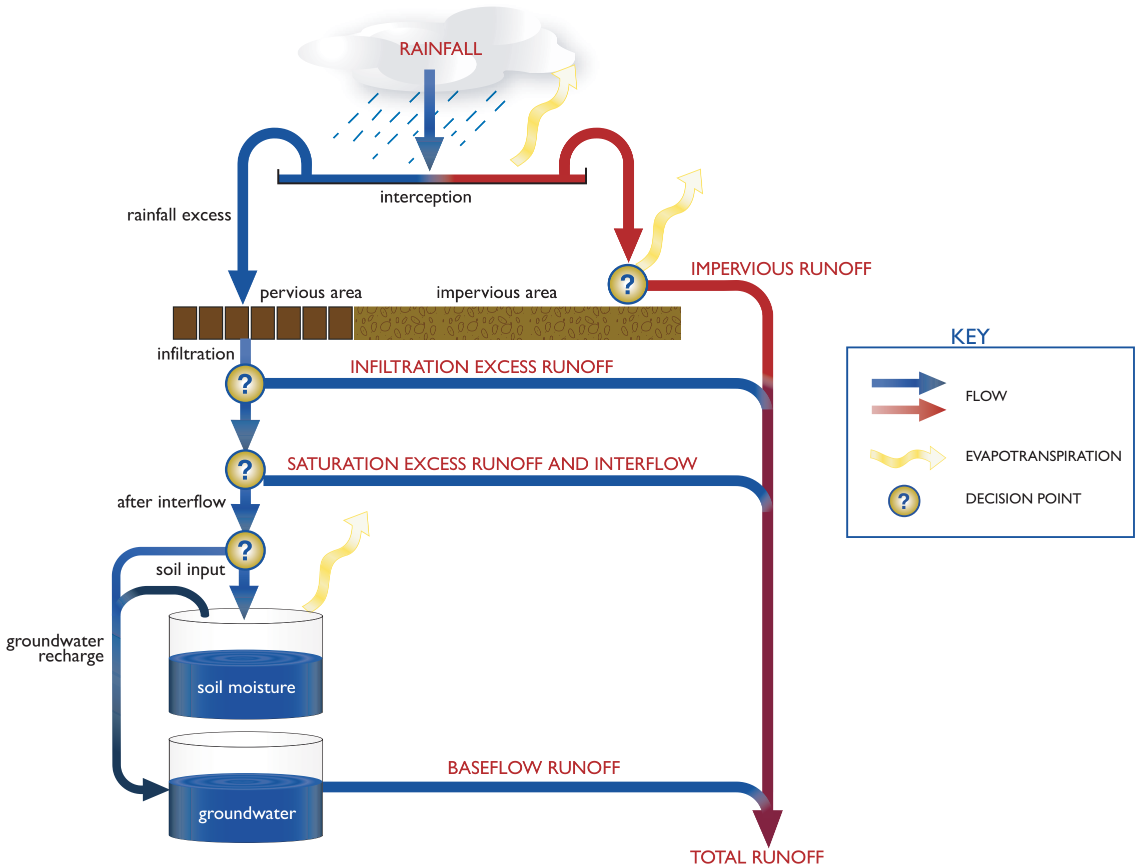



Figure 2. SimHyd Conceptual Diagram.

the catchment as a whole is somewhat limited, particularly EMC data. Model uncertainty due to water quality data limitations is discussed further in Section 4.6.2.

Input data to the Colobus model are daily rainfall, mean monthly areal potential evapotranspiration, Simhyd model parameters, and pollutant concentration (EMC and DWC) values. Model outputs are total daily runoff, TSS, TP and TN.

Figure 2 provides a conceptual overview of the SimHyd process.

### 3.3.2 Stream Routing Model (Marmoset)

The basic approach to stream routing is Muskingham-Cunge routing, using Manning's equation to relate depth to discharge to get wave celerity (speed). Muskingham-Cunge is mentioned in most basic hydrology texts (e.g. V. T. Chow *et. al.* 1988; D. L. Fread 1993).

Basically Muskingham-Cunge routing works by using the inflow to a reach at the current time step and the inflow and outflow at the previous time step, along with any losses or gains due to lateral inflows or infiltration along the reach. These are weighted as shown below and the weighting coefficients are all related to one parameter. Sub-time steps are used to ensure some numerical stability criteria are satisfied for application of Muskingham-Cunge.

Out(t)=C1.In(t)+C2.In(t-1)+C3.Out(t-1)+C4.LateralIn

• weighting terms C1, C2, C3=1-C1-C2, C4 are computed from a function that includes a single parameter.

Sediment is routed through the reach by comparing the incoming sediment load to the maximum transport capacity (given by an empirical function of slope and discharge, aQbSc). If the incoming load is greater than the capacity, the deposition occurs. Erosion does not occur if the opposite is true – i.e. simply what comes in the reach is assumed to go out.

### 3.3.3 Storage Model (Mandrill)

Mandrill provides a simple representation of flows and changes in pollutant loads resulting from reservoirs. With respect to flows, storages are represented as a simple bucket with outflows being of three types:

- overflows (flood release);
- controlled releases; or
- extractions.

For each reservoir, a relationship between depth and volume is required, so a volumetric water balance can be performed at each time step and the new level (depth) determined. Extractions are presently not implemented but are expected to be included in forthcoming re-releases of EMSS as a time series of extraction values that are read at a given storage node.

For controlled releases/extractions, the model uses mean monthly values which can have a temporal demand trend superimposed on them. To estimate flood (rather than demand) releases, the model uses a spillway rating or the emergency rules for reservoirs with gates/valves.

Controlled releases are provided either as:

- twelve monthly averages which are repeated for every year (and divided to give daily); or
- monthly time series (divided to give daily). In EMSS, there is the capability to make changes to controlled releases by making a percentage alteration in the appropriate dialogue box. This works only if the repeating cycle of 12, monthly averages are used (i.e. it does not work if a full time series of releases are included).

Flood releases are implemented via a lookup table for the reservoir that relates the computed reservoir level to discharge.

It should be noted that Mandrill does not incorporate any form of routing (time delay) through the storage. More complex hydrodynamic reservoir models (e.g. DYRESM, ELCOM etc.) are required to properly model reservoir hydrodynamic processes. Complex hydrodynamic and ecological storage models will be built for Lake Eildon and possibly Goulburn Weir as a later phase of the MSWQS.

For sediment output from the reservoir, the storage is considered to be a 'fully mixed tank' with a decay term (K, a calibration parameter) used to represent sediment delivery ratio. The equation is as follows:

**loadout = loadin.deliveryratio**

where delivery ratio =1- K = calibration _ parameter

For nutrients, an enrichment ratio (ER) is defined and then multiplied by the sediment delivery ratio – i.e. it is assumed that the nutrient changes are directly related to the deposition of sediment. A separate ER is used for TP and TN. Note that this is quite a crude approach, particularly for TN which is less closely correlated with sediment.

# 4 EMSS-Goulburn

This section details the application of the EMSS model to the Upper-Mid Goulburn Catchment.

## 4.1 Background

### 4.1.1 Setting

Lake Eildon and Goulburn Weir are situated on the Goulburn River system in north eastern Victoria. Water provided to the Goulburn system is collected from the northern side of the Great Dividing Range areas in central eastern Victoria via a large number of tributary streams and rivers before entering Lake Eildon, a man-made storage constructed on the Upper Goulburn River. Water released from Eildon enters the Mid Goulburn River and flows westward then northward to the Goulburn Weir near Nagambie. Much of the water is then diverted at Goulburn Weir to irrigation areas, while water released to the Lower Goulburn River flows further northward to join the Murray River near Echuca.

Lake Eildon has a storage capacity of 3,400,000 megalitres (ML), and a catchment comprising a total area of 3,885 $km^2$. Goulburn Weir has a capacity of 25,500 ML, and a catchment area of 10,627 $km^2$.

The Upper-Mid Goulburn Catchment area as a whole (i.e. areas above Goulburn Weir) comprises a highly diverse range of geological zones, landform and land use types, topography and climatic zones (Goulburn-Murray Water, 2003).

### 4.1.2 Water Quality Concerns

Goulburn-Murray Water manages Lake Eildon and Goulburn Weir and is responsible for the management of water delivery to water users. Water from these storages is vital to the economic, social and environmental health of Victoria. In addition to the obvious economic and related social benefits of the Goulburn system (e.g. provides water to the Goulburn Valley irrigation areas, the 'food bowl' of Victoria), the Goulburn system also fulfils a vital economic and social function in the Upper and Mid-Goulburn areas through recreation and tourism activity. Equally importantly, the Goulburn system is crucial to the environmental health of the northern half of the state, and the potential impacts of any significant decline in the health of this river system are immense.

As a manager of water resources Goulburn-Murray Water is committed to investigate catchment and storage processes, and the effect of these processes on water quality in the storages (and hence on water supplied to downstream users).

Storage water quality trend analysis commissioned by Goulburn-Murray Water as part of the MSWQS identified increasing water quality trends for several key parameters including nutrients in the storages. Closely related are blue-green algae blooms, a frequent and often serious problem in Lake Eildon, thought at least partially attributable to elevated nutrient concentrations.

Further details of water quality issues of relevance to the Lake Eildon, Goulburn Weir and Upper-Mid Goulburn Catchment are provided in 'Catchment and Storage Issues Affecting Water Quality in the Upper-Mid Goulburn Catchment' (Goulburn-Murray Water, 2003).

## 4.2 How Will We Use EMSS-Goulburn Outputs?

Goulburn-Murray Water will use the information generated by EMSS-Goulburn to help us assess risks to water quality and develop effective, scientifically based water management plans, guidelines and protocols. Importantly, Goulburn-Murray Water also hopes to use the EMSS-Goulburn to work with other agencies, including the Goulburn-Broken Catchment Management Authority (GBCMA), Local Government and other interested agencies and stakeholders to develop appropriate strategies and actions to better manage threats to water quality in the Upper-Mid Goulburn Catchment.

However the effectiveness of the EMSS-Goulburn tool will be limited if the model outputs are not understood or useful to the broader community. Individuals and local community groups (e.g. Landcare) are unlikely to be experienced water quality modellers, but are often responsible for implementation of actual 'on ground' works in catchment areas. An important feature of the EMSS system is that it can also be used by people with little to no modelling experience. Complicated data and results can be shown as easy to understand graphics. This means that many of the models generated in EMSS-Goulburn can be used by the community to address local issues of land management impacts on water quality.

For example, an easy to use modelling tool that can predict the water quality impacts of various activities, say reforestation, land use change and riparian rehabilitation works, would greatly assist Landcare and other community groups with project planning and priority setting. Goulburn-Murray Water intends to take advantage of these features of EMSS-Goulburn to work with relevant organisations and groups to help achieve our water resource management goals.

In doing so, we need to be conscious of the fact that while EMSS-Goulburn is very useful and a big step forward in terms of catchment surface water quality modelling capability, it is really just a decision support tool. Important catchment management decisions should be based on broader risk assessments, which are informed by tools such as EMSS-Goulburn.

## 4.3 So What Can We Do With EMSS-Goulburn?

The potential applications of EMSS-Goulburn are many and varied. Some of the applications of the current version of EMSS-Goulburn include:

- modelling the water quality (sediments and nutrient) impacts of catchment land use;
- quantifying and predicting surface water contributions to catchment scale pollutant export;
- predicting the impacts of land use change on pollutant movement at catchment scale;
- predicting the impacts of riparian management on pollutant movement at catchment scale;
- predicting the impacts of point source management on pollutant movement at catchment scale;
- assessing and setting realistic, achievable water quality targets for the catchment and its rivers and streams;
- comparing the effects of water quality of current land use with past (e.g. pre-European) and likely future land use scenarios; and
- linking the EMSS with other models from the CRC for Catchment Hydrology's Catchment Modelling Toolkit to better predict the impacts of management scenarios on downstream storage water quality, water allocations, environmental flows and end-of valley targets.

Further to these, future product upgrades subsequent versions of EMSS-Goulburn are expected to incorporate enhanced features that will further improve the functionality of EMSS-Goulburn (See Section 10.1).

## 4.4 Construction of the EMSS-Goulburn model

In preparing the EMSS-Goulburn model, the 10,700 $km^2$ Upper-Mid Goulburn region was disaggregated into 150 sub-catchments, each of an average 70 $km^2$. The EMSS-Goulburn sub-catchments and composite catchments are shown in Figure 3.

## 4.5 EMSS-Goulburn Data Requirements

An inventory of all data used to build the EMSS-Goulburn model is provided in Appendix A. The following section outlines some of the key datasets used.

### 4.5.1 Digital Elevation Model (DEM)

The EMSS-Goulburn stream network and sub-catchment delineation was based on a 1:25,000 hydrologically-enforced digital elevation model, re-sampled to 1:100,000. A hill-shaded view of the DEM is shown in Figure 4.

### 4.5.2 Land Use Data

Land use for the EMSS was reclassified from 1:100,000 land use mapping for the Goulburn-Broken Catchment, completed in 2003. Of the twelve land use types used in the EMSS model (see Table 2), eleven are represented in the upper-mid Goulburn region. The ‘Future Urban’ classification available in the EMSS was not used for the Goulburn application. The spatial distribution of land use in the region is shown in Figure 5. The lower (north-western) part of the region is predominantly used for grazing, while the upper (southern-eastern) part of the region is predominantly national park and managed forest.

### 4.5.3 Streamflow Data

All streamflow data for the model was sourced from the ‘Victorian Water Resources Data Warehouse’ (www.vicwaterdata.net), the statewide data repository

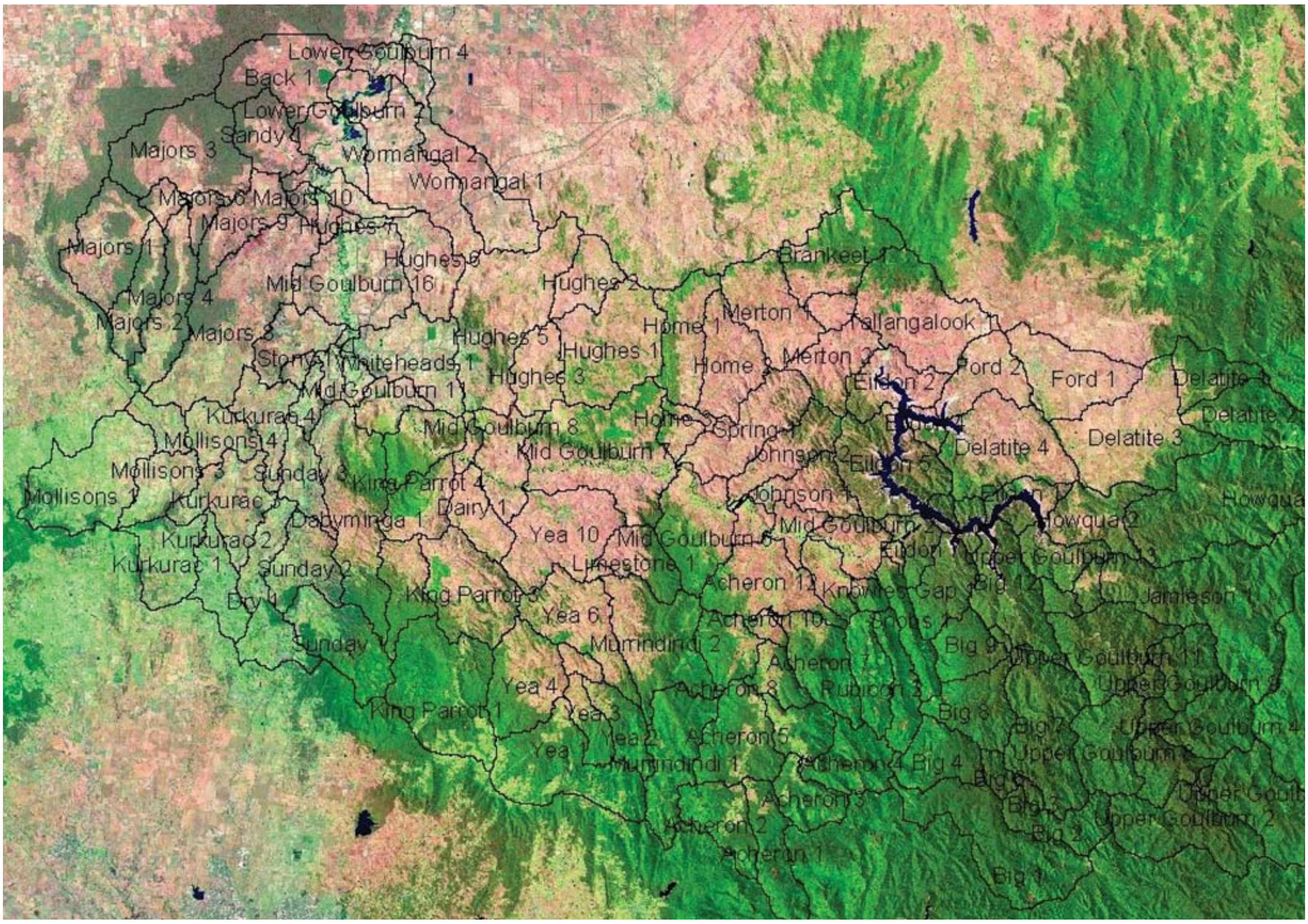



Figure 3. EMSS-Goulburn Catchments and Sub-catchments.

Figure 4. Goulburn-EMSS Digital Elevation Model.

Table 2. EMSS-Goulburn Land Use Data Classifications.

| Class | Description |
|---|---|
| National Park | An area of native vegetation preserved for conservation |
| Managed Forest | An area of native vegetation preserved for later use, recreation of forestry |
| Plantation | An area of vegetation specifically for forestry purposes |
| Native Bush | Native vegetation that isn't part of a National Park or State Park |
| Grazing | Areas of grassland potentially used for grazing |
| Broadacre Agriculture | Large areas of crops such as corn |
| Intensive Agriculture | Crops such as sugarcane, and horticultural areas of fruit, vines and nuts may be included |
| Rural Residential | Rural areas with some settlement |
| Future Urban | Areas that are flagged for conversion into urban areas in the future |
| Suburban Areas | Suburbs with backyard and parks |
| Dense Urban Areas | Built up urban areas with little or no vegetation |
| Water | Water bodies, includes reservoirs, lakes and estuaries |

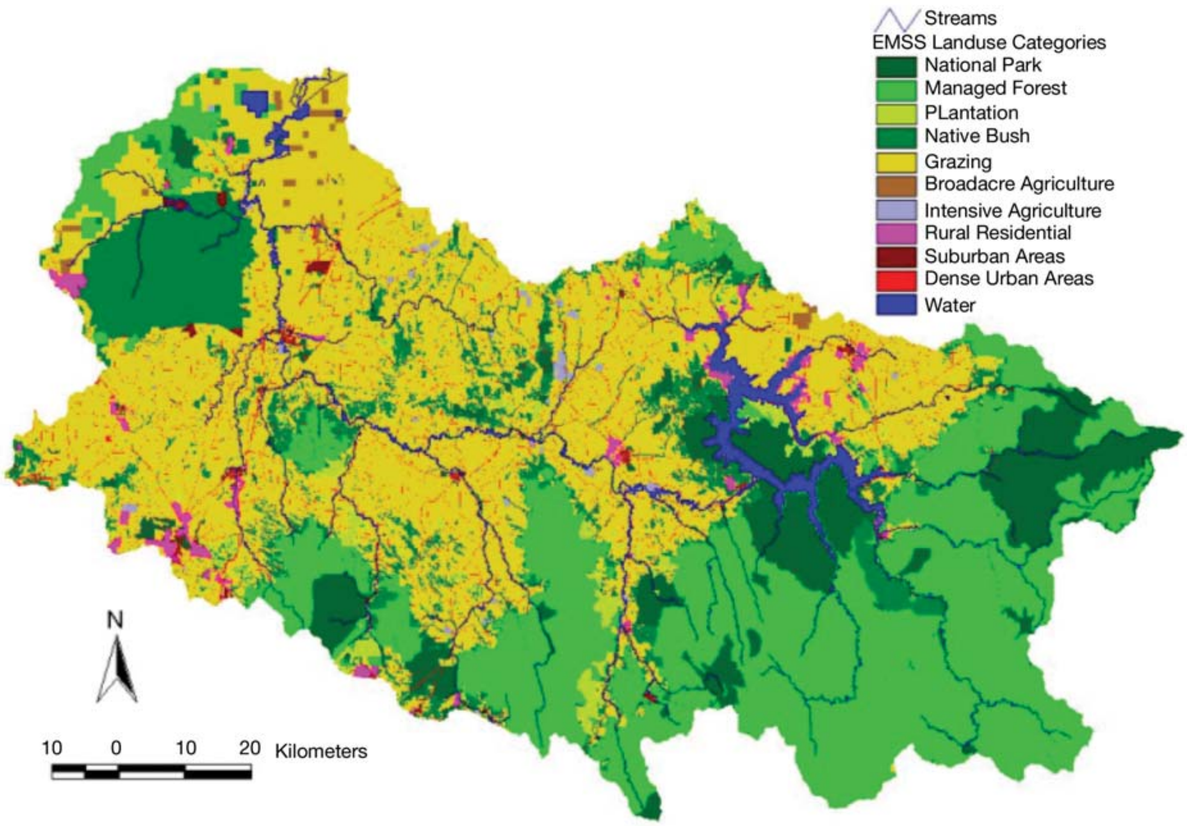



Figure 5. EMSS-Goulburn Current Land Use.

for surface water information in Victoria.

### 4.5.4 Climate Data

The SimHyd rainfall-runoff model requires continuous daily rainfall and areal potential evapotranspiration as inputs. For the Upper-Mid Goulburn model, SILO national gridded rainfall dataset was used. The SILO rainfall data, interpolated on a 0.05° x 0.05° grid, was aggregated to produce a lumped catchment-average daily rainfall time series for each sub-catchment.

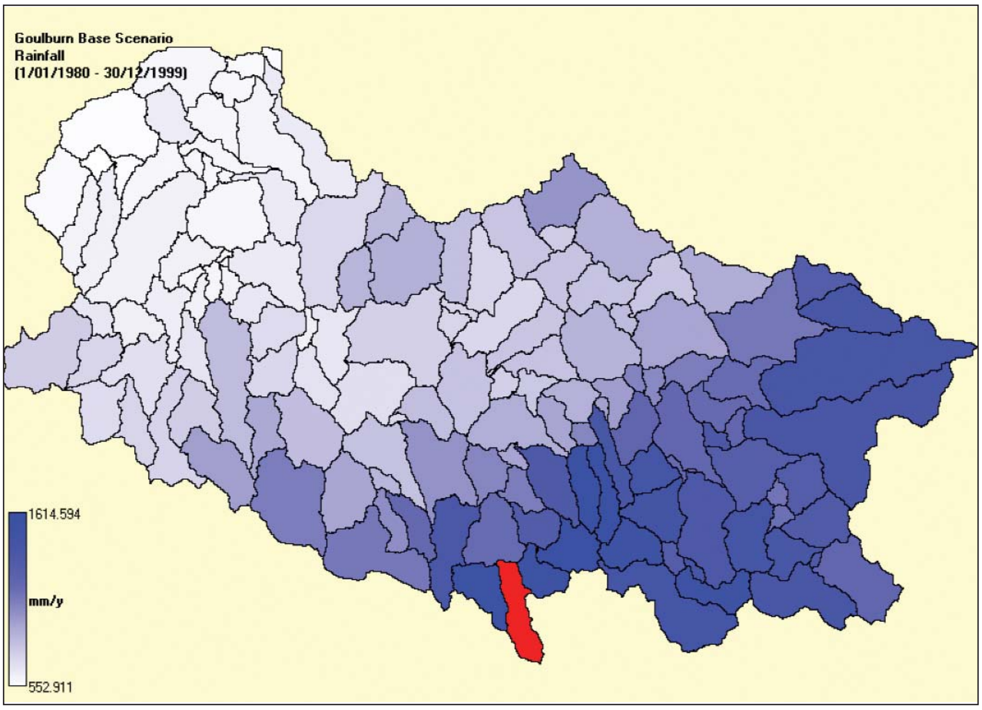



Figure 6. Upper-Mid Goulburn Sub-catchment Mean Annual Rainfall.

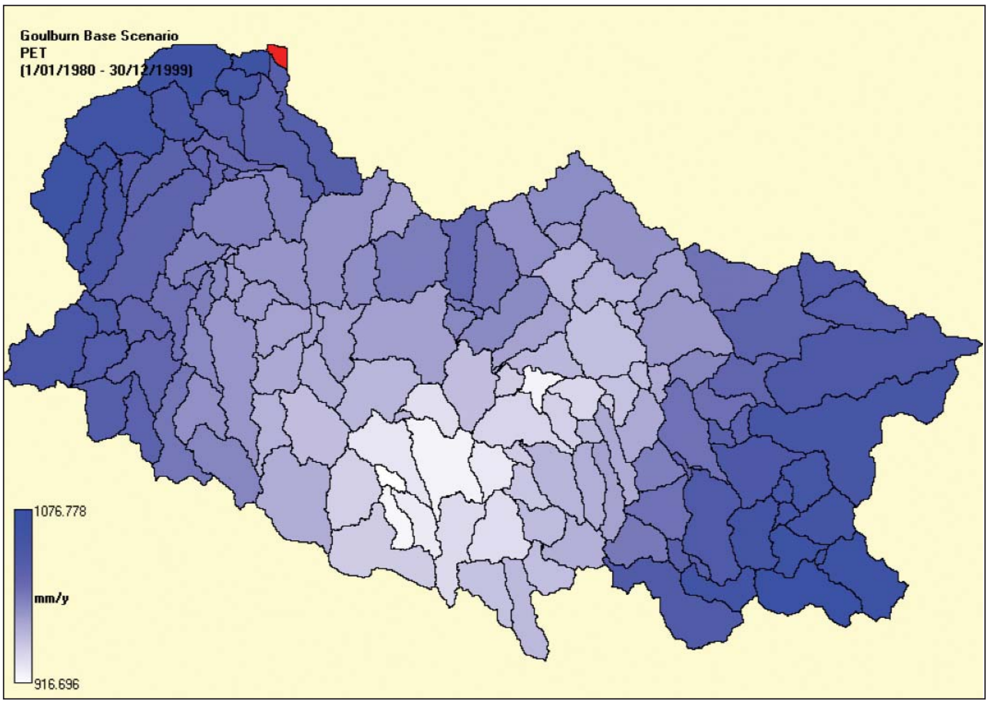



Figure 7. Upper-Mid Goulburn Sub-catchment Mean Annual Areal Potential Evapotranspiration.

Lumped catchment-average daily evapotranspiration time series for each sub-catchment were generated based on twelve mean monthly areal potential evapotranspiration maps, produced jointly by the CRC for Catchment Hydrology and Australian Bureau of Meteorology.

The Upper-Mid Goulburn Catchment-average mean annual rainfall and areal potential evapotranspiration are shown in Figure 6 and Figure 7, respectively.

Calibration of the rainfall-runoff model requires recorded streamflow data. Streamflow data was available for 28 gauging stations in the upper Goulburn Catchment, sourced from the Victorian Water Data Warehouse (www.vicwaterdata.net). Of these, 21 were suitable for calibration of the hydrologic model. Gauging stations used for the Goulburn model calibration are shown in Table 3, with the unsuitable gauging stations shown in Table 4. Gauging station locations are shown in Figure 8.

Table 3. Goulburn Stream Gauging Stations Used for Model Calibration.

| Station | Station Name | Area-Theiss (km2) | Area-EMSS (km2) | Rainfall (mm/yr) | Runoff (mm/yr) | Runoff Coeff | Start | End | Years |
|---|---|---|---|---|---|---|---|---|---|
| 405205A | Murrindindi River @ Murrindindi Above Colwells | 108 | 106 | 1330 | 490 | 0.37 | 1975 | 2003 | 29 |
| 405209B | Acheron River @ Taggerty | 619 | 617 | 1350 | 472 | 0.35 | 1973 | 2003 | 31 |
| 405212D | Sunday Creek @ Tallarook | 337 | 329 | 786 | 113 | 0.14 | 1975 | 2002 | 28 |
| 405214A | Delatite River @ Tonga Bridge | 368 | 344 | 1156 | 306 | 0.26 | 1957 | 2003 | 47 |
| 405215B | Howqua River @ Glen Esk | 368 | 364 | 1366 | 471 | 0.34 | 1974 | 2003 | 30 |
| 405217B | Yea River @ Devlins Bridge | 360 | 358 | 1015 | 281 | 0.28 | 1975 | 2001 | 27 |
| 405218B | Jamieson River @ Gerrang Bridge | 368 | 364 | 1370 | 565 | 0.41 | 1959 | 2003 | 45 |
| 405219A | Goulburn River @ Dohertys | 694 | 693 | 1305 | 500 | 0.38 | 1967 | 2003 | 37 |
| 405227A | Big River @ Jamieson | 619 | 621 | 1419 | 504 | 0.36 | 1970 | 2003 | 34 |
| 405228A | Hughes Creek @ Tarcombe Road | 471 | 479 | 774 | 165 | 0.21 | 1975 | 2003 | 29 |
| 405231A | King Parrot Creek @ Flowerdale | 181 | 181 | 1078 | 213 | 0.20 | 1974 | 2001 | 28 |
| 405238A | Mollison Creek @ Pyalong | 163 | 158 | 764 | 223 | 0.29 | 1973 | 2002 | 30 |
| 405240A | Sugarloaf Creek @ Ash Bridge | 609 | 601 | 707 | 118 | 0.17 | 1973 | 2002 | 30 |
| 405241B | Rubicon River @ Rubicon | 129 | 131 | 1518 | 871 | 0.57 | 1973 | 2003 | 31 |
| 405245A | Ford Creek @ Mansfield | 115 | 113 | 870 | 107 | 0.12 | 1970 | 2003 | 34 |
| 405248A | Major Creek @ Graytown | 282 | 291 | 593 | 59 | 0.10 | 1971 | 2001 | 31 |
| 405251A | Brankeet Creek @ Ancona | 121 | 117 | 970 | 141 | 0.15 | 1973 | 2003 | 31 |
| 405263A | Goulburn River @ u/s of Snake Creek Junction | 327 | 320 | 1282 | 438 | 0.34 | 1975 | 2003 | 29 |
| 405264A | Big River @ d/s of Frenchman Creek Junction | 333 | 330 | 1414 | 500 | 0.35 | 1975 | 2003 | 29 |
| 405274A | Home Creek @ Yarck | 187 | 187 | 741 | 143 | 0.19 | 1977 | 2003 | 27 |
| 405291A | Whiteheads Creek @ Whiteheads Creek | 51 | 30 | 638 | 80 | 0.13 | 1988 | 2001 | 14 |

Table 4. Goulburn Stream Gauging Stations Unsuitable for Hydrologic Modelling.

| Station | Station Name | Area-Theiss (km2) | Area-EMSS (km2) | Start (mm/yr) | End (mm/yr) | Years | Comment |
|---|---|---|---|---|---|---|---|
| 405201B | Goulburn River @ Trawool | 7335 | 7244 | 1974 | 2003 | 30 | > 1500 km2 |
| 405202B | Goulburn River @ Seymour | 8601 | 8460 | 1975 | 2001 | 27 | > 1500 km2 |
| 405203C | Goulburn River @ Eildon | 3911 | 3878 | 1974 | 2001 | 28 | > 1500 km2 |
| 405290A | Pine Creek @ Broadford | 3 | 104 | 1988 | 2001 | 14 | < 10 km2 |
| 405304A | Big River @ u/s Frenchman Creek | - | 258 | 1996 | 2001 | 6 | < 7 years data |
| 405305A | Black River @ u/s of Goulburn River Junction | - | 134 | 1996 | 2001 | 6 | < 7 years data |
| 405309A | Hughes Creek @ Goulburn Valley Hwy | - | 558 | 1998 | 2001 | 4 | < 7 years data |


Figure 8. Locations of Goulburn Stream Gauging Stations Used for Model Calibration.

