Nattai River Catchment Source Catchments Application Project

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eWater Technical Report

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eWater Cooperative Research Centre Technical Report

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eWater CRC is a cooperative joint venture whose work supports the ecologically and economically sustainable use of Australia's water and river systems. eWater CRC was established in 2005 as a successor to the CRCs for Freshwater Ecology and Catchment Hydrology, under the Australian Government's Cooperative Research Centres Program.

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Executive Summary

The Nattai River catchment is located in the Southern Highlands of NSW, approximately 150km south-west of Sydney. It is located within the Hawkesbury-Nepean catchment and is a tributary of Lake Burragorang and Warragamba Dam, Sydney's main drinking water supply. Its situation within the drinking water catchment means that both water quantity and water quality are significant issues for yields estimation and catchment management. The catchment has an area of 446km^2 and is mostly vegetated, including areas of wilderness, with cleared rural areas and small clusters of urban areas also comprising the study area. The terrain of the study area is typically rugged and consists of hillcrests/ tablelands, sandstone escarpments and deeply incised valleys and gorges carved by the Nattai River and its tributaries. Ground elevations in the catchment range from 860m AHD along the southern-most boundary of the catchment to 120m AHD at the catchment outlet in the north of the catchment. Average annual rainfall ranges from 800 to 1300mm.

The catchment has been selected as the study area for one of the NSW Application Projects for testing of the Source Catchments model. Sinclair Knight Merz (SKM) worked in collaboration with the Sydney Catchment Authority (SCA) as industry partners of the eWater CRC with the aim of developing and calibrating a Source Catchments model for the study area for estimating flow yields and water quality assessment.

The Source Catchments model has been developed and calibrated to represent hydrological processes in the Nattai River catchment. The model is configured to represent the catchment as 29 sub-catchments comprised of 27 functional units, derived from land use and soil facet spatial information.

The model has been calibrated to two streamflow gauges located in the upper catchment (Station 2122801, The Crags) and near the catchment outlet (Station 212280, The Causeway) to data from July 1990 – March 2008, and validated to the streamflow gauge located near the catchment outlet for the period January 1976 – July 1990. The calibration and validation periods are relatively dry and wet periods, respectively, and hence the model is considered to be calibrated over a range of climatic conditions. Predicted total discharge volumes over the period of record are within -10% and +1% of observed discharge volumes at the upper and lower gauges, respectively, and predicted monthly discharges are typically within +/- 30% of observed discharges. The statistics describing the fit of the daily and monthly predicted flows, including R^2 and Nash-Sutcliffe coefficient of efficiency "E", are high (> 0.8).

The model has also been configured to represent constituent generation in the catchment. Constituents of interest include TN, TP and TSS. The EMC/DWC model has been adopted as the constituent generation model. EMCs and DWCs have been selected from literature for the functional units in the catchment from Australia- and World-wide data. Some data on effluent quality from Mittagong/Braemar STP is available and hence the STP is included as a major point source of pollutants in the catchment.

The model has only been partially calibrated to the available water quality data. The predicted constituent EMCs appear to be of the same order of magnitude

as the observed EMCs, however, there is significant error in the event constituent loads since the model has not predicted the event flow volumes accurately for the particular calibration events. The Source Catchments model, while reasonably representing hydrologic conditions on monthly or yearly scales, is unable to predict daily discharges or specific event discharges accurately, and this unreliability is transferred to the water quality component of the model. It may therefore be more appropriate to compare long term differences in loads rather than focussing on event loads.

A full model calibration has not been undertaken due to a lack of reliable data from the lower gauge. There is only a limited amount of event water quality data in the study area, and it is suspected that the data is unreliable for a number of events which occurred in the 1990s, due to inconsistencies in the loads calculated at the upper and lower gauges for individual events. This rules out all identified events at the lower gauge. There are also inconsistencies between the STP effluent constituent concentrations and the upper gauge in-stream observed constituent concentrations during low flows. This issue requires further investigation.

To further enhance the water quality component of the Nattai River Source Catchments model it is recommended that additional event water quality data be collected from the dominant land use types in particular forestry, cleared areas and urban areas. Validation data is also required at both the upper and lower gauges targeting high flow events. Sampling should ensure that instantaneous flow data is collected at the same time to enable constituent loads to be calculated. This is preferred over attempting to resolve the inconsistencies in the water quality data for historic events, as this may not lead to a conclusive outcome.

Alternative constituent generation models other than the EMC/DWC model should be trialled to see if a better fit to the water quality data can be achieved. These include a power-relationship between concentration and flow, however, there is insufficient water quality data at present to derive a reliable relationship.

Clarification is needed from the STP operators regarding the effluent quality data to determine whether the reported constituent concentrations represent daily maximums or daily averages. This clarification could not be obtained during the course of this study. The flow data at the upper gauge at low flows should also be assessed for reliability, in light of the inconsistencies in the reported constituent concentrations in the STP effluent and at the upper gauge.

At this stage the variability in the soil facet across each FU has been utilised only for varying the hydrologic response of each area. Future work could include scaling of the EMC/DWC values based on soil facet (which considers soil type and terrain) and if applicable gully density spatial data.

In summary, the Nattai River Source Catchments model requires additional water quality data and further development to ensure its reliability as a predictor of constituent loads generated in the catchment and delivered to its receiving waters. The model, however, has been configured to represent catchment hydrology and predicts discharge volumes to satisfactory accuracy, and could be considered as a flow yields model.

1 Introduction

1.1 Background

The Nattai River catchment is located in the Southern Highlands of NSW, approximately 150km south-west of Sydney. It is located within the Hawkesbury-Nepean catchment and is a tributary of Lake Burragorang and Warragamba Dam, Sydney's main drinking water supply. Its situation within the drinking water catchment means that both water quantity and water quality are significant issues for yields estimation and catchment management.

The catchment has been selected as the study area for one of the NSW Application Projects for testing of the Source Catchments model. Sinclair Knight Merz (SKM) worked in collaboration with the Sydney Catchment Authority (SCA) as industry partners of the eWater CRC to develop and calibrate a Source Catchments model for the study area. This report documents the background to the project, the available data, model development and calibration. Issues encountered during the project are also highlighted and discussed.

1.2 Purpose of Project

The SCA is currently in the process of evaluating catchment modelling packages for yields estimation and water quality assessment. The current HSPF hydrologic models of the Sydney drinking water catchment are 15 – 20 years old, hence SCA are considering upgrades of their models to contemporary, state-of-the-art modelling software. SCA ultimately intend to have their entire area of operations modelled using the selected software in order to allow more effective operation and management of the catchment from a yields estimation and water quality perspective. Therefore the Source Catchments model was evaluated as part of the eWater applications project.

1.3 Description of the Model

Source Catchments is a water quality and quantity modelling framework that supports decision-making and a whole-of-catchment management approach. It allows the user to model the amounts of water and contaminants flowing through an unregulated catchment and into major rivers, wetlands, lakes, or estuaries.

The software gives you access to a collection of models, data and knowledge that simulate the effects of climatic characteristics (like rainfall and evaporation) and catchment characteristics (like land-use or vegetation cover) on runoff and contaminant loads from unregulated catchments.

Source Catchments can be used to predict the flow and load of constituents at any location in the catchment over time.

The model is based on the following building blocks:

- **Sub-Catchments**: The sub-catchment is the basic spatial unit in Source Catchments, which is then divided into hydrological response units (or functional units) based on a common response or behaviour such as land use. Within each functional unit, three models can be assigned: a rainfall-runoff model, a constituent generation model and a filter model.

- **Nodes**: Nodes represent sub-catchment outlet, stream confluences or other places of interest such as stream gauges or dam walls. Nodes are connected by links, forming a representation of the stream network.
- **Links**: Links represent the river reaches. Within each link, a selection of models can be applied to:
    - Route or delay the movement of water along the link, or
    - Modify the contaminant loads due to processes occurring within the links, such as decay of a particular constituent over time.

Inputs into the model include:

- Hydrometeorologic data, including rainfall and evaporation data;
- Catchment data, including sub-catchment areas and functional unit areas (which may be defined by areas of different hydrologic response, land use, soil type, geology, etc.);
- Streamflow data, in order to calibrate and verify the hydrologic representation of the catchment by the model; and
- Water quality data, in order to calibrate and verify the constituent generation processes represented in the model.

The input data used in developing the Nattai River Source Catchments model are described in the following sections in this report, including discussion on the quality of each data set.

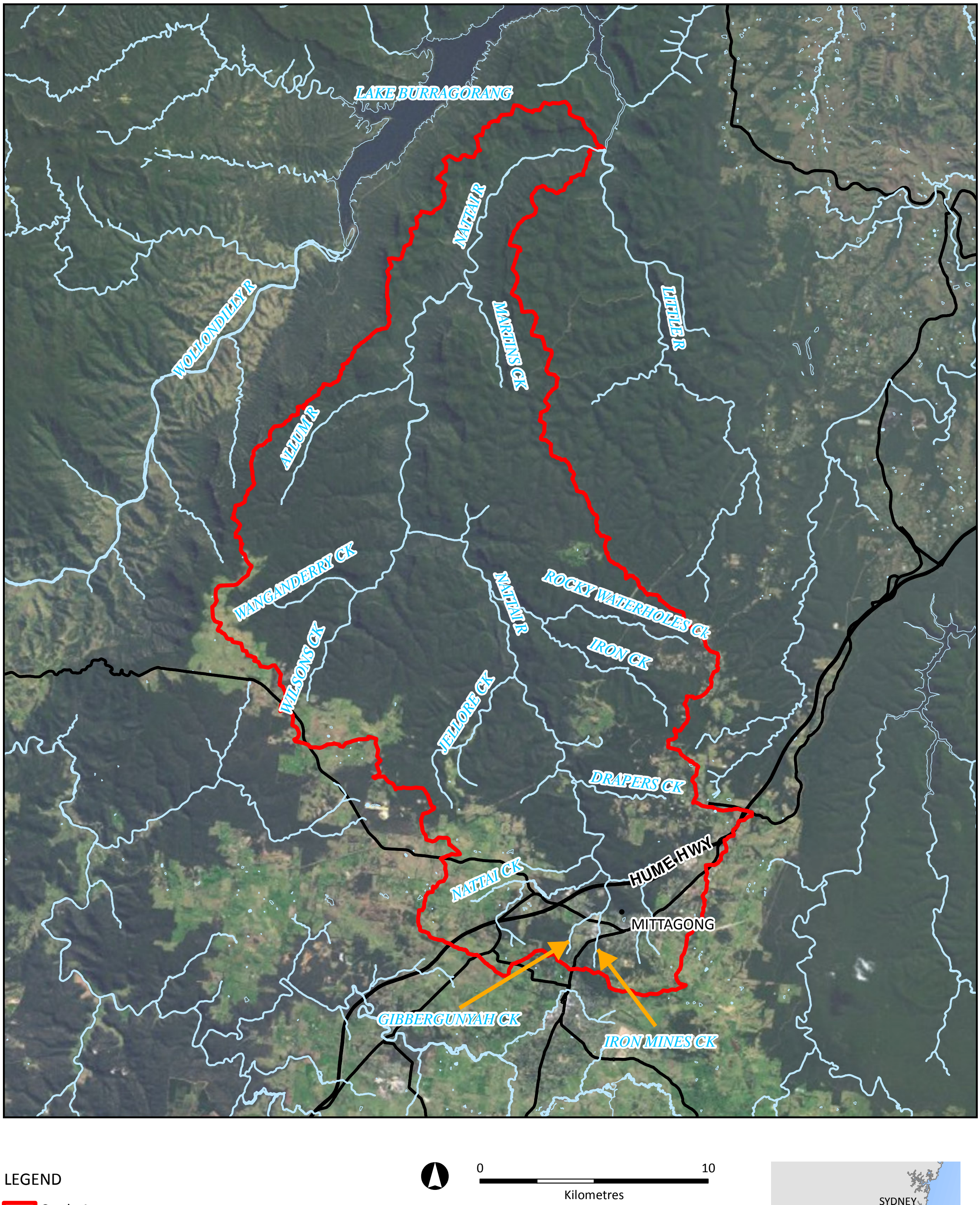
2 Description of the Study Area

2.1 Locality

The study area is located in the Southern Highlands region of NSW, 150km south-west of Sydney, as shown in Figure 1. The town of Mittagong and the surrounding villages of Colo Vale, Braemar and Hilltop are located at the far-upstream (southern) portion of the catchment. Major roads through the catchment include the South Western Freeway (Hume Highway) which passes to the north-west of Mittagong.

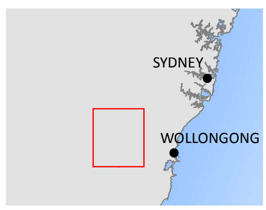
The 446km^2 catchment is drained by the Nattai River and numerous minor tributaries, including Nattai Creek, Gibbergunyah Creek, Iron Mines Creek, Rocky Waterholes Creek, Jellore Creek, Drapers Creek,, Wilsons Creek, Alum Creek and Martins Creek. The Little River confluences with the Nattai River 2km upstream of the Nattai River's outlet into Lake Burragorang. This study focuses on the Nattai River catchment upstream of the Little River junction.

FIGURE 1 | STUDY AREA LOCALITY



LEGEND

- Study Area
- Waterways
- Main Highway



Datum: GDA 1994 MGA Zone 56

2.2 Terrain and Soils

The terrain of the study area is typically rugged and consists of hillcrests/ tablelands, sandstone escarpments and deeply incised valleys and gorges carved by the Nattai River and its tributaries. Ground elevations in the catchment range from 860m AHD along the southern-most boundary of the catchment to 120m AHD at the catchment outlet in the north of the catchment.

The underlying bedrock geology of the study area includes large areas of Hawkesbury Sandstone, underlain by smaller seams of Narrabeen Group Sandstone (DEC, 2004). The geology in areas along the southern and south-western catchment boundary is composed of Wianamatta Shale, with basalt outcrops found in the Mt Jellore area in the southern portion of the catchment.

Soil types on the tablelands are generally coarse-grained sandy soils which are typically shallow and rocky, originating from the Hawkesbury Sandstone geology. Soils on the escarpment slopes and valley floors are predominantly comprised of Permian Sediments mostly from the Shoalhaven Group, and are derived from sedimentary rocks of varying grain size occur, including sandstone, shale and siltstone. The shale and siltstone material tends to occur in flatter locations, where a clay loam soil tends to develop (DEC, 2004).