Gauging stations were selected for calibration based on the following criteria (from Chiew *et al.,* 2002):

- catchment areas between 10 km$^2$ and 1500 km$^2$;
- at least seven years of historical streamflow data; and
- the gauge is not located downstream of a major storage.

### 4.5.5 Pollutant Concentration Data

No pollutant concentration data for different land use types exists for the Upper-Mid Goulburn Catchment. Default lower limit, median and upper limit Event Mean Concentration (EMC) and Dry Weather Concentration (DWC) values for TSS, TP and TN that are adopted for use in the EMSS-Goulburn are presented in Table 1. These values are default values which were largely derived from investigations during the development of the south-east Queensland EMSS model (Chiew *et al.* 2002b). This work incorporated an extensive literature review conducted by the CRC for Catchment Hydrology of over 500 Australian and overseas data sets. Cross checking of these default values against select data from the Victorian Water Quality Monitoring Network (VWQMN) program indicated that DMC values for 'vegetated' land uses (e.g. 'Managed Forests', 'Plantations', Native Bush' etc) are in agreement with data from streams in predominantly forested catchments. However, water quality data for the catchment as a whole is somewhat limited, with no EMC data currently available for example. Model uncertainty due to water quality data limitations is discussed further in Section 4.6.2.

### 4.5.6 Point Source Data

Point source licence information for the Upper-Mid Goulburn region was obtained from the Environment Protection Authority (EPA). As of early 2004, there were 17 EPA licences for discharge of wastewater to surface streams for the region, including aquaculture enterprises, urban wastewater treatment facilities and various miscellaneous commercial and industrial enterprises. Point source annual loads are estimated from licensed daily discharge rates and concentrations.

Other 'point sources' undoubtedly exist within the region, though data is limited on these and hence they have not been incorporated in the current version. Better information about other likely point sources would improve model predictions.

### 4.5.7 Erosion Hazard

Erosion hazard is constructed by EMSS through the combination of two types of erosion data. These are hillslope erosion, derived from the Universal Soil Loss Equation (USLE), and gully density mapping.

Gully density mapping employed by EMSS-Goulburn is fairly coarse in scale, and as a result, often tends to exaggerate and distort the differences in erosion hazard between some adjacent catchments. This problem would be overcome if finer scale gully density mapping were available for the Goulburn Catchment region, which would ‘smooth out’ the boundaries between high and low density gully areas.

It should also be noted that EMSS does not consider the effects of streambank erosion. No sediment accounting or sediment budgets are employed by EMSS, this means that the model only reports the export generation of sediment by the landscape. Therefore, the effects of this generation upon downstream conditions are not considered.

Other models such as SedNet, another model currently in development by the CRC for Catchment Hydrology, are more suited to an exploration of sediment accounting and sediment budgets. An enhanced version of EMSS known as ‘E2’ (due for release in early 2005) is also expected to incorporate a capability to model streambank erosion and bedload processes.

## 4.6 Model Assumptions and Limitations

### 4.6.1 Model Uncertainty and Confidence Limits

It is important to preface any discussion of model outputs, and in particular predictions of absolute values of pollutant loads, by acknowledging the limitations and uncertainties inherent in water quality modelling processes. The prediction of water quality pollutant loads with any surface water model carries with it a degree of uncertainty. Some of the causes of error commonly associated with surface water quality models are listed below.

- *Incorrect application of default model parameters.* In the absence of reliable local data, assumptions are usually made about model parameters. Assumptions made about typical pollutant concentrations associated with different land use types in EMSS-Goulburn are examples of this. As discussed further in Section 4.6.2, good local data is relatively sparse, and so default EMSS values are used (Chiew. *et al.*, 2002b). While these numbers are likely to be good approximations, they may not accurately reflect local conditions and hence the potential for increase model error. Better parameter estimation through improved local datasets would greatly enhance model outputs.
- *Incorrect model calibration.* Often, a model can be calibrated with different parameter values, which all still give apparently reasonable results that demonstrate ‘good fit’ and hence good calibration. In other words, there will often be no single ‘unique solution’, and multiple solutions are possible. Perfect model ‘fit’ during calibration therefore doesn’t necessarily mean the model is providing good results. Models successfully calibrated with incorrect parameters will give erroneous model outputs.
- *Model complexity.* Underpinning much of this uncertainty is the fact that through modelling, we are attempting to simulate highly complex natural systems, which contain any number of highly spatially and temporally variable, interdependent, usually poorly understood variables, which can all affect the particular system attribute (flow, TSS etc.) being modelled. When confronted by this problem, modellers and managers often attempt to overcome the complexity of natural systems by increasing the complexity of models applied. However this usually multiplies the potential for error, as each variable has its own ‘error margin’ associated with it. This may be compounded by the usual absence of good quality local data for each of the many variables.
- *Model simplicity.* Conversely, oversimplifying a model to avoid the problems discussed above may, in its own right, introduce a degree of bias and hence increase model uncertainty.

For these reasons, all model outputs, and predictions of absolute values in particular, must be treated with caution.

However it should be noted that while estimations of absolute values are useful, an equally useful and perhaps 'safer' application of a surface water quality model such as EMSS-Goulburn is its potential application as a tool to investigate and make predictions of the relative magnitude of impacts on water quality. Errors associated with estimation of the relative proportions of water quality pollutants generated in different catchments, or in the same area under different land use scenarios, are usually not as critical as for predictions of absolute values.

Representation of actual confidence limits on model outputs is not addressed well in the current version of EMSS (or, for that matter, any other surface water models currently available), and model outputs should be interpreted and used with this in mind. Future releases of EMSS are expected to address the model uncertainty issue in a more satisfactory manner, including visual representation of uncertainty limits (a range, rather than an absolute value) on model outputs.

Nevertheless predictions made using models like EMSS-Goulburn are likely to be more reliable than other less sophisticated forms of prediction and prioritisation (such as load estimates based on limited monitoring data sets for example). Other potential model limitations specific to EMSS-Goulburn are noted below.

### 4.6.2 Limited Water Quality Monitoring Data

As discussed previously, water quality data in the Upper-Mid Goulburn Catchment is relatively sparse, albeit better than many comparable catchments in Victoria. Routine water quality samples are collected from approximately 21 monitoring stations, with a single monthly grab sample collected from most stations.

Other water quality monitoring programs (e.g. Waterwatch) exist, though to date this data has not been used to validate EMSS-Goulburn due to data continuity and quality assurance/quality control uncertainty.

Importantly, no permanent, in-situ probes are installed in the catchment area, nor have any 'event' (i.e. high rainfall period, storms etc) sampling programs been initiated. Event monitoring data is important as the bulk of pollutant loads are mobilised and transported during high rainfall events, but these are usually missed by routine monitoring programs.

While predictions of loads based on water quality monitoring data has its own inherent uncertainties and limitations, the relative lack of data, particularly 'event' data to calibrate and check EMSS model outputs increases the degree of uncertainty, and reduces confidence in model predictions.

### 4.6.3 Point Source Data

Similarly, in the absence of reliable information on local pollutant point sources, only limited point source data colleted from EPA discharge licences (current to December 2003) have been included in the current version of EMSS-Goulburn. Better information on the existence and magnitude of point sources would allow a better assessment of the effects of any point sources in the Upper-Mid Goulburn Catchment.

### 4.6.4 Water Extractions

The current version of EMSS does not consider the effects of extractions (irrigation pumping, town water supply etc.) from rivers and streams. Future releases of EMSS (E2) are expected to incorporate a capability to model the effect of extractions on stream flows as a daily time series.

### 4.6.5 Rainfall Data

The SILO rainfall database used in EMSS-Goulburn only interpolates predictions of rainfall data between actual meteorological recording stations. Actual values at points between measuring stations are unknown.

### 4.6.6 Storage Processes

As noted previously, storage model components of the current version of EMSS-Goulburn comprise very simple 'bucket' type models that does not incorporate any form of routing (time delay) through the storage. Hence EMSS-Goulburn predictions of reservoir pollutant trapping efficiency must be interpreted with caution. More complex models that properly represent hydrodynamic and ecological storage processes will be built for Lake Eildon and possibly Goulburn Weir as a later phase of the MSWQS.

### 4.6.7 Streambank Erosion and Bed Load

As previously noted, EMSS combines two types of erosion data, namely hillslope erosion and gully erosion to model the export generation of sediment by the landscape. However, the current version of EMSS does not model streambank erosion processes, or make an estimations of sediment transported as bedload. Therefore, the effects of this generation upon downstream conditions are not considered by EMSS.

Future releases of EMSS are expected to incorporate a capability to model steambank erosion and bedload processes. Other models such as SedNet, another model currently in development by the CRC for Catchment Hydrology, are also suited to an exploration of sediment accounting and sediment budgets.

### 4.6.8 Erosion Hazard Data Issues

EMSS uses gully density mapping and USLE data (combined with land use mapping and other data sources) to calculate sediment export rates. Gully density mapping currently employed by EMSS-Goulburn is fairly coarse in scale, and as a result tends to exaggerate and distort the differences in erosion hazard between adjacent catchments in some areas. This problem would be overcome with finer scale gully density mapping with a larger number of data classes, which would 'smooth out' the boundaries between high and low gully density areas.

This problem is compounded by the fact that considerably greater weighting is currently given to gully density than USLE data in the calculation of erosion hazard. Adjustment of the relative weighting of gully density data and USLE data may overcome this problem, although this would need consideration and advice from those who did the original mapping.

### 4.6.9 Averaging Pollutant Generation Rates

Another limitation becomes apparent when a significant proportion of a catchment or sub-catchment comprises a lake or reservoir (e.g. Eildon 5 sub-catchment). EMSS uses the relative proportions of various land uses and the average pollutant generation rate for each to calculate an average pollutant generation rate for each catchment/sub-catchment. When a large proportion of the land surface has as 'Water' land use classification, which generates no pollutant, the process of averaging pollutant generation rates out over the entire sub-catchment means that EMSS underestimates the actual pollutant load generation rate (in tonnes/ha/yr) for the sub-catchment as a whole.

The Eildon catchments and sub-catchments in particular are affected by this problem, and predicted pollutant loads and yields are probably not representative of 'true' generation rates, which are probably much higher.

Again, this problem would be overcome by a refined version of EMSS which could model to a finer scale, such that pollutant generation rates of different areas of a sub-catchment could be differentiated and modelled.

### 4.6.10 Spatial Scale Issues

EMSS-Goulburn is a regional scale catchment water quality model. Accordingly, its capability to predict pollutant loads and generation rates, and its usefulness for targeting management actions (revegetation, riparian repair etc.) at a finer scale is somewhat limited. While the data set used for EMSS-Goulburn is good quality, high-resolution data, it still only gives at best a 'broad brush' prediction of sediment and nutrient generation rates.

An enhanced version of EMSS-Goulburn that had the capacity to model identified problem areas at a finer scale would be useful, whereby pollutant generation rates of different areas of a sub-catchment could be differentiated and modelled. To do this properly we would need a high quality, high resolution dataset appropriate to the size of that area.

In any case, no model should be used in isolation to target sediment and nutrient control measures. On-ground field inspections are an essential reality check of model predictions.

# 5. Model Application – Prediction of Water Quality Impacts Under Current Conditions

At its most basic level, EMSS-Goulburn is a useful tool for predicting the likely impacts of catchment processes on water quality under current land use conditions. To do this, climatic data for a 20-year period (1980 – 1999) is applied to the EMSS-Goulburn 'Base Scenario', which incorporates existing (at December 2003) land use conditions.

This 20 year period of data encompasses a full range of 'wet', 'dry' and 'normal' climatic periods, including an extended drought period in the late 1990s. This data is used by EMSS-Goulburn to estimate the relative contributions to pollutant (TSS, TN and TP) loads from the Upper-Mid Goulburn Catchments and sub-catchments.

## 5.1 Estimated Pollutant Loads

Predicted pollutant loads vary considerably on a daily, monthly and annual basis. However, EMSS-Goulburn estimates of average long-term (1980 – 1999) annual pollutant loss rates from the Upper-Mid Goulburn Catchment as a whole are 75,000 t/yr (TSS), 1,800 t/yr (TN) and 250 t/yr (TP).

Note that these predictions do not include pollutants trapped within the 'in-line' storages Lake Eildon and Goulburn Weir, or deposited in rivers, streams and floodplains in transit.

Estimated average pollutant loads actually exported to the Lower Goulburn Catchment (i.e. below Goulburn Weir) are much lower, being approximately:

**TSS 19,900 t/yr**

**TN 480 t/yr**

**TP 70 t/yr**

Figure 9 depicts the relative TSS loads generated from the major catchments over a 20 year period, and demonstrates that the largest proportion of TSS load (~9.5%) is generated in the 'Mid-Goulburn' Catchment, which essentially comprises catchment areas immediately adjacent to the Goulburn River downstream of Lake Eildon and upstream of Goulburn Weir (See Figure 3). It also illustrates the pronounced variation in loads evident in the catchments.

Similarly, Figure 10 and Figure 11 depict the relative average loads of TN and TP, respectively, generated from the major catchments over the period 1980 – 1999. Catchments producing the highest proportional

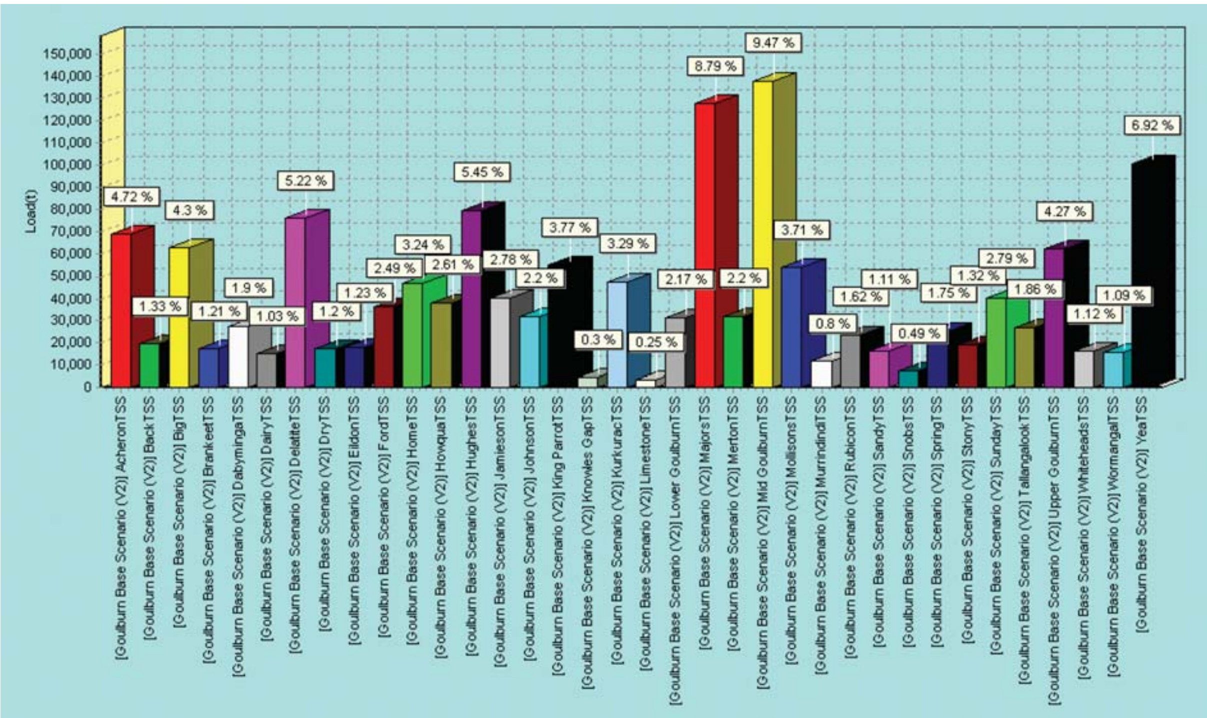



Figure 9. Relative Contributions of Major Catchments to TSS Loads (average tonnes/year 1980 – 1999).

TN loads are predicted to be Upper Goulburn (8.8%), Big (8.7%) and Acheron (8.6%). Catchments producing the highest proportional TP loads are predicted to be Mid Goulburn (8.6%), Big (8.3%) and Upper Goulburn 4 (8.0%).

At sub-catchment scale, pollutant generation rates show significant variation throughout the Upper-Mid Goulburn Catchment. While there are too many sub-catchments (148 in total) to represent on a single figure with any clarity, Figure 12 demonstrates the capability of EMSS-Goulburn for investigating the relative proportions of pollutant loads being produced by individual sub-catchments.

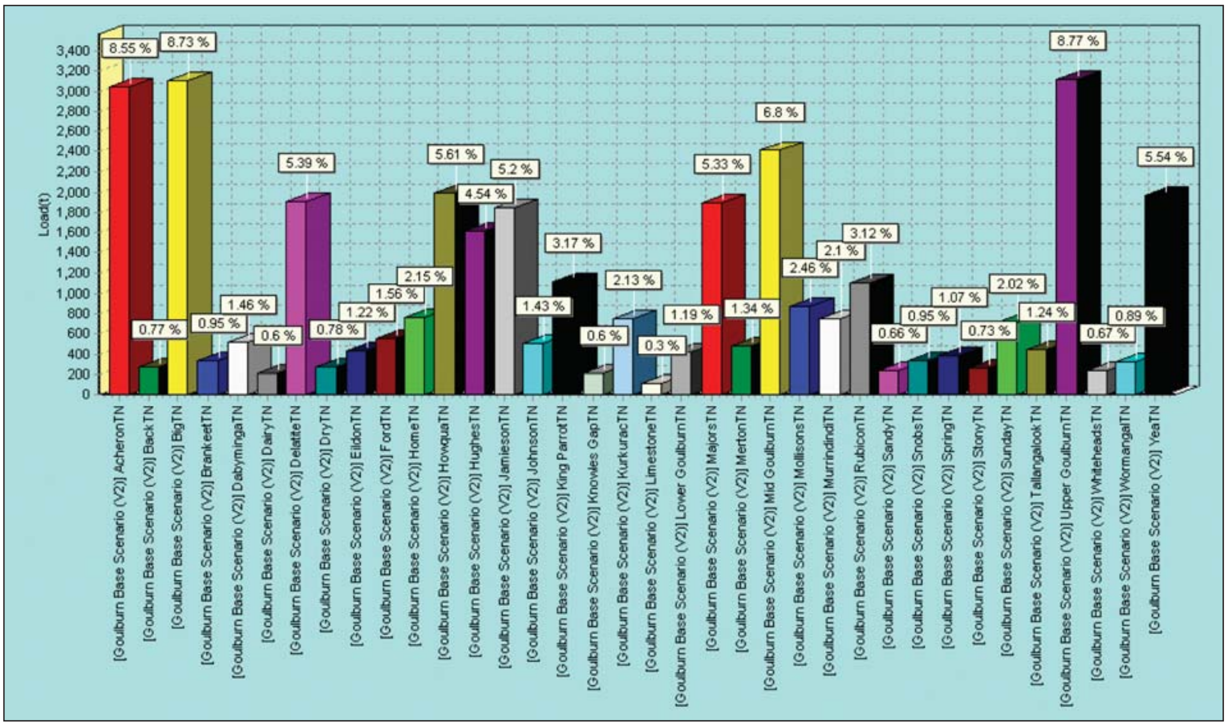



Figure 10. Relative Contributions of Major Catchments to TN loads (average tonnes/year 1980 – 1999).

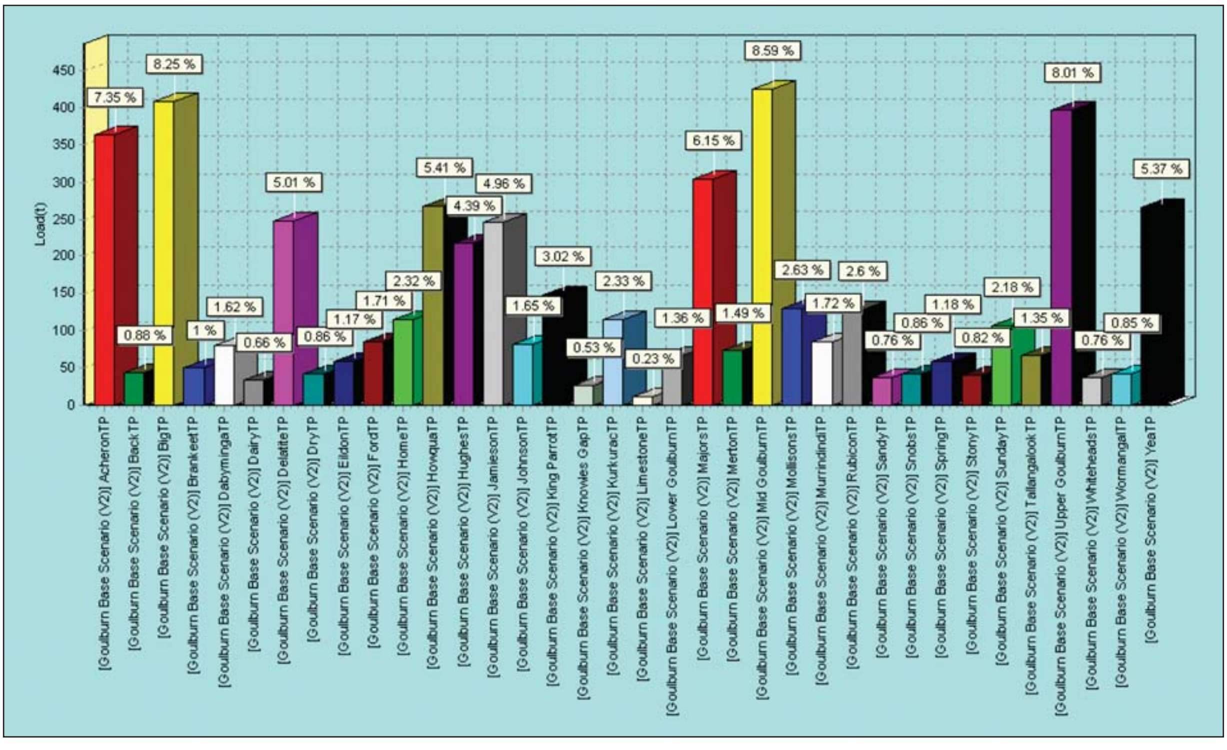



Figure 11. Relative Contributions of Major Catchments to TP loads (average tonnes/year 1980 – 1999).

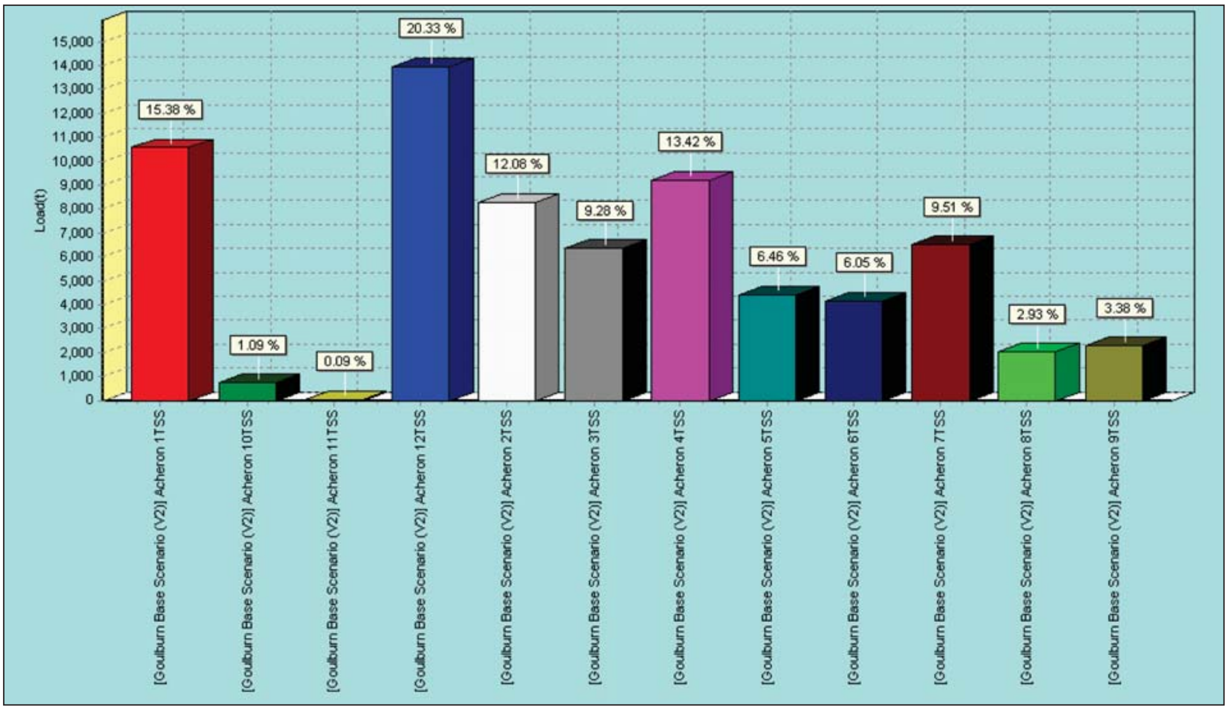



Figure 12. Relative Contributions of Individual Sub-catchments from the Acheron Catchment (average tonnes/year 1980 – 1999).

Figure 12 represents the proportional TSS loads generated by individual sub-catchments within the Acheron catchment. In this area, the sub-catchment producing the highest proportional TSS loads is predicted to be Acheron 12 (20.3% of total load generated in the Acheron catchment), while the sub-catchment with the lowest proportional loads is Acheron 11 (0.09%). While this may be largely attributable to the variable sizes of the catchments, other factors such as land use, gully density, soil types, topography etc could all play a part, and the relative importance of these could be assessed as part of a more detailed investigation.

## 5.2 Sub-catchment Specific Yields

While estimation of total average loads from catchments is interesting, it can be misleading due to the fact that the sub-catchments are all different in size. Larger sub-catchments will usually generate larger pollutant loadings. It is usually more useful to look beyond total pollutant loads generated by each sub-catchment (in tonnes/year), and instead consider the specific yield, or relative loading rates per unit area (i.e. tonnes/hectare/year).

Proportional generation rates for TSS, TN and TP predicted by EMSS-Goulburn are shown in Figure 13, Figure 14 and Figure 15, respectively. Variation between sub-catchments is depicted by a sliding colour scale, where sub-catchments predicted to have the highest pollutant generation rates (in t/ha/yr) are depicted in progressively darker shades of blue. The red coloured area indicates the sub-catchment with the highest predicted pollutant generation rates.

*Caution: There currently exists a problem with the ability of EMSS-Goulburn to properly determine pollutant generation rates in the sub-catchments immediately adjacent to Lake Eildon, and hence the relatively low specific yields on the Figures below appear lower than 'true' specific yields. This problem is explained more fully in Section 4.6.9.*

*An interesting feature evident in Figure 14 and Figure 15 is that many of the catchments and sub-catchments with the highest nutrient production rates are actually the heavily vegetated, largely undisturbed catchments in the south-eastern parts of the Upper-Mid Goulburn Catchment. If true, this is interesting as it tends to conflict with the intuitive expectation that that the highest nutrient producers will be the cleared, 'open' catchments, where the gully erosion is often more*

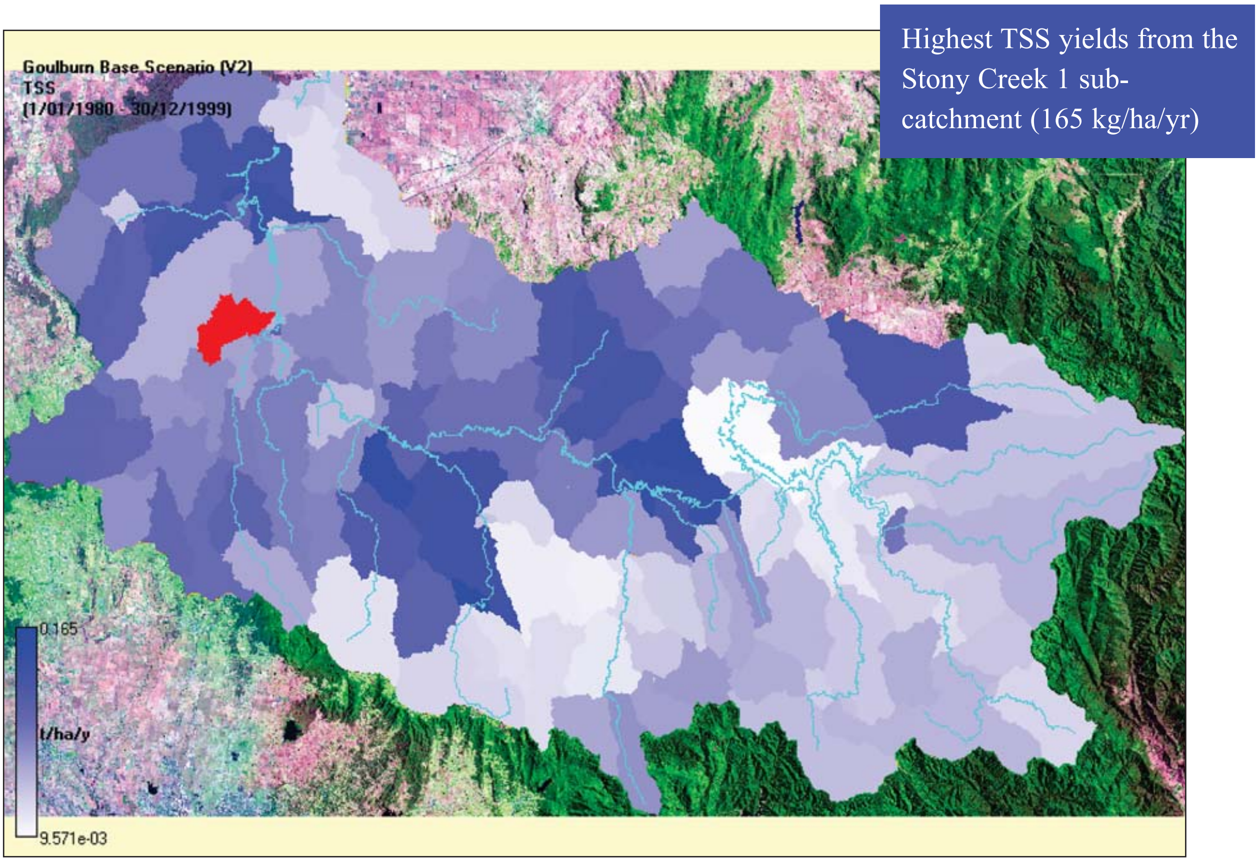



Figure 13. TSS Generation Rates - Sub-catchments.

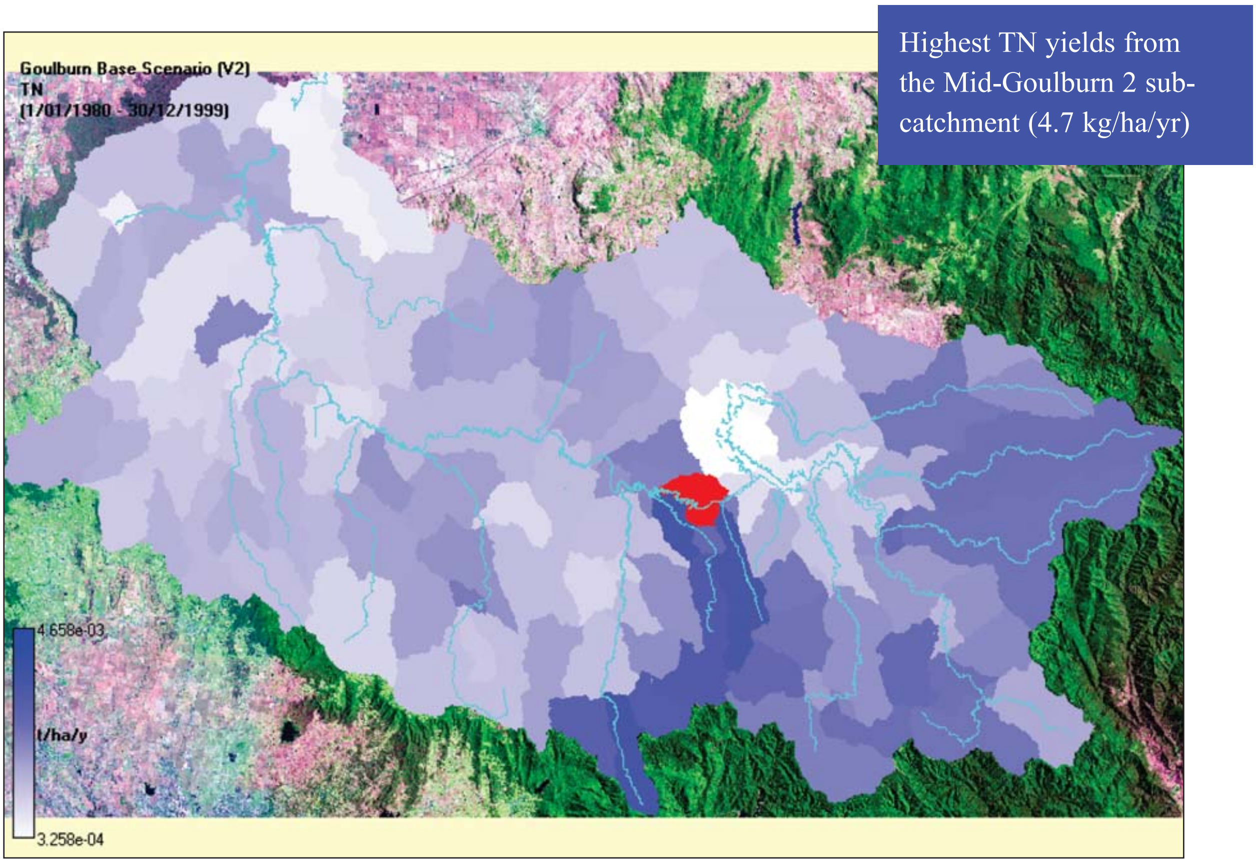



Figure 14. TN Generation Rates - Sub-catchments.

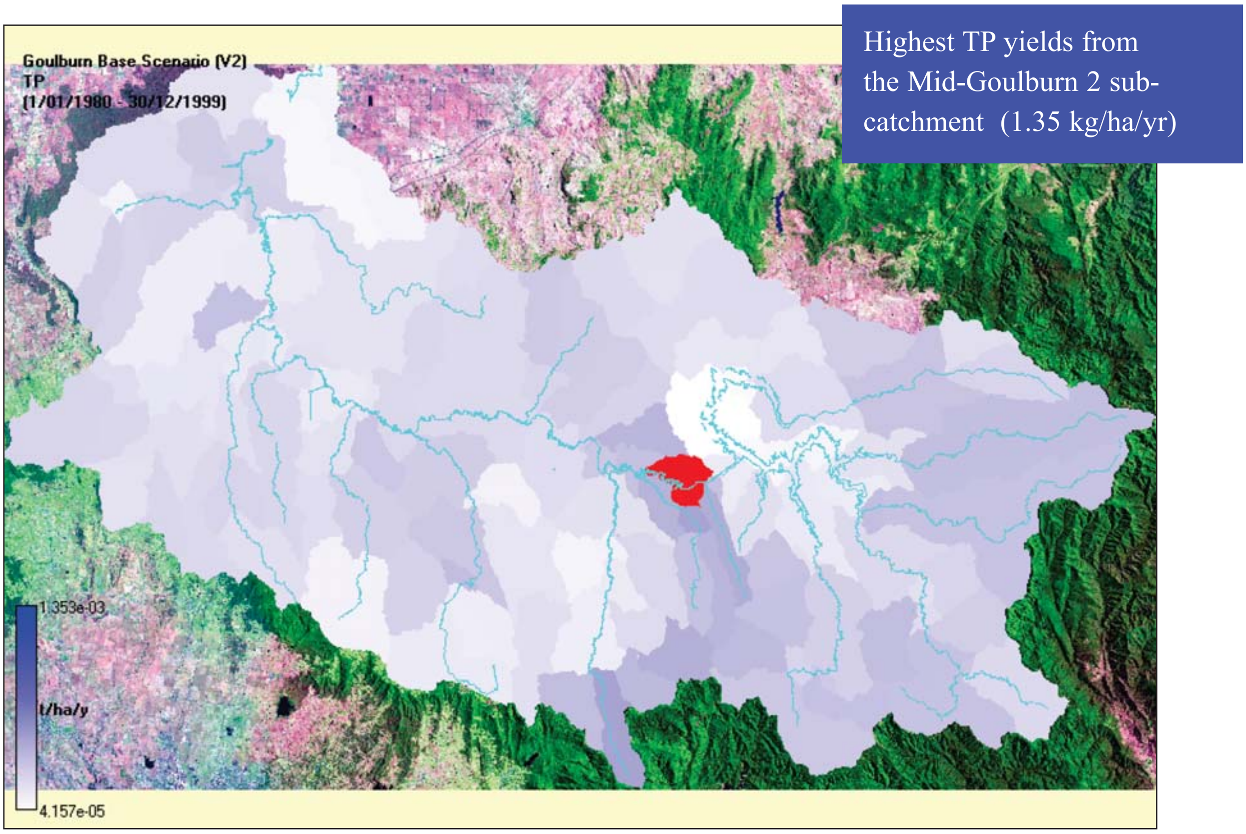



Figure 15. TP Generation Rates - Sub-catchments.

*evident for example. The much higher rainfall and steeper topography of these catchments are factors that may explain this apparent 'anomaly'. Further discussion and investigation is warranted.*

This is valuable information, as it gives managers a good indication of where, at sub-catchment scale, remedial effort and expenditure to manage water quality pollutants can be directed to best effect.

As an example, using this information, a preliminary assessment of high, medium and low priority sub-catchments for control of sediment (TSS) loss is included in Table 5. This was done by simply comparing specific yield in each of the sub-catchments. Any sub-catchments with an average specific yield of 100 kg/ha/yr or greater were classified as 'high' priority, those less than 50 kg/ha/yr classified as 'low' priority, with those in between 'medium' priority status.

## 5.3 Model Application - Comparison of Wet and Dry Climatic Periods

Another useful application of EMSS-Goulburn is its ability to compare, in relative terms, pollutant loads generated during climactic periods, and thereby the effect that climatic conditions have on pollutant loads.

It is widely understood that pollutant generation rates are greater in wetter climatic periods than during drier periods. However the magnitude of this difference as it applies to the Upper-Mid Goulburn Catchment has, to the best of our knowledge, never been directly investigated or estimated. EMSS-Goulburn allows us to quantify this difference.

### 5.3.1 Estimated Pollutant Loads

Estimated sediment loads for the Upper-Mid Goulburn Catchment during 'wet', 'dry' and 'average' years for the catchments are reported in Table 6. As expected, pollutant generation rates in the Upper-Mid Goulburn Catchment predicted by EMSS-Goulburn are highly dependent on climatic conditions, particularly rainfall.

Figure 16 is typical of the patterns observed in many sub-catchments. Monthly pollutant loads from 'Sandy Creek' catchment for 1981 and 1982 are depicted. Predicted TSS loads for 1981, a relatively wet year, are far greater than for the much drier 1982. Similar effects are also seen for nutrient export rates.

Table 5. Priority Sub-catchments for Mitigation of Sediment Loss.

| Sub-catchment | High Priority | Medium Priority | Low Priority |
|---|---|---|---|
| Acheron 1 | | | X |
| Acheron 2 | | | X |
| Acheron 3 | | | X |
| Acheron 4 | | | X |
| Acheron 5 | | | X |
| Acheron 6 | | | X |
| Acheron 7 | | | X |
| Acheron 8 | | | X |
| Acheron 9 | | | X |
| Acheron 10 | | | X |
| Acheron 11 | | | X |
| Acheron 12 | | X | |
| | | | |
| Back 1 | | X | |
| | | | |
| Big 1 | | | X |
| Big 2 | | | X |
| Big 3 | | | X |
| Big 4 | | | X |
| Big 5 | | | X |
| Big 6 | | | X |
| Big 7 | | | X |
| Big 8 | | | X |
| Big 9 | | | X |
| Big 10 | | | X |
| Big 11 | | | X |
| Big 12 | | | X |
| | | | |
| Brankeet 1 | | X | |
| Brankeet 2 | | X | |
| | | | |
| Dabyminga 1 | | X | |
| | | | |
| Dairy 1 | X | | |
| | | | |
| Delatite 1 | | | X |
| Delatite 2 | | | X |
| Delatite 3 | X | | |
| Delatite 4 | | X | |
| | | | |
| Dry 1 | X | | |
| | | | |
| Eildon 1* | | | |
| Eildon 2 | | X | |
| Eildon 3* | | | |
| Eildon 4* | | | |
| Eildon 5* | | | |
| Eildon 6* | | | |
| Eildon 7 | | | X |
| | | | |
| Ford 1 | X | | |
| Ford 2 | | X | |
| | | | |
| Home 1 | X | | |
| Home 2 | X | | |
| Home 3 | X | | |
| Home 4 | X | | |
| | | | |
| Howqua 1 | | | X |
| Howqua 2 | | | X |
| | | | |
| Hughes 1 | | X | |
| Hughes 2 | | X | |
| Hughes 3 | X | | |
| Hughes 4 | | X | |
| Hughes 5 | | X | |
| Hughes 6 | | X | |
| | | | |
| Jamieson 1 | | | X |
| Jamieson 2 | | X | |
| | | | |
| Johnson 1 | X | | |
| Johnson 2 | X | | |
| | | | |
| King Parrot 1 | | | X |
| King Parrot 2 | | X | |
| King Parrot 3 | X | | |
| King Parrot 4 | | X | |
| | | | |
| Knowles Gap 1 | | | X |
| | | | |
| | | | |
| Kurkurac 1 | | X | |
| Kurkurac 2 | X | | |
| Kurkurac 3 | | X | |
| Kurkurac 4 | | X | |
| Kurkurac 5 | | X | |
| | | | |
| Limestone 1 | | | X |
| | | | |
| Lower Goulburn 1 | X | | |
| Lower Goulburn 2 | X | | |
| Lower Goulburn 3 | | | X |
| Lower Goulburn 4 | | | X |
| Lower Goulburn 5 | | | X |
| | | | |
| Majors 1 | | X | |
| Majors 2 | X | | |
| Majors 3 | | X | |
| Majors 4 | X | | |
| Majors 5 | | X | |
| Majors 6 | X | | |
| Majors 7 | X | | |
| Majors 8 | | X | |
| Majors 9 | X | | |
| Majors 10 | X | | |
| | | | |
| Merton 1 | | X | |
| Merton 2 | | X | |
| | | | |
| Mid Goulburn 1 | X | | |
| Mid Goulburn 2 | X | | |
| Mid Goulburn 3 | X | | |
| Mid Goulburn 4 | X | | |
| Mid Goulburn 5 | | X | |
| Mid Goulburn 6 | | X | |
| Mid Goulburn 7 | | X | |
| Mid Goulburn 8 | X | | |
| Mid Goulburn 9 | | X | |
| Mid Goulburn 10 | | X | |
| Mid Goulburn 11 | | X | |
| Mid Goulburn 12 | | X | |
| Mid Goulburn 13 | | X | |
| Mid Goulburn 14 | X | | |
| Mid Goulburn 15 | | X | |
| Mid Goulburn 16 | | X | |
| Mid Goulburn 17 | X | | |

* Note: The as explained in Section 4.6.9 pollutant generation rates for the 'Eildon' catchments and sub-catchments predicted by EMSS-Goulburn are likely to be incorrect, and are probably not representative of true generation rates, which are probably much higher.

Table 5. (Cont.d)

| Sub-catchment | High Priority | Medium Priority | Low Priority |
|---|---|---|---|
| Mollisons 1 | X | | |
| Mollisons 2 | | X | |
| Mollisons 3 | X | | |
| Mollisons 4 | | X | |
| | | | |
| Murrindindi 1 | | | X |
| Murrindindi 2 | | | X |
| | | | |
| Rubicon 1 | | | X |
| Rubicon 2 | | | X |
| Rubicon 3 | | | X |
| Rubicon 4 | X | | |
| | | | |
| Sandy 1 | X | | |
| | | | |
| Snobs 1 | | X | |
| | | | |
| Spring 1 | X | | |
| Spring 2 | X | | |
| | | | |
| Stony 1 | X | | |
| | | | |
| Sunday 1 | | X | |
| Sunday 2 | X | | |
| Sunday 3 | | X | |
| Sunday 4 | | X | |
| Sunday 5 | | X | |
| | | | |
| Tallangalook 1 | | X | |
| | | | |
| Upper Goulburn 1 | | | X |
| Upper Goulburn 2 | | | X |
| Upper Goulburn 3 | | | X |
| Upper Goulburn 4 | | | X |
| Upper Goulburn 5 | | | X |
| Upper Goulburn 6 | | | X |
| Upper Goulburn 7 | | | X |
| Upper Goulburn 8 | | | X |
| Upper Goulburn 9 | | | X |
| Upper Goulburn 10 | | | X |
| Upper Goulburn 11 | | | X |
| Upper Goulburn 12 | | | X |
| Upper Goulburn 13 | | | X |
| | | | |
| Whiteheads 1 | | X | |
| | | | |
| Wormangal 1 | | | X |
| Wormangal 2 | | | X |
| | | | |
| Yea 1 | | | X |
| Yea 2 | | | X |
| Yea 3 | | | X |
| Yea 4 | X | | |
| Yea 5 | X | | |
| Yea 6 | X | | |
| Yea 7 | X | | |
| Yea 8 | X | | |
| Yea 9 | | | X |
| Yea 10 | X | | |

*Similar exercises could readily be done for TN and TP.*

*While this is an over simplification of actual conditions, it does provide a useful 'first cut' indication of priority areas for targeting remedial works programs, or those which at the least warrant further investigation. This might comprise on-ground field truthing, comparison with other predictive modelling tools (e.g. SedNet) or construction of a finer scale EMSS for particular catchments and sub-catchments of interest.*

Similarly, pollutant loads generated are also, as expected, far greater during wetter months (July-September) than drier months.

Figure 17 depicts results for Sandy Creek Catchment during the period 1986-1989, and illustrates a pattern typical of most sub-catchments where the majority of pollutant loads are usually generated during the Winter-Spring period, though substantial loadings are occasionally generated at other times of year (i.e. summer storms).

The relationship between predicted TSS loads and climatic conditions is illustrated even more dramatically when model outputs are viewed as a daily time-step.

*On occasion, large proportions of total monthly, or even yearly total sediment loadings may be generated in a single 'extreme' 1-2 day event.*

Figure 18 clearly illustrates this phenomenon, depicting daily TSS loads generated in Yea 6 sub-catchment in the year 1989.

For reference, the predicted TSS load generated for the entire year (1989) in Yea 6 sub-catchment was approximately 2,055 tonnes.

Information of this type is particularly useful for water quality target setting. Pronounced, short term variation of loads illustrates the inappropriateness of

Table 6. Comparison of Approximate Pollutant Loads Generated During Wet, Dry and Average Years.

| | TSS | | | TN | | | TP | | |
|---|---|---|---|---|---|---|---|---|---|
| **Catchment** | 20 yr average (t/yr) | 1981 (t) | 1982 (t) | 20 yr average (t/yr) | 1981 (t) | 1982 (t) | 20 yr average (t/yr) | 1981 (t) | 1982 (t) |
| **TOTAL** | **75,400** | **108,200** | **15,200** | **1,800** | **2,780** | **450** | **250** | **370** | **65** |

*As a general rule, EMSS-Goulburn predicts that pollutant loads during a particularly dry year (1982) are of the order of 5-30 % of those generated during a wetter year (1981).*

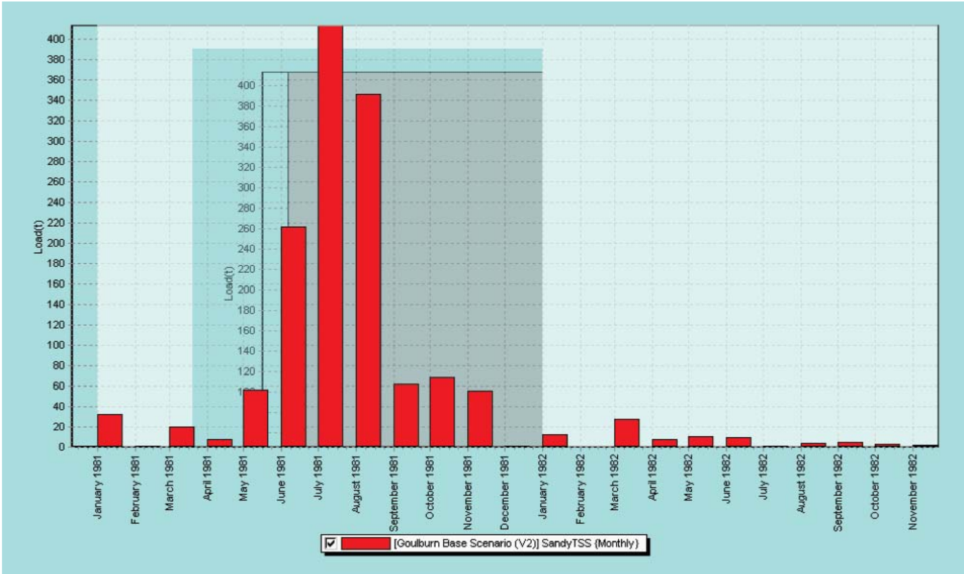



Figure 16. Comparative Monthly TSS Loads in ‘Sandy Creek’ Catchment 1981 – 1982.

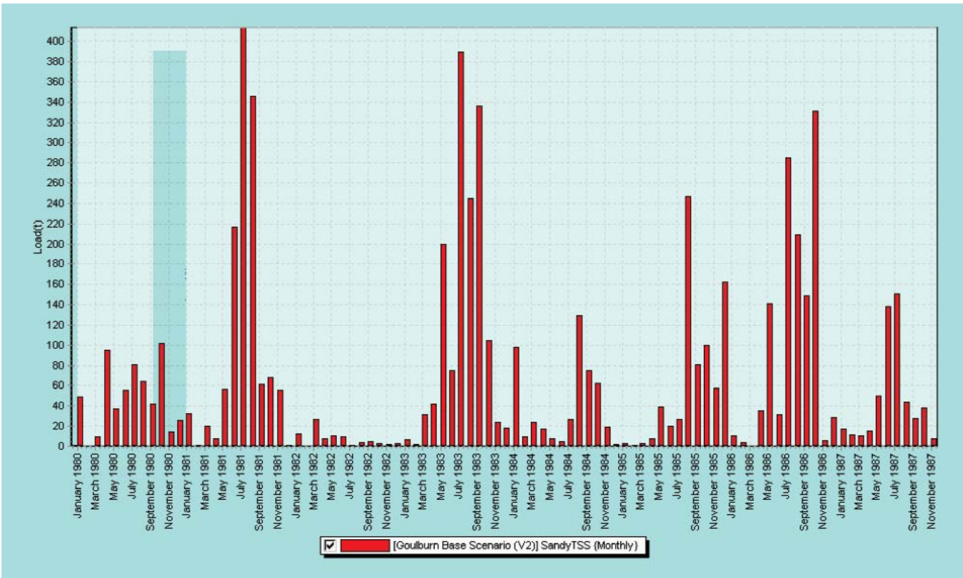



Figure 17. TSS Generation rates – Sandy Creek Catchment 1980 - 1987.

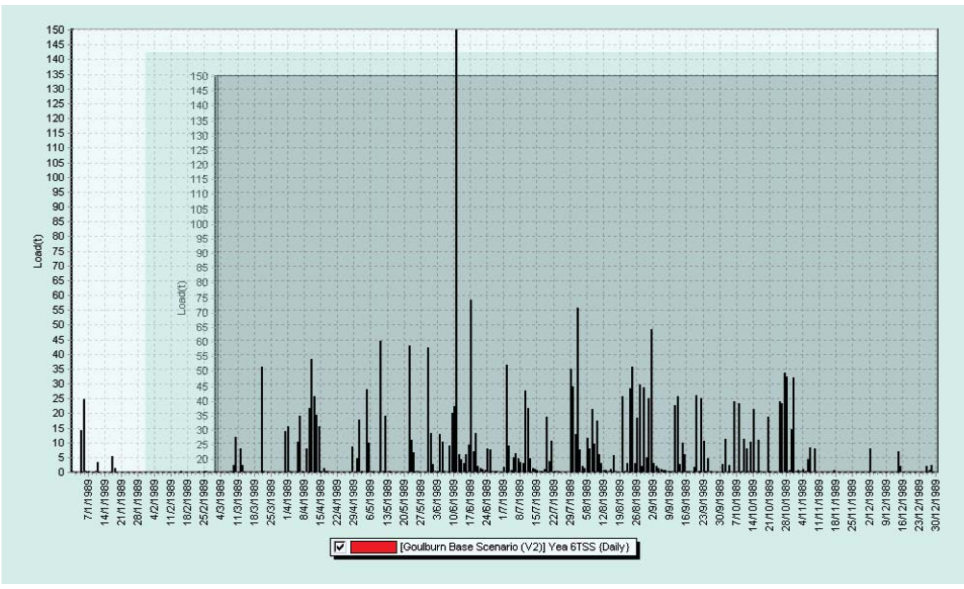





Figure 18. Daily TSS Loads Generated Yea 6 Sub-catchment – 1989.

Table 7. Sediment Yields for Select Sub-catchments During Wet, Dry and Average Years.

| | TSS (kg/ha/yr) | | TN (kg/ha/yr) | | TP (kg/ha/yr) | |
|---|---|---|---|---|---|---|
| Subcatchment | 1981 | 1982 | 1981 | 1982 | 1981 | 1982 |
| Acheron 5 | 27 | 9 | 1.62 | 0.52 | 0.15 | 0.05 |
| Big 4 | 72 | 18 | 3.56 | 1.06 | 0.46 | 0.12 |
| Back 1 | 134 | 3 | 2.03 | 0.05 | 0.32 | <0.01 |
| Dairy 1 | 230 | 21 | 3.71 | 0.27 | 0.55 | 0.04 |
| Delatite 3 | 133 | 28 | 3.05 | 0.45 | 0.40 | 0.07 |
| Dry 1 | 134 | 16 | 2.61 | 0.20 | 0.37 | 0.03 |
| Ford 1 | 161 | 23 | 2.95 | 0.29 | 0.42 | 0.05 |
| Hughes 1 | 117 | 7 | 3.27 | 0.12 | 0.38 | 0.02 |
| Limestone 1 | 43 | 12 | 1.45 | 0.29 | 0.15 | 0.04 |
| Majors 8 | 97 | 4 | 1.87 | 0.05 | 0.27 | <0.01 |
| Mid-Goulburn 6 | 101 | 19 | 1.89 | 0.27 | 0.26 | 0.04 |
| Mollisons 1 | 150 | 12 | 3.08 | 0.15 | 0.41 | 0.03 |
| Upper Goulburn 11 | 51 | 8 | 2.76 | 0.39 | 0.31 | 0.05 |

*These figures illustrate the spatial and temporal dependence of pollutant generation rates on climatic conditions, predominantly rainfall, in the Upper-Mid Goulburn Catchment.*

setting rigid, absolute water quality targets for many catchments and streams like those in the Upper-Mid Goulburn Catchment, which often experience extreme variation on a yearly, monthly, daily (and probably sub-daily) basis.

Similarly, this information may be useful for the establishment of water quality monitoring programs.

*Any water quality monitoring program which does not capture 'event' data will most likely not be truly representative of actual pollutant loads exported, and conclusions drawn from this data alone will be misleading.*

### 5.3.2 Estimated Specific Yields

Predictions of loads generated from catchments and sub-catchments during wet and dry climatic periods are useful, but they are not the complete story. Predicted TSS generation rates for sub-catchments under wet (1981), dry (1982) and 'typical' (average 1980 – 1999) climatic conditions are shown in Figure 19, Figure 20 and Figure 21, respectively.

Note the scale bars in the bottom left hand corners of the pictures. Sediment yield during the wet year 1981 is far higher than the dry year 1982, with maximum average yields estimated at 243 kg/ha/yr and 60 kg/ha/yr, respectively. Model predictions for TP and TN exhibit a similar dependency.

To demonstrate this further, Table 7 summarises TSS, TN and TP generation rates for select sub-catchments under both 'wet' (1981) and 'dry' (1982) years.

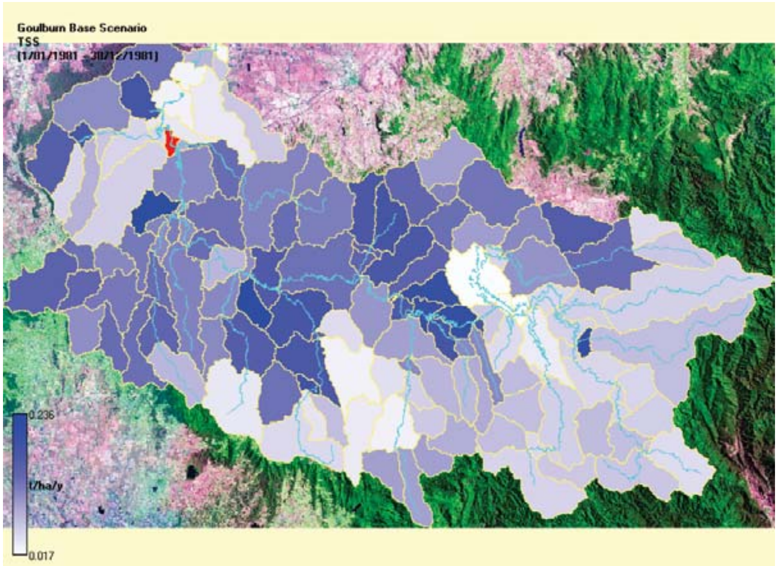



Figure 19. Relative TSS Generation Rates Under Wet Conditions (1981).

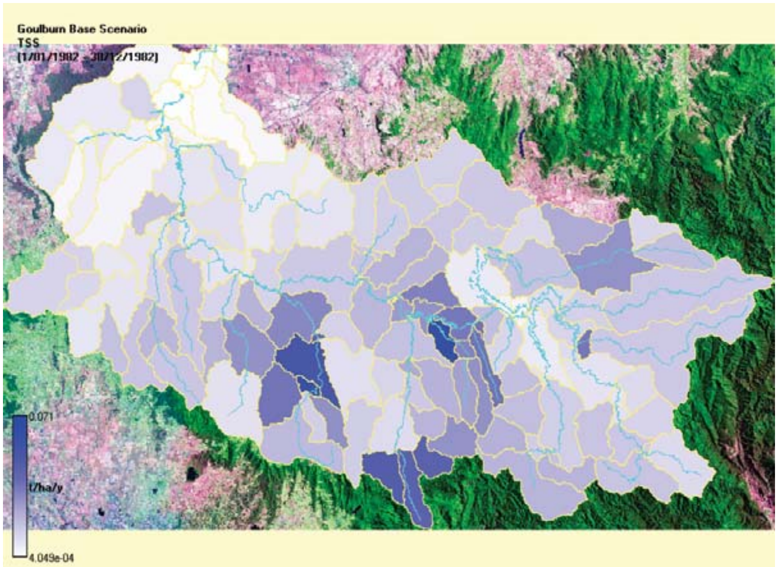



Figure 20. Relative TSS Generation Rates Under Dry Conditions (1982).

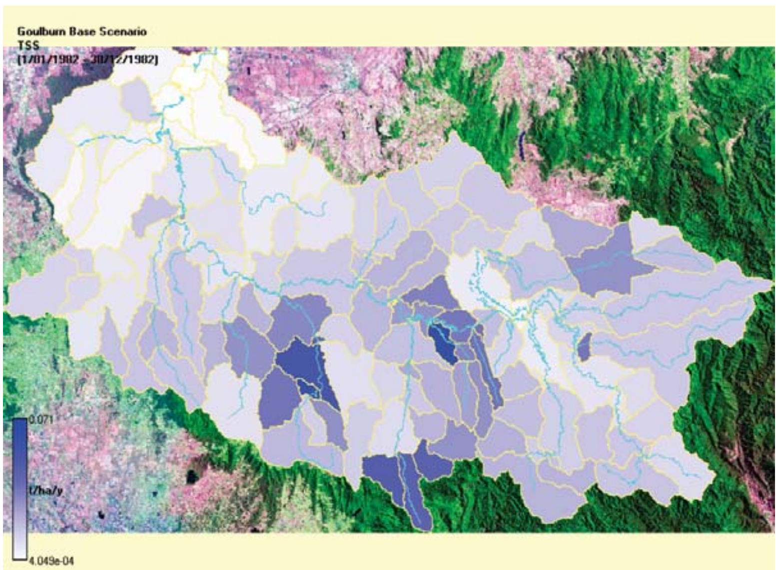



Figure 21. Relative TSS Generation Rates Under 'Typical' Conditions (average 1980 - 1999).

## 6. Model Application – Pollutant Loadings into Lake Eildon and Goulburn Weir

EMSS-Goulburn can also be used to estimate the loads from the entire catchment passing various locations (nodes) in the model. Cumulative pollutant loads passing nodes situated immediately upstream of storages gives an estimation of pollutant loads entering the storages. Conversely, pollutant loads passing nodes situated immediately downstream of storages give an estimation of pollutant loads leaving the storages.

Accordingly, EMSS-Goulburn can be used to estimate the mean pollutant loadings entering and leaving Lake Eildon and Goulburn Weir over any given period. Predicted average loads over a 20 year period (1980 – 1999) are provided in Table 8.

*As intuitively expected, EMSS-Goulburn predicts that Lake Eildon and Goulburn Weir act as effective sediment and nutrient traps, removing most of the pollutant loads from the upper catchments.*

While this may be viewed as a positive environmental impact as it substantially reduces the pollutant loads exported to the downstream river systems, the long term effect of cumulative pollutant loading on water quality within the storages needs to be considered. It is intended that these effects will be modelled as a later storage modelling phase of the MSWQS.

These results need to be interpreted with some caution, as the storage models are very simple 'bucket' type models which do not accurately model the complex hydrodynamic and ecological processes known to occur within storages. Nevertheless they do indicate a dramatic reduction in water quality pollutants leaving the catchment.

Our understanding of sediment fate and transport processes within Lake Eildon and Goulburn Weir will soon be improved with the forthcoming development and application of comprehensive hydrodynamic and ecological model for these storages in a subsequent phase of the MSWQS.

Table 8. Mean Annual Pollutant Loadings into Lake Eildon and Goulburn Weir.

| | **Lake Eildon** | | | **Goulburn Weir** | | |
|---|---|---|---|---|---|---|
| Mean Inflow | 1,340,689 ML | | | 2,534,536 | | |
| | In (t/yr) | Out (t/yr) | Efficiency | In (t/yr) | Out (t/yr) | Efficiency |
| Mean TSS | 21,369 | 637 | 97% | 50925 | 18891 | 63% |
| Mean TN | 743 | 21 | 97% | 1063 | 465 | 56% |
| Mean TP | 99 | 3 | 96% | 153 | 67 | 56% |

# 7. Model Application – Comparison with Past and Future Land Use Conditions

The impacts of past and likely future land use conditions in the Upper-Mid Goulburn Catchment on water quality can be assessed using EMSS-Goulburn. Modified versions of the EMSS-Goulburn base model have been constructed, one representative of likely pre-European (1770) land use conditions, and one for possible future (2020) land use conditions.