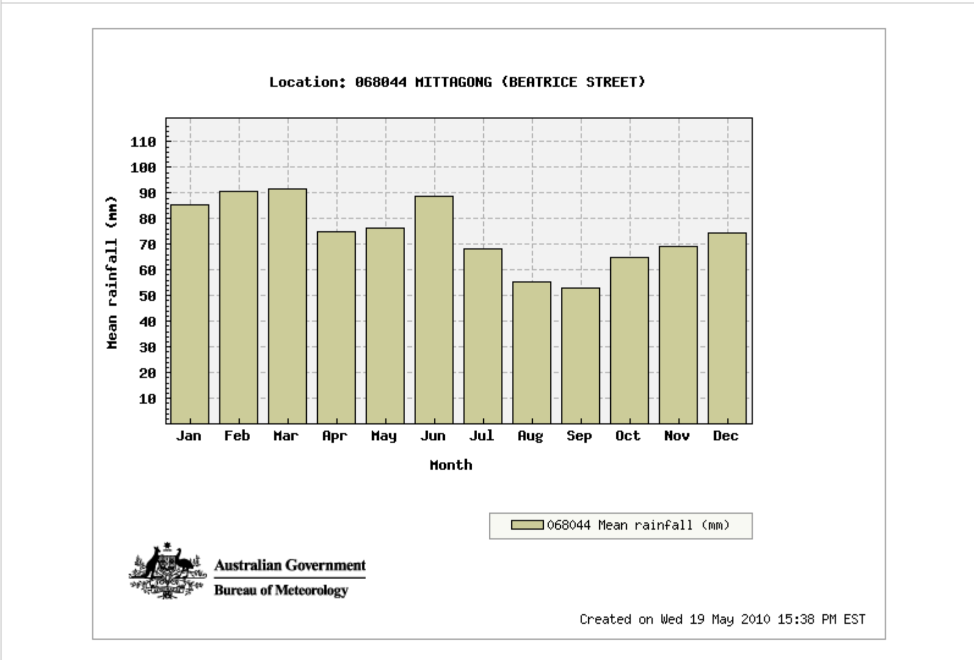
Alluvial deposits of varying depth and composition occur along the waterways, with shallow sandy alluvium typical of smaller upland creeks and deeper deposits on the main river flats of the lower Nattai River.

Plate 1 Nattai River valley at The Crags. This tablelands and canyon terrain is typical of the catchment.

2.3 Rainfall Hydrology

The rainfall pattern in the Nattai River catchment is typical of the central NSW coastal region, in that rainfall events are produced by a range of rainfall-producing weather systems and that neither summer nor winter are the dominant seasons for rainfall. Mean monthly rainfall at Mittagong (BOM station 068044) ranges from 53mm in September to 92mm in March.

Figure 2 Mean Annual Rainfall for BOM Station 068044 (Mittagong at Beatrice St)



Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Mean rainfall (mm) for years 1886 to 2010	85.4	90.5	91.6	75.1	76.1	88.8	68.2	55.3	52.8	64.7	69.2	74.5	890.7	110

(Source: BOM Website. http://www.bom.gov.au/climate/averages/tables/cw_068044.shtml)

Mean annual rainfall is highly variable throughout the study area, ranging from 1300mm on the upstream (southern) boundary of the catchment, to 800mm at the outlet (northern portion) of the catchment, according to SCA data. The highest rainfall occurs along the south-eastern boundary of the catchment, with areas of high rainfall also occurring in other areas within the southern portion of the catchment. Areas of low rainfall occur along the catchment centreline and in the northern half of the catchment, due to rainshadow effects caused by the terrain.

2.4 Land Use

Land use in the catchment is predominantly vegetated areas (85% of catchment), including large areas of forest wilderness. Large areas of the catchment are within the Jellore State Forest, Nattai and Bargo State Conservation Areas and Nattai National Park, which forms a part of the Greater Blue Mountains World Heritage Area. The majority of these combined forest areas constitutes restricted access Special Areas administered by SCA for the protection of Sydney's water supply. Vegetation types are typically dry sclerophyll forest with local variations depending on the soil type and

topography, with riparian vegetation including significant areas of *Casuarina sp.* occurring along the river flats.

Cleared areas for historic farming and grazing occupy approximately 10% of the catchment area. These areas are located on the tablelands in the southern portion of the catchment. The remaining areas of the catchment are occupied by urban, peri-urban (rural-residential) and transport corridor areas. There are also isolated locations of intensive agricultural land use, including piggeries and mushroom farms. Refer to Figure 7.

2.5 Water Quality and Quantity Issues

Water quality is a significant issue in the catchment since it is within Sydney's drinking water catchment. SCA's catchment management operations aim to ensure that the security of the drinking water supply is not threatened. Algal blooms have historically occurred in Lake Burragorang, and hence nutrients (Total Phosphorus and Total Nitrogen) are constituents of particular concern. Turbidity and Total Suspended Solids (TSS) are also water quality parameters of significance to the drinking water catchment. Faecal coliforms are an additional issue as a number of Sewage Treatment Plants operate within the Warragamba Dam catchment, include the Mittagong/Braemar Sewage Treatment Plant (STP) in the Nattai River Catchment. However in this study, only nutrients (TN, TP) and TSS are assessed.

The natural forested areas typically have good water quality. Pollution sources are confined to the headwaters of the catchment, and include point sources such as Mittagong/Braemar STP and intensive agricultural lots; and non-point sources such as grazing lands and urban areas.

There are numerous small farm dams located in the rural areas of the catchment. There are no significant water extractions within the catchment.

3 Review of Available Data

3.1 Sub-Catchment Boundary Spatial Data

Source Catchments has the capability of internally delineating sub-catchment boundaries based on an input Digital Elevation Model (DEM). For this study however, the sub-catchments were created in a GIS environment prior to input into the model, to gain better user control of where boundaries should be located, particularly with respect to stream gauge locations.

The sub-catchment boundaries in the Source Catchments model were derived from a GIS layer of 152 minor sub-catchments for the Nattai River Catchment, which were previously created by the SCA. The minor units were aggregated into 29 sub-catchments, which was considered to be a more reasonable number of sub-catchments for the study area while still preserving a high level of detail in the modelling. The sub-catchment boundaries are shown in Figure 3.

A total of 152 sub-catchments would have been cumbersome to work with in the model without gaining any significant benefits in resolution of the modelling. The sub-catchments were aggregated based on the following priorities:

- Similarity in size and shape (where possible)
- Maximising area within 'true catchments' (rather than remainder areas).
- As close as possible, keeping boundaries at each of the three gauging sites within the catchment.

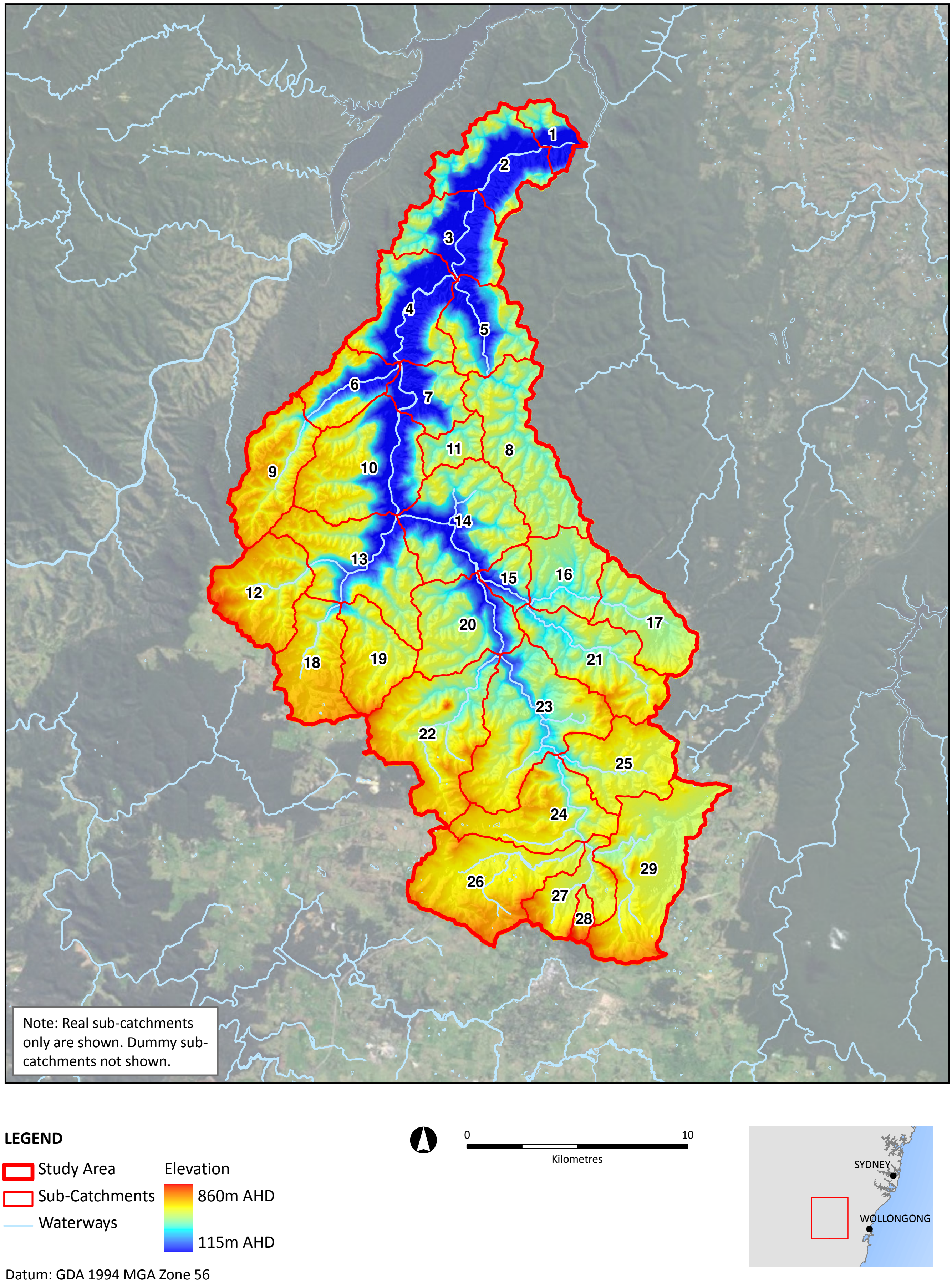
3.2 Rainfall Data

Rainfall data is required as input data into the hydrologic component of the model. Where possible, a wide spatial distribution of rainfall data should be obtained. Daily rainfall data was therefore obtained for 12 sites in and within close proximity of the study area. These are listed in Table 1, and their locations shown on Figure 4. A gantt chart showing the temporal coverage and data gaps of the rainfall data is shown in Figure 5.

Table 1 Nattai River Region Rainfall Stations

Station ID	Station Name	Owner	Period of Record	Missing data
068102	Bowral (Parry Drive)	BOM	11 October 1961 – present	2%
068044	Mittagong (Beatrice Street)	BOM	1 January 1886 – present	14%
068005	Bowral Post Office	BOM	1 February 1885 – 30 November 1965	1%
563036	Yerranderie (Byrnes Creek)	SCA	27 May 1966 - present	4%
568038	Wollondilly (Jooriland)	SCA	2 June 1962 – present	6%
568094	Mittagong (High Range)	SCA	1 January 1945 - present	1%
568099	Mittagong (Leicester Park)	SCA	1 January 1946 - present	5%
568098	Mittagong (Kia-Ora)	SCA	1 January 1945 – 30 September 2006	6%
568054	Mittagong (Maguires Crossing)	SCA	1 January 1965 – present	3%
568050	Hilltop (Starlights Track)	SCA	25 May 1981 – present	4%
568164	Hilltop (Nattai Tableland)	SCA	29 June 1990 – present	8%
568140	Nattai Causeway	SCA	9 April 1981 – present	7%