## 7.1 Comparison with Pre-European Land Use Conditions

Investigation of historical land use on water quality involved constructing and running a pre-European (1770) scenario. This involved making educated guesses regarding likely land use classifications prior to European settlement. For EMSS-Goulburn, this simply involved re-running the existing EMSS model with much of the catchment area converted to pre-1770 land uses. In other words, land classified as 'Broadacre Agriculture', 'Rural Residential' and other land uses were re-classified as either 'Forest' or 'Native Bush' etc. Other input datasets remain unchanged.

Pre-European land use data is based on the DPI 1770 EVC mapping, and is depicted on Figure 22.

Note that the 'Grazing' land use classification used by EMSS-Goulburn is really, in effect, a proxy for the open grasslands that are thought to have existed at this time. Typical pollutant generation rates for grazing land and grassland are likely to be similar. Similarly the 'National Parks' land use classification is really a surrogate for previously forested areas.

Also note that while estimation of pre-European land use can be done with a reasonably high degree of confidence, it is only an educated guess of prevailing land use conditions at that time. Nevertheless results obtained, particularly on a whole catchment scale, are interesting when compared with results generated from current (2003) land use conditions.

### 7.1.1 Load Predictions

Predicted pollutant loads generated using the 1770 scenario are summarised in Table 9.

Table 9 Comparison of estimated average annual pollutant loads (20 year period) generated under pre-European and current land use conditions

As expected, pollutant generation rates predicted by EMSS-Goulburn have greatly increased since pre-European times.

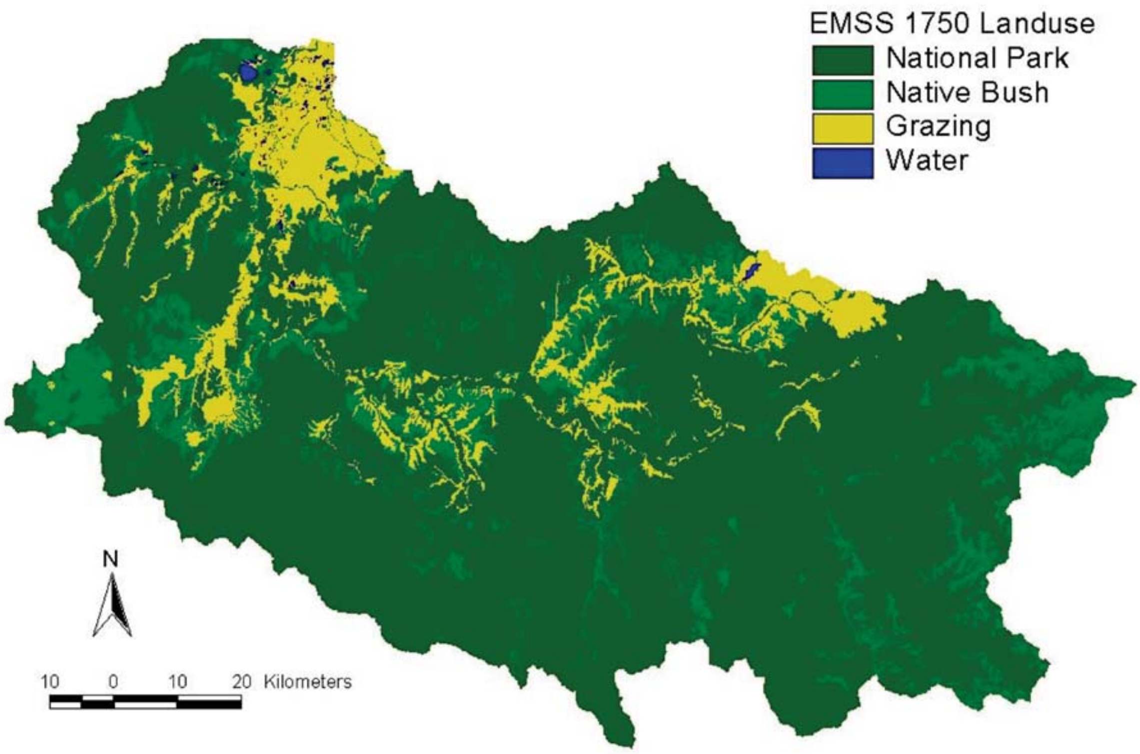



Figure 22. EMSS - Goulburn 1770 Land Use.

*EMSS-Goulburn predicts that on average, mean TSS, TN and TP pollutant loads generated within the catchment have increased by approximately 180%, 67% and 88%, respectively, from loads that would have been generated under pre-European (1770) land use conditions.*

However predicted increases are not uniform across the catchment. Changes in pollutant generation rates predicted for sub-catchments vary considerably. For example, in Home Creek catchment, increases of 250 - 450% from pre-European levels are predicted, whereas the percentage increases predicted for many other sub-catchments are much lower.

This has important implications for management. It gives us quantifiable 'upper limits' for water quality improvement targets. In other words it gives us an indication of the absolute maximum improvement in water quality that could be expected to be achieved under a return to 'undisturbed' catchment conditions.

In reality, this is not going to happen. Existing development and land use practices will not revert to pre-European conditions. Accordingly, the best improvement in pollutant export rates and water quality that will ever be achieved will no doubt be substantially less than this 'upper limit'.

Importantly, with the construction of Lake Eildon and Goulburn Weir, most of this increased load is no longer passed downstream. In fact, pollutant loads actually exported to the Lower Goulburn and Murray River systems are substantially reduced from pre-European loads, as illustrated in Table 10.

*On average, EMSS-Goulburn predicts that since pre-European times, mean TSS, TN and TP pollutant loads exported to the lower Goulburn system below Goulburn Weir have actually decreased by approximately 30%, 58% and 51%, respectively.*

Table 10. EMSS-Goulburn Predicted Difference in Mean Annual Pollutant Loads Exported to the Lower Goulburn System under Current and Pre-European Land Use Scenarios.

| | **Pre-European (t/yr)** | **Current (t/yr)** | **% change** |
|---|---|---|---|
| Mean TSS | 27,080 | 18,891 | -30% |
| Mean TN | 1100 | 465 | -58% |
| Mean TP | 136 | 67 | -51% |

In other words, EMSS-Goulburn predicts that water quality in flows passing to Lower Goulburn areas would actually have been significantly poorer in pre-European times than under the current regulated flow regime.

### 7.1.2 Relative Yields

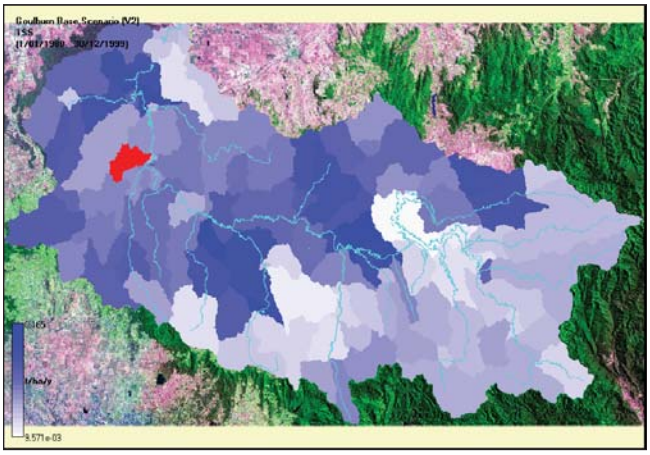
Again, while estimates of loads produced from catchments and sub-catchments during pre-European land use conditions are useful, they are not the complete picture. Figure 23 includes representations of TSS, TN and TP generation rates for sub-catchments under both 'current' (2003) and 'pre-European' (1770) land use conditions.

*Pre-European TSS, TN and TP yields were typically much lower than current rates, often less than 50% of current rates. The distribution of sub-catchments with relatively high and relatively low contributions has also changed substantially.*

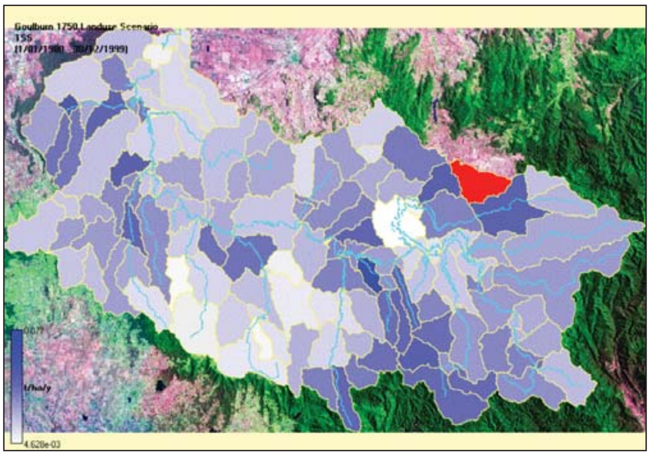
Table 9. Comparison of Estimated Average Annual Pollutant Loads (20 year period) Generated Under Pre-European and Current Land Use Conditions.

| | **TSS** | | | **TN** | | | **TP** | | |
|---|---|---|---|---|---|---|---|---|---|
| Catchment | 1770 (t/yr) | Current (t/yr) | % diff | 1770 (t/yr) | Current t/yr) | % diff | 1770 (t/yr) | Current (t/yr) | % diff |
| TOTAL | 27,043 | 75,366 | 179% | 1,101 | 1,836 | 67% | 136 | 256 | 88% |

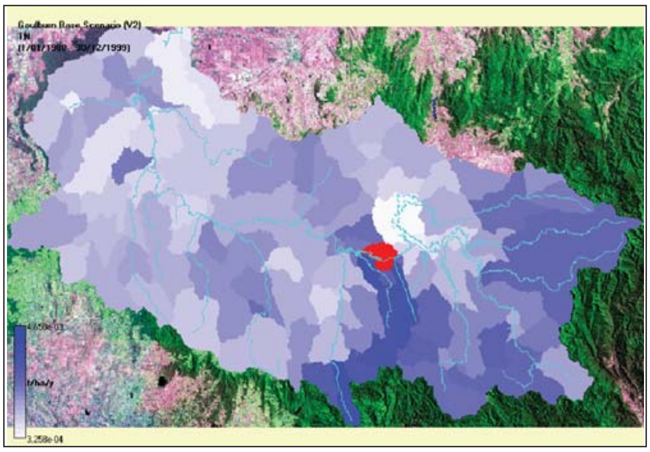
*Caution: Note the predicted pollutant loads for 'Big 4' and 'Upper Goulburn 11' sub-catchments appear to have increased. While the magnitude of the increase is small, an increase is unexpected, as these catchments remain largely forested and unchanged in terms of land use since pre-European times. This may indicate a problem with the global scaling processes of EMSS-Goulburn, although the exact cause is unknown and is currently being investigated. Again, caution is advised in the interpretation of absolute values.*



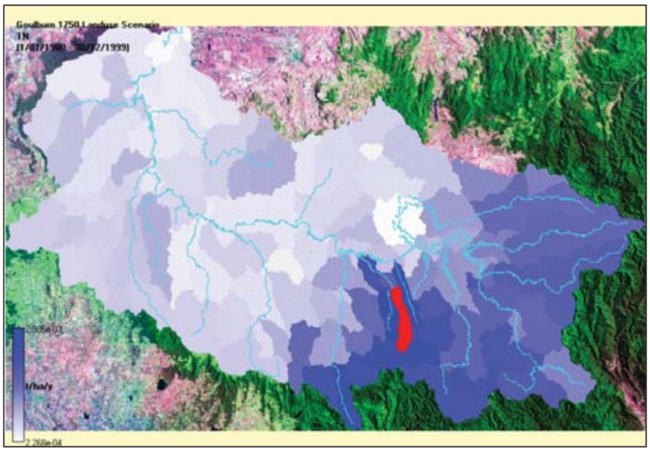
2003 - Max TSS ~165 kg/ha/yr (Stony 1)



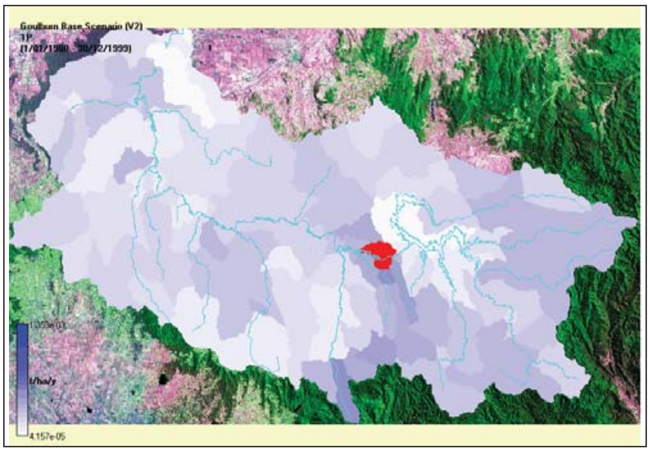
1770 - Max TSS ~77 kg/ha/yr (Tallangalook)



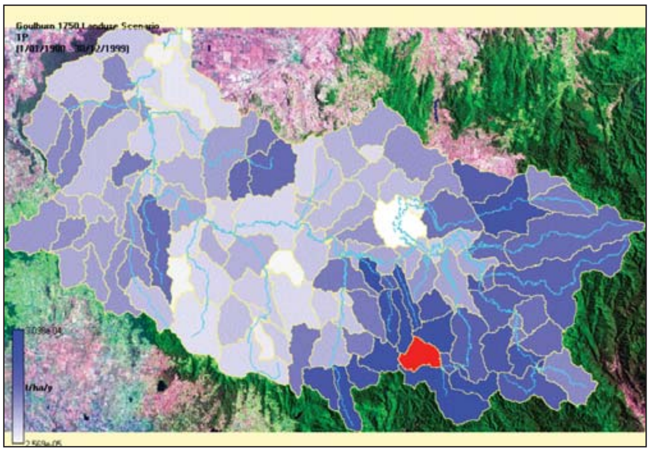
2003 - Max TN ~4.7 kg/ha/yr (Mid Goulburn 2)



1770 - Max TN ~2.9 kg/ha/yr (Snobs Ck 1)



2003 - Max TP ~1.3 kg/ha/yr (Mid Goulburn 2)



1770 - Max TP ~ 0.3 kg/ha/yr (Big 4)

Figure 23. Comparison of Sub-catchment Pollutant Yield Estimates for Current and Pre-European Land Use Scenarios.

Table 11. Sediment Yields for Select Catchments under Current and Pre-European Land Use Conditions.

| | TSS (kg/ha/yr) | | TN (kg/ha/yr) | | TP (kg/ha/yr) | |
|---|---|---|---|---|---|---|
| Subcatchment | 1770 | Current | 1770 | Current | 1770 | Current |
| Acheron 5 | 14 | 23 | 1.09 | 1.36 | 0.09 | 0.13 |
| Back 1 | 20 | 83 | 0.44 | 1.16 | 0.08 | 0.19 |
| Big 4 | 46 | 52 | 2.51 | 2.57 | 0.31 | 0.34 |
| Dairy 1 | 38 | 144 | 0.64 | 2.05 | 0.10 | 0.32 |
| Delatite 3 | 45 | 119 | 1.61 | 2.48 | 0.23 | 0.33 |
| Dry 1 | 27 | 94 | 0.72 | 1.48 | 0.12 | 0.23 |
| Ford 1 | 77 | 122 | 0.13 | 1.89 | 0.19 | 0.29 |
| Hughes 1 | 25 | 76 | 0.97 | 1.82 | 0.17 | 0.22 |
| Limestone 1 | 8 | 33 | 0.37 | 0.97 | 0.35 | 0.11 |
| Majors 8 | 19 | 55 | 0.49 | 0.85 | 0.09 | 0.13 |
| Mollisons 1 | 18 | 102 | 0.67 | 1.70 | 0.12 | 0.25 |
| Mid-Goulburn 6 | 21 | 83 | 0.56 | 1.42 | 0.08 | 0.21 |
| Upper Goulburn 11 | 28 | 37 | 1.76 | 1.96 | 0.18 | 0.23 |

To illustrate this further, Table 11 summarises TSS, TN and TP generation rates for select sub-catchments under both ‘current’ (2003) and ‘pre-European’ (1770) land use conditions.

## 7.2 Comparison with Future Land Use Conditions

EMSS-Goulburn can also be used to investigate future land use scenarios. This involves making assumptions about likely land use classifications that are reasonably likely to exist in 2020, and re-running the EMSS model with select catchment areas converted to potential future land uses.

To illustrate this capability, a future land use Forest Plantations scenario or ‘theme’ was run, based upon projections of incremental growth this industry up to the year 2020 made by Primary Industries Research Victoria (PIRVic). For the Forest Plantations theme, it is considered the existing land use of broadacre cropping and grazing is the most likely to change to forest plantations by 2020.

The Forest Plantations theme was based upon integrating climate (rainfall), slope and soil data, collected as a part of the PIRVic Land Resource Assessment (LRA) project for the Goulburn Broken region at 1:100 000 scale. Soil data from the Goulburn Broken LRA was used to formulate capability ratings for blue gum plantations (blue gum is used as the surrogate hardwood plantation timber). This was integrated with climate (rainfall) data and slope information, a DEM and rules generated to determine high and moderate capability. It is assumed that the entire high capability zone and 10% of the moderate zone will be used for timber plantations by 2020. A random sampling algorithm was utilised to select the 10% from the moderate zone. This was then added to the high capability zone to give a total of approximately 385km$^2$ of forestry plantation expansion by 2020.

Note that this EMSS-Goulburn scenario does not specifically model additional water quality benefits that might be achieved by spatial targeting of plantations within sub-catchments, and does not account for different water consumption at different stages of tree growth.

Note also that while other concurrent land use changes will no doubt also have an effect on water quality over the next 20 years, these changes have not been modelled in this scenario.

### 7.2.1 Load Predictions

Predicted pollutant loads generated using the Forest Plantations scenario described above are summarised in Table 12.

Table 12. EMSS-Goulburn Predicted Difference in Mean Annual Pollutant Loads Exported to the Lower Goulburn System Under Current and 2020 Forest Land Use Scenarios.

| | Current (t/yr) | 2020 ‘forest’ (t/yr) | % change |
|---|---|---|---|
| Mean TSS | 18,891 | 16,764 | -11% |
| Mean TN | 465 | 420 | -10% |
| Mean TP | 67 | 60 | -10% |

*On average, EMSS-Goulburn predicts that under the 'Forest Plantations' scenario, predicted mean TSS, TN and TP pollutant loads exported to the lower Goulburn system (below Goulburn Weir) would decrease by approximately 11%, 10% and 10%, respectively.*

It is also important to remember that while this is a substantial potential environmental benefit, it needs to be assessed against the economic and environmental cost of the likely reduction in catchment yield that could be expected as a result of widespread plantings of this magnitude.

***Comparison with Catchment Water Quality Targets***

*It is interesting to compare these predictions with catchment water quality targets. For instance, the Goulburn Broken Regional Catchment Strategy (GBCMA, 2003) lists a key target being to reduce phosphorous loads by 65% by the year 2016. This is to be achieved, in part, by reducing loads from dryland and diffuse sources by 25% over the same period.*

*EMSS-Goulburn predicts an accelerated program of plantation forestry in the Upper-Mid Goulburn Catchment would go a considerable way to meeting the catchment target for diffuse source phosphorous loads (roughly 10.4% of the 25% required). However, it is worth remembering that this is really a 'best case' scenario. In reality, it is highly unlikely that by 2016 all 'high potential' land will be given over to plantation forestry, and the total area of farm forestry projects will probably be significantly smaller.*

### 7.2.2 Relative Yields

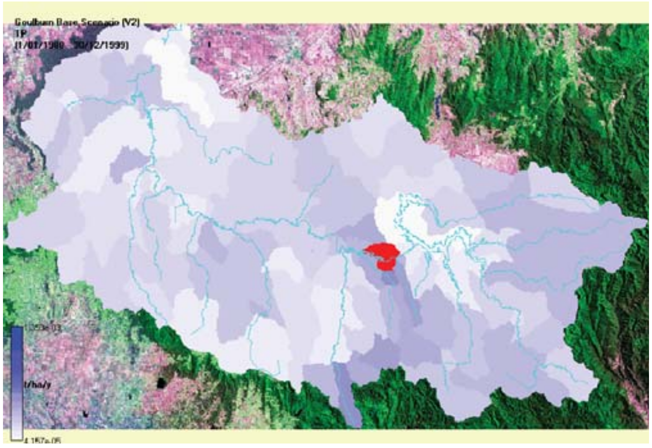
Again, while estimates of loads produced from catchments and sub-catchments during pre-European land use conditions are useful, they are not the complete picture. Figure 24 includes representations of TSS, TN and TP generation rates for sub-catchments under both 'current' (2003) and 'forest plantations' (2020) land use conditions.

To illustrate this further, Table 13 summarises TSS, TN and TP generation rates for select sub-catchments under both 'current' (2003) and 'forest' (2020) land use conditions.

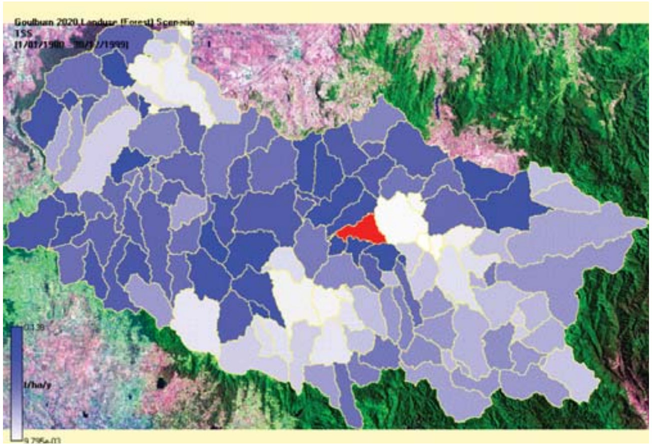
*Future TSS, TN and TP yields are predicted to be similar to current yields. Average pollutant yields are predicted to decrease by 5-20 % on average, though this varies between catchments and sub-catchments, depending on the spatial distribution of forestry activities.*

Table 13. Sediment Yields for Select Catchments Under Current and 2020 'forest' Land Use Conditions.

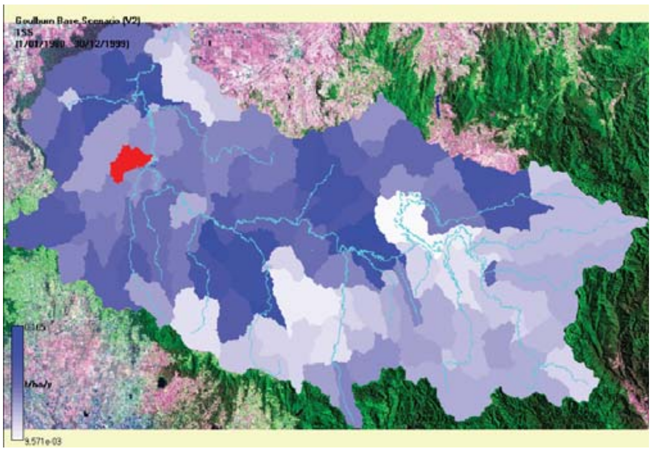
| | TSS (kg/ha/yr) | | TN (kg/ha/yr) | | TP (kg/ha/yr) | |
|---|---|---|---|---|---|---|
| Subcatchment | Current | 2020 | Current | 2020 | Current | 2020 |
| Acheron 5 | 23 | 20 | 1.36 | 1.27 | 0.13 | 0.11 |
| Back 1 | 83 | 81 | 1.16 | 1.14 | 0.19 | 0.18 |
| Big 4 | 52 | 57 | 2.57 | 2.80 | 0.34 | 0.68 |
| Dairy 1 | 144 | 133 | 2.05 | 1.91 | 0.32 | 0.29 |
| Delatite 3 | 119 | 114 | 2.48 | 2.41 | 0.33 | 0.33 |
| Dry 1 | 94 | 86 | 1.48 | 1.39 | 0.23 | 0.21 |
| Ford 1 | 122 | 114 | 1.89 | 1.79 | 0.29 | 0.27 |
| Hughes 1 | 76 | 72 | 1.82 | 1.75 | 0.22 | 0.22 |
| Limestone 1 | 33 | 24 | 0.97 | 0.77 | 0.11 | 0.08 |
| Majors 8 | 55 | 30 | 0.85 | 0.58 | 0.13 | 0.96 |
| Mollisons 1 | 102 | 97 | 1.70 | 1.64 | 0.25 | 0.24 |
| Mid-Goulburn 6 | 83 | 65 | 1.42 | 1.17 | 0.21 | 0.17 |
| Upper Goulburn 11 | 37 | 37 | 1.96 | 1.95 | 0.23 | 0.23 |



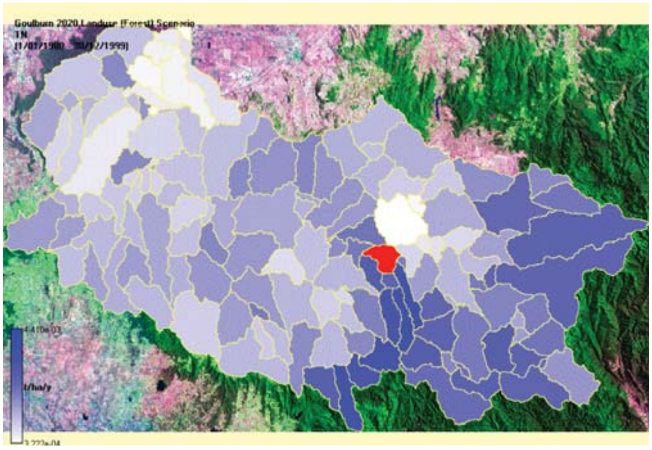
2003 - Max TSS ~165 kg/ha/yr (Stony 1)



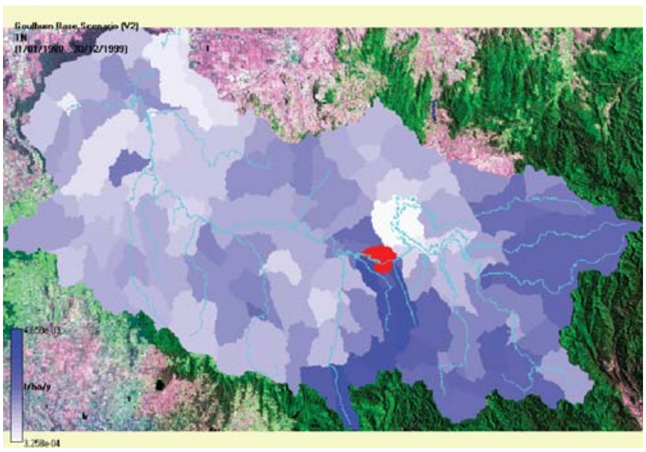
2020 Forest - Max TSS ~138 kg/ha/yr (Johnson 1)



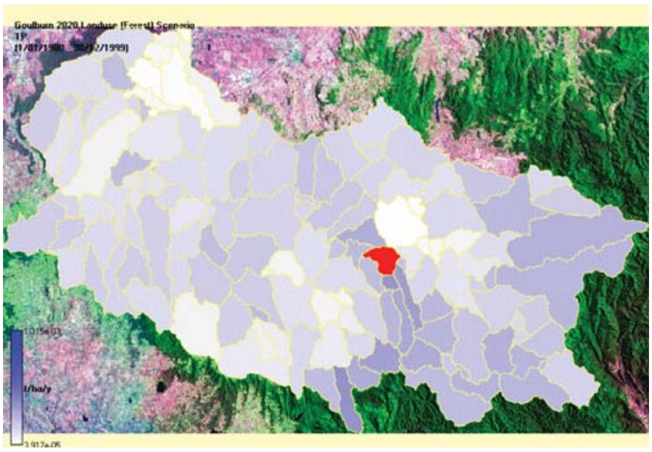
2003 - Max TN ~4.7 kg/ha/yr (Mid Goulburn 2)



2020 Forest - Max TN ~4.4 kg/ha/yr (Mid-Goulburn 2)



2003 - Max TP ~1.3 kg/ha/yr (Mid Goulburn 2)



2020 Forest - Max TP ~1.3 kg/ha/yr (Mid Goulburn 2)

Figure 24. Comparison of Sub-catchment Pollutant Yield Estimates for Current and 2020 'Forest' Land Use Scenarios.

# 8. Comparisons with Other Studies

In recent years several other studies of sediment and nutrient budgets for the Goulburn Catchment have been undertaken. Comparison with other studies is a useful reality check of EMSS-Goulburn model predictions and methods.

## 8.1 Comparison with SedNet Modelling of the Goulburn Catchment

Of particular relevance to EMSS-Goulburn modelling are two projects related to the mapping of sediment and nutrient exports from dryland catchments, recently undertaken by CSIRO Land and Water. One project, funded by the Murray-Darling Basin Commission (MDBC) was undertaken at the Murray-Darling Basin scale, but used the Goulburn Broken, Murrumbidgee and Namoi catchments as case studies. The other project, funded by the National Land and Water Resources Audit (NLWRA), was undertaken in the Goulburn Broken Catchment. There has been considerable interaction between the two projects. Both projects follow on from national scale mapping undertaken earlier for the Audit.

Both projects have used a budgeting (or mass balance) approach for predicting movement and export of sediments and nutrients within, and from, catchments. Each component of the budget is estimated using the SedNet model.

SedNet is a suite of programs used in a geographical information system (GIS) to make spatial, long term estimates of sediment and material budgets. SedNet was developed by the CRC for Catchment Hydrology, and has many similarities to the EMSS approach, although the conceptual models employed and underlying algorithms are different. An advantage of the SedNet approach is that it incorporates streambank erosion and an ability to evaluate the effect of spatially targeted riparian rehabilitation works, though unlike EMSS it does not readily model short term (monthly, weekly, daily) system processes with results reported as long-term averages.

Both SedNet studies are bigger in scale and cover larger areas than this study, which focuses upon the Goulburn River catchment areas upstream of Goulburn Weir. Nevertheless, a comparison of EMSS-Goulburn and SedNet model predictions is useful.

### 8.1.1 NLWRA Project

Findings of the NLWRA funded project which covers the whole of the Murray-Darling Basin area are reported in the report 'Summary of Sediment and Nutrient Budgets for the Murray-Darling Basin' (DeRose, *et. al.*, 2003).

Key findings are:

- 75% of the sediment contributed to the lowlands comes from approximately 20% of the upstream area;
- in most upland areas of the Murray Darling Basin current suspended sediment loads are more than 50 times predicted natural loads;
- in the southern part of the Murray Darling Basin riverbank and gully erosion are the dominant sediment sources;
- less than 1% of the sediment and attached nutrients entering rivers is exported from the Murray River mouth due to deposition along rivers, floodplains and within storages; and
- a higher proportion of TP and TN is exported due to dissolved phosphorus and nitrogen.

### 8.1.2 MDBC Project

Findings of the MDBC funded project, which covers the entire Goulburn Broken catchment area, are reported in the CSIRO technical report 'Regional Patterns of Erosion and Sediment and Nutrient Transport in the Goulburn-Broken River Catchment, Victoria', (De Rose *et. al.*, 2003a).

**Key findings of the project are:**

- gully erosion is the dominant erosion process, contributing about 57% of the total predicted sediment supply;
- gully erosion is dominant in a SW-NE trending zone through the middle of the catchment;
- river bank erosion also makes a significant contribution as a sediment source (36%);
- only 11% of the catchment has moderate to high surface erosion potential and much of this is restricted to steeper slopes on grazing land or to cropping areas;

- 42% of the sediment load delivered to rivers in any year is exported to the river mouth, the balance is stored in lakes, reservoirs and on floodplains;
- spatial patterns of nutrient supply and transport differ;
- TP loads are dominated by sediment bound sources from areas of gully and riverbank erosion; and
- TN is dominated by dissolved sources from agricultural areas, particularly irrigation areas.

A comparison of predicted long-term average TSS loads (kT/year) predicted by EMSS-Goulburn and the SedNet model is included Table 14.

Table 14. Comparison of EMSS-Goulburn and SedNet Modelling Project Predictions of TSS Loads at Key Monitoring Stations.

| Monitoring Station | Average TSS loads (kt/yr) | |
|---|---|---|
| | SedNet* | EMSS |
| 405201 – Goulburn River at Trawool | 32 | 36 |
| 405212 – Sunday Creek at Tallarook | 6 | 6 |
| 405240 – Sugarloaf Creek at Ash Bridge | 4 | 3 |
| 405231 – King Parrot Creek at Flowerdale | 0.9 | 0.5 |
| 405205 – Murrindindi River at Colemans | 0.6 | 0.3 |
| 405209 – Acheron River at Taggerty | 4 | 3 |
| 405203 – Goulburn River at Eildon | 6 | 0.6 |
| 405227 – Big River at Jamieson | 4 | 3 |
| 405264 – Big River at Frenchmans | 2 | 2 |
| 405219 – Goulburn River at Dohertys | 3 | 3 |
| 405214 – Delatite River at Tonga Bridge | 4 | 3 |
| 405251 – Brankeet Creek at Ancona | 0.6 | 0.7 |

* from De Rose *et. al.*, 2003a

In general terms, EMSS-Goulburn predictions and SedNet predictions of sediment load appear to correlate very well. Similar correlation is apparent for TN and TP predictions. A notable exception is the predicted loads for the gauging station situated on the Goulburn River at Eildon (site 405203). This may be due to either SedNet or EMSS-Goulburn miscalculating the effect of the highly regulated flows at this point, or possibly differences in application of reservoir storage model trapping efficiency. Further investigation would be advisable, and results at this location should be treated with caution.

However, given that SedNet and EMSS are different models and have inherently different underlying assumptions, the close correlation of predicted loads at most locations provides added confidence in the predictive capability of both modelling systems.

## 8.2 Comparison with AEAM and CMSS Modelling

The application of two early models to the Goulburn-Broken Basin in the early 1990s is documented in a report prepared by Water Ecoscience 'The Use of Decision Support Systems to Assess Nutrient Export from the Goulburn-Broken Basin' (Water Ecoscience, 1994). Two very different models, the Adaptive Environmental Assessment and Management (AEAM) process, and the Catchment Management Support System (CMSS) were applied to the Goulburn-Broken Basin as part of early attempts by the Goulburn-Broken Water Quality Working Group to establish a strategy to reduce nutrient export to surface waters.

### AEAM

In some ways AEAM is not a particularly sophisticated computer 'model', but more a process used for the development of management policies and options for a variety of issues, including catchment management, ecological and economic processes and resource management. AEAM depends on the output from workshops held to enable stakeholders to identify key issues related to a particular problem. AEAM works by developing communication links between stakeholders and collating existing information sets, then creating a computer simulation of an area to allow testing of policy and management options.

As such, the AEAM 'model' is very different to the EMSS-Goulburn model, and direct comparison between the models is not really appropriate. AEAM model only gives predictions for one water quality monitoring station, namely the Goulburn River at Trawool. A comparison is included in Table 15, and shows close agreement with EMSS-Goulburn modelling predictions for TP, but a substantial difference for TN predictions.

Table 15. Comparison of EMSS-Goulburn and AEAM Modelling Predictions of Nutrient Loads at Key Monitoring Stations.

| Monitoring Station | Average Loads (t/yr) | | | |
|---|---|---|---|---|
| | TN | | TP | |
| | AEAM | EMSS | AEAM | EMSS |
| 405201 – Goulburn River at Trawool | 1300 | 656 | 80 | 91 |

AEAM studies also found that the major sources of nutrients in the Goulburn-Broken catchment to be:

- runoff from dryland agricultural and forest areas during high flow periods
- irrigation drainage during high and low rainfall periods
- sewage effluent during low flow periods

Other sources (septic tanks, trout farms, urban stormwater) did not appear to contribute high nutrient loads on a regional scale, but were recognised to be significant at a local level.

**CMSS**

CMSS is a software application developed in the early 1990s and is based upon nutrient export data producing annual loads. Nutrient loads are represented as baseloads (nutrient load exported from a particular region of a catchment) and assimilated loads (loads transported through surface waters). The purpose of CMSS is to use these processes to identify sources of elevated nutrient generation and areas which reduce surface water nutrients via natural assimilation. At the time of the report CMSS was still under development.

A comparison of select CMSS and EMSS-Goulburn model outputs is included in Table 16. Direct comparison is difficult given differing definitions of catchment and sub-catchments areas. CMSS predictions show reasonable agreement with EMSS-Goulburn modelling predictions in some catchments, though substantial differences are noted in other catchments.

Table 16. Comparison of EMSS-Goulburn and CMSS Modelling Predictions.

| Catchment Region* | Average Loads (kg/ha/yr) | | | |
|---|---|---|---|---|
| | TN | | TP | |
| | CMSS | EMSS | CMSS | EMSS |
| Howqua/ Jamieson Rivers | 2.047 | 2.43/ 2.56 | 0.211 | 0.27/ 0.34 |
| Delatite River | 2.575 | 2.04 | 0.269 | 0.26 |
| Yea/ King Parrot Creeks | 2.652 | 1.71/ 1.36 | 0.283 | 0.18/ 0.23 |
| Acheron/ Snobs Creeks | 2.552 | 2.19/ 3.47 | 0.296 | 0.26/0 0.47 |
| Majors Creek | 2.579 | 1.24 | 0.278 | 0.19 |
| Hughes Creek | 2.802 | 1.49 | 0.309 | 0.20 |
| Sunday/ Sugarloaf Creeks | 2.961 | 1.37 | 0.370 | 0.20 |

*from Water Ecoscience 1999

## 8.3 Comparison with 'Measured' Load Calculations

Estimates of 'measured' pollutant loads can be made relatively easily using routine monitoring and observed daily flow rates, albeit with a high degree of uncertainty. Some validation estimates of this type have been done as a part of this report and are included in Appendix C.

Similarly, a report prepared for Goulburn-Murray Water by Australian Water Technology 'Nutrients and Suspended Solids Load Calculations for VWQMN sites in Goulburn-Broken Catchment for 1999' (AWT, 2000) reported results of load calculations made using this method for select VWQMN monitoring sites in the Goulburn Catchment during 1999.

More specifically, the methodology employed includes use of routine monthly water quality monitoring results (TN, TP and TSS concentrations) and mean daily flow readings for each month for select VWQMN sites in the Goulburn-Broken catchment. Loads were calculated for each month as follows.

Load (kg/month) = Concentration Reading for the month (mg/L) x Mean Daily Flow for the month (ML/d) x No. of days in the month

For months with no concentration, monthly load was taken as zero. The annual load was then estimated as the sum of the calculated monthly load. Therefore where there is missing data the total loads were underestimated.

A comparison of reported estimated average loads calculated by AWT, and loads predicted by EMSS-Goulburn for the year 1999 are included Table 17.

EMSS predictions generally exceed those calculated manually by AWT, usually quite substantially. While this might indicate a tendency of EMSS to overestimate pollutant loads, it is thought more likely that manual calculations are actually underestimating the pollutant loads. Errors associated with manual calculations are substantial, and manual calculations usually tend to underestimate loads. This happens because collection of routine water quality samples rarely coincides with peak flow events, the time when the majority of pollutants are mobilised, which produces relatively large errors in the estimation of river loads. Further, these estimates are based on mean daily flow data for each month, which will further increase the margin for error given the large fluctuations in flow observed at most locations.

An exception is site 405203 (Goulburn River at Eildon), just downstream of Lake Eildon. Here, TSS, TN and TP predictions substantially exceed those of EMSS Goulburn. It may be that the simple storage model in EMSS somewhat overestimates the trapping efficiency of Lake Eildon, in which case pollutants exported from the catchment are likely to be higher than EMSS-Goulburn estimates. Alternatively, the AWT calculations may not accurately reflect the variability of the regulated outflows from Lake Eildon, which vary substantially. Further investigation is warranted, and caution advisable until this apparent discrepancy is further clarified.

Table 17. Comparison of EMSS-Goulburn and Manually Calculated Predictions of Pollutant Loads - 1999.

| **Monitoring Station** | **TSS loads - 1999 (T/yr)** | | **TN loads - 1999 (kg/yr)** | | **TP loads - 1999 (kg/yr)** | |
|---|---|---|---|---|---|---|
| | AWT | EMSS | AWT | EMSS | AWT | EMSS |
| 405231 – King Parrot Creek at Flowerdale | 86 | 386 | 9732 | 13244 | 305 | 1467 |
| 405205 – Murrindindi River at Colemans | 230 | 235 | 12726 | 14223 | 614 | 1545 |
| 405209 – Acheron River at Taggerty | 1189 | 1905 | 67645 | 92985 | 4502 | 11058 |
| 405203 – Goulburn River at Eildon | 3411 | 859 | 314774 | 22020 | 11639 | 3561 |
| 405264 – Big River at Frenchman Ck | 332 | 1050 | 20208 | 40590 | 1069 | 5417 |
| 405219 – Goulburn River at Dohertys | 718 | 1561 | 21181 | 76163 | 2959 | 10473 |
| 405214 – Delatite River at Tonga Bridge | 279 | 2401 | 24821 | 62306 | 727 | 7994 |
| 405251 – Brankeet Creek at Ancona | 50 | 647 | 8467 | 11688 | 516 | 1763 |

# 9. Model Application - Management Scenarios

Users of EMSS-Goulburn can mimic various management scenarios (land use change, point source management, riparian management etc.) and investigate the resultant impacts on sediment and nutrient load predictions. Natural resource managers can use this facility to identify and prioritise management actions which are likely to have the greatest (and the least) impact on water quality.

To illustrate this capability, a selection of management actions has been applied to the current baseline scenario (current land use data, 1980 – 1999 climatic data). Results are discussed as follows.

## 9.1 Land Use change

One of the most useful potential applications of EMSS is to investigate and predict the likely effects of changes to land use practices on surface water pollutant generation rates and loads. This can be done either at whole of catchment scale, as was done in Section 7, or sub-catchment scale.

For sub-catchments scale investigations, the process involves applying simple 'rules' to catchments and sub-catchments to mimic the effect of land use change.

For example, a typical scenario might involve changing the relative proportions of different land use classifications such as 'Grazing' and, say, 'Managed Forest' or 'Broadacre Agriculture' land uses in a sub-catchment, re-running EMSS-Goulburn and comparing the effects on predictions of long-term average pollutant loads generated.

While this analysis is perhaps overly simplistic, and ignores the effect of spatial targeting of land use changes within sub-catchments, this tool can with relative ease give an approximate indication of the magnitude of change that could be expected under various changes in land use.

This application of EMSS-Goulburn could prove useful for working with Local Government for assessing the likely water quality impacts of land use change that could be expected to result from large scale re-zoning proposals.

**Case Study: Land use change in Ford 1 sub-catchment – increased rural residential land**

Ford 1 sub-catchment is a relatively large sub-catchment located in the Ford Creek catchment upstream of Lake Eildon. Ford Creek flows through the sub-catchment, which incorporates the township of Mansfield and surrounding areas.

Current land use comprises approximately 83% 'Grazing' land use, a significant 'Urban' (6.5%) and 'Rural Residential' (~5.9%) land uses, with the remainder of the catchment comprising a variety of land use classifications ('Native Bush' etc).

Changes were applied to Ford 1 sub-catchment, whereby the proportions of the catchment comprising 'Rural Residential' land use was increased to 15%, and 'Urban' land use was increased to 10%, at the expense of 'Grazing' which was decreased to ~73%. Approximate changes in yields and loads estimated by EMSS are as follows:

**Approx. yields - current land use**

TSS ~ 1,285 t/yr
TN ~ 20 t/yr
TN ~ 20 t/yr

**Approx. yields - modified land use**

TSS ~ 1,376 t/yr
TN ~ 21.4 t/yr
TN ~ 3.2 t/yr

This simple analysis indicates that a land use change of this type and magnitude, perhaps not entirely unreasonable given recent trends, would likely only result in a relatively modest increase (6-7%) in average pollutant load export rates from this sub-catchment.

## 9.2 Riparian Management

EMSS-Goulburn has a capacity to be used to investigate the likely effects of riparian zone management on water quality. In theory, EMSS users can simulate changes to the extent and quality of riparian vegetation in the catchment or sub-catchments of interest, and assess the likely magnitude of resultant changes to pollutant loads (sediments and nutrients) entering the stream network.

For each riparian management 'treatment' applied, users can ascribe, for each stream order:

- the length (%) of the stream within each sub-catchment to be treated;
- the effectiveness of the management within that sub-catchment by manipulating the pollutant loading rate threshold, and pollutant loading rate maximum buffer capacity.

Again, this will be a useful tool for natural resource managers, local organisations and individuals seeking to prioritise works programs to improve water quality, both locally and at whole of catchment scale.

It is also important to note that EMSS-Goulburn makes no assessment of the effect of riparian zone management on streambank erosion. Further, EMSS-Goulburn makes no assessment of the biodiversity or other ecological habitat benefits of riparian zone management actions.

Further, while EMSS may, in theory, provide a useful tool for partially quantifying the effectiveness of riparian buffers on water quality, it does not spatially differentiate between riparian works on different reaches of stream within a sub-catchment. Other tools such as SedNet could be used provide a better synoptic assessment of the likely consequences of targeted riparian rehabilitation on river loads.

In practice, the sediment and nutrient delivery parameters used in the riparian zone model calculations need further evaluation and validation using a range of data. These calculations have not yet been done to provide an adequate level of confidence in model outputs, and as such, results of riparian zone management scenarios are not reported in this document.

Many of these potential improvements are likely to be addressed with the forthcoming development of an enhanced version of EMSS (E2), as discussed previously.

### 9.3 Point Source Management

EMSS-Goulburn can also be used to investigate the relative and cumulative contributions of point source impacts on water quality, and the likely effect of point source management. A number of existing point sources have been included in the model, as discussed in

Section 4.5.1.6. EMSS-Goulburn can be used to easily assess the likely impact of additional pollutant point sources, or reduction of existing point sources on either a sub-catchments and whole of catchment scale.

# 10. Future Developments

## 10.1 Upgraded EMSS (E2)

A future development of interest is the expected forthcoming release by the CRC for Catchment Hydrology of a revised and upgraded version of EMSS. Release of the upgraded modelling system, tentatively called 'E2' is expected in late 2005. E2 is expected to incorporate a number of features, including:

- visualisation of model uncertainty and error;
- extractions and basic water management modelling capacity;
- local scale EMSS;
- stochastic data options; and
- various minor software 'bug' fixes.

### 10.1.1 Visualisation of Model Uncertainty and Error

Considerable discussion is given in this report to the issues of model uncertainty and confidence limits. The current version of EMSS does not calculate or report uncertainty in model outputs and predictions. E2 is expected to incorporate a capacity to undertake multiple modelling runs (e.g. Monte Carlo approaches), and represent model uncertainty and confidence limits on model graphical outputs.

### 10.1.2 Water Extractions

At present EMSS does not consider the effects of extractions (pumping) from rivers and streams. E2 is expected to incorporate a capacity to incorporate consideration of the effect of significant extractions such as high flow irrigation pumping or town supply off-takes on flows releases and pollutant export rates as a daily time series.

### 10.1.3 Local Scale EMSS

A potentially useful, logical extension of building a catchment scale EMSS would be an ability to 'drill down' to a finer, local scale. This would involve construction of a more detailed model for a particular sub-catchment, or other comparable area of interest, and enable more detailed investigation and assessment of areas of concern identified in the larger, whole of catchment scale EMSS-Goulburn. This finer scale information would be particularly useful to agencies, groups and individuals looking to target works programs, monitoring programs etc. for best effect at a local scale.

At present, construction of local scale EMSS models is not practicable due to software limitations. Smaller scale modelling is also constrained by the availability of adequate data. While it may soon be physically possible to build smaller scale catchment models, model outputs would be constrained somewhat by the likely scarcity of data to calibrate these models. Nevertheless, a capacity to build finer scale models would be useful.

## 10.2 Application of other Toolkit Models

Part of the original design specification for the EMSS when it was originally conceived was that it should be designed as a 'living tool' that can be used to harness and integrate a range of other predictive models as they become available. Those other models of most interest to the MSWQS include pathogen models and a salt balance models.

### 10.2.1 Salt Balance Models

Project 2C of the current CRC for Catchment Hydrology project portfolio is entitled 'Predicting Salt Movement in Catchments'. This project is building on previous work and aims to deliver a capacity to identify salinity hotspots in catchments and predict the effectiveness of revegetation in reducing salt loads into rivers. The project aims to deliver a modelling tool that can be used to set priorities on which catchments to revegetate, and allow predictions of salt loads for water quality target setting purposes.

Application of this sort of tool to the Upper-Mid Goulburn Catchment would be of interest, and would compliment previous work done in priority areas of concern of the catchment.

### 10.2.2 Pathogen Models

Similarly, a project has recently been initiated by the Cooperative Research Centre for Water Quality and Treatment (CRCWQ&T) involving the development of a catchment pathogen modelling project. CRCWQ&T research program 2.1.0.3 'Development Of Pathogen and Nom Modules for Integration with

CRC for Catchment Hydrology's Catchment Modelling Toolkit' aims to develop pathogen and natural organic matter models that integrate knowledge developed on drinking water quality processes collected by several CRCWQ&T catchment program projects into existing allied CRC for Catchment Hydrology modelling frameworks (i.e. E2).

If successful, application of these models will allow catchment managers to make quantitative assessments of pathogen loads, fate and transport in catchments. The project commenced in 2003 and has a four year time frame, so unfortunately project outputs may not be available for integration into the current EMSS-Goulburn for some time.

#### 10.2.3 SedNet

As discussed previously, another useful 'tool' that can be used to improve our understanding of catchment sediment accounting and sediment budgets is the SedNet model which was also developed by the CRC for Catchment Hydrology. While SedNet does not incorporate a daily time-step, which to some extent limits its predictive capability, SedNet is able to consider the major sources, stores, and fluxes of material within a stream network such as streambank erosion and floodplain deposition (as long term averages).

The different conceptual models and modelling techniques employed by SedNet and EMSS will also mean that application of SedNet would provide a useful 'sanity check' of EMSS predictions, and visa versa.

Alternatively, it is anticipated that E2 may also incorporate some of the more useful features of Sednet currently missing from EMSS.

### 10.3 Storage Models

As discussed previously, the capabilities of the storage process model currently incorporated in EMSS-Goulburn (Mandrill) are limited. Algorithms representing storage processes in the model are highly simplified, and do not give an accurate representation of the complex, real life storage hydrodynamic processes.

It is intended to construct sophisticated models to enable a better understanding of hydrodynamic and ecological processes on pollutant fate and transport in major storages, including Lake Eildon. Outputs from catchment models (EMSS-Goulburn) will likely be used as a data source for the storage models.

### 10.4 Further Data Collection

#### 10.4.1 Water Quality Data

While the Upper-Mid Goulburn Catchment is relatively data rich compared with many other equivalent Victorian catchments, the extent of the stream network in the Upper-Mid Goulburn Catchment means that water quality data in the Upper-Mid Goulburn Catchment is relatively scarce. This is a significant problem that hampers the development of an understanding of catchment processes. Current EMSS-Goulburn predictions of sediment and nutrient loads have a very large degree of uncertainty associated with them partly because of this lack of water quality data for calibration/ verification purposes. As such, our confidence in model outputs is significantly constrained.

Given increasing water quality concerns, there is a need for further catchment water quality monitoring to calibrate and validate EMSS-Goulburn predictions of pollutant loads and yields. Collection of additional monitoring data (i.e. TSS, TN and TP) would greatly enhance the reliability of the model.

Any additional EMC data would be useful. However, it would be far more useful to collect monitoring data from local catchments with one predominant land use (e.g. a predominantly 'Grazing' source catchment or a predominantly 'Managed Forest' source catchment etc.). Data collected from 'mixed' catchments cannot be accurately used for calibration and validation elsewhere.

Collection of EMC data (i.e. data collected over storm events) would be particularly useful. The monitoring of EMC is more important than the monitoring of DWC for pollutant load estimation (Chiew *et al.*, 2002b). This is because EMC is higher than DWC, the variability of EMC values is higher and runoff volumes are bigger during storm events. As such, the bulk of pollutant loads are transported during storm events.

To interpret results with any confidence, numerous samples need to be collected. A minimum of ten EMC and ten DWC samples are required from any given sampling location to be able to interpret results with any confidence. Of greater benefit would be the collection of in situ, real time monitoring data over extended periods. Permanent or semi-permanent data loggers installed at key locations in the catchment would be an invaluable data source that would greatly aid modelling efforts.

While EMSS-Goulburn could be used to assist with the selection of potential monitoring locations by highlighting priority sub-catchments, monitoring site selection requires on-ground inspection combined with an understanding of the hydrological characteristics of that particular stream.

### 10.4.2 Erosion Hazard Data

EMSS-Goulburn estimation of sediment generation rates and loads would be greatly enhanced by the availability of finer scale gully density and hillslope erosion potential mapping, with data represented by a larger number of classes consistent with the continuous spatial transitioning of erosion in the landscape.

### 10.4.3 Additional Climatic Data

The current version of EMSS-Goulburn has been run using twenty years of climatic data, commencing in the year 1980. Earlier data is available and could be used to enhance the model. Provided the additional data processing requirements did not slow down and hamper model performance unduly, there is no reason why this data could not be used. This would give greater statistical confidence to EMSS-Goulburn predictions of mean pollutant loads and specific yields.

### 10.4.4 Additional Point Source Data

Limited point source information is included in the current version of EMSS-Goulburn. As of December 2003 a total of seventeen EPA discharge licences were current for the Upper-Mid Goulburn Catchment. These point sources information have been added to EMSS-Goulburn.

Numerous other pollutant point sources are likely to exist in the catchment, but reliable information on these has not been sourced to date. Consideration was also given to inclusion of point source data compiled used during the development of the original regional catchment strategy (GHD, 1995a and 1995b), though this data is now ten years old and thought likely to be outdated and inaccurate.

Better up to date information on the existence and nature of potential pollutant point sources such as intensive animal industries, wastewater treatment facilities, septic systems etc. would improve model predictions.

# 11. Conclusion

This report provides an introduction to a new surface water quality model built for the Upper-Mid Goulburn Catchment. Specifically it has:

- outlined the aims and objectives of the Goulburn-Murray Water Major Storages Water Quality Study;
- documented the construction of a catchment surface water quality model for the Upper-Mid Goulburn Catchment;
- reported preliminary model outputs;
- acknowledged the uncertainties and limitations of the EMSS modelling process;
- illustrated the potential of EMSS to be used as a tool to predict likely impacts of catchment management actions on water quality; and
- outlined likely future developments of the EMSS-Goulburn model.

**So What Have we Found?**

Key findings of this preliminary investigation that should be considered by managers of the Upper-Mid Goulburn Catchment are as follows.

- On a 'whole catchment' scale, average long-term (1980 – 1999) pollutant generation rates from the catchment upstream of Goulburn Weir are 75,00 t/yr (TSS), 1,800 t/yr (TN) and 250 t/yr (TP). These predictions do not include pollutants trapped within the 'in-line' storages Lake Eildon and Goulburn Weir, or deposited in rivers, streams and floodplains in transit. Estimated long-term average pollutant loads actually exported to the Lower Goulburn river system (i.e. below Goulburn Weir) are approximately:

**TSS 19,900 t/yr**

**TN 480 t/yr**

**TP 70 t/yr**

Although these values are dependant on the estimated trapping efficiencies of storages and these are uncertain.

- Pollutant generation rates vary considerably both in space and time, and are highly dependent upon climatic conditions in the Upper-Mid Goulburn Catchment.
- Contrary to expectations, many of the catchments and sub-catchments with the highest nutrient production rates appear to be the heavily vegetated, largely undisturbed catchments in the south-eastern parts of the Upper-Mid Goulburn Catchment. This is most likely because these are steep areas of high rainfall and runoff.
- EMSS-Goulburn can be used to help identify catchments and sub-catchments which, in a relative sense, should be the focus of future catchment management activities for water quality improvements (erosion control, revegetation, riparian works etc.) and/or further investigation in the Upper-Mid Goulburn Catchment.
- Lake Eildon and Goulburn Weir act as sediment and nutrient traps, trapping most of the pollutant loads entering from upper catchment rivers and streams. Lake Eildon is particularly efficient, **trapping approximately 96-97% of pollutants** entering the storage.
- Most pollutant load is generated during wetter climatic periods as high flow events over short duration flow periods. As a general rule, EMSS-Goulburn predicts that **pollutant loads generated during drier years are of the order of 5-30 % of those generated during the wetter years.** Any water quality monitoring program which does not capture 'event' data will not be truly representative of actual pollutant loads exported, and conclusions drawn from this data alone will be misleading.
- Mean pollutant loads exported from the catchment in pre-European times are estimated at approximately 27,080 t/yr (TSS), 1,100 t/yr (TN) and 136 t/yr (TP). Pollutant loads generated under current land use conditions have increased by approximately 180% (TSS), 67% (TN) and 88% (TP), from loads that would have been generated under pre-European conditions. However, since pre-European times, mean pollutant loads exported to the lower Goulburn system below Goulburn Weir have, on average, **actually decreased by approximately 30% (TSS), 58% (TN) and 51% (TP)**, respectively, due to pollutant trapping within Lake Eildon and Goulburn Weir.

- Likewise, **pre-European TSS, TN and TP yields were typically much lower than current rates, in many cases less than 50% of current rates**. The distribution of sub-catchments with relatively high and relatively low contributions has also changed substantially.
- Under a 'Forest Plantations' future land use scenario where all land with 'high' potential for hardwood (bluegum) plantation forestry and some of the 'moderate' potential land is converted to plantations, **average pollutant yields are predicted to decrease by 5-20 %**, though this varies between catchments and sub-catchments, depending on the spatial distribution of forestry activities. Predicted mean pollutant loads exported to the lower Goulburn system (below Goulburn Weir) would decrease by approximately 11.2% (TSS), 9.7% (TN) and 10.4% (TP), respectively.

Of course, the water quality problems, issues and management actions that could be investigated by EMSS-Goulburn are many and varied, and a comprehensive analysis of all is beyond the scope of this preliminary document. Also, catchment managers will not just be concerned with water quality issues, but will have to consider the multiple benefits and costs of management actions and programs, and weigh up the priorities of the Upper-Mid Goulburn Catchment against those of other catchments.

**Where To From Here?**

Time and budget constraints permitting, it is desirable that as additional data becomes available it should be progressively added to this model, to improve and refine model predictions. Of highest priority for managers should be the establishment of targeted surface water quality monitoring programs for the catchment.

Similarly, the EMSS modelling system has been replaced with E2 and so upgrading the current EMSS-Goulburn model with E2 would provide enhanced functionality and greater confidence in model outputs.

While additional data and refined software applications will improve EMSS-Goulburn and extend the scope of its use, the model in its current form still provides a highly useful tool for improving our knowledge of catchment processes and their impacts on water quality in the Upper-Mid Goulburn Catchment. In EMSS-Goulburn we have a tool which can be used to assist the prioritisation and prediction of the impacts of catchment management actions on water quality.

EMSS-Goulburn (and E2) has the potential to be of great assistance to organisations such as the Goulburn-Broken Catchment Management Authority in reviewing, setting and evaluating performance against catchment and water quality strategy management action targets. Local area planning processes, Landcare program planning and other related activities could also benefit from EMSS-Goulburn outputs. EMSS-Goulburn may also prove to be useful for planning and evaluating water quality monitoring programs, and partner organisations such as Goulburn Valley Water may have an interest in using EMSS-Goulburn as a tool to aid risk ranking/prioritization processes. EMSS-Goulburn is also seen as being used as a tool to assist local government. The predictive capability of the model can also be used to provide scientifically based input to large scale planning processes, such as relevant planning scheme reviews and amendments.

Ultimately, it is envisaged that there will be a linking of EMSS-Goulburn with other models from the CRC for Catchment Hydrology's Catchment Modelling Toolkit to better predict the impacts of management scenarios on downstream storage water quality, water allocations, environmental flows and end of valley targets.

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## Appendix A – Input Data Summary

The following Goulburn-EMSS input data sources have been arranged in accord with the EMSS User Guide (Cuddy 2003).