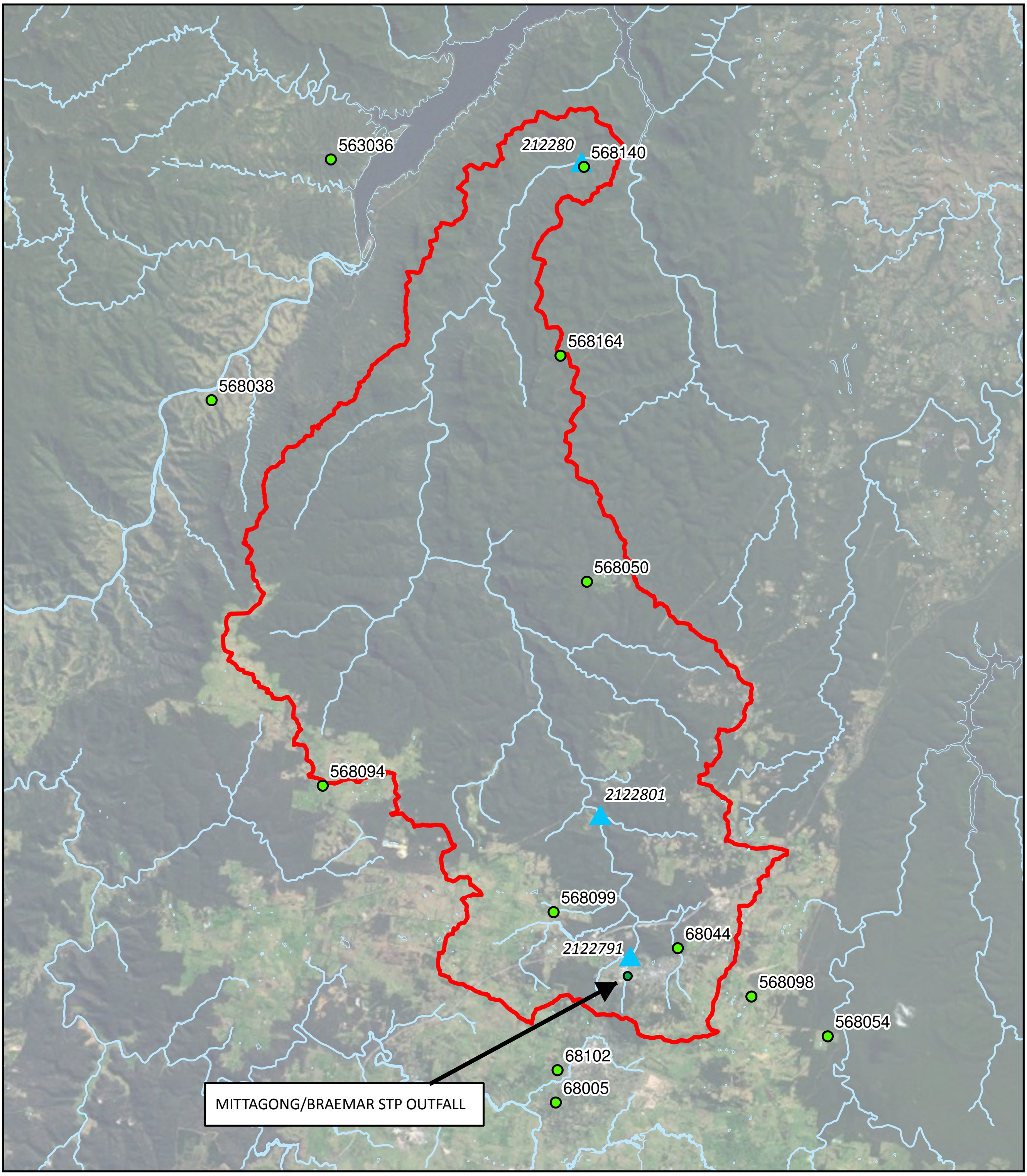
FIGURE 3 | GROUND ELEVATIONS AND SUB-CATCHMENT BOUNDARIES

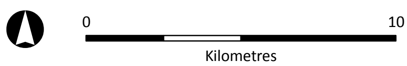


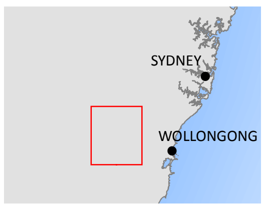
SKM eWater CRC

June 1, 2010

FIGURE 4 | RAINFALL AND STREAMFLOW GAUGE LOCATIONS





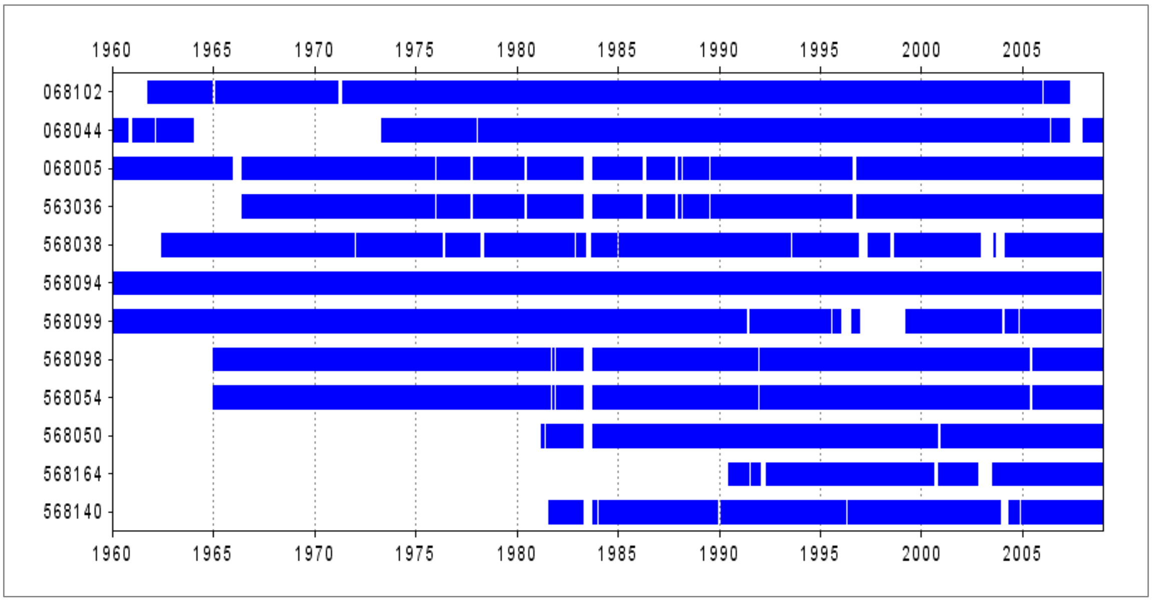


LEGEND

- Rainfall Stations Analysed
- Streamgauge
- Study Area
- Waterways

Datum: GDA 1994 MGA Zone 56

Figure 5 Daily Rainfall Data Gantt Chart



The available rainfall data at SCA rainfall stations 568054, 568099, 568094, 568038 and 563036 is comprised of both daily-read rainfall depth and pluvio data at the same location. Historically, the daily-read rainfall data has been collected as the primary rainfall data type upon the commissioning of these rainfall stations. During the 1980's, pluviographs were introduced at most of these stations[1], resulting in an overlap of the two data sets for a number of years, until the daily-readings were discontinued. SCA staff confirmed that the daily-read rainfall gauge and the pluviograph were located at exactly the same location. The daily-read rainfall data and the pluviograph data was observed to give different daily rainfall depths for the same period on numerous occasions.

The rainfall data was visually reviewed, with consideration of data quality codes. Suspect data was culled and periods for data disaggregation were identified and processed.

For SCA stations with coinciding daily-read data and pluviograph data, a unified rainfall time series was created. The pluviograph data was assumed to be more reliable, due to often inconsistent quality of the daily-read rainfall data.

All the rainfall data sets from SCA and BOM had a number of data gaps. Infilling of these gaps was undertaken by performing a multiple linear regression analysis between the daily rainfall datasets to determine the best correlation between the rainfall stations. The data gaps of each station were then filled based on the linear relationship $Y = a*X$ between the rainfall datasets.

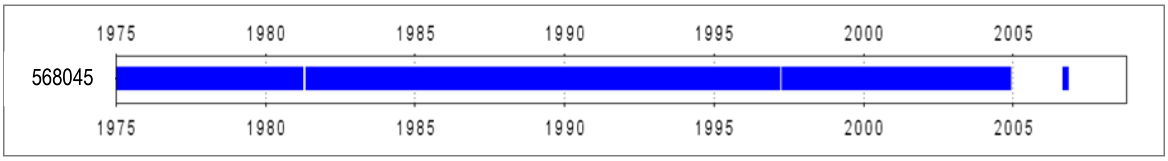
Not all rainfall station datasets were used in the Source Catchments model. Six stations were selected for modelling inputs based on their location within or in close proximity to the catchment and their period of record. These are stations 068044, 568099, 568094, 568050, 568038 and 568140.

[1] With exception of 568099, where pluviograph data is available from March 1999.

3.3 Evaporation Data

Evaporation data is required to estimate loss of soil moisture on a daily basis. Daily time series Class A Pan evaporation data was obtained for the SCA station 568045 (Warragamba Dam) for input into the Source Catchments model. Data only from this single site was considered as the Warragamba Dam station is one of the main weather stations in the region and therefore the integrity of the evaporation data is significantly greater than that from other minor weather stations in the region. A gantt chart for the evaporation data is shown in Figure 6. The daily time series was infilled and extended using monthly-averaged daily evaporation for input into the Source Catchments model.

Figure 6 Evaporation Data Gantt Chart



3.4 Land Use and Land Coverage

3.4.1 Preliminary Land Use based Functional Units

Land use information is typically used as a basis for defining the spatial variation in catchment hydrologic characteristics, as each land use is likely to have a different rainfall-runoff response. Land use and land coverage GIS layers held by SCA were reviewed by SCA and SKM project team members, and interpreted to create a Functional Units ("FUs") layer for input into the Source Catchments model. The eight FUs for the Nattai River Catchment were defined based on the dominant land use/land cover categories likely to influence runoff and water quality in the Nattai River, and include:

- Cleared Areas
- Horticulture
- Intensive Animal Production
- Rural Residential
- Transport and Other Corridors
- Urban Sewered
- Urban Unsewered
- Vegetated Areas.

The FUs are assigned different model parameters to describe the hydrologic and pollutant generation characteristics of these areas. The pervious fraction of the FUs is one parameter which determines the runoff potential from an area. The total impervious surfaces area within each FU was estimated from SCA spatial data of actual paved areas in the study area. From this, the spatially-averaged pervious fraction of each FU was estimated. These are summarised in Table 2. The FU coverage in the study area is shown in Figure 7.

FIGURE 7 | FUNCTIONAL UNITS

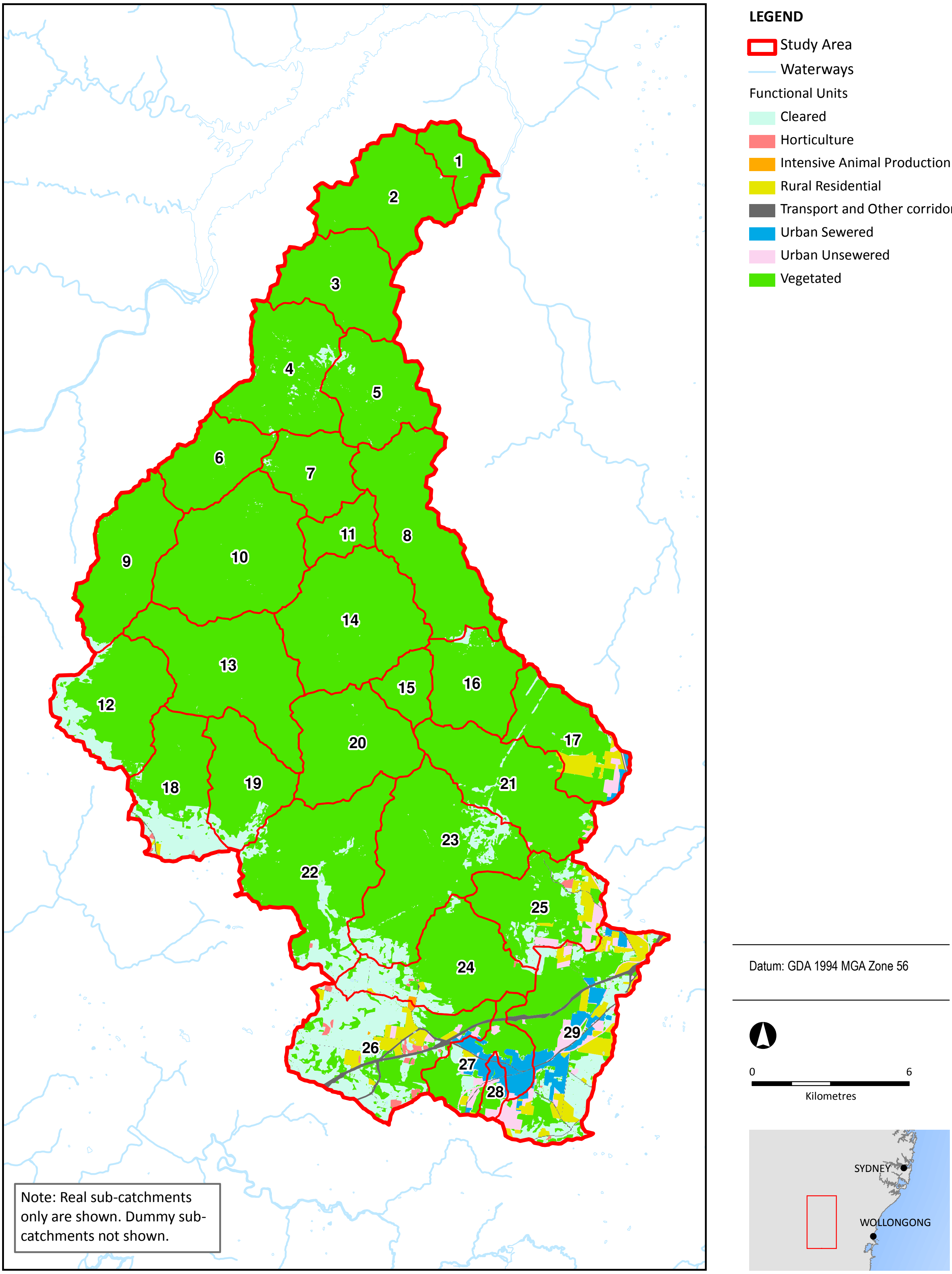


Table 2 Functional Unit Pervious Fractions

Functional Unit	Pervious Fraction	Functional Unit	Pervious Fraction
Cleared	1.0	Transport/Other Corridors	0.6
Horticulture	1.0	Urban Sewered	0.72
Intensive Animal Production	1.0	Urban Unsewered	0.94
Rural Residential	0.99	Vegetated	1.0

3.4.2 Discretisation of Functional Units based on Soil Facets

Further detail in the catchment hydrologic response can be introduced by considering the different hydrologic properties of different soil facets. The eight preliminary FUs were further sub-divided into smaller units based on the soil facets GIS layer in order to utilise the information available for these soil facets. SCA had previously engaged consultants to analyse the soil facets to estimate various soil characteristics (Morse McVey, 2006). This GIS layer indicates that 37 soil facets are present in the Nattai River catchment, which potentially results in 296 land use/soil facet combinations.

To limit the number of FUs to be defined in the Source Catchments model, the soil facets layer was rationalised based on their area of coverage within each FU type. For the Cleared, Rural Residential, Urban (Sewered and Unsewered) land use units, the top three soil facets are expressed separately and the remaining soil facets grouped. For the Vegetated land use/land cover unit, the top seven soil facets are expressed separately and the remaining soil facets grouped. The vegetated area FU was discretised to a greater degree than the other FUs since it occupies the vast majority of the study area (85% of the total area). The total surface area of each FU and the soil facet composition within each FU is summarised in Appendix A. The following procedure was used:

- In GIS, sub-divide the eight preliminary land use FUs based on the soil facets layer. Calculate the cumulative surface area for each land use/soil facet FU group and rank each soil facet based on the area proportion taken up in each land use/land cover unit.
- Group the soil facets such that approximately 70% (minimum) of each major land use/land cover unit is represented by separate soil facets:
- For the Cleared, Rural Residential, Urban Sewered and Urban Unsewered land use/land cover units, identify/separate the top three soil facets and group the remaining soil facets. These land use/land cover types occupy 1 – 10% of the overall Nattai River catchment area.
- For the Vegetated land use/land cover unit, identify/separate the top seven soil facets and group the remaining soil facets. Vegetated areas occupy 85% of the overall Nattai River catchment area.
- Soil facets “ERht1” and ERht2” were lumped together, based on the similarity in the MUSIC model hydrologic parameters estimated for these soil facets (Morse McVey, 2006).
- The soil facets for the Horticulture, Intensive Animal Production and Transport/Other Corridors land use units were lumped together, since

these areas occupy less than 1% of the overall Nattai River catchment area and did not necessitate further discretisation.

The above procedure produced a total of 27 detailed FUs for representation in the Source Catchments model. Refer to Table 7.

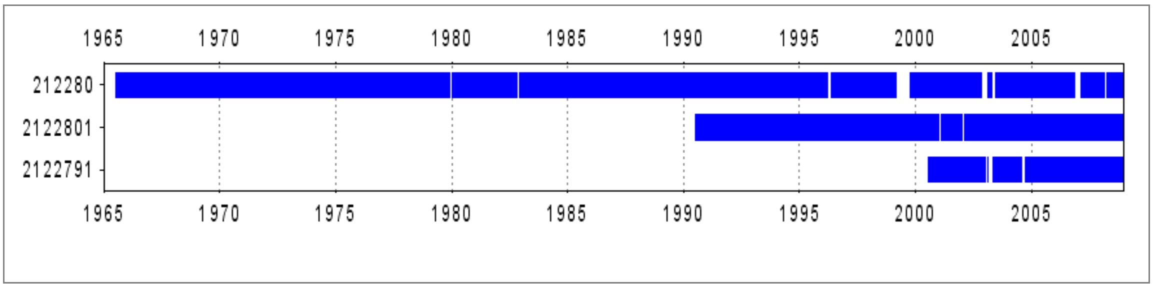
3.5 Streamflow Data

Streamflow data is required to calibrate the hydrologic component of the Source Catchments model, and validate the rainfall-to-runoff processes in addition to any flow routing procedures represented in the model. This data was obtained for the three stream gauges operating in the catchment. The period of record and missing data are summarised in Table 3 and their locations are shown on Figure 4. A gantt chart indicating the temporal coverage of the streamflow data is shown in Figure 8.

Table 3 Available Streamflow Data

Station ID	Station Name	Period of Record	Missing data
212280	Nattai at The Causeway (Smallwoods Crossing)	July 1965 – present	5%
2122801	Nattai River at The Crags	July 1990 – present	2%
2122791	Gibbergunyah Creek D/S of Mittagong STP	July 2000 – present	11%

Figure 8 Streamflow Data Gantt Chart



The streamflow data sets were reviewed for suitability, specifically the period of record, integrity of the data, data quality codes and data gaps (% missing data) for the hydrologic calibration of the Source Catchments model. Data from Stations 212280 and 2122801 were selected for the hydrologic calibration. Station 2122791 was excluded for a number of reasons:

- Relatively short period of record, a number of years of which were drought years;
- Small upstream catchment: The catchment upstream of Station 2122791 is only 1.7km^2 (approximately 0.4% of the overall study area).
- Multiple (5) land uses are represented in the upstream catchment. It would have been difficult to parameterise individual FUs from this data.

  Uncertainty in the STP flows (refer to Section 3.6) meant that there would be a significant amount of noise in the daily flow data at this station.

Plate 2 Nattai River just upstream of The Crags

3.6 In-Stream Water Quality Data

3.6.1 Monitoring Sites

Water quality data is required to validate the representation of water quality constituent generation processes in the Source Catchments model, in addition to any water quality filtering processes adopted in the model. A review of SCA's water quality database indicated that there is water quality data for approximately 20 locations within the study area. Of these, three water quality monitoring sites (E203, E206 and E210) correspond with the three flow gauges within the study area which therefore potentially permits the estimation of constituent loads during flow events during the water quality calibration stage. Constituent loads are calculated by multiplying the measured concentration by the flow, hence highlighting the necessity for flow data at the water quality monitoring sites.

Table 4 Water Quality Monitoring Sites

Site Code	Site Name	Corresponding Stream Gauge	Period of Record	Parameters (Number of Samples)
E203	Gibbergunyah Creek at Mittagong STP	2122791	28 Jul 1999 – present	TN (147); TP (105); TSS (96)
E206	Nattai River at The Crags	2122801	3 Jan 1991 – present	TN (559); TP (551); TSS (398)
E210	Nattai River at Smallwoods Crossing	212280	14 Jan 1960 – present	TN (478); TP (510); TSS (283)

The data from these sites was reviewed for quality and usefulness. Data from sites E206 and E210 was identified as being suitable for the purposes of this study, with a number of periods present where multiple water quality samples were collected over the duration of a flow event, thus permitting constituent loads to be estimated for these events. Data from site E203 was discarded as there was not sufficient data for estimating event loads. A maximum of two samples were available over the course of the flow events captured by this dataset.

The remainder of the water quality monitoring sites in the Nattai River catchment have datasets which are comprised of one-off samples or which constituted short-term (less than 2 years) monitoring programs, Further, instantaneous flow data is not available at these sites to allow an estimation of constituent loads during flow events with any confidence.

3.6.2 Sampling Methods

Water quality sampling at the selected locations consists of routine manual sampling every two to four weeks, in addition to autosamplers which are triggered by flow events to collect samples at various intervals throughout the event.

3.7 Sewerage Treatment Plant Flow and Effluent Quality Data

3.7.1 Description of STP Data

Mittagong/Braemar STP is operated by Wingecaribee Shire Council and is located in the headwaters of the catchment, and serves the urban area of Mittagong and surrounds. Its location is indicated on Figure 4. The original Mittagong STP was commissioned in 1939 and was replaced with the Braemar STP in 2001 to improve the treatment capacity of the STP. While the location of the plant was shifted several kilometres to the neighbouring village of Braemar, the effluent outfall remains in its original location on Iron Mines Creek (a tributary of Gibbergunyah Crek). The STP has been identified as a potentially significant point source of water quality constituents and hence effluent discharge data is required to represent the STP in the model.

Discharge data from the Mittagong/Braemar Sewerage Treatment Plant (STP), which is the only STP located in the catchment, was obtained from Wingecarribee Shire Council. The data consisted of the following:

- Monthly total discharge for 2000 – 2006
- Daily discharge data for 24 March 2007 – 23 March 2008

Therefore there is a 3 month gap in the data between the end of the monthly data and the start of the daily data.

The monthly STP discharge for the period 2000 – 2008 is shown in Figure 9. Estimated Equivalent Population (EP) data was also obtained by SCA from Wingecaribee Shire Council, and is shown in Table 5.

Figure 9 Measured Monthly STP Discharge from Mittagong/Braemar STP

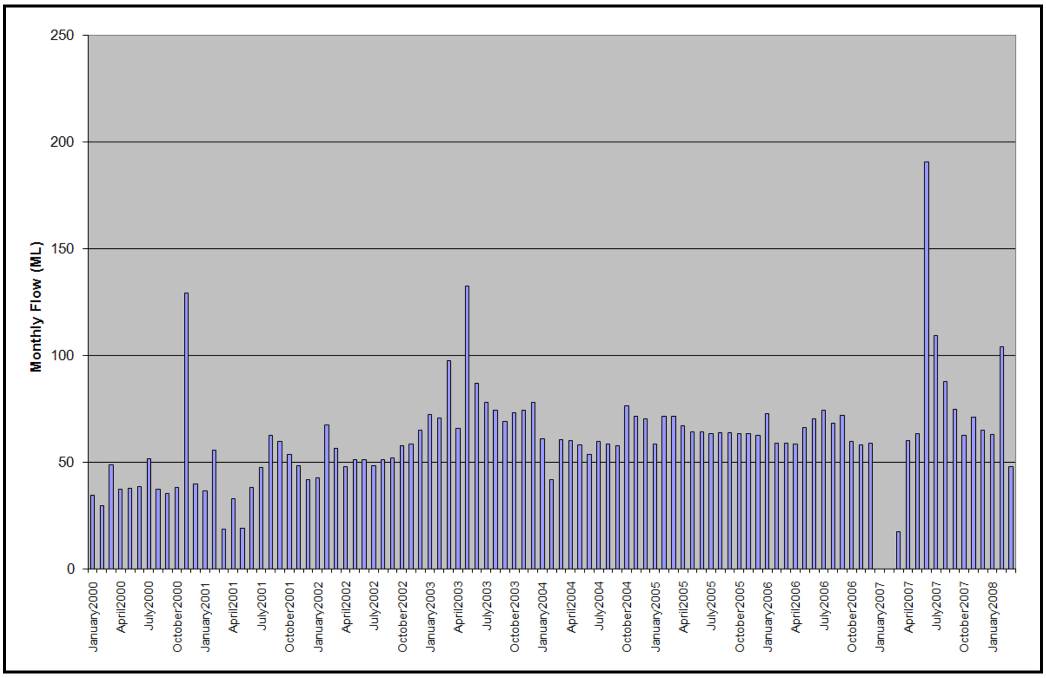


Table 5 Estimated EP Data for Braemar STP

Year	EP	ADWF (L/sec)	ADWF (kL/d)	Annual Flow (ML/yr)
2002	9,000 (approx)			
2007	12,164	33.8	2,919	1,332
2008	13,550		3,252	
2012	15,730	43.7	3,775	1,722

Effluent quality data was also obtained for the study. Data was available for the period 2000 – 2007 as fortnightly sample data. Parameters of interest to this study included suspended solids, Total Nitrogen (TN) and Total Phosphorus (TP). Issues to note with the data, and the STP:

- The original Mittagong STP was commissioned in 1939.
- An upgraded STP was constructed in a new location in Braemar, 6.4km from the original site due to the old STP being over capacity, and to cater for a growing population in the area. The upgraded plant was commissioned in 2002. The upgraded STP still discharges to the original outfall location on Iron Mines Creek.
- The monthly STP discharges rise from approximately 35ML/month pre-2002, to approximately 60ML/month post-2002, and appears to coincide with the commissioning of the upgraded plant.
- The STP discharge data is measured prior to offtake for irrigation on Mittagong Golf Course. The offtake is approximately 10 – 15% of the STP discharge during spring, summer and autumn, with limited offtake during winter.

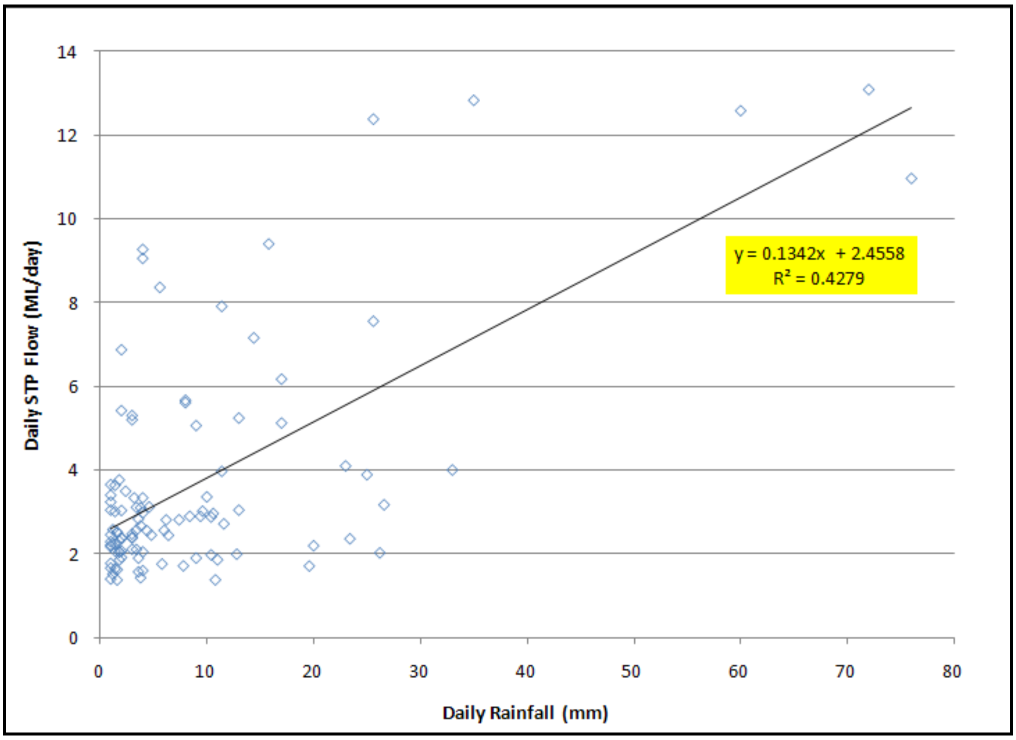
- The Mittagong STP reportedly bypassed flows into the adjacent Mittagong River in August 1998 due to power failure. It is not known whether overflows entered the Nattai River during this event, however, this information may be relevant for the water quality component of the project.

3.7.2 Processing and Extension of STP Flow Data

A daily time series for STP flows was required for input into the Source Catchments model for the selected modelling period. The procedure used to extend the length of the daily STP flow data set is described below:

- A regression analysis was performed on the available daily STP flow data (March 2007 – March 2008), correlating the STP flow with daily rainfall on days where the rainfall exceeded 1mm. The rationale for this is based on the following:
    - STP flows were assumed to increase proportionally with increasing rainfall, due to infiltration of rainwater into the sewerage network
    - The STP daily flows were assumed to be independent from rainfall on days where the rainfall depth was less than 1mm.
- The results of the regression analysis are shown in Figure 10. A daily time series of STP flow for the period 1975 – February 2007 was produced based on the linear relationship derived from the regression analysis. The relatively low R^2 value indicates that there is some uncertainty in the predicted STP flow values.

Figure 10 Plot of Daily Rainfall Greater than 1mm versus Daily STP Flow



- The monthly STP flow data (January 2000 – December 2006) was disaggregated based on the temporal pattern in the synthesised daily time series.
- The daily time series for the period 1975 – 1999 was scaled based on the estimated EP for the STP. From Section 3.6, the EP data provided by SCA/Council indicates an EP of 12,164 in 2007, and an EP of 9,000 in 2002, following the upgrade of the STP. Based on the average monthly STP flows of 35kL/day pre-2002 and 60kL/day post-2002, an EP of approximately 6,000 was estimated for the period pre-2002. It was assumed that the 12,000EP was associated with the 60kL/day flow. The synthesised daily time series for the period 1975 – 1999 was therefore reduced by approximately 50%.
- The final STP daily flow time series therefore consists of the following:
    - 1975 – 1999: Synthesised daily time series based on the regression equation derived for the linear trendline in Figure 10, scaled by estimated EP of 6,000.
    - 2000 – 2006: Monthly STP flow data, disaggregated based on synthesised daily time series temporal pattern.
    - January – 23rd March 2007: Synthesised daily time series based on the regression equation derived for the linear trendline in Figure 10, unscaled.
    - 24th March 2007 – 23rd March 2008: Reported daily STP flow.