### Spatial Data - Grid Format

| **Digital elevation model (DEM)** | |
|---|---|
| Layer | DEM100 |
| Description | Goulburn-EMSS digital elevation model (raster) |
| Scale | 1:100 000 |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Layer | DEM25BUF |
| Description | Digital elevation model at 1:25 000 scale |
| Scale | 1:25 000 |
| Custodian | PIRVic Bendigo, DPI |
| Data processing details: | |
| • Grid resampled from 1:25 000 to 1:100 000 | |

| **Storages raster** | |
|---|---|
| Layer | STORAGES |
| Description | Goulburn-EMSS storage (raster) |
| Scale | 1:100 000 |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Layer | HYDROP100 |
| Description | Hydrological features (polygons) |
| Scale | 1:100 000 |
| Custodian | Land Victoria, DSE |
| Data processing details: | |
| • Source data converted from vector (shapefile) format to grid format<br>• Waterbodies other than Eildon and Goulburn cropped from layer | |

| **Land uses raster (existing land use)** | |
|---|---|
| Layer | LANDUSE100 |
| Description | Goulburn-EMSS land use (raster) |
| Scale | 1:100 000 |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Layer | LU20_HS |
| Description | Landuse mapping (polygons) |
| Scale | 1:100 000 |
| Custodian | PIRVic Tatura, DPI |
| Data processing details: | |
| • Reclassified from Australian Land Use Mapping (ALUM) version 4 to EMSS<br>• Source data converted from vector (shapefile) format to grid format | |

| **Catchments raster** | | | |
|---|---|---|---|
| Layer | CATCHMENT | | |
| Description | Goulburn-EMSS catchment (raster) | | |
| Scale | | | |
| Custodian | PIRVic Bendigo, DPI | | |
| Source data: | | | |
| (1) Layer | CATCH100 | (2) Layer | SUBCATCH100 |
| (1) Description | Goulburn-EMSS sub-catchments (raster) | (2) Description | Goulburn Catchments (polygons) |
| (1) Scale | 1:100 000 | (2) Scale | 1:25 000 |
| (1) Custodian | PIRVic Bendigo, DPI | (2) Custodian | PIRVic Bendigo, DPI |
| Data processing details: | | | |
| • Subcatchments (1) aggregated to catchments, based on catchment layer (2) | | | |

| **Regionalisation raster** | |
|---|---|
| Layer | REGION100 |
| Description | Goulburn-EMSS hydrological regions (raster) |
| Scale | |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Layer | CATCH100 |
| Description | Goulburn-EMSS sub-catchments (raster) |
| Scale | 1:100 000 |
| Custodian | PIRVic Bendigo, DPI |
| Data processing details: | |
| • Subcatchments aggregated to EMSS hydrological regions | |

| **Gully density raster** | |
|---|---|
| Layer | GULLYDENSITY |
| Description | Goulburn-EMSS gully density (raster) |
| Scale | 9” grid resolution (approximately 250 m) |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Layer | GULLYDENS |
| Description | Erosion gully density (raster) |
| Scale | 9” grid resolution (approximately 250 m) |
| Custodian | CSIRO, Land & Water, Black Mountain |
| Data processing details: | |
| • Source data re-sampled from 265 m cell size to 100 m cell size | |

| **USLE raster** | |
|---|---|
| Layer | USLE |
| Description | Goulburn-EMSS hill slope erosion (raster) |
| Scale | 9” grid resolution (approximately 250 m) |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Layer | GULLYDENS |
| Description | Erosion gully density (raster) |
| Scale | 9” grid resolution (approximately 250 m) |
| Custodian | CSIRO, Land & Water, Black Mountain |
| Data processing details: | |
| • Source data resampled from 265 m cell size to 100 m cell size | |

| **Background image** | |
|---|---|
| Layer | GLBRN_CLIP3 |
| Description | Goulburn-EMSS background image (raster) |
| Scale | |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Layer | VIC-MOSAIC_AGD55N & VIC_MOSAIC_AGD55S |
| Description | 1995 LANDSAT Imagery for use at 1:100 000 |
| Scale | 30 metre pixels (1:100 000) |
| Custodian | Land Victoria, DSE |
| Data processing details: | |
| • TIF images clipped and converted to JPEG format using ENVI version 4 | |

## Spatial Data – Vector Format

| **Catchments** | |
|---|---|
| Layer | CATCHMENT |
| Description | Goulburn-EMSS catchment (polygon) |
| Scale | |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Layer | CATCHMENT |
| Description | Goulburn-EMSS catchment (raster) |
| Scale | 1:100 000 |
| Custodian | PIRVic Bendigo, DPI |
| Data processing details: | |
| • Source data converted from grid format to vector (shapefile) format | |

| **Sub catchments** | |
|---|---|
| Layer | CATCH100 |
| Description | Goulburn-EMSS sub catchments (polygon) |
| Scale | |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Layer | CATCH100 |
| Description | Goulburn-EMSS sub catchments (raster) |
| Scale | 1:100 000 |
| Custodian | PIRVic Bendigo, DPI |
| Data processing details: | |
| • Source data converted from grid format to vector (shapefile) format<br>• Sub catchments named according to parent catchment names | |

| **Streams** | |
|---|---|
| Layer | STREAMS |
| Description | Goulburn-EMSS streams (line) |
| Scale | 1:100 000 |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Layer | HYDRO100 |
| Description | Linear hydrological features |
| Scale | 1:100 000 |
| Custodian | Land Victoria, DSE |
| Data processing details: | |
| • Minor tributaries removed | |

| **Roads** | |
|---|---|
| Layer | ROADS |
| Description | Goulburn-EMSS roads (line) |
| Scale | 1:100 000 |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Layer | ROAD100 |
| Description | Roads |
| Scale | 1:100 000 |
| Custodian | Land Victoria, DSE |
| Data processing details: | |
| • Minor roads removed | |

| **Towns** | |
|---|---|
| Layer | TOWNS |
| Description | Goulburn-EMSS towns (line) |
| Scale | 1:100 000 |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Layer | LOCN |
| Description | Place names |
| Scale | 1:100 000 |
| Custodian | Land Victoria, DSE |
| Data processing details: | |
| • Minor towns removed | |

## Climate Data

| **Potential Evapotranspiration (PET)** | |
|---|---|
| Description | Goulburn-EMSS PET time series |
| Units | mm |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Layer | AP_JAN; AP_FEB; AP_MAR; …; AP_DEC |
| Description | Monthly average PET maps for Australia |
| Scale | 10 km grid resolution |
| Custodian | BOM |
| Data processing details: | |
| • Time series created from monthly average raster maps | |

| **Rainfall** | |
|---|---|
| Description | Goulburn-EMSS rainfall time series |
| Units | mm |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Description | SILO gridded rainfall time series |
| Scale | 0.05’ grid resolution |
| Units | mm |
| Custodian | QDNRM |
| Data processing details: | |
| • Time series collated from SILO grid time series | |

| **Flow files** | |
|---|---|
| Description | Goulburn-EMSS daily flow time series |
| Units | m3/d |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Description | Victorian Water Resources Data Warehouse daily flow data (www.vicwaterdata.net) |
| Units | ML/d |
| Custodian | Catchment & Water, DSE |
| Data processing details: | |
| • Time series formats converted from VWRDW CSV format | |

| **Storage releases** | |
|---|---|
| Description | Goulburn-EMSS storage releases time series |
| Units | m3/month |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Description | Goulburn-Murray Water storage flows |
| Units | ML/d |
| Custodian | Headworks, Goulburn-Murray Water |
| Data processing details: | |
| • Time series format converted from Excel format | |

## Miscellaneous tabular data

| **Global soil erosion indices** | | | |
|---|---|---|---|
| Description | Goulburn-EMSS global soil erosion indices (tabular) | | |
| Custodian | PIRVic Bendigo, DPI | | |
| Source data: | | | |
| (1) Layer | USLE | (2) Layer | GULLYDENSITY |
| (1) Description | Goulburn-EMSS hill slope erosion (raster) | (2) Description | Goulburn-EMSS gully density (raster) |
| (1) Scale | 9” grid resolution (approximately 250 m) | (2) Scale | 9” grid resolution (approximately 250 m) |
| (1) Custodian | PIRVic Bendigo, DPI | (2) Custodian | PIRVic Bendigo, DPI |
| Data processing details: | | | |
| • File created using erosion hazard layer, generated from USLE (1) and Gully density (2) layers | | | |

| **Observed Data** | | **Local soil erosion indices** | |
|---|---|---|---|
| Description | Goulburn-EMSS local soil erosion indices | | |
| Custodian | PIRVic Bendigo, DPI | | |
| Source data: | | | |
| (1) Layer | USLE | (2) Layer | GULLYDENSITY |
| (1) Description | Goulburn-EMSS hill slope erosion (raster) | (2) Description | Goulburn-EMSS gully density (raster) |
| (1) Scale | 9" grid resolution (approximately 250 m) | (2) Scale | 9" grid resolution (approximately 250 m) |
| (1) Custodian | PIRVic Bendigo, DPI | (2) Custodian | PIRVic Bendigo, DPI |
| Data processing details: | | | |
| • File created using erosion hazard layer, generated from USLE (1) and Gully density (2) layers | | | |

| **Gauging station sites** | |
|---|---|
| Description | Goulburn-EMSS gauging station sites (tabular) |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Description | Victorian Water Resources Data Warehouse gauging sites (www.vicwaterdata.net) |
| Custodian | Catchment & Water, DSE |
| Data processing details: | |
| File format converted from VWRDW format | |

| **Dam wall sites** | |
|---|---|
| Description | Goulburn-EMSS dam wall sites (tabular) |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Layer | HYDROP100 |
| Description | Hydrological features (polygons) |
| Scale | 100,000 |
| Custodian | Land Victoria, DSE |
| Data processing details: | |
| • File created using estimated dam wall locations | |

| **Storage geometry** | |
|---|---|
| Description | Goulburn-EMSS storage geometry (tabular) |
| Units | m; ML; hectares |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Description | Goulburn-Murray Water storage rating tables |
| Units | m; ML; hectares |
| Custodian | Headworks, Goulburn-Murray Water |
| Data processing details: | |
| • File format converted from Excel format | |

| **Point source pollutants** | |
|---|---|
| Description | Goulburn-EMSS point source pollutants (tabular) |
| Units | Kg/yr |
| Custodian | PIRVic Bendigo, DPI |
| Source data: | |
| Description | EPA point source data |
| Units | mg/L; ML/d |
| Custodian | EPA North East |
| Data processing details: | |
| • Annual loads estimated from licensed daily discharge rates and concentrations | |

## Appendix B - Streamflow Model Calibration and Validation

Parameters of the SimHyd hydrologic model the drives EMSS-Goulburn are determined by calibration against recorded streamflow data. In the Upper-Mid Goulburn Catchment, the network of streamflow gauging stations captures the basic dendritic structure of the catchment, providing an adequate streamflow record for model calibration.

To test the suitability of the selected gauging stations for model calibration, the hydrologic model was first calibrated against each of the three gauged catchments individually. The calibration process is described in full in Chiew *et al.* (2002a), but in essence uses an automatic pattern search optimisation method to achieve a best fit between the modelled and recorded monthly streamflows. For each catchment model, ten parameters were optimised, five for the forested pervious areas and five for the non-forested pervious areas. The other two parameters of the seven parameter SimHyd model were fixed as they had only limited influence on the model optimisation. Each of the catchment models was optimised to minimise the objective function, OBJ:

$$OBJ = \sum_{i=1}^{n} (EST_i - REC_i)^2$$

*where* ESTi is monthly modelled streamflow
RECi is monthly recorded streamflow

To ensure that other streamflow characteristics were adequately modelled, constraints were applied to the optimisation. These constraints were applied as penalties to the objective function, minimising the instances of solutions that did not accurately simulate total catchment yield, surface flow proportion and interannual variability. The constraints used for the optimisation are as follows:

Total catchment yield:

$$0.95 < \frac{\sum_{i=1}^{n} ESTi}{\sum_{i=1}^{n} RECi} < 1.05$$

Quickflow (or surface flow) proportion:

$$0.8 < \frac{modelled\_quickflow\_ratio}{recorded\_quickflow\_ratio} < 1.2$$

Inter-annual variability:

$$0.8 < \frac{Cv\_of\_annual\_modelled\_streamflow}{Cv\_of\_annual\_recorded\_streamflow} < 1.2$$

The automatic optimisation procedure used twelve starts to determine twelve sets of optimum parameter values for each gauged catchment. To enable comparison between models, a dimensionless coefficient of efficiency, E was evaluated for each of the alternative sets of parameter values. A high value of E (approaching 1) indicates a good ability by a model to reproduce recorded flows. The parameter set with the highest E value was then selected from the alternative parameter sets.

Results of the individual gauging catchment calibration are provided in Table 18. Example calibration results for the individual catchments are provided in Figure 25 and Figure 26.

Results indicated that all the selected gauging catchments could be calibrated successfully, with E values greater than 0.76 for all catchments. In general, runoff estimates can be considered 'good' where E is greater than 0.8 and 'acceptable for most applications' where E is greater than 0.6 (Chiew *et al.* 2002).

Table 18. EMSS-Goulburn Individual Catchment Calibration Results.

| Gauge | E | VOL (mod/rec) | SFR (mod) | SFR (rec) | Rainfall | Total Runoff | Impervious Component | Forest Component | Other Pervious Component |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | (mm) | (mm) | (mm) | (mm) | (mm) |
| 405205 | 0.79 | 0.92 | 0.17 | 0.14 | 1354 | 457 | 0 | 457 | 0 |
| 405209 | 0.93 | 0.97 | 0.15 | 0.18 | 1381 | 477 | 3 | 408 | 66 |
| 405212 | 0.90 | 1.07 | 0.52 | 0.52 | 797 | 117 | 14 | 10 | 93 |
| 405214 | 0.79 | 1.02 | 0.32 | 0.28 | 1163 | 306 | 3 | 149 | 153 |
| 405215 | 0.76 | 1.08 | 0.19 | 0.24 | 1354 | 499 | 0 | 493 | 6 |
| 405217 | 0.92 | 1.00 | 0.29 | 0.25 | 1033 | 279 | 4 | 143 | 132 |
| 405218 | 0.87 | 0.98 | 0.27 | 0.25 | 1387 | 578 | 0 | 572 | 6 |
| 405219 | 0.94 | 1.00 | 0.19 | 0.23 | 1360 | 505 | 0 | 505 | 0 |
| 405227 | 0.92 | 1.02 | 0.17 | 0.20 | 1445 | 528 | 0 | 528 | 0 |
| 405228 | 0.95 | 1.00 | 0.42 | 0.35 | 790 | 170 | 0 | 14 | 156 |
| 405231 | 0.86 | 1.01 | 0.18 | 0.23 | 1085 | 219 | 9 | 178 | 32 |
| 405238 | 0.92 | 1.04 | 0.50 | 0.43 | 759 | 146 | 10 | 20 | 116 |
| 405240 | 0.92 | 1.04 | 0.54 | 0.52 | 707 | 121 | 10 | 8 | 102 |
| 405241 | 0.84 | 0.94 | 0.18 | 0.17 | 1547 | 844 | 0 | 825 | 20 |
| 405245 | 0.79 | 1.34 | 0.72 | 0.60 | 887 | 153 | 18 | 0 | 134 |
| 405248 | 0.86 | 1.10 | 0.50 | 0.62 | 607 | 73 | 12 | 35 | 26 |
| 405251 | 0.91 | 1.07 | 0.37 | 0.32 | 985 | 159 | 0 | 72 | 87 |
| 405263 | 0.93 | 1.02 | 0.18 | 0.22 | 1285 | 432 | 0 | 432 | 0 |
| 405264 | 0.88 | 1.03 | 0.15 | 0.18 | 1439 | 527 | 0 | 527 | 0 |
| 405274 | 0.96 | 1.03 | 0.58 | 0.49 | 767 | 162 | 4 | 9 | 149 |
| 405291 | 0.91 | 1.10 | 0.45 | 0.55 | 668 | 95 | 0 | 0 | 95 |

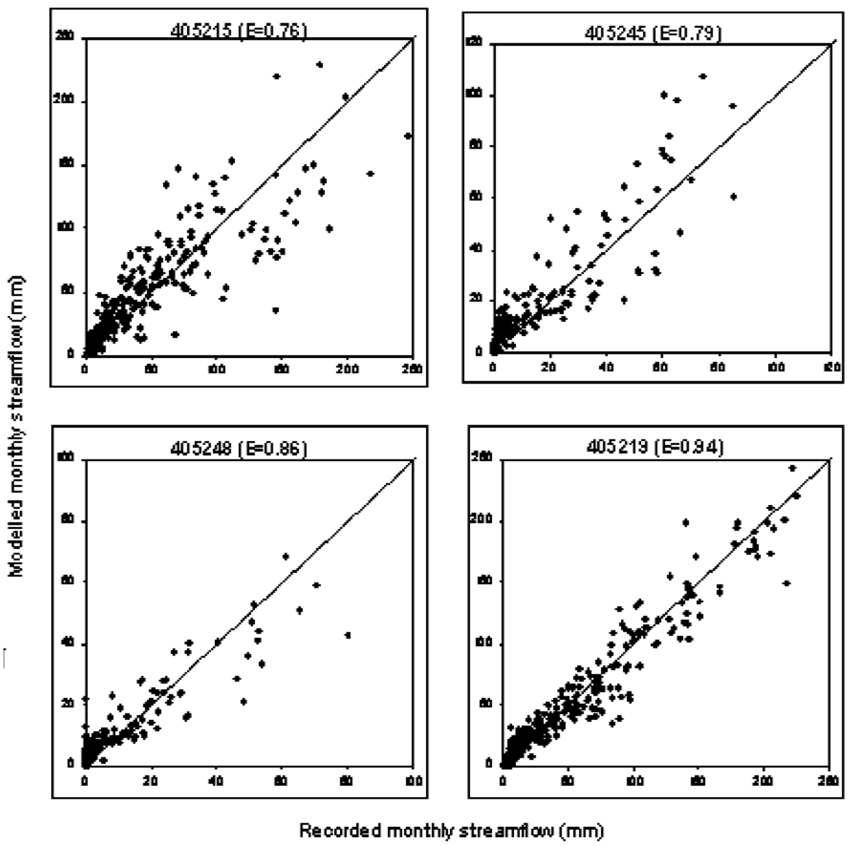



Figure 25. Typical Individual Catchment Calibration Scatter Plots.

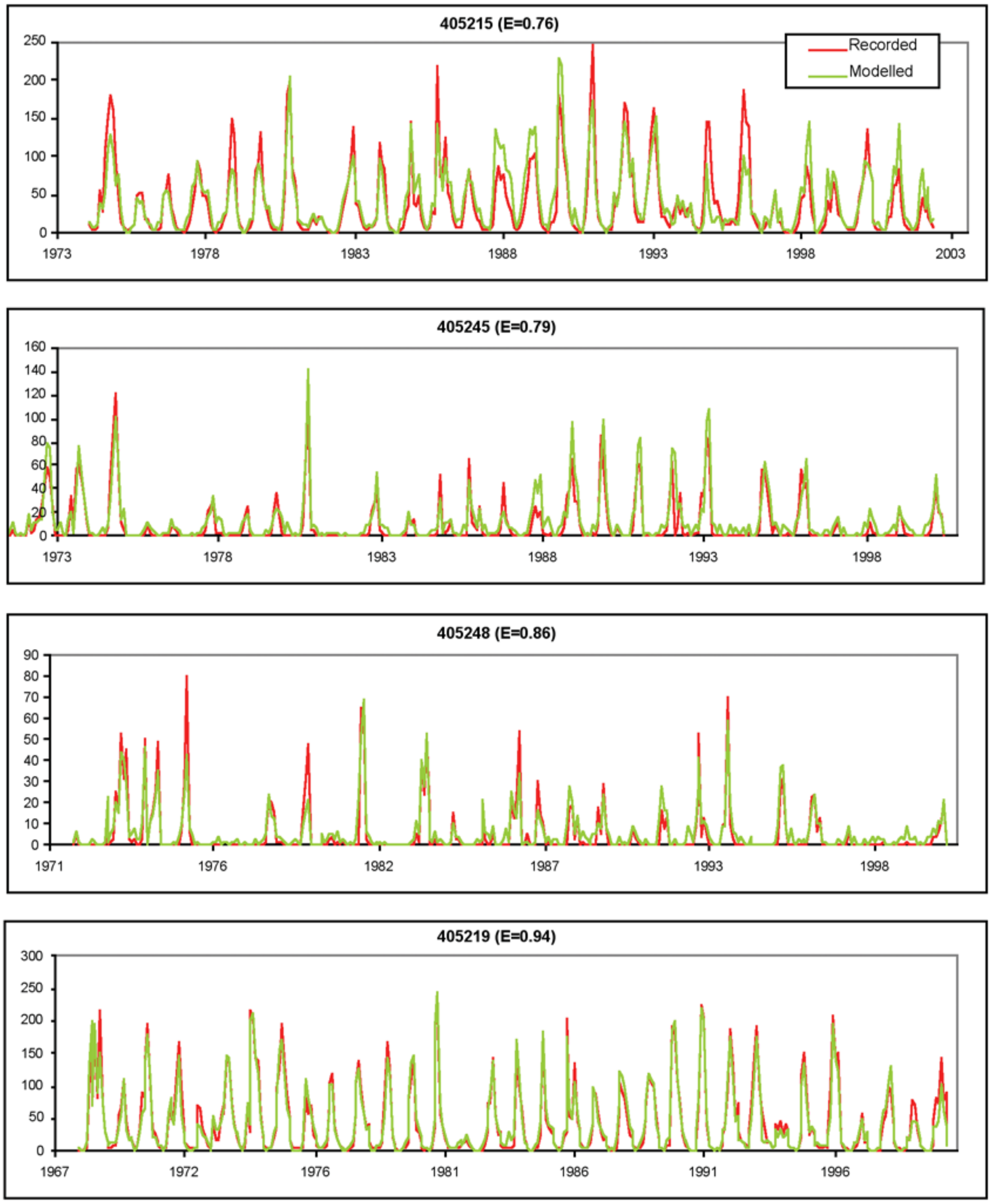



Figure 26. Typical Individual Catchment Calibration Hydrographs.

As discussed previously, two pervious models were calibrated for each catchment, one for forested areas and one for non-forested areas. Based on generally-accepted hydrological principles, the optimisation procedure was set to ensure that total runoff and surface flow ratios for the non-forested areas was higher or the same as values from the forested areas. For the Goulburn model, it is not clear whether these assumptions are valid, with Figure 27 showing no clear relationship between forest cover and recorded runoff. Only the surface flow ratio appears to have a relationship with forest cover, with an inverse relationship between percentage forest cover and surface flow ratio.

It is important to note however, that rainfall is highly variable in the Goulburn Catchment, and the forested areas tend to correspond with the higher rainfall region. As such, it is difficult to directly compare the forested and non-forested catchments.

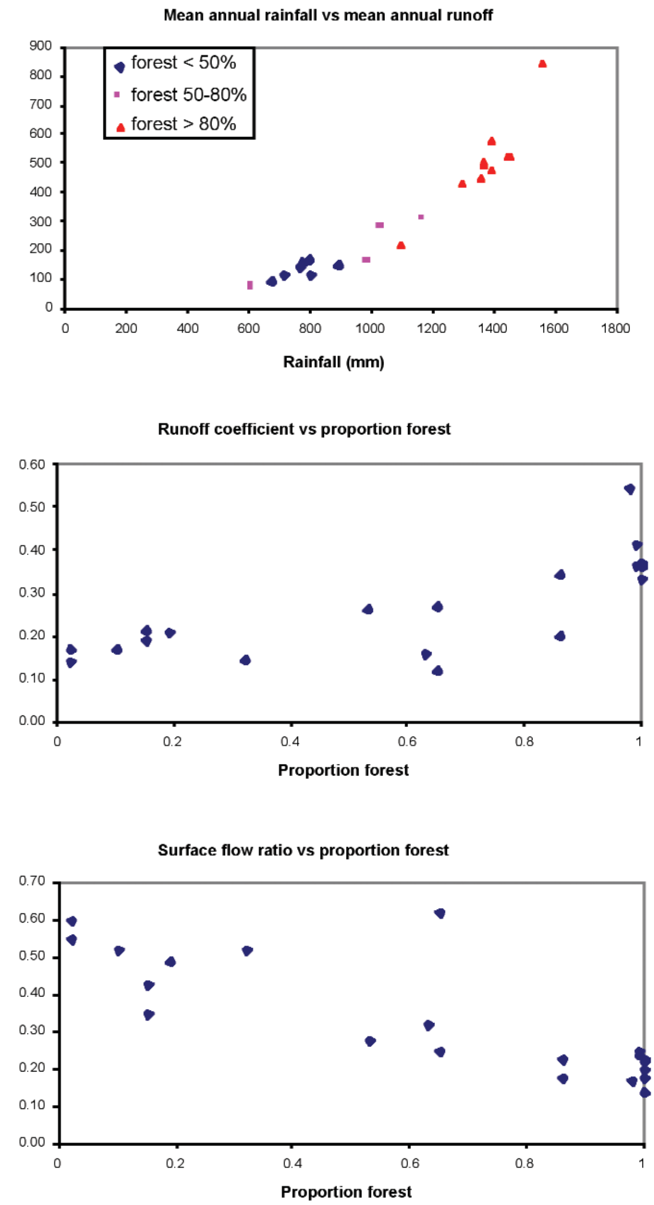



Figure 27. Influence of Forest Land Use on Catchment Hydrologic Characteristics.

Results of the individual gauging catchment calibrations showed that the SimHyd hydrologic model could be successfully calibrated for the Upper-Mid Goulburn Catchment. The EMSS model however requires parameters to be determined for each sub-catchment. Because of the sparsity and boundaries of the gauging catchments, it is not possible to directly translate the individually calibrated parameters to each of the EMSS sub-catchments.

To overcome this, the Goulburn Catchment was divided into six hydrologically and climatically similar regions. For each region, a hydrologic model was separately calibrated to determine a single set of regional parameters. These parameters were then applied to each sub-catchment within the region. The six Goulburn regions are shown in Figure 28.

Rather than calibrating each gauging catchment individually, the hydrologic model for each region was calibrated simultaneously against all the streamflow data within the region. Model optimisation for each region was achieved by minimising a combined objective function that included the individual objective functions for each gauging catchment. The hydrologic parameters determined for each region are presented in Table 19, while the modelling results for the six regions are presented in Figure 29 to Figure 34.

**Region 1** (refer Figure 13) comprises the western part of the catchment, upstream of Goulburn Weir, and includes the Majors, Mollisons, Kurkurac, Sunday, Dabyminga, Hughes and Mid Goulburn Catchments. The region is generally lower-lying and has a

Table 19. EMSS-Goulburn Hydrologic Parameters.

| Region | Forest land use | | | | | | | Other pervious land use | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Natural bush<br>National park<br>Managed forest<br>Plantation | | | | | | | Grazing<br>Intensive agriculture<br>Broadacre agriculture<br>Pervious fraction of dense urban<br>Pervious fraction of suburban | | | | | | |
| | INSC | COEFF | SQ | SMSC | SUB | CRAK | K | INSC | COEFF | SQ | SMSC | SUB | CRAK | K |
| 1 | 1.800 | 200 | 1.5 | 315.000 | 0.206 | 0.319 | 0.300 | 1.775 | 200 | 1.5 | 143.125 | 0.213 | 0.031 | 0.194 |
| 2 | 4.500 | 200 | 1.5 | 330.000 | 0.050 | 0.225 | 0.060 | 1.200 | 200 | 1.5 | 110.000 | 0.275 | 0.150 | 0.300 |
| 3 | 5.000 | 200 | 1.5 | 500.000 | 0.106 | 0.150 | 0.003 | 4.800 | 200 | 1.5 | 223.750 | 0.200 | 0.113 | 0.300 |
| 4 | 0.500 | 200 | 1.5 | 185.000 | 0.188 | 1.000 | 0.020 | 0.500 | 200 | 1.5 | 20.000 | 0.200 | 1.000 | 0.003 |
| 5 | 5.000 | 200 | 1.5 | 425.000 | 0.150 | 0.687 | 0.050 | 4.600 | 200 | 1.5 | 250.000 | 0.150 | 0.163 | 0.084 |
| 6 | 1.650 | 200 | 1.5 | 230.000 | 0.131 | 0.425 | 0.080 | 1.500 | 200 | 1.5 | 130.000 | 0.550 | 0.400 | 0.016 |


Figure 28. EMSS-Goulburn Hydrologic Regions.

relatively low mean annual rainfall, ranging from around 550 mm in the north-west to around 850 mm in the south and east of the region. Runoff coefficients (the proportion of rainfall that becomes runoff) in the region range from around 0.1 to 0.3. Land use in the region is predominantly grazing, with some forested areas in the north-west and south of the region. Stream flow data from six gauging stations was used to calibrate the hydrologic model for Region 1, with the resulting hydrologic parameters presented in Table 19. Calibration of Region 1 was generally very good, with E values greater than 0.8 for all catchments and estimated streamflow volumes within 10% of total recorded streamflow volumes in five of the six gauged catchments. Surface flow ratios for the estimated flows were all within 20% of surface flow ratios for the recorded flows.

**Region 2** (refer Figure 14) comprises the central part of the catchment, upstream of Region 1, and includes the King Parrot, Yea, Home and Mid Goulburn Catchments. Rainfall in the region is relatively moderate, ranging from around 650 mm in the centre to around 1100 mm in the south of the region. Runoff coefficients in the region range from around 0.2 to 0.3. Land use in the region is predominantly grazing, with some forested areas in the higher-rainfall parts of the region, in the south and north. Stream flow data from three gauging stations were used to calibrate the hydrologic model for Region 2, with the resulting hydrologic parameters presented in Table 19. Calibration of Region 2 was generally very good, with E values greater than 0.8 for all catchments and estimated streamflow volumes within 10% of total recorded streamflow volumes in two of the three gauged catchments. Surface flow ratios for the estimated flows were all within 20% of surface flow ratios for the recorded flows.

**Region 3** (refer Figure 31) comprises the northern Eildon catchment, and includes the Merton, Brankeet, Tallangalook and Ford catchments. Rainfall in the region is relatively moderate, ranging from around 750 mm to 1000 mm. Runoff coefficients in the region range from around 0.1 to 0.2. Land use in the region is predominantly grazing, with some forested areas in the north. Stream flow data from two gauging stations was used to calibrate the hydrologic model for Region 3, with the resulting hydrologic parameters presented in Table 19. Calibration of Region 3 was very good in one catchment, with an E value greater than 0.8 and estimated streamflow volume within 10%

of total recorded streamflow volume. Calibration of the other catchment was satisfactory, with an E value greater than 0.7 and estimated streamflow volume within 40% of total recorded streamflow volume. Surface flow ratios for the estimated flows were all within 20% of surface flow ratios for the recorded flows.

**Region 4** (refer Figure 16) includes the Rubicon and Snobs catchments, downstream of Eildon Reservoir. Rainfall in the region is relatively high, ranging from around 900 mm in the north to around 1600 mm in the south. The runoff coefficient in the region is the highest of all the regions, at around 0.6. Land use in the region is predominantly managed forest. Stream flow data from only one gauging stations was used to calibrate the hydrologic model for Region 4, with the resulting hydrologic parameters presented in Table 19. Calibration of Region 4 was very good, with an E value greater than 0.8 and estimated streamflow volume within 10% of total recorded streamflow volume. The surface flow ratio for the estimated flow was within 20% of the surface flow ratio for the recorded flow.

**Region 5** (refer Figure 17) comprises the eastern and southern Eildon catchment and the south-central part of the Goulburn Catchment, downstream of Eildon, and includes the Delatite, Howqua, Big, Acheron and Murrindindi catchments. Rainfall in the region is relatively high, ranging from around 900 mm in the centre to around 1600 mm in the south of the region. Runoff coefficients in the region range from around 0.3 to 0.4. Land use in the region is predominantly managed forest and national park. Stream flow data from six gauging stations was used to calibrate the hydrologic model for Region 5, with the resulting hydrologic parameters presented in Table 19. Calibration of Region 5 was generally very good, with E values greater than 0.8 in three of the six catchments and estimated streamflow volumes within 10% of total recorded streamflow volumes for all the catchments. Surface flow ratios for the estimated flows were within 20% of surface flow ratios for the recorded flows in five of the six catchments.

**Region 6** (refer Figure 18) comprises the south-eastern Eildon catchment, and includes the Jamieson and Upper Goulburn Catchments. Rainfall in the region is relatively high, ranging from around 1100 mm to 1400 mm. Runoff coefficients in the region range from around 0.3 to 0.4. Land use in the region is predominantly managed forest and national park. Stream flow data from three gauging stations was used to calibrate the hydrologic model for Region 6, with the resulting hydrologic parameters presented in Table 19. Calibration of Region 6 was generally very good, with E values greater than 0.8 and estimated streamflow volumes within 10% of total recorded streamflow volumes for all the catchments. Surface flow ratios for the estimated flows were all within 20% of surface flow ratios for the recorded flows.

## GOULBURN-EMSS REGION 1

| Gauge | E | VOL (mod/rec) | SFR (mod) | SFR (rec) | Rainfall (mm) | Total Runoff (mm) | Impervious Component (mm) | Forest Component (mm) | Other Pervious Component (mm) | Impervious Runoff (mm) | Forest Model Surface | Forest Model Interflow | Forest Model Baseflow | Forest Model Runoff (mm) | Other Pervious Model Surface | Other Pervious Model Interflow | Other Pervious Model Baseflow | Other Pervious Model Runoff (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 405212 | 0.85 | 1.30 | 0.50 | 0.52 | 797 | 143 | 14 | 34 | 95 | 598 | 0.00 | 0.42 | 0.58 | 106 | 0.01 | 0.45 | 0.54 | 144 |
| 405228 | 0.89 | 0.94 | 0.42 | 0.35 | 790 | 160 | 0 | 17 | 142 | 609 | 0.00 | 0.41 | 0.58 | 115 | 0.00 | 0.42 | 0.58 | 168 |
| 405238 | 0.90 | 1.08 | 0.47 | 0.43 | 759 | 150 | 10 | 16 | 125 | 584 | 0.00 | 0.42 | 0.58 | 105 | 0.00 | 0.43 | 0.57 | 150 |
| 405240 | 0.92 | 1.04 | 0.51 | 0.52 | 707 | 120 | 10 | 8 | 101 | 526 | 0.00 | 0.42 | 0.58 | 83 | 0.00 | 0.47 | 0.53 | 115 |
| 405248 | 0.81 | 1.06 | 0.56 | 0.62 | 607 | 71 | 12 | 38 | 22 | 460 | 0.00 | 0.41 | 0.59 | 58 | 0.00 | 0.59 | 0.41 | 68 |
| 405291 | 0.85 | 1.04 | 0.53 | 0.55 | 668 | 90 | 0 | 1 | 89 | 500 | 0.00 | 0.41 | 0.59 | 69 | 0.00 | 0.53 | 0.47 | 91 |

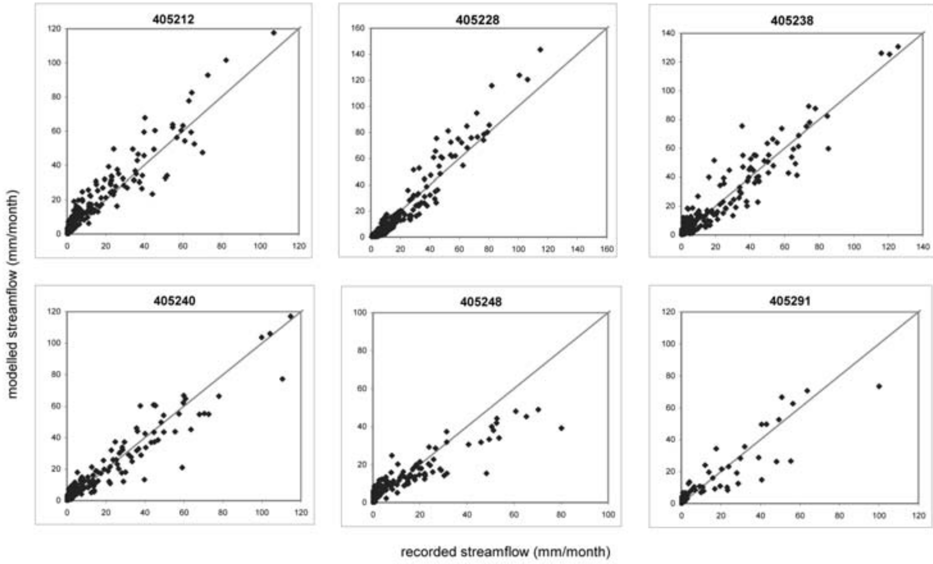



Figure 29. Region 1 Model Calibration Results.

## GOULBURN-EMSS REGION 2

| Gauge | E | VOL (mod/rec) | SFR (mod) | SFR (rec) | Rainfall (mm) | Total Runoff (mm) | Impervious Component (mm) | Forest Component (mm) | Other Pervious Component (mm) | Impervious Runoff (mm) | Forest Model Surface | Forest Model Interflow | Forest Model Baseflow | Forest Model Runoff (mm) | Other Pervious Model Surface | Other Pervious Model Interflow | Other Pervious Model Baseflow | Other Pervious Model Runoff (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 405217 | 0.85 | 0.82 | 0.30 | 0.25 | 1033 | 229 | 4 | 111 | 114 | 803.6 | 0.00 | 0.13 | 0.87 | 171 | 0.00 | 0.43 | 0.57 | 329 |
| 405231 | 0.81 | 1.09 | 0.22 | 0.23 | 1085 | 235 | 9 | 178 | 49 | 862 | 0.01 | 0.12 | 0.87 | 207 | 0.00 | 0.42 | 0.58 | 374 |
| 405274 | 0.95 | 1.02 | 0.47 | 0.49 | 767 | 159 | 4 | 11 | 145 | 595.8 | 0.01 | 0.18 | 0.81 | 58 | 0.01 | 0.48 | 0.52 | 180 |

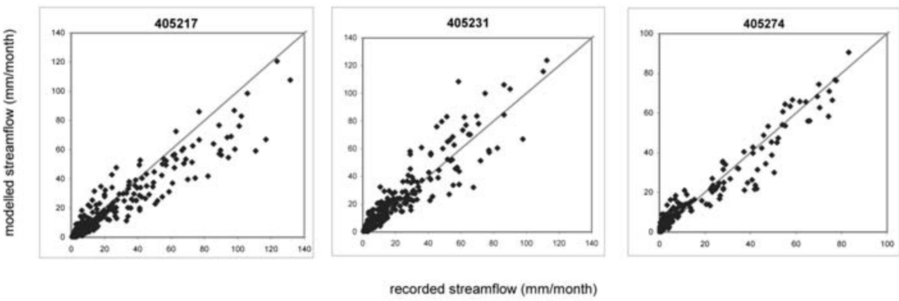



Figure 30. Region 2 Model Calibration Results.

## GOULBURN-EMSS REGION 3

| Gauge | E | VOL (mod/rec) | SFR (mod) | SFR (rec) | Rainfall (mm) | Total Runoff (mm) | Impervious Component (mm) | Forest Component (mm) | Other Pervious Component (mm) | Impervious Runoff (mm) | Forest Model | | | | Other Pervious Model | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Surface | Interflow | Baseflow | Runoff (mm) | Surface | Interflow | Baseflow | Runoff (mm) |
| 405245 | 0.78 | 1.35 | 0.54 | 0.60 | 887 | 155 | 18 | 1 | 135 | 703.3 | 0.03 | 0.42 | 0.55 | 65 | 0.01 | 0.46 | 0.52 | 141 |
| 405251 | 0.91 | 1.06 | 0.38 | 0.32 | 985 | 158 | 0 | 73 | 84 | 803.9 | 0.02 | 0.34 | 0.64 | 116 | 0.01 | 0.38 | 0.61 | 228 |

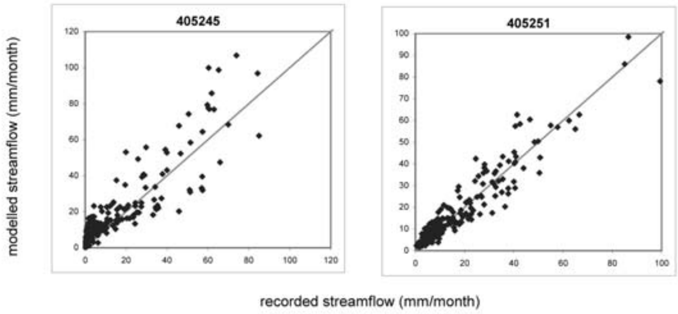



Figure 31. Region 3 Model Calibration Results.

## GOULBURN-EMSS REGION 4

| Gauge | E | VOL (mod/rec) | SFR (mod) | SFR (rec) | Rainfall (mm) | Total Runoff (mm) | Impervious Component (mm) | Forest Component (mm) | Other Pervious Component (mm) | Impervious Runoff (mm) | Forest Model | | | | Other Pervious Model | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Surface | Interflow | Baseflow | Runoff (mm) | Surface | Interflow | Baseflow | Runoff (mm) |
| 405241 | 0.84 | 0.93 | 0.18 | 0.17 | 1511 | 819 | 0 | 800 | 19 | 1282 | 0.01 | 0.16 | 0.83 | 817 | 0.01 | 0.61 | 0.38 | 928 |

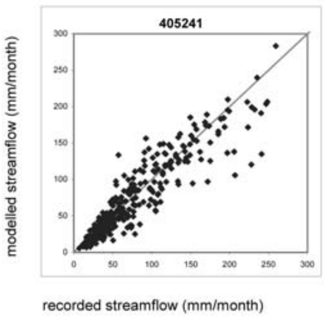



Figure 32. Region 4 Model Calibration Results.

## GOULBURN-EMSS REGION 5

| Gauge | E | VOL (mod/rec) | SFR (mod) | SFR (rec) | Rainfall (mm) | Total Runoff (mm) | Impervious Component (mm) | Forest Component (mm) | Other Pervious Component (mm) | Impervious Runoff (mm) | Forest Model | | | | Other Pervious Model | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Surface | Interflow | Baseflow | Runoff (mm) | Surface | Interflow | Baseflow | Runoff (mm) |
| 405205 | 0.69 | 0.93 | 0.20 | 0.14 | 1354 | 466 | 0 | 466 | 0 | 1103.1 | 0 | 0.19 | 0.8 | 465.7 | 0.01 | 0.24 | 0.75 | 482 |
| 405209 | 0.92 | 1.00 | 0.21 | 0.18 | 1381 | 493 | 3 | 419 | 70 | 1121.7 | 0 | 0.19 | 0.81 | 487.1 | 0 | 0.23 | 0.77 | 513.2 |
| 405214 | 0.78 | 1.06 | 0.24 | 0.28 | 1163 | 317 | 3 | 167 | 147 | 953.5 | 0 | 0.19 | 0.8 | 315 | 0.01 | 0.27 | 0.72 | 314.7 |
| 405215 | 0.72 | 0.96 | 0.20 | 0.24 | 1354 | 442 | 0 | 437 | 5 | 1130.7 | 0 | 0.19 | 0.8 | 441.4 | 0.01 | 0.24 | 0.74 | 452.2 |
| 405227 | 0.86 | 0.99 | 0.20 | 0.20 | 1445 | 513 | 0 | 513 | 0 | 1200 | 0 | 0.19 | 0.8 | 513.4 | 0.01 | 0.23 | 0.76 | 542.5 |
| 405264 | 0.86 | 0.99 | 0.20 | 0.18 | 1439 | 505 | 0 | 505 | 0 | 1193 | 0 | 0.19 | 0.8 | 505.1 | 0.01 | 0.23 | 0.76 | 531.9 |

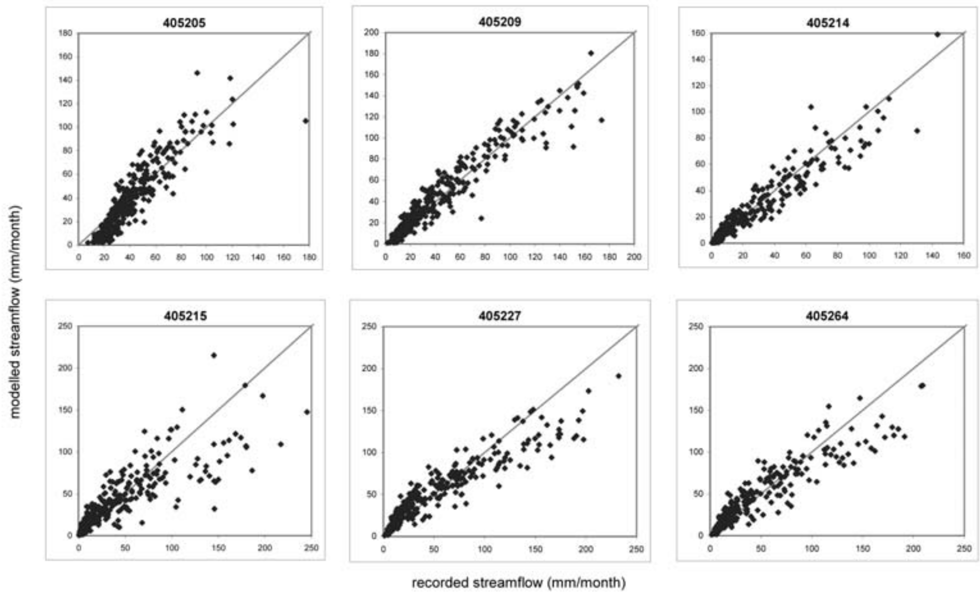



Figure 33. Region 5 Model Calibration Results.

## GOULBURN-EMSS REGION 6

| Gauge | E | VOL (mod/rec) | SFR (mod) | SFR (rec) | Rainfall (mm) | Total Runoff (mm) | Impervious Component (mm) | Forest Component (mm) | Other Pervious Component (mm) | Impervious Runoff (mm) | Forest Model | | | | Other Pervious Model | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Surface | Interflow | Baseflow | Runoff (mm) | Surface | Interflow | Baseflow | Runoff (mm) |
| 405218 | 0.87 | 0.91 | 0.20 | 0.25 | 1387 | 537 | 0 | 531 | 6 | 1154.2 | 0.01 | 0.19 | 0.8 | 536.1 | 0.01 | 0.64 | 0.36 | 634.6 |
| 405219 | 0.94 | 1.01 | 0.19 | 0.23 | 1360 | 512 | 0 | 512 | 0 | 1119 | 0 | 0.19 | 0.81 | 511.8 | 0 | 0.64 | 0.36 | 610.8 |
| 405263 | 0.93 | 1.05 | 0.20 | 0.22 | 1285 | 446 | 0 | 446 | 0 | 1049.7 | 0 | 0.2 | 0.8 | 445.7 | 0 | 0.64 | 0.36 | 546.9 |

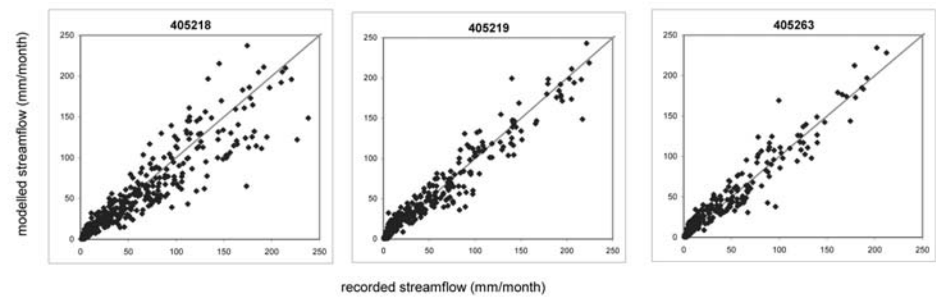
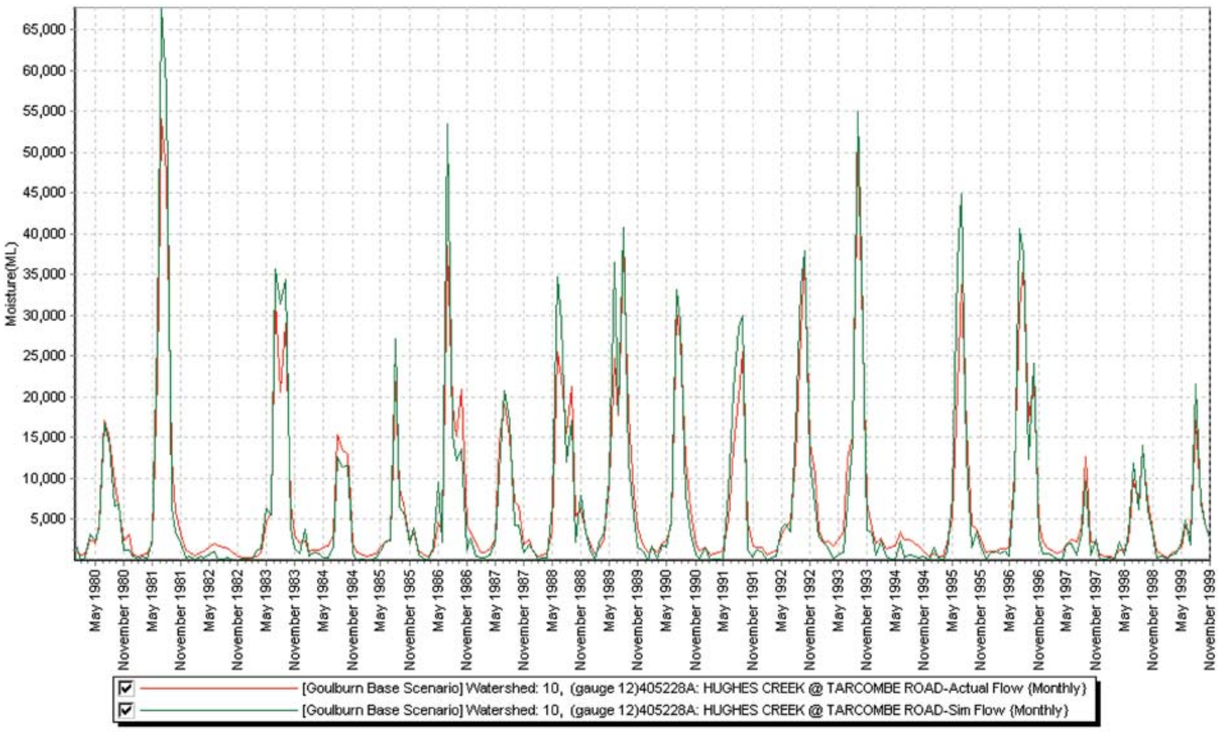
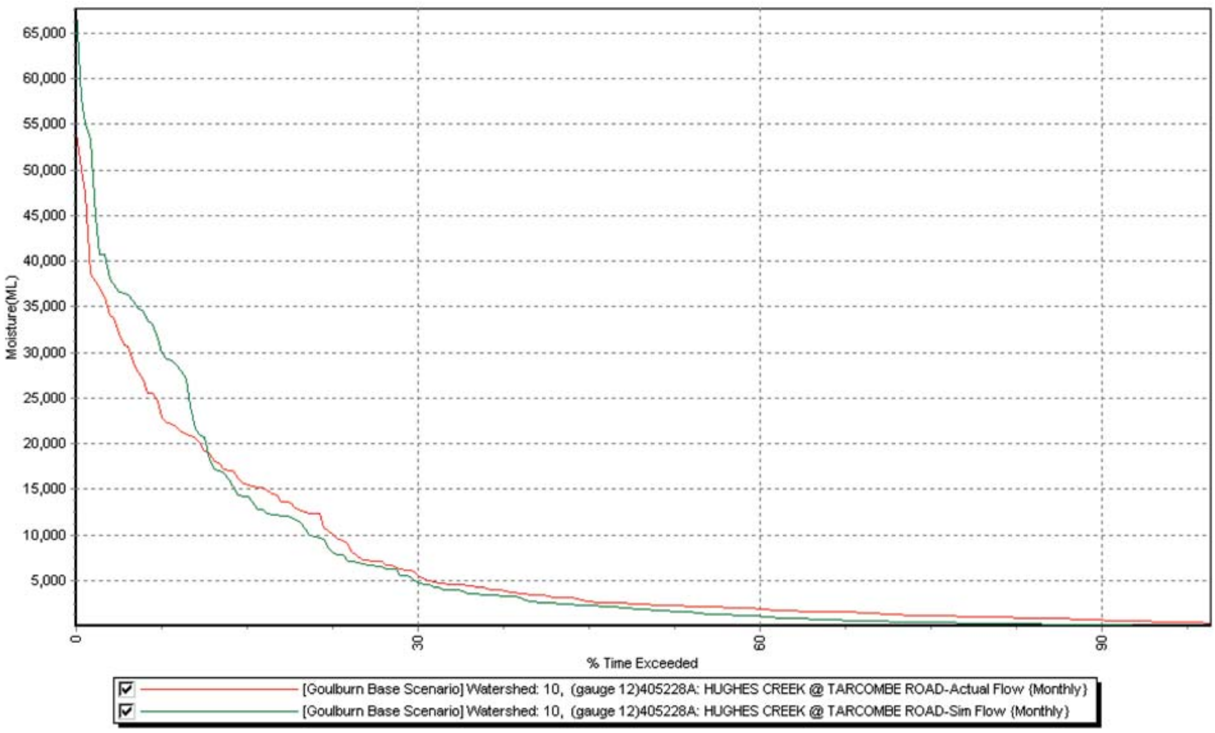



Figure 34. Region 6 Model Calibration Results.

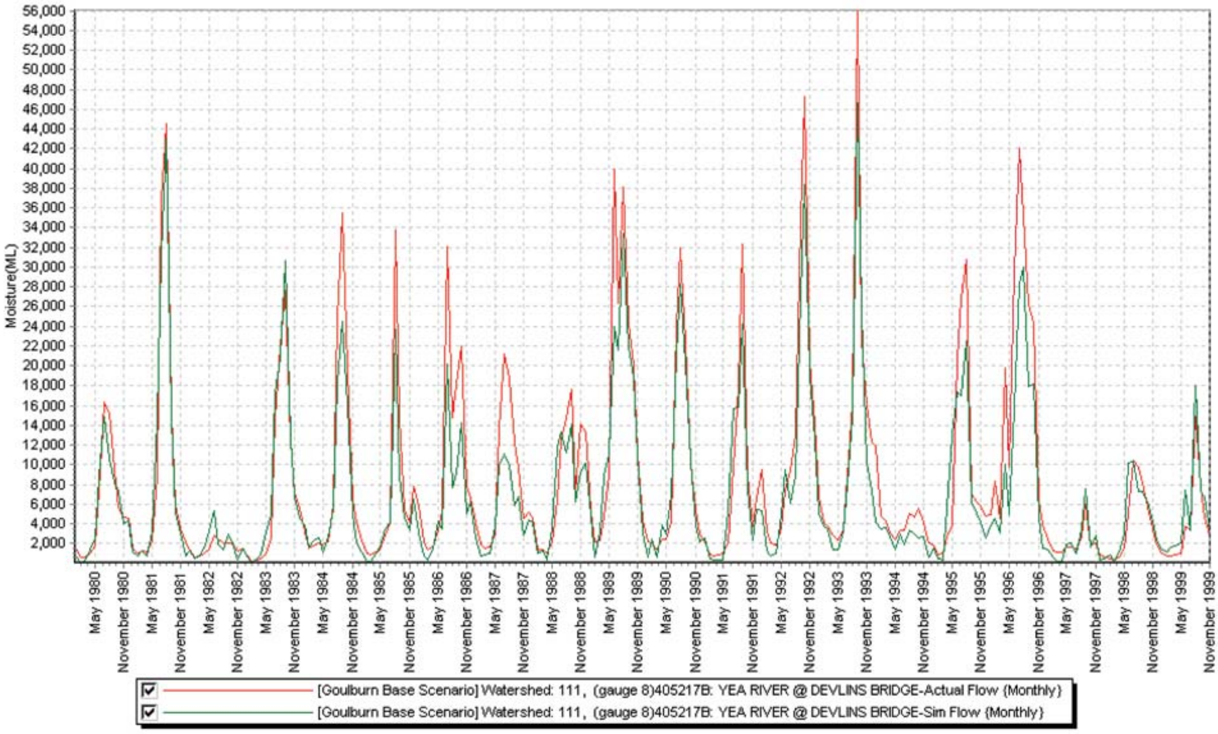
Graphs of observed versus simulated flows produced by EMSS-Goulburn at key monitoring stations further illustrate the close correlation observed at most locations.

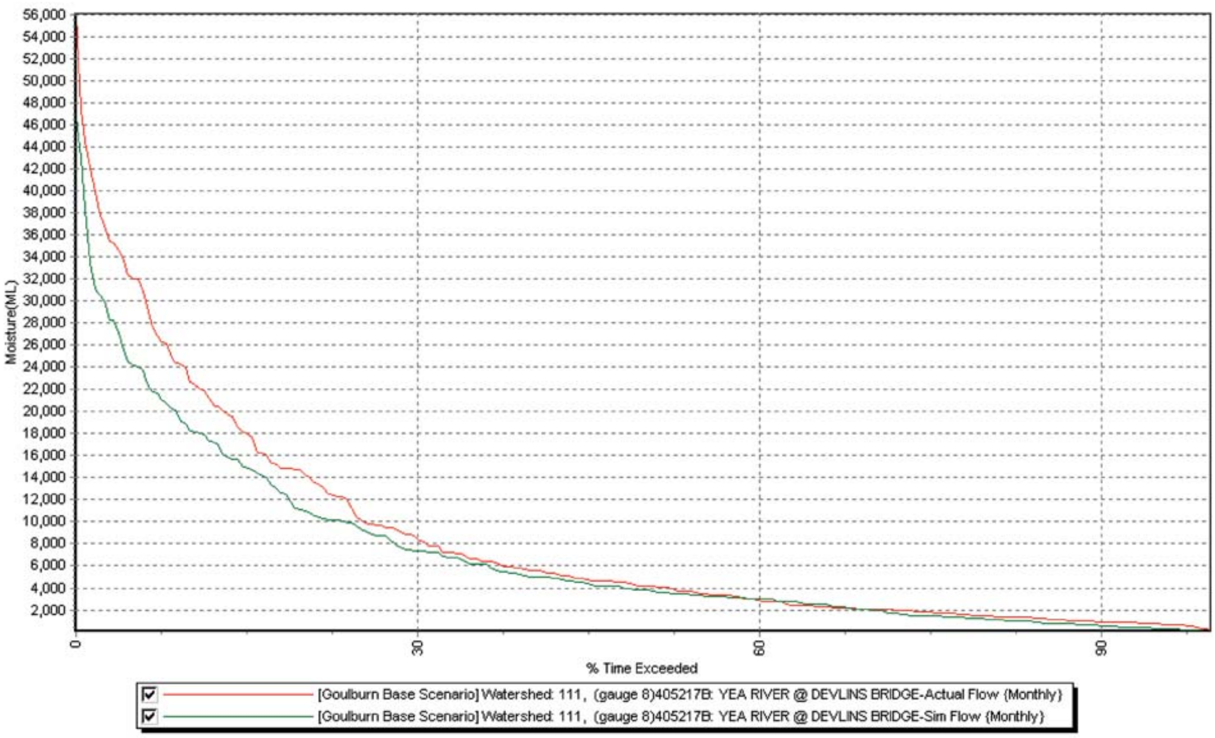
A notable exception is the highly regulated flow at stations on the Goulburn River immediately downstream of Lake Eildon. Simulated hydrographs predicted by the model while similar in shape often differ in magnitude, particularly for flows prior to 1990. Model predictions of pollutant loads in this river reach and downstream reaches should therefore be interpreted with some caution.



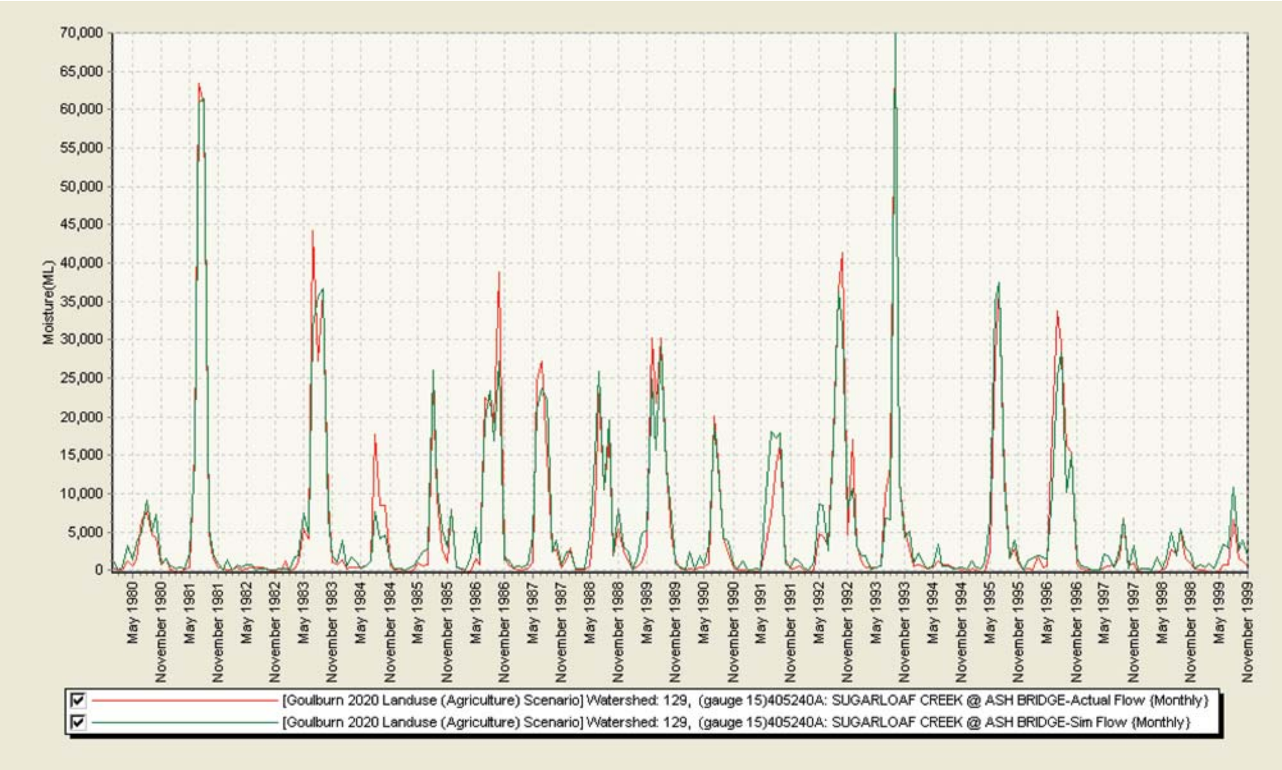




Example 1. Hughes Creek @ Tarcombe Road (405228).



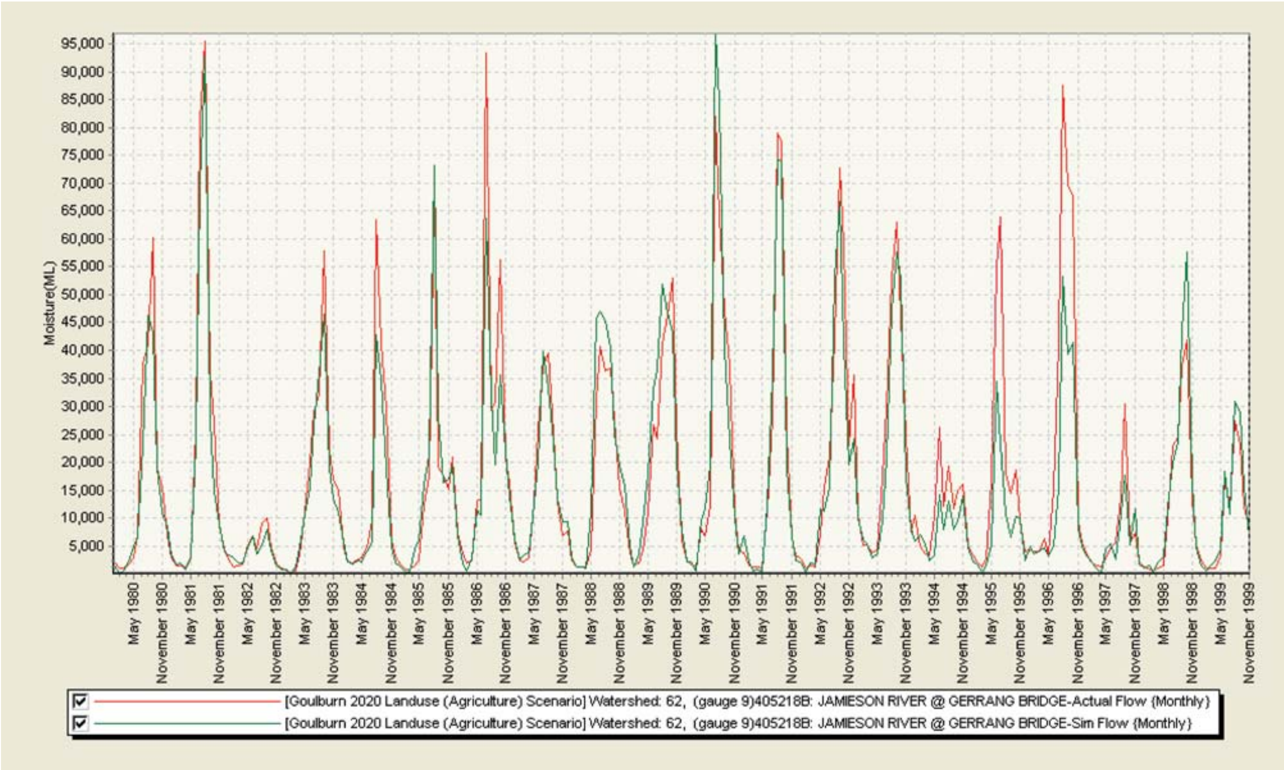



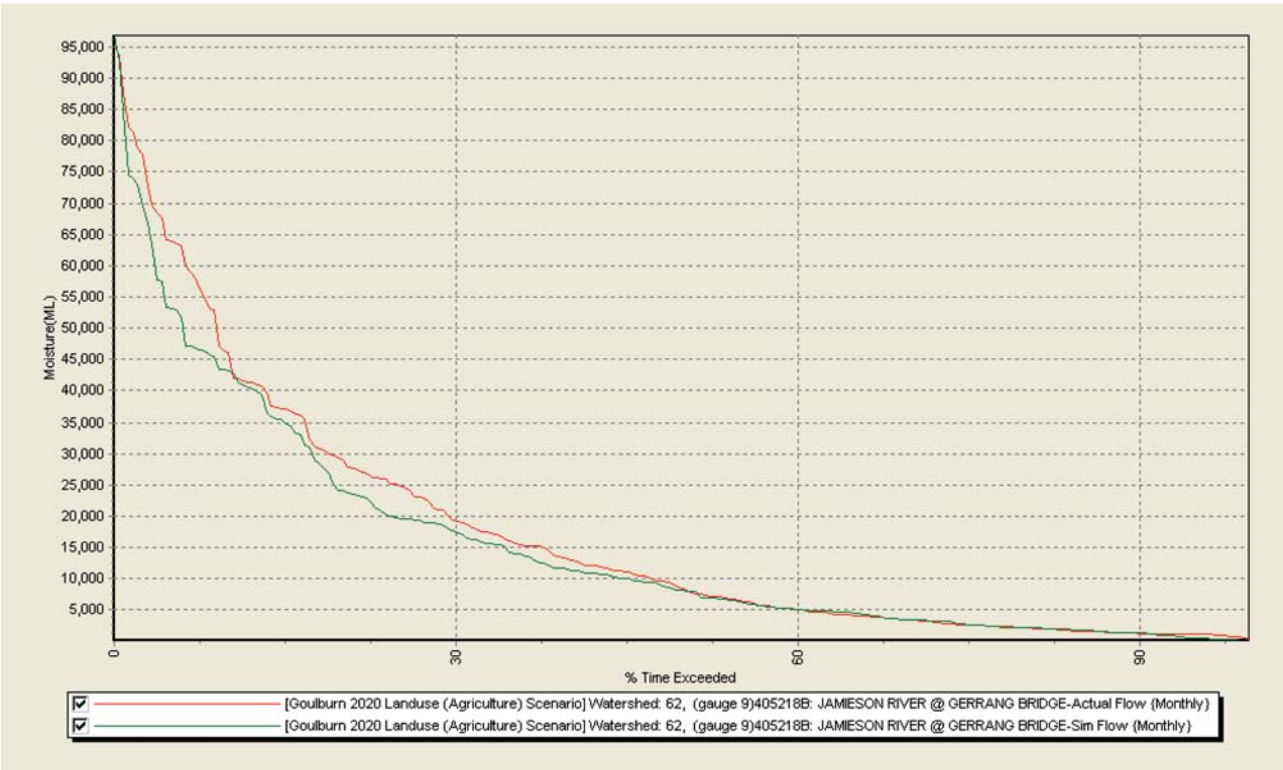

Example 2. Yea River @ Devlin's Bridge (405205).