3.7.3 Characterisation of STP Effluent Quality

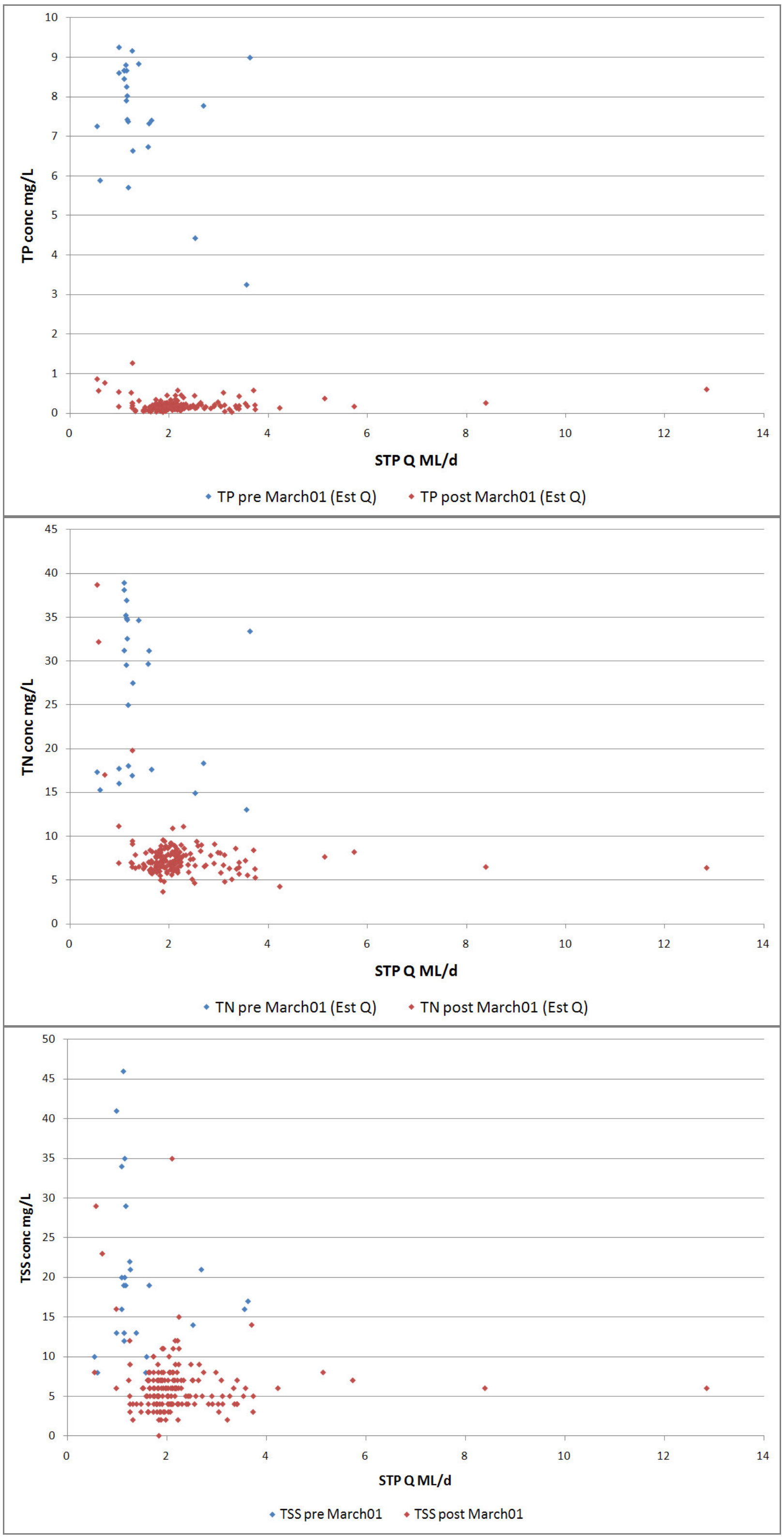
The effluent TN, TP and TSS concentrations were reviewed to characterise the STP effluent quality. The fortnightly sample concentrations were plotted against the daily effluent discharge, as shown in Figure 11. The data before March 2001 is plotted separately to the data after March 2001.

The effluent can be seen to have higher and more variable concentrations of TP, TN and TSS prior to March 2001, when compared to the post-March 2001 data. This date coincides with the change-over from the old Mittagong STP to the upgraded Braemar STP. The mean concentrations for these periods are summarised in Table 6 below. The data indicates that constituent concentrations were reduced significantly as a result of the STP upgrade. Additionally, the variability of the concentrations not only decreased as a result of the upgrade but also decreased with time at the new STP.

Table 6 Mittagong/Braemar STP Effluent Constituent Concentrations (mg/L)

	TSS		TN		TP	
	Mean	St Dev	Mean	St Dev	Mean	St Dev
Pre March 2001	20	9.9	26.8	8.7	7.65	1.48
Post March 2001	6	3.8	7.7	3.4	0.22	0.44
Most Recent (2007-08)	5	1.6	6.8	1.1	0.17	0.10

Figure 11 Mittagong/Braemar STP – TP, TN and TSS Concentration vs. Daily Discharge



4 Model Development and Hydrologic Calibration

4.1 Model Setup

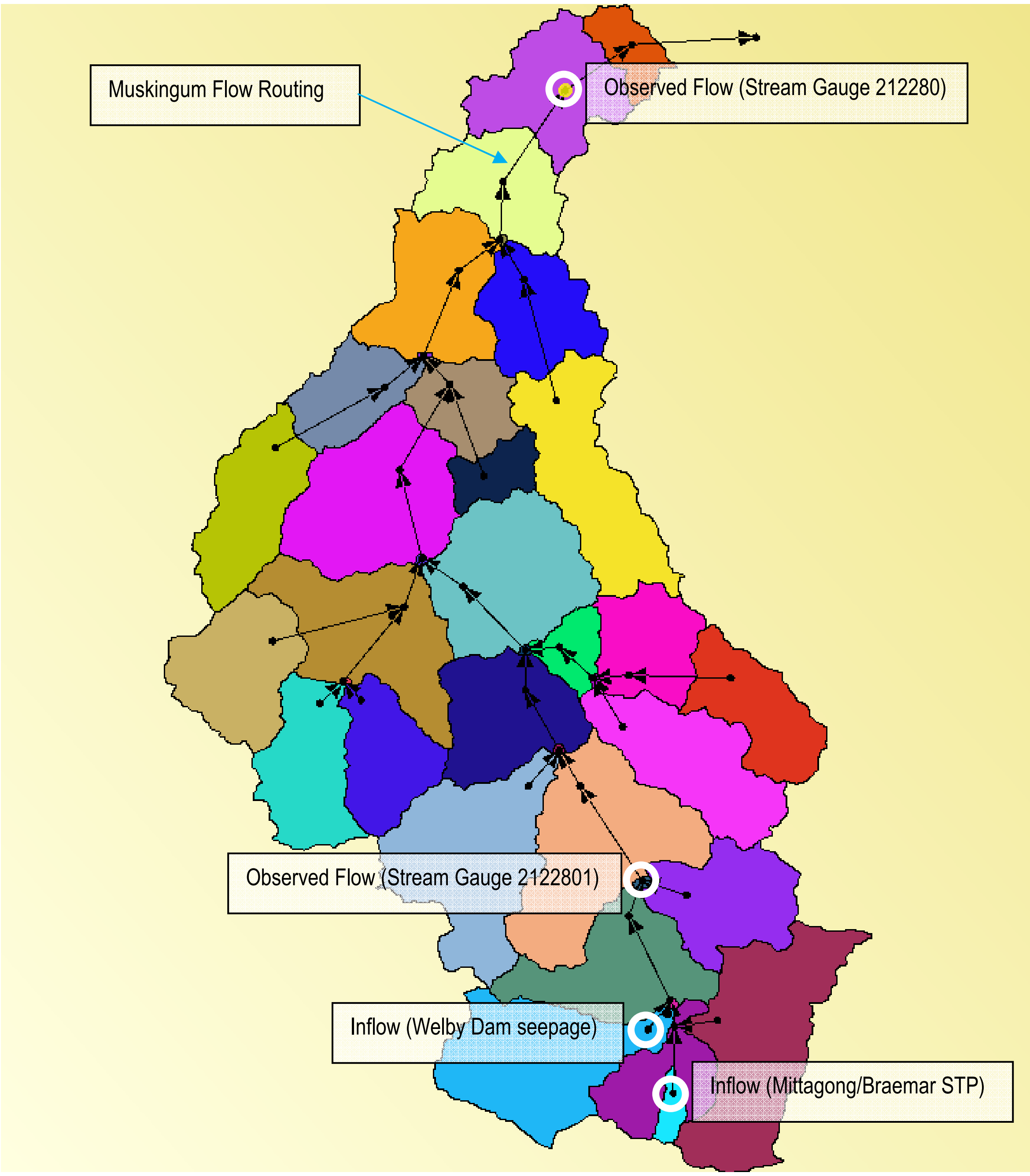
The Source Catchments model was configured based on the defined sub-catchments and the drainage lines through the study area. The model network is shown in Figure 12. The model was developed and run in Source Catchments version 1.0.2b.

Source Catchments use the concept of component models that can be applied to a functional unit, “node” and or “link”. These models allow the user to simulate generation to in-stream processes such as streamflow recession, flow extractions/ demands and flow routing. Observed inflow data can also be applied at a node. The node models and link models used in the Nattai model hydrologic calibration are indicated on Figure 12. A description of the various models used in the Source Catchments model is given below:

- Observed flows: Historically recorded stream flows at Stations 212280 (Nattai at The Causeway) and 2122801 (Nattai at The Crags) have been input into the model at the indicated locations for comparison with the Source Catchments model time series flow results.
- Inflow from Mittagong/Braemar STP: Time series of STP daily discharge derived using the approach described in Section 3.6.
- Inflow from Welby Dam seepage: Inflow of 0.2ML/d due to seepage through old dam wall at Welby Dam. Review of preliminary flow duration curves indicated that low flows were being underestimated. It was thought that this discrepancy could have been due to seepage through the dam wall. Conversations with SCA staff confirmed that there was some seepage visible at the base of the wall.
- Muskingum Flow Routing: Applied to one model link in lower catchment to improve the concurrence of observed and modelled flow event peaks. Default values of K = 86,400s and X = 0.3 adopted.
- Streamflow losses to groundwater were initially thought to be significant, however, previous studies and SCA staff confirmed that the Nattai River is most likely to be a gaining stream. Hence, losses at model nodes were not represented.

Each of these models were typically added during the model calibration stage to achieve a better fit of the modelled flow results to the observed flows. The rationale behind the model calibration is described in Section 5.3

Figure 12 Nattai Source Catchments Model Network and Node/Link Models



4.2 Model Simulation Period

The model was set up to run from 1st January 1975 – 23rd March 2008. The model run start date was selected in agreement with SCA, to minimise data gaps in the rainfall data sets (refer to Figure 5). The model run end data coincides with the end of the available recorded STP discharge data. This period of simulation was selected to cover both wet and dry periods. Change in land use over this period is not considered to have a significant impact on hydrology, since the forested and cleared areas in the catchment, which make up 95% of the catchment area, have remained stable over that period. Any urban development over this period would have affected less than 2% (which is the current coverage of urban area in the catchment) of the catchment area.

4.3 Hydrologic Calibration and Validation Rationale

4.3.1 Calibration and Validation Periods

The period 12th July 1990 – 23rd March 2008 was selected as the model calibration period, which coincides with the beginning of streamflow gauge records at Station 2122801and the end of the available STP discharge records. Data is therefore available at both streamflow gauges. Hence it was felt this would be the most appropriate period for model calibration. It was observed that the calibration period coincides with a period of below-average rainfall.

The period 1st January 1976 – 11th July 1990 was selected as the model validation period, which allows a 1 year warm-up period from the agreed start of the model simulation time (1st January 1975). Data for this period is only available at the lower gauge, Station 212280.It was observed that the validation period coincides with a period of above-average rainfall.

Selection of the periods for calibration and validation was based primarily on maximising the data available for calibrating the model to the upper gauge data (Station 2122801), while the model validation made use of the remaining data at the lower gauge (Station 212280). By doing so, a *differential split-sample test* has been undertaken as a part of the model validation, whereby the flow data has been split into two subsets (one for calibration and the other for validation) with the data displaying non-stationarity (Argent et, al., 2008).

4.3.2 Parameter Adjustment

The SimHyd hydrologic model was adopted to model catchment hydrology in all parts of the study area. SimHyd was initially chosen for the Nattai River due to the relatively small number of parameters (seven parameters) used in the modeland is easily parameterised. Further, information for the different soil facets was available in the study area that was considered useful for parameterising the SimHyd model.

It was intended to trial alternative hydrologic models, however, SimHyd provided a good representation of hydrologic response in the catchment and therefore trialling of other models was deemed unnecessary.

Calibration of the model was undertaken by adjusting the parameters for each of the FUs to achieve satisfactory model statistics including R^2, Nash-Sutcliffe coefficient of efficiency (E) and total volume error at both of the streamflow gauges used in the calibration. These statistics were calculated based on daily

and aggregated monthly results. A good fit between the modelled and recorded daily flow duration curves was also achieved. The model statistics and flow duration curves excluded flow values on days in the time series when there were gaps in the observed flow data.

An initial parameterisation exercise was undertaken for the eight initial FUs (based on land use only), where the FU parameter values were adjusted to obtain a satisfactory fit between the modelled and recorded daily flows at Station 2122801.

The model was then run and calibrated with the full set of 27 FUs, with the refinement of parameter values being guided by the MUSIC model[2] parameters estimated for various soil facets (Morse McVey, 2006). The MUSIC model parameters were used to scale the "average" initial FU parameter values. This detailed calibration was undertaken to obtain a satisfactory fit between the modelled and recorded daily flows at both Station 212280 and Station 2122801. The SimHyd parameter values for the 27 detailed FUs are tabulated in Table 7.

4.4 Calibration and Validation Results

The model calibration results for the upper and lower streamflow gauges are presented in the figures and tables on the following pages:

- *Flow duration curves* for upper gauge calibration, lower gauge calibration and lower gauge validation in Figure 13, Figure 14, and Figure 15, respectively.
- *Model results statistics* (mean daily flow, R^2, Nash-Sutcliffe Efficiency "E" and daily flow total volume error) for daily and aggregated monthly flows for upper and lower gauge in Table 8 and Table 9, respectively, for the calibration and validation periods.
- *Comparison of mean daily and mean monthly flows* over the period of gauge record at upper and lower gauges in Table 10.
- *Scatter plots* of monthly discharges at the upper and lower gauges for the calibration and validation periods in Figure 16
- *Time series plots* of monthly discharges at the upper and lower gauges for the calibration and validation periods in Figure 17.

[2] The hydrologic model in MUSIC is a variant of the SimHyd model.

Table 7 SimHyd Calibration Parameters

Functional Unit	Baseflow Coeff	Imperv Threshold	Infiltration Coeff	Infiltr Shape	Interflow Coeff	Perv Fraction	RISC	Recharge Coeff	SMSC
Cleared ERlm1	0.03	0.50	106	4.50	0.08	1.00	5.00	0.12	270
Cleared ERlm2	0.03	0.50	142	4.50	0.08	1.00	5.00	0.09	360
Cleared REsf1	0.06	0.50	142	2.00	0.08	1.00	5.00	0.15	220
Cleared Mixed Soil	0.05	0.50	130	4.5	0.10	1.00	5.00	0.15	230
Horticulture Mixed Soil	0.05	0.50	130	4.0	0.08	1.00	5.00	0.15	350
Intensive Animal Production Mixed Soil	0.05	0.50	130	4.0	0.08	1.00	5.00	0.15	355
Rural Residential ERlm1	0.03	0.50	106	4.50	0.08	0.99	5.00	0.12	270
Rural Residential ERht1	0.08	0.50	142	3.00	0.08	0.99	5.00	0.12	360
Rural Residential Resf1	0.06	0.50	142	2.00	0.08	0.99	5.00	0.15	220
Rural Residential Mixed Soil	0.06	0.50	130	2.5	0.08	0.99	5.00	0.15	350
Transport/Other Corridors Mixed Soil	0.06	0.50	130	2.5	0.08	0.80	5.00	0.15	350
Urban Sewered ERlm1	0.03	0.50	106	4.50	0.08	0.72	5.00	0.15	360
Urban Sewered ERlm2	0.03	0.50	142	4.50	0.08	0.72	5.00	0.09	360
Urban Sewered ERht1	0.08	0.50	142	3.00	0.08	0.72	5.00	0.12	260
Urban Sewered Mixed Soil	0.06	0.50	130	2.5	0.08	0.72	3.00	0.15	350
Urban Unsewered ERht1	0.08	0.50	142	3.00	0.08	0.94	5.00	0.15	260
Urban Unsewered ERlm1	0.03	0.50	106	4.50	0.08	0.94	5.00	0.15	270
Urban Unsewered REsf1	0.06	0.50	142	2.00	0.08	0.94	5.00	0.15	220
Urban Unsewered Mixed Soil	0.08	0.50	130	2.5	0.08	0.94	5.00	0.15	350
Vegetated ERnt1	0.04	0.50	342	2.0	0.03	1.00	5	0.05	250
Vegetated Cohw2	0.04	0.50	114	2.7	0.02	1.00	5	0.05	450
Vegetated COha2	0.06	0.50	285	3.5	0.03	1.00	5	0.05	150
Vegetated ERht1	0.05	0.50	342	3.0	0.04	1.00	5	0.05	340
Vegetated ERmf2	0.04	0.50	154	3.5	0.04	1.00	5	0.04	400
Vegetated COhw3	0.06	0.50	285	3.5	0.03	1.00	5	0.05	100
Vegetated COhwa1	0.04	0.50	260	3.5	0.02	1.00	5	0.05	100
Vegetated Mixed Soil	0.04	0.50	263	3.5	0.04	1.00	4.8	0.05	300

Figure 13 Daily Flow Duration Curves for Upper Gauge (Station 2122801), Calibration Period (12th July 1990 – 23rd March 2008)

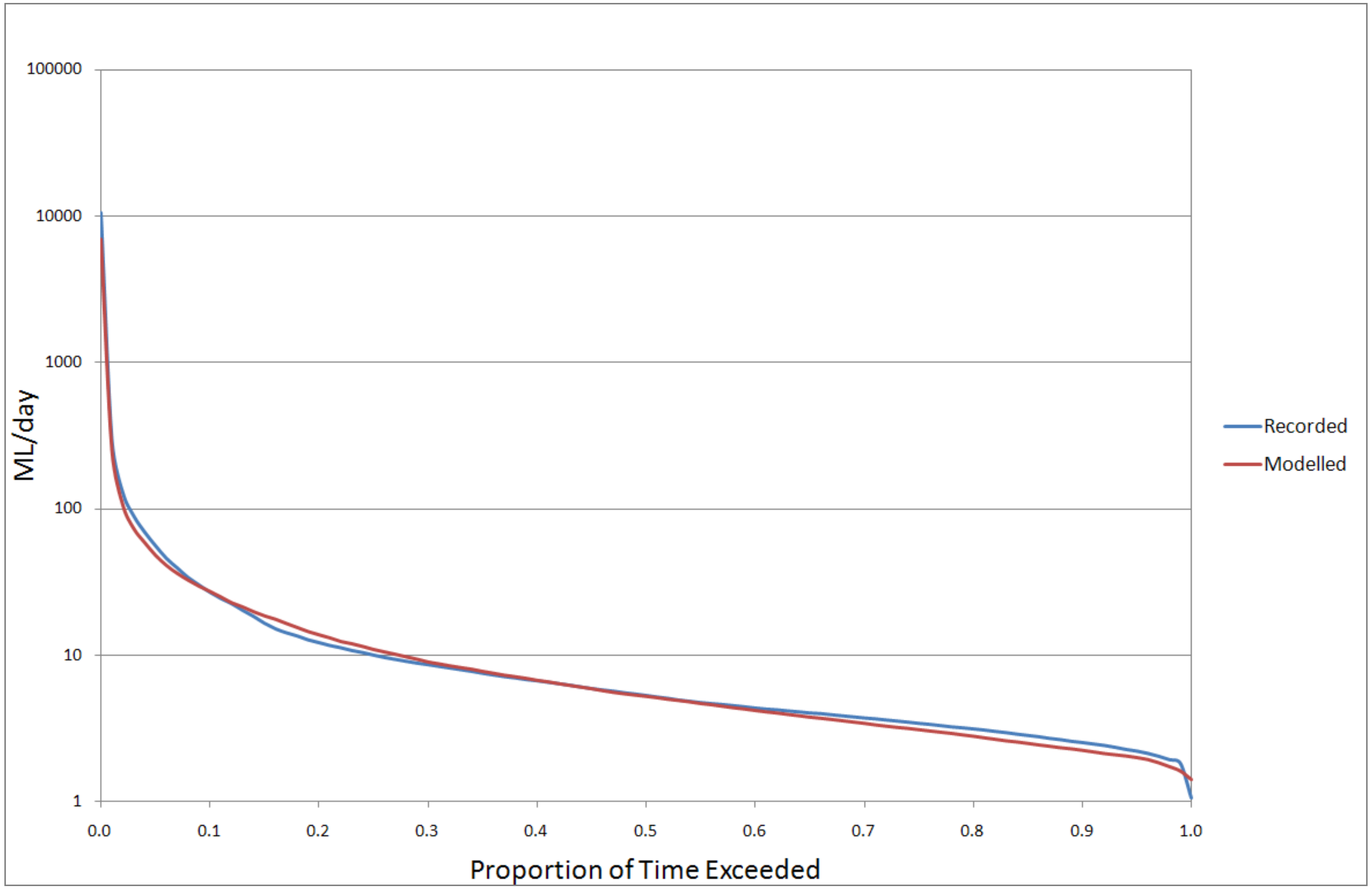


Figure 14 Daily Flow Duration Curves for Lower Gauge (Station 212280), Calibration Period (12th July 1990 – 23rd March 2008)

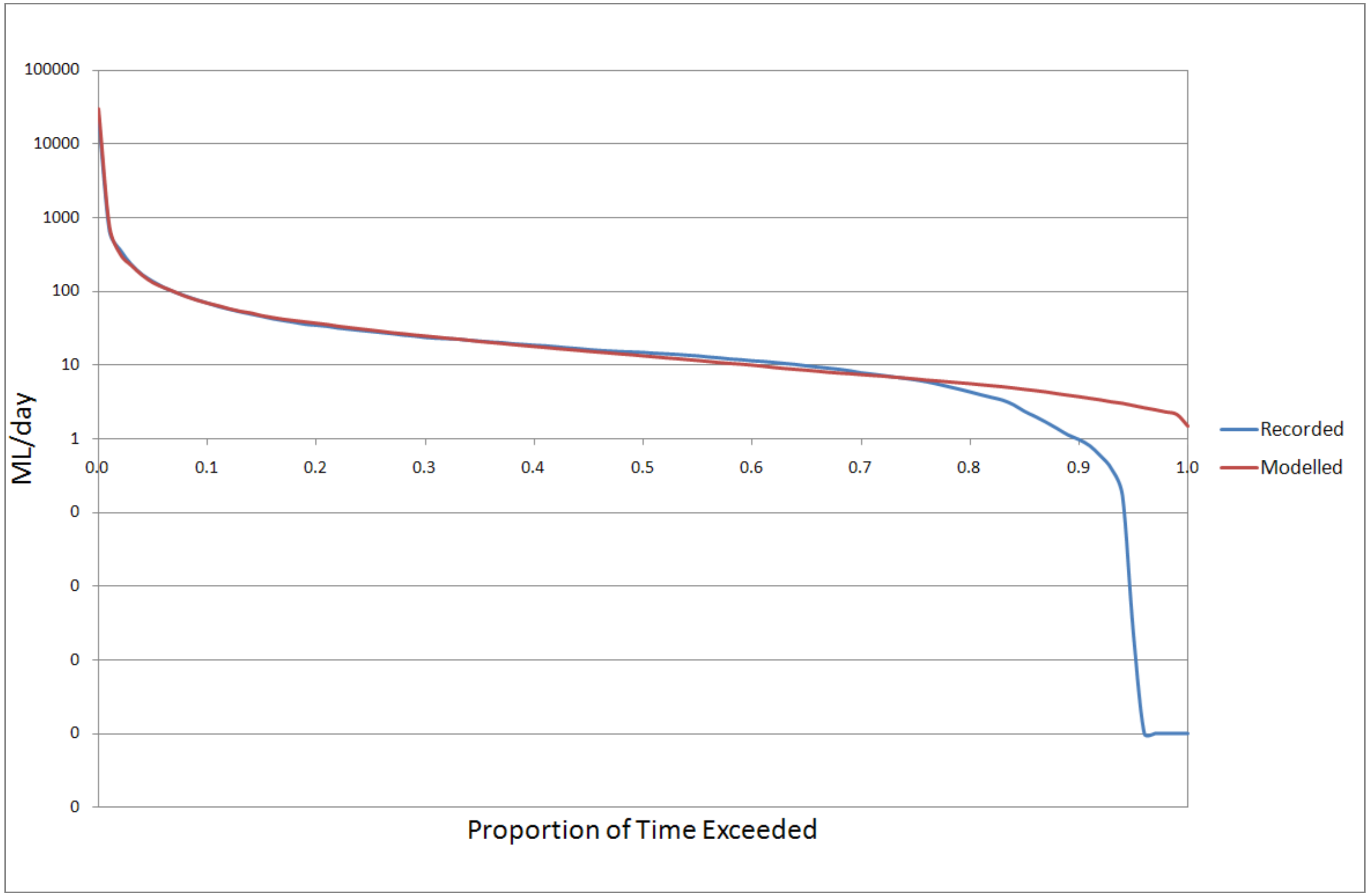


Figure 15 Daily Flow Duration Curves for Lower Gauge (Station 212280), Validation Period (1st January 1975 – 11th July 1990)

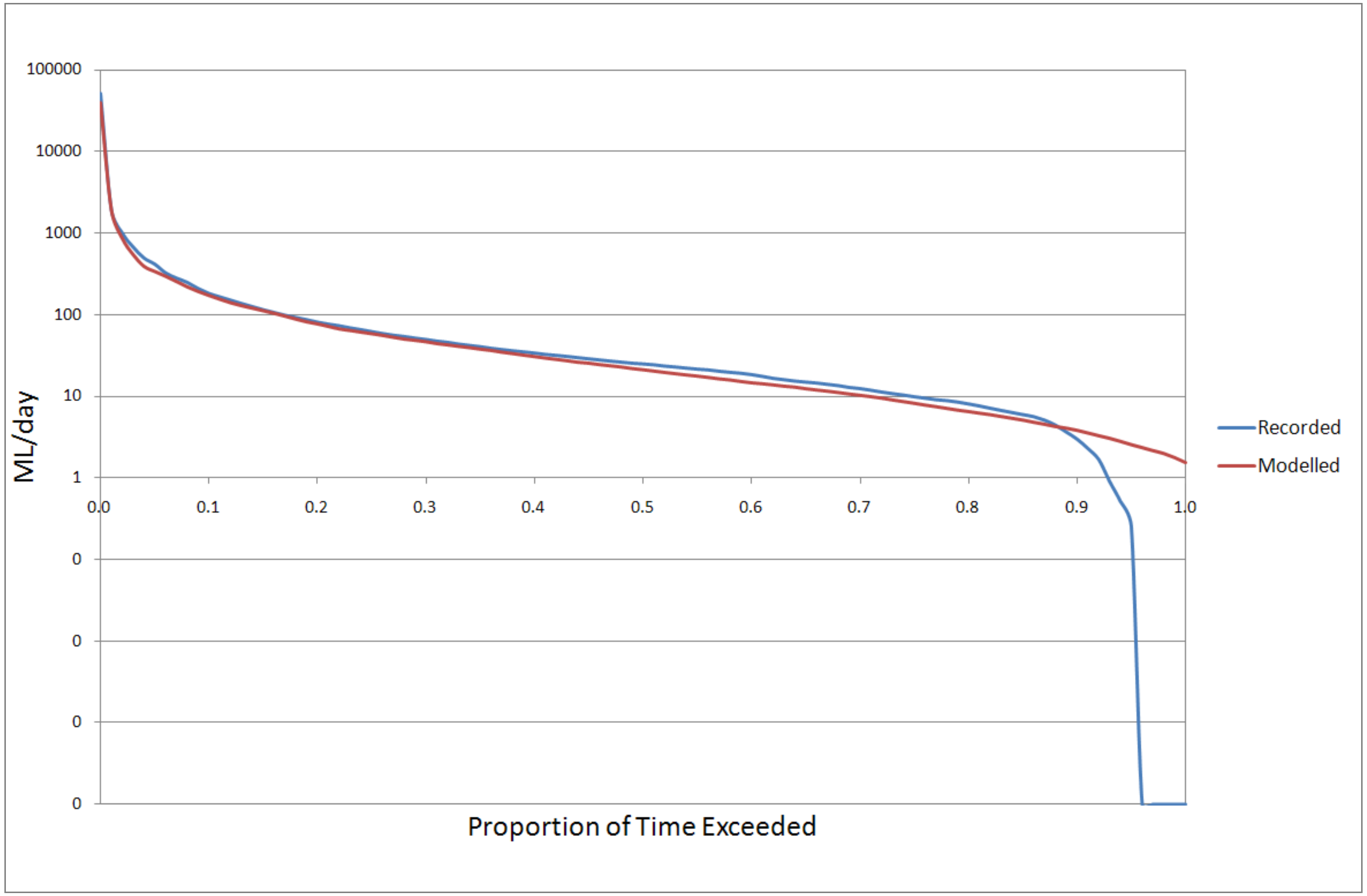


Table 8 Model Flow Results Statistics for Upper Gauge (Station 2122801), Calibration Period (12th July 1990 – 23rd March 2008)

	Calibration Period 12 July 1990 – 23 March 2008		Verification Period[1] 1 January 1976 – 11 July 1990	
	Daily Flows	Aggregated Monthly Flows	Daily Flows	Aggregated Monthly Flows
Mean Observed Daily Discharge (ML/d)	24.8	-	-	-
R^2	0.803	0.965	-	-
Efficiency (E)	0.800	0.937	-	-
Daily Flow Total Volume Error	-10.0%	-	-	-

[1] Streamflow data not available at Station 2122801 for verification period.