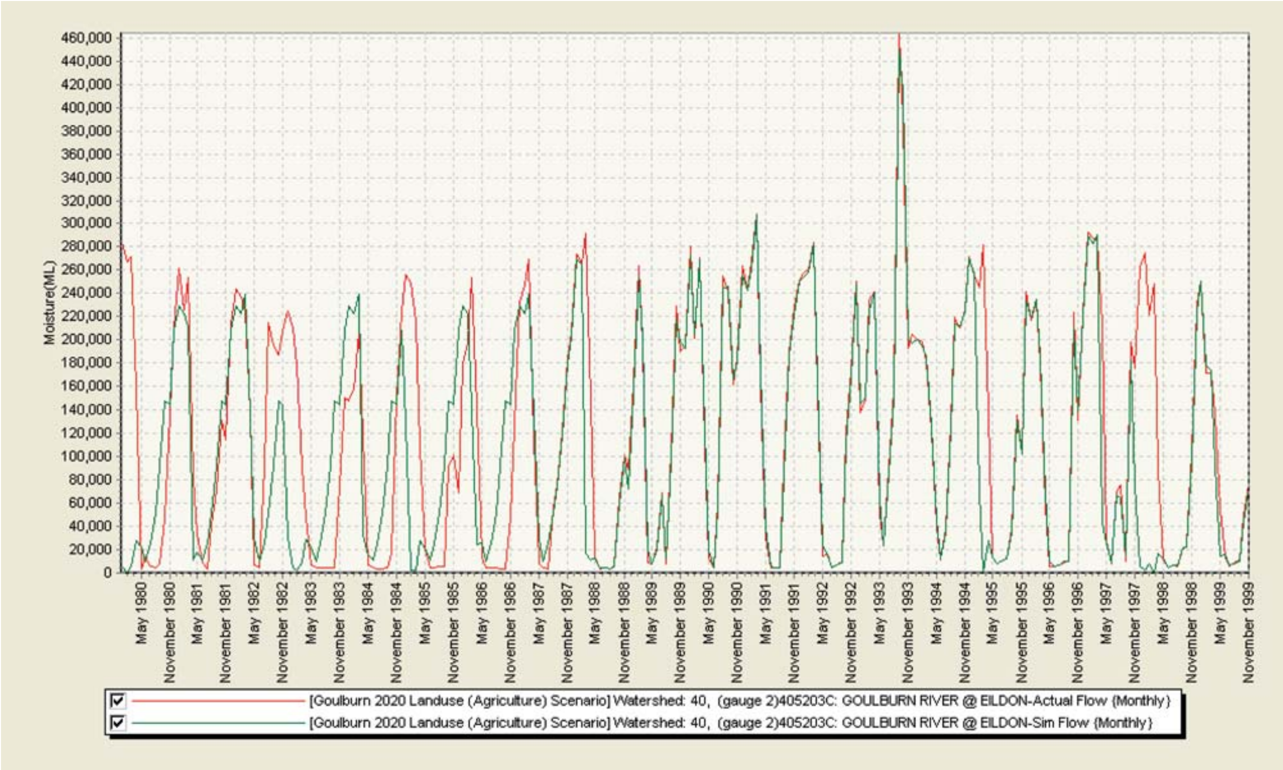


Example 3. Sugarloaf Creek @ Ash Bridge (4052240a).




Example 4. Goulburn River @ Jamieson (405218B).





Example 5. Goulburn River @ Eildon (405203).

## Appendix C - Pollutant Load Validation

Pollutant loads generated by the EMSS model are not calibrated, but are a function of landuse, erosion hazard, and the calibrated runoff volumes. To assess how well the EMSS-Goulburn model simulates pollutant loads, an attempt was made to validate the results. Modelled TP, TN and TSS were compared against observed loads calculated from the Victorian Water Quality Monitoring Network (www.vicwaterdata.net) data.

Graphs of validation results are provided below. Graphs depict loads calculated from monitoring data plotted against loads predicted by EMSS-Goulburn for select gauging stations.

Overall there is a good agreement between the loads predicted by EMSS-Goulburn and measured loads. Most of the results show a good correlation between the recorded and modelled data, however some results differ substantially, with differences of up to an order of magnitude apparent at some stations.

Given the potential sources of error associated with the measurement of water quality data and the model input data, differences between the modelled and recorded data should be expected. Significant error should also be expected for any calculation of mean loads from datasets. The poor replication of event based flows, typical of most gauging stations, always results in an underestimation, often large, of pollutant loads.

However, the results do indicate that DWC and EMC values for some land uses in the EMSS-Goulburn model may require refinement, and this should be an area for further investigation and data collection where possible. Model predictions should always be interpreted with caution, as discussed in Section 4.6.

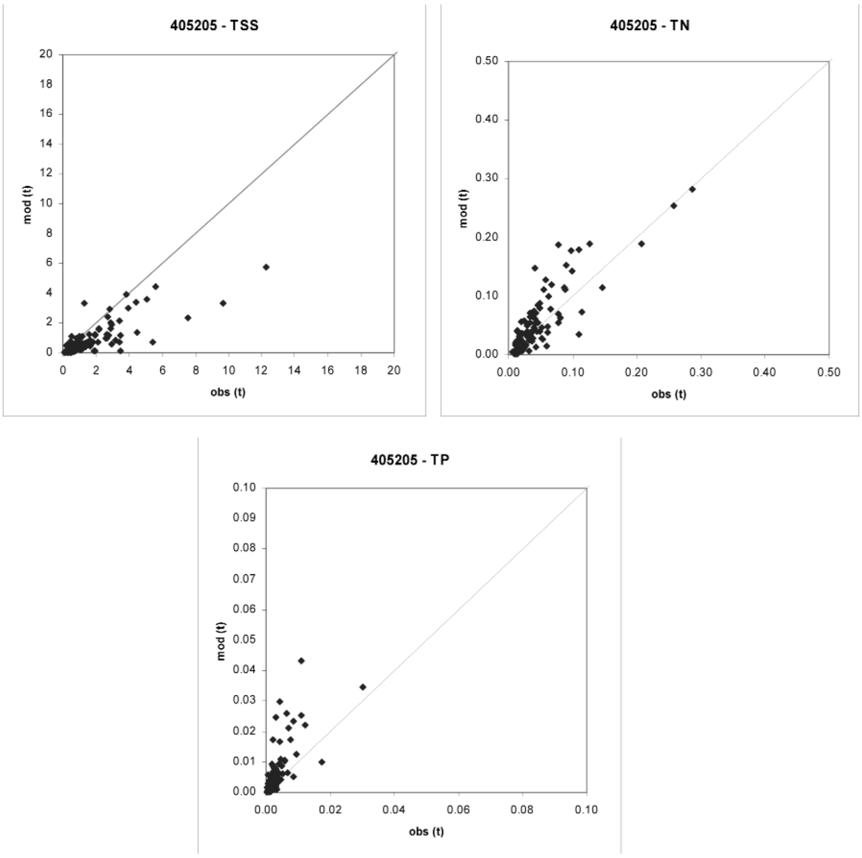



Figure 35. Simulated vs Modelled Pollutant Loads - 405205.

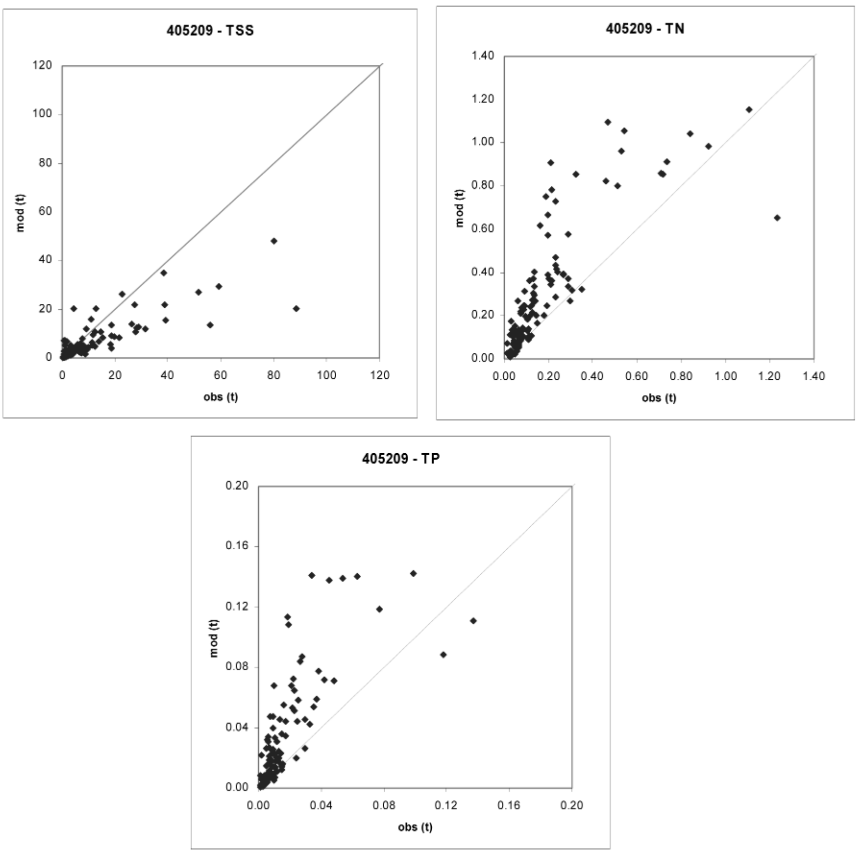



Figure 36. Simulated vs Modelled Pollutant Loads - 405209.

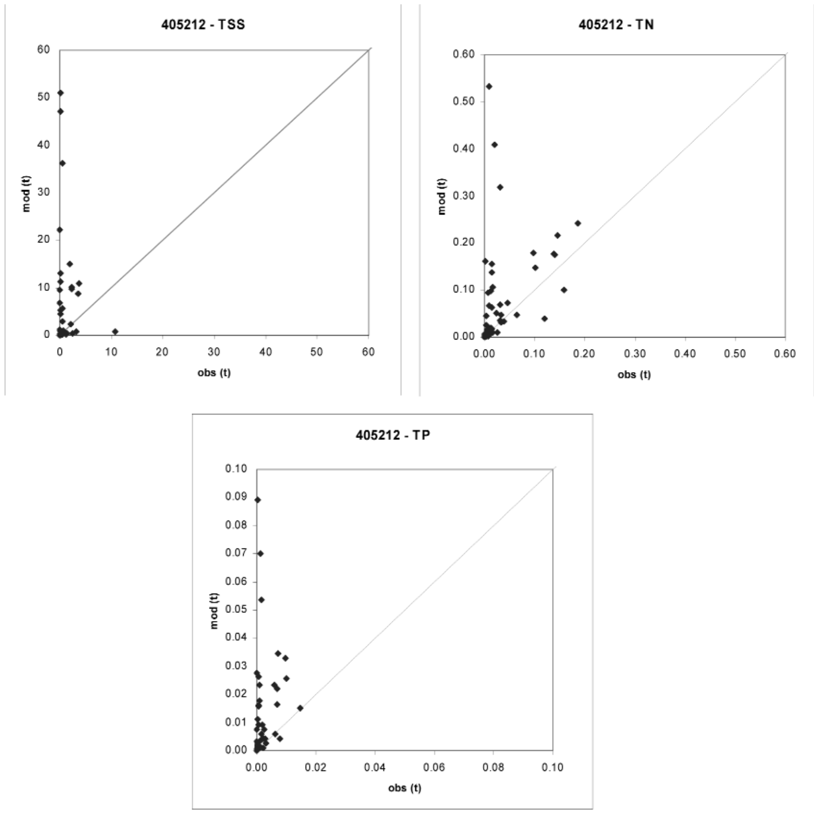



Figure 37. Simulated vs Modelled Pollutant Loads - 405212.

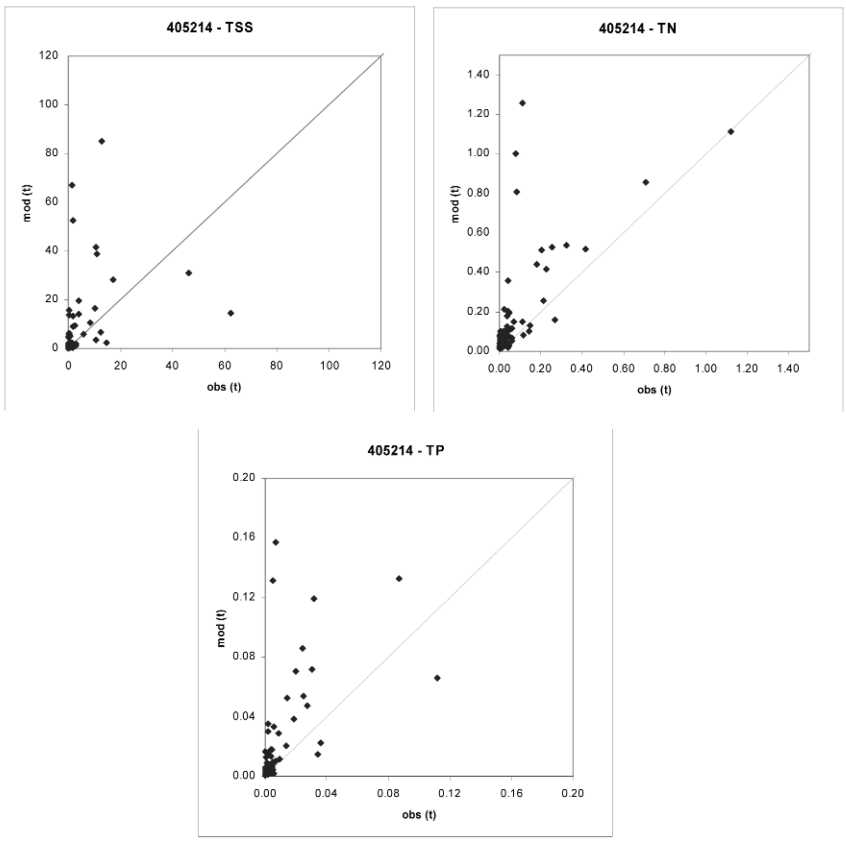



Figure 38. Simulated vs Modelled Pollutant Loads - 405214.

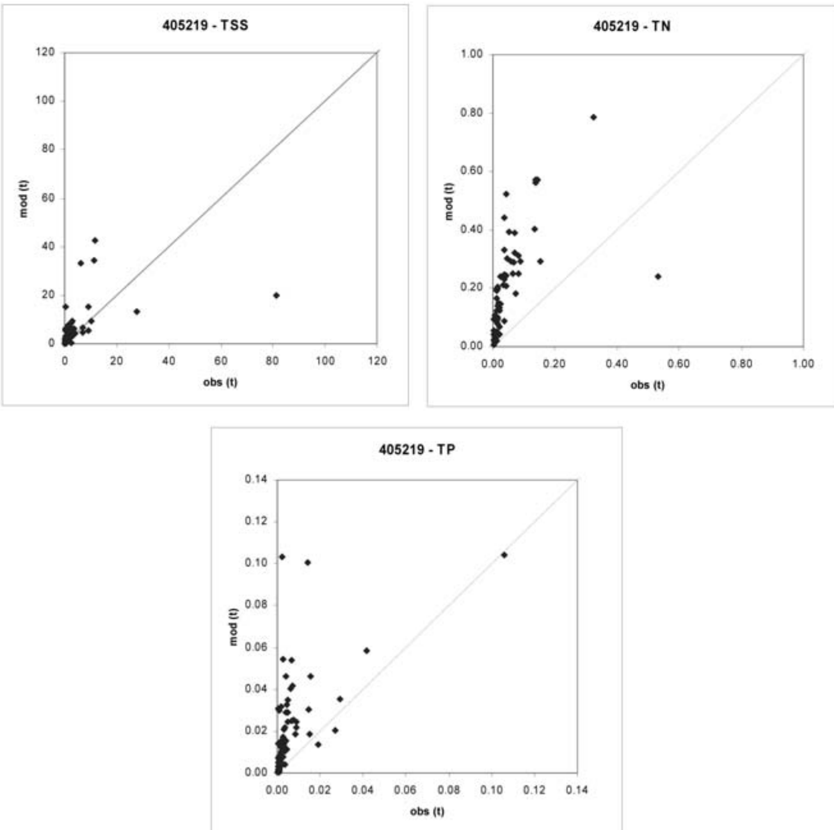



Figure 39. Simulated vs Modelled Pollutant Loads - 405219.

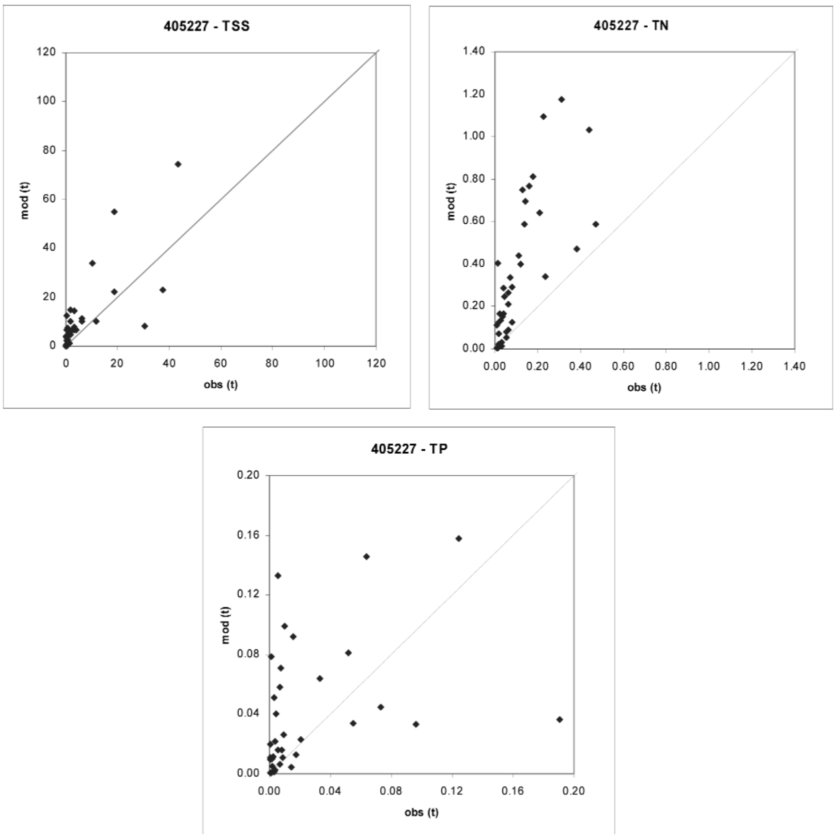



Figure 40. Simulated vs Modelled Pollutant Loads - 405227.

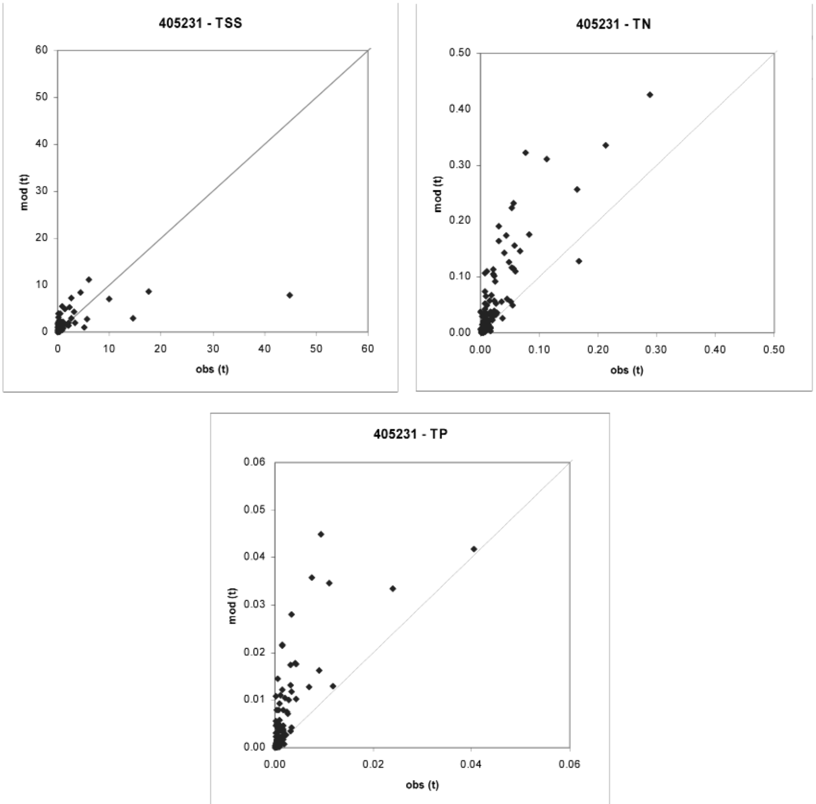



Figure 41. Simulated vs Modelled Pollutant Loads - 405231.

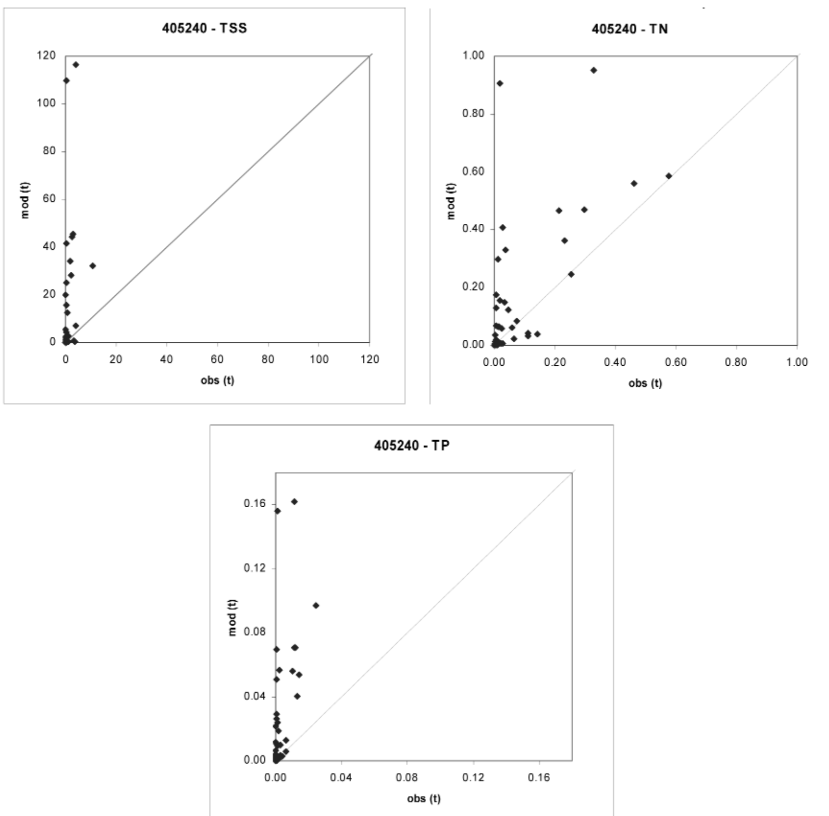



Figure 42. Simulated vs Modelled Pollutant Loads - 405240.

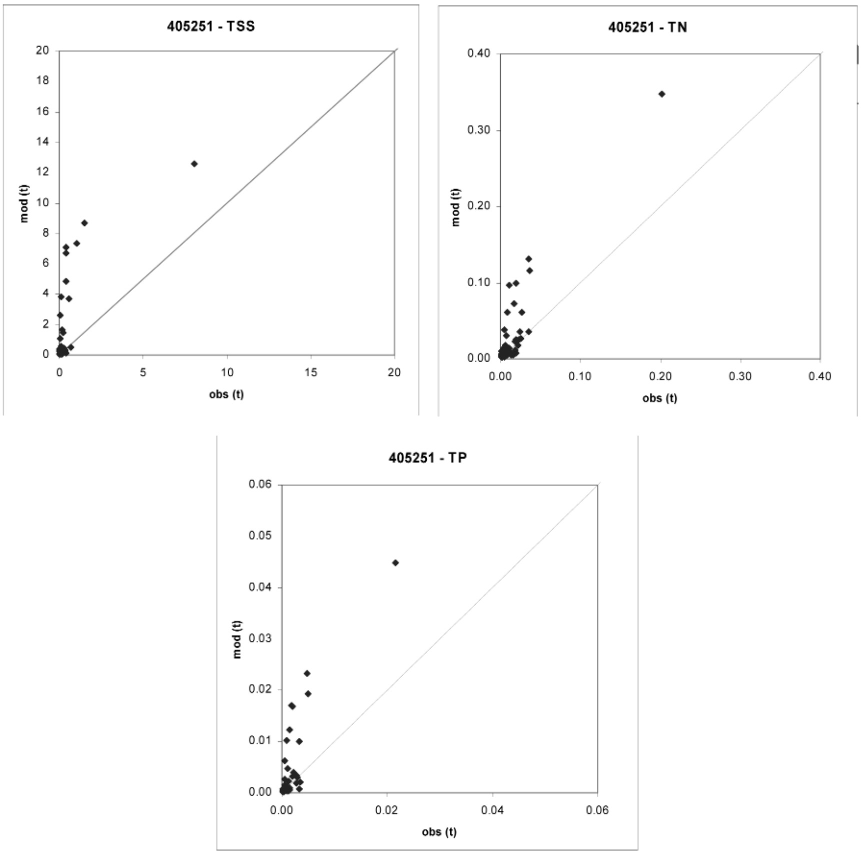



Figure 43. Simulated vs Modelled Pollutant Loads - 405251.

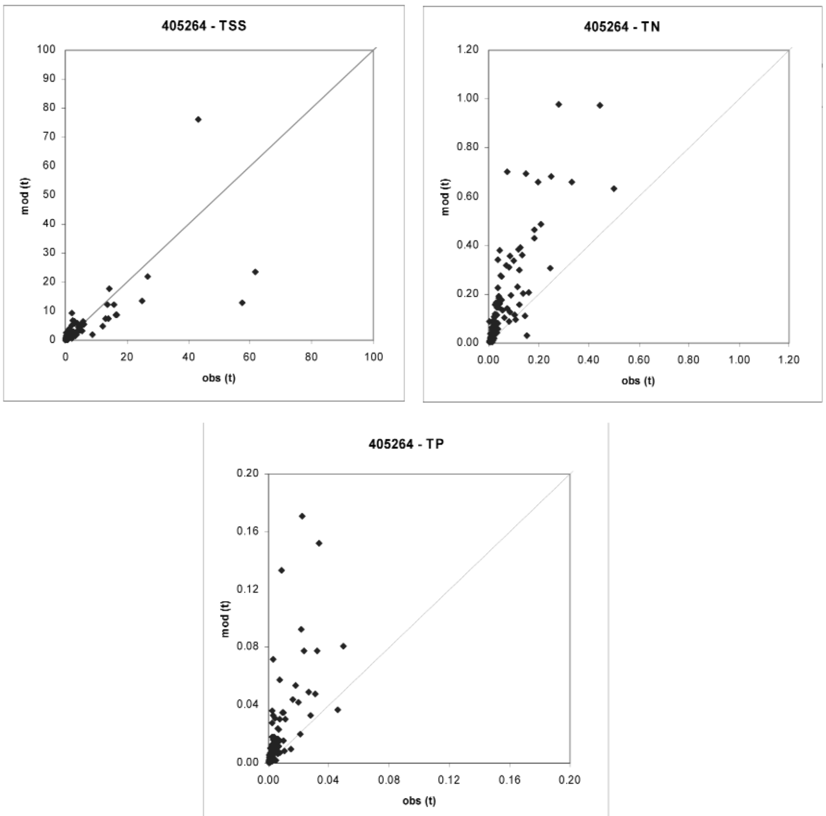



Figure 44. Simulated vs Modelled Pollutant Loads - 405264.

**CRC for Catchment Hydrology**
The CRC for Catchment Hydrology ceased operations in September 2005. The CRC for Catchment Hydrology's successor is the eWater CRC - for further information please visit www.ewatercrc.com.au

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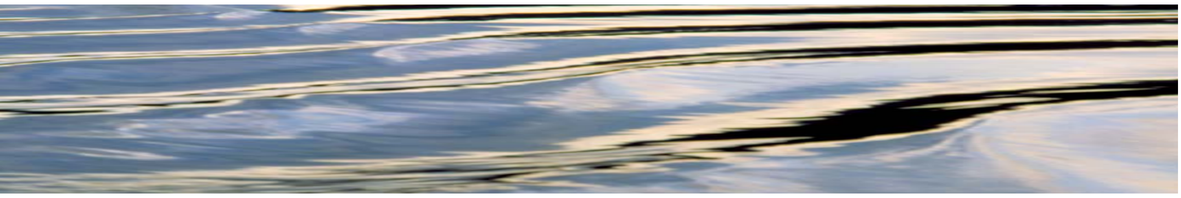

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- Grampians Wimmera Mallee Water
- Griffith University
- Melbourne Water
- Monash University
- Murray-Darling Basin Commission
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- Water Corporation of Western Australia

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- National Institute of Water and Atmospheric Research, New Zealand
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