Table 9 Model Flow Results Statistics for Lower Gauge (Station 212280), Calibration Period (12th July 1990 – 23rd March 2008)

	Calibration Period 12 July 1990 – 23 March 2008		Verification Period 1 January 1976 – 11 July 1990	
	Daily Flows	Aggregated Monthly Flows	Daily Flows	Aggregated Monthly Flows
Mean Observed Daily Discharge (ML/d)	67.1	-	144.3	-
R^2	0.827	0.977	0.658	0.927
Efficiency (E)	0.816	0.976	0.621	0.911
Daily Flow Total Volume Error	1.0%	-	1.3%	-

Table 10 Observed and Modelled Mean Daily and Annual Discharges at Upper and Lowere Gauges

	Upper Gauge Station 2122801 A = 92.9km²			Lower Gauge Station 212280 A = 441km²		
	Observed	Modelled	Difference	Observed	Modelled	Difference
Mean Daily Discharge (ML/d)[1]	24.8	22.6	-8.9%	103.3	104.5	1.1%
Mean Annual Discharge (ML/yr)[2]	7,705	7,046	-8.6%	35,502	35,936	1.2%

[1] Days with missing gauge data excluded from mean modelled value.
[2] Partial years of record excluded (2008 both gauges, 1990 upper gauge). Model warm-up year (1975) excluded. Days with missing gauge data excluded from mean modelled value.

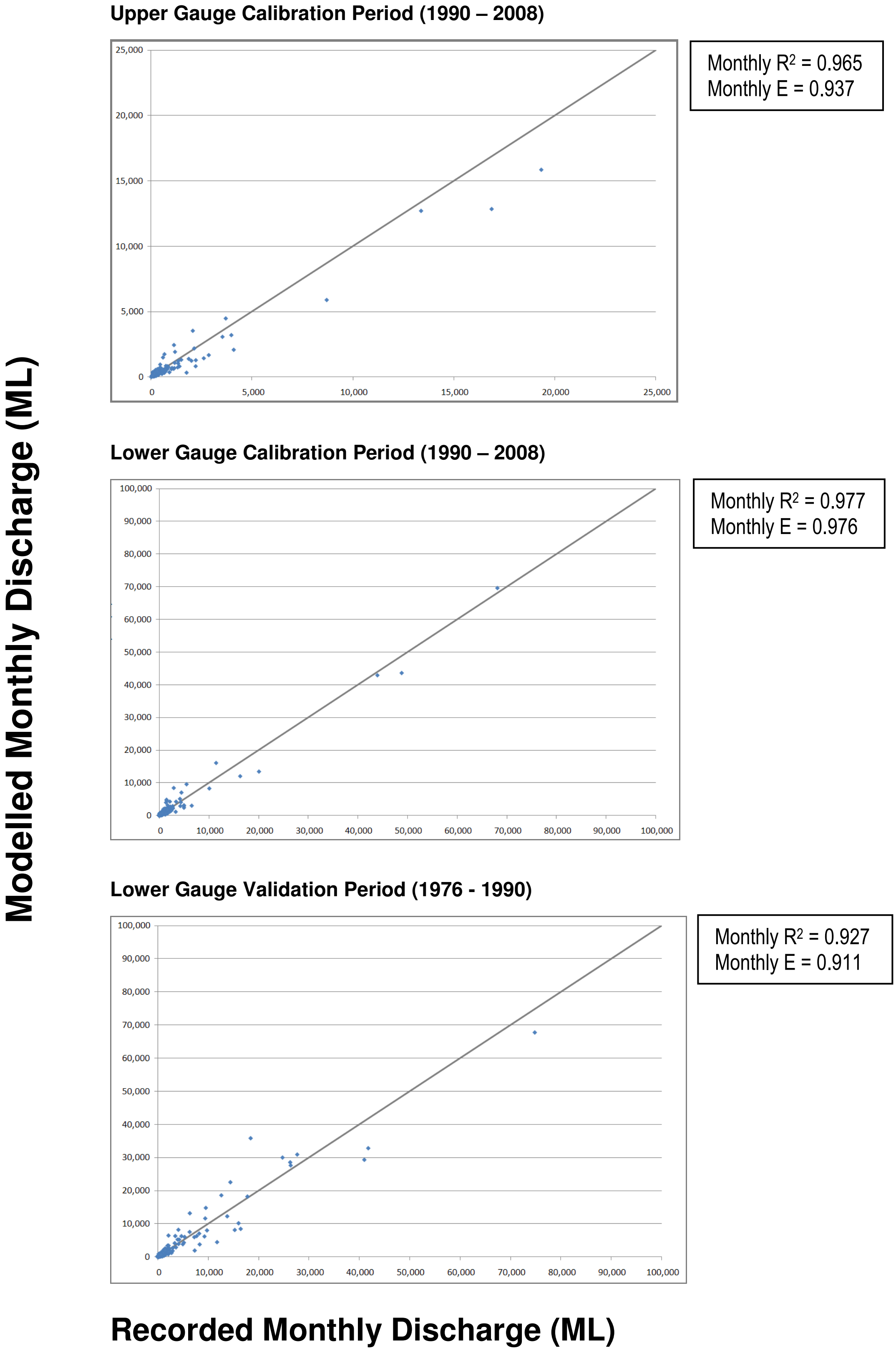
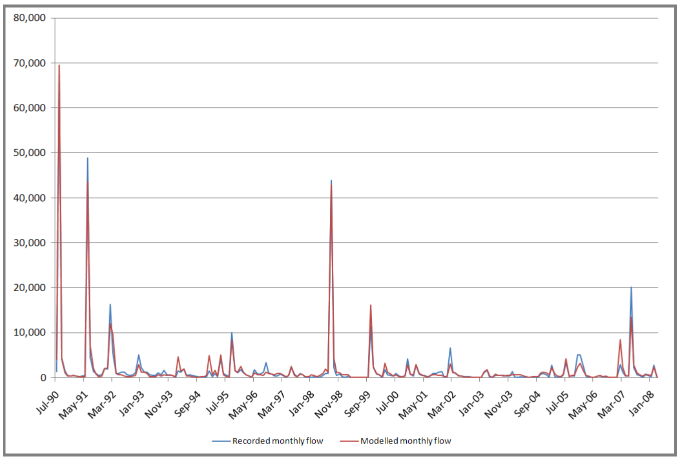


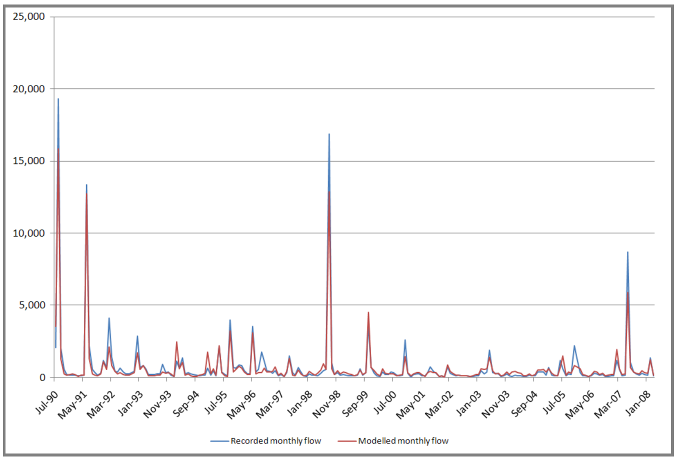
Figure 16 Recorded and modelled monthly discharges scatter plots for upper gauge and lower gauge showing good correlation of results. Calibration and validation periods presented separately for lower gauge.

Monthly Discharge (ML)

Upper Gauge Calibration Period (1990 – 2008)



Lower Gauge Calibration Period (1990 – 2008)



Lower Gauge Validation Period (1976 - 1990)

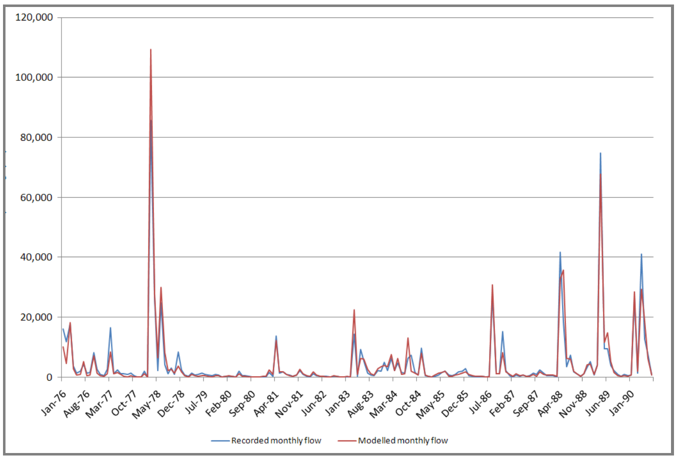


Figure 17 Recorded and modelled monthly discharge time series plots for upper gauge and lower gauge. Calibration and validation periods presented separately for lower gauge.

4.5 Discussion of Model Calibration and Validation Results

The daily flow duration curves show a good match between the observed and modelled flows at both the upper and lower gauges for the calibration and validation periods. There is deviation between the recorded and modelled curves at the lower gauge for flows less than the 75th percentile flow, although it is possible that gauging error at low flows contributes to this result. Flows at the lower gauge flow across a wide, shallow causeway, which would influence the accuracy of flow gaugings at low flows. In any case, low flows of this magnitude do not significantly contribute to total flow volumes or constituent loads.

High (> 0.8) values for R^2 and E indicate a good fit for both daily and aggregated monthly flows. Runoff estimates could be considered “good” where monthly E values are greater than 0.8 (Chiew and McMahon 1993).

Low daily flow volume errors of -10% and +1% for the upper and lower gauges respectively, in both the calibration and validation periods, demonstrate that the model is able to satisfactorily replicate long-term streamflow volumes. This is confirmed by a comparison of the mean daily and monthly discharges of -9% and +1% at the upper and lower gauges, respectively.

Further evidence of a good calibration are the scatter plots in Figure 16, where it can be seen that the recorded versus modelled monthly flow points are generally aligned with the 1:1 line, which indicates a good correlation between the observed and predicted monthly flows.

Table 9 indicates that there is a significant difference in mean daily flows between the calibration and the validation periods at the lower gauge (Station 212280), with the pre-1990 mean daily flows of 144ML/day being more than double those for the post-1990 period of 67ML/day. The model was therefore calibrated over a relatively dry period, and verified over a relatively wet period. This confirms that in effect, a *differential split-sample test* has been undertaken as a part of the model validation. The model is therefore considered to perform satisfactorily over a range of climatic conditions.

4.6 Consideration of Annual Flows

From a flow yields perspective it is generally considered good practice to analyse the flows on an annual basis in order to evaluate the performance of a hydrologic model in predicting runoff volumes at discrete timescales. This was undertaken for both the upper and lower gauges, whereby the modelled daily flows were summed for each year and compared to the recorded yearly flows. To establish a common basis for comparison only modelled daily flows on days when gauge data was available were summed (i.e. excluding missing-data days). The annual flows at the upper and lower gauges are tabulated in Table 11 and Table 12, respectively. The years are also ranked according to the un-culled modelled discharge as an indication of the wetness of year, in which the modelled annual discharge includes all days in the year (including missing data days). This provides a clearer understanding on whether the greatest mismatches in annual discharge occur during wet or dry years.

Table 11 Comparison of Recorded and Modelled Flows at Upper Gauge (Station 2122801)

Unranked				Ranked by Un-Culled Modelled Discharge[3]				
Year	Recorded	Modelled[3]	Difference	Rank	Year	Recorded	Modelled[3]	Difference
1990[1]	24,309	21,229	-13%	1	1990	24,309	21,229	-13%
1991	18,746	16,676	-11%	2	1998	20,506	17,566	-14%
1992	12,131	7,237	-40%	3	1991	18,746	16,676	-11%
1993	4,995	3,791	-24%	4	2007	13,110	11,418	-13%
1994	4,804	5,445	13%	5	1995	10,361	10,369	0%
1995	10,361	10,369	0%	6	1999	6,617	8,096	22%
1996	10,257	7,200	-30%	7	1996	10,257	7,200	-30%
1997	4,398	4,237	-4%	8	1992	12,131	7,237	-40%
1998	20,506	17,566	-14%	9	2005	6,977	6,139	-12%
1999	6,617	8,096	22%	10	2003	4,393	5,164	18%
2000	5,061	4,251	-16%	11	1994	4,804	5,445	13%
2001	2,815	2,886	3%	12	1997	4,398	4,237	-4%
2002	2,053	2,603	27%	13	2000	5,061	4,251	-16%
2003	4,393	5,164	18%	14	1993	4,995	3,791	-24%
2004	2,031	3,755	85%	15	2001	2,815	2,886	3%
2005	6,977	6,139	-12%	16	2004	2,031	3,755	85%
2006	1,739	2,945	69%	17	2006	1,739	2,945	69%
2007	13,110	11,418	-13%	18	2002	2,053	2,603	27%
2008[1]	1,587	1,645	4%	19	2008	1,587	1,645	4%

1 Partial year.
2 Modelled annual discharge values presented here exclude those days when there is missing gauge data.
3 Modelled discharge includes all days the year (including missing data days).Ranking by un-culled modelled discharge is equivalent to ranking by total catchment runoff, or “wetness of year”.

Table 12 Comparison of Recorded and Modelled Flows at Lower Gauge (Station 212280)

Unranked				Ranked by Un-Culled Modelled Discharge[3]				
Year	Recorded	Modelled[3]	Difference	Rank	Year	Recorded	Modelled[3]	Difference
1975	77,097	68,406	-11%	1	1978	161,095	194,455	21%
1976	71,761	52,832	-26%	2	1990	166,584	165,547	-1%
1977	28,690	15,005	-48%	3	1988	79,898	91,622	15%
1978	161,095	194,455	21%	4	1989	112,667	111,607	-1%
1979	9,418	4,673	-50%	5	1975	77,097	68,406	-11%
1980	4,762	3,744	-21%	6	1991	60,581	57,329	-5%
1981	24,929	25,806	4%	7	1998	50,109	56,165	12%
1982	3,402	4,634	36%	8	1976	71,761	52,832	-26%
1983	41,203	50,576	23%	9	1983	41,203	50,576	23%
1984	44,542	47,537	7%	10	1984	44,542	47,537	7%
1985	13,797	11,873	-14%	11	1986	48,803	45,857	-6%
1986	48,803	45,857	-6%	12	2007	29,540	31,011	5%
1987	9,997	8,966	-10%	13	1992	35,783	30,287	-15%
1988	79,898	91,622	15%	14	1995	23,346	26,892	15%
1989	112,667	111,607	-1%	15	1981	24,929	25,806	4%
1990	166,584	165,547	-1%	16	1999	15,050	20,547	37%
1991	60,581	57,329	-5%	17	1977	28,690	15,005	-48%
1992	35,783	30,287	-15%	18	1996	11,890	8,285	-30%
1993	11,082	7,006	-37%	19	2005	18,156	15,718	-13%
1994	7,107	10,092	42%	20	2003	6,937	7,074	2%

Table 12 Comparison of Recorded and Modelled Flows at Lower Gauge (Station 212280) (cont')

Unranked				Ranked by Un-Culled Modelled Discharge[3]				
Year	Recorded	Modelled[3]	Difference	Rank	Year	Recorded	Modelled[3]	Difference
1995	23,346	26,892	15%	21	1985	13,797	11,873	-14%
1996	11,890	8,285	-30%	22	2000	10,616	11,516	8%
1997	7,023	8,112	16%	23	1994	7,107	10,092	42%
1998	50,109	56,165	12%	24	1987	9,997	8,966	-10%
1999	15,050	20,547	37%	25	2001	10,108	8,196	-19%
2000	10,616	11,516	8%	26	1997	7,023	8,112	16%
2001	10,108	8,196	-19%	27	1993	11,082	7,006	-37%
2002	10,185	6,508	-36%	28	2002	10,185	6,508	-36%
2003	6,937	7,074	2%	29	2004	2,979	6,370	114%
2004	2,979	6,370	114%	30	1982	3,402	4,634	36%
2005	18,156	15,718	-13%	31	2006	4,022	4,121	2%
2006	4,022	4,121	2%	32	1979	9,418	4,673	-50%
2007	29,540	31,011	5%	33	1980	4,762	3,744	-21%
2008[1]	2,853	2,847	0%	34	2008	2,853	2,847	0%

1 Partial year.
2 Modelled annual discharge values presented here exclude those days when there is missing gauge data.
3 Modelled discharge includes all days the year (including missing data days).Ranking by un-culled modelled discharge is equivalent to ranking by total catchment runoff, or "wetness of year".

The modelled annual discharges are generally reasonable matches to the recorded annual discharges, being typically within +/- 30% of the recorded discharges. At the upper gauge, only three out of 19 years have an annual discharge error of greater than +/-30%.

At the lower gauge, only nine of 34 years have an annual discharge error of greater than +/-30%, the majority of these being low-flow years, during which persistent broad shallow flow over the causeway throughout the year is likely to result in significant proportional differences in discharge. For example, a persistent daily error of 5ML/day (equivalent to 0.06m3/s, which is considerably low) would result in a cumulative error of approximately 2,000ML/year. Therefore, gauging error could potentially account for a significant proportion of the difference between the recorded and modelled discharges.

Particularly high differences in annual discharge are shown for the 2004, where there is a difference of 85% and 114% at the upper and lower gauges respectively, in addition to 69% at the upper gauge in 2006. During these years the recorded discharge is less than the modelled discharge. These extremely high values are attributed to the severe bushfire event in late 2001, which burnt through the majority of the forested areas of the Nattai River Catchment. The severity and intensity of the fire caused total forest destruction (including tree death) in a significant part of the burnt area. Forest regeneration in the years following a severe bushfire generally results in a much denser canopy with significantly higher total leaf areas that the pre-burnt forest, in addition to higher rates of evapotranspiration during rapid plant growth. This results in increased rainfall interception and soil moisture uptake and subsequently reduced runoff (Cornish and Vertessy, 2001). Hence, forest recovery is likely to have contributed to lower recorded runoff volumes than expected.

The high difference in annual discharges of -36% in 2002 at the lower gauge is also attributed to the post-fire effects on the catchment hydrology. During this year the recorded discharge is greater than the modelled discharge. Severe bushfires are known to result in increased peakiness in runoff events, in addition to increased longer-term runoff volumes. This is due to the reduction of rainfall interception losses caused by loss of leaf area and fire-induced hydrophobic properties of burnt soil surfaces (Chafer 2007; Wallbrink et. al. 2004). These effects on the catchment are likely to have contributed to higher recorded runoff rates and volumes than expected.

5 Constituent Generation Model Development

5.1 Model Selection

An EMC/DWC model was adopted for generation of constituents within the E2 model. The EMC/DWC model has two parameters for each FU: the Event Mean Concentration (EMC) and the Dry Weather Concentration (DWC). The EMC/DWC model assumes that a single representative constituent concentration can be adopted for each water quality constituent in each FU, for quick flow (surface runoff) and slow flow (baseflow), respectively. EMCs describe catchment wash-off processes during runoff events and are typically higher than the corresponding DWCs.

Other models for representing constituent generation were not considered since they did not represent the variation in constituent concentrations between dry and wet weather flows at daily time steps (e.g. fixed concentration, annual areal generation rate) or since insufficient data was available to accurately derive the model (e.g. power curve model).

5.2 Event Water Quality Data

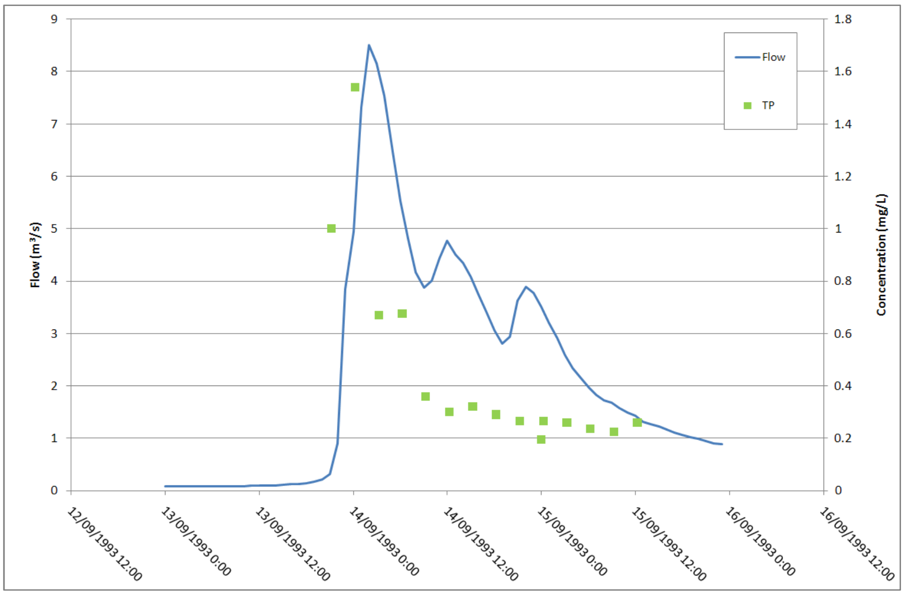
The EMC/DWC model calibration exercise was undertaken based on the water quality data described in Section 3.6, with a focus on achieving a satisfactory representation of constituent loads generated during flow events, since event loads constitute a high proportion of total constituent load. The water quality data was therefore reviewed to identify potentially suitable flow events for model calibration, where sample points and instantaneous flows are available over the course of the flow event. These events are summarised in Table 13. Constituents of interest in this study included Total Phosphorus (TP), Total Nitrogen (TN) and Total Suspended Solids (TSS).

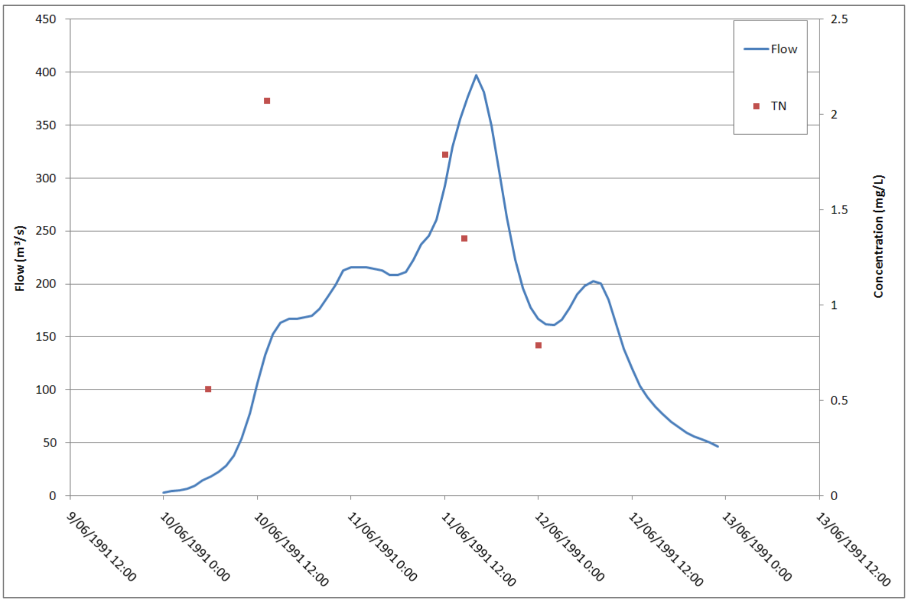
Table 13 Summary of Identified Flow Events for Water Quality

Event Number	Event Duration	Number of Samples	Range of Concentrations (mg/L)	Peak Flow (m^3/s)
Site E210 Nattai River at Smallwoods Crossing (The Causeway)				
1	10 – 12/6/1991	5 (TP,TN, TSS)	TP: 0.018 – 0.085 TN: 0.56 – 2.17 TSS:194 – 15,110	396
2	5 – 9/12/1992	26 (TP); 24 (TN); 1 (TSS)	TP: 0.01 – 0.43 TN: 0.26 – 8.7 TSS: 14	11
3	14 – 18/9/1993	25 (TP,TN, TSS)	TP: 0.048 – 0.487 TN: 0.74 – 5.1 TSS: 1 – 31	5.8
Site E206 Nattai River at The Crags				
4	4 – 7/12/1992	22 (TP, TN); 23 (TSS)	TP: 0.048 – 1.98 TN: 1.96 – 52.7 TSS: 19 – 893	17
5	13 – 15/9/1993	15 (TP, TN, TSS)	TP: 0.225 – 1.54 TN: 1.4 – 6.9 TSS: 18 – 282	8.5
6	2 – 3/6/2006	7 (TP, TN, TSS)	TP: 0.09 – 0.24 TN: 0.9 – 2.5 TSS: 32 - 77	2.3
7	11 – 12/2/2007	10 (TP, TN); 3 (TSS)	TP: 0.01 – 0.17 TN: 0.4 – 3.4 TSS: 10 - 22	14.3

Plots of the water quality sample points and flow hydrographs for these events are shown in Appendix B. Water quality data coverage for individual events varies, with a high number of samples taken for some events and only a few samples taken for other events. Example hydrographs are shown in Figure 18.

Figure 18 Examples of good water quality data coverage with numerous samples over the course of the event (top), and poor coverage with few data points (bottom).





The number of identified suitable events for calibration is limited by the absence of coinciding continuous water quality sampling (over individual events) and streamflow gauging. Review of the water quality data indicates that there are long periods when no autosampler observations of water quality are available (September 1993 – February 2003 at site E210; September 1993 – November 2005 at site E206). This is further compounded by frequent gaps in the flow record at site E210. Ideally, flow events occurring post-2001 would have been used for calibration as STP discharge and effluent quality is available for the post-2001 period. As mentioned above, there is evidence for sewer overflows in the pre-upgrade water quality event data, which has been considered in the constituent loads estimation.

From a review of the water quality plots in Appendix B and the constituent concentrations in Table 13 it is observed that the 1992 and 1993 events at both sites exhibit extremely high concentrations at the start of each event, particularly for TN which occurs at concentrations of approximately 8mg/L at both sites in the 1993 event and up to 53mg/L in the 1992 event at site E206. These concentrations are considered to be extremely high for typical catchment wash-off processes and are more likely to be a result of sewage or septic system overflows.

5.3 Analysis of Water Quality Data

A number of issues were identified with the water quality data which affects the reliability of the data for calibration. These issues are discussed below

5.3.1 Event Loads

Event constituent loads were calculated for the flow events within the Nattai catchment identified in Table 13 based on continuous hourly flows (m^3/s) and the water quality sample points for the purposes of the water quality calibration. The event loads are summarised below in Table 14.

Table 14 Nattai River Catchment Estimated Event Constituent Loads

Event Number	Event Duration	Discharge (ML)	Constituent Load (kg)		
			TP	TN	TSS
Site E210 Nattai River at Smallwoods Crossing (The Causeway)					
1	10 – 12/6/1991	41,448	1,693	56,793	-
2	5 – 9/12/1992	1,361	85	931	-
3	14 – 18/9/1993	815	147	1,507	15,038
Site E206 Nattai River at The Crags					
4	4 – 7/12/1992	825	1,059	2,707	425,243
5	13 – 15/9/1993	576	297	1,360	73,095
6	2 – 3/6/2006	89	13	152	4,111
7	11 – 12/2/2007	524	60	732	-

Event 2 at site E210 corresponds with Event 4 at site E206, having occurred on similar dates. Similarly, Event 3 at site E210 corresponds with Event 5 at site E206.

Comparison of the TP and TN loads at each site indicate that for Events 2 and 4, the TP load decreases from 1,059kg to 85kg and the TN load decreases from 2,707kg to 931kg. This represents a decrease of 92% and 65% of the TP and TN load, respectively, between the two sites.

For Events 3 and 5, the TP load decreases from 297 kg to 147kg, and the TSS load decreases from 73 tonnes to 15 tonnes. This represents a decrease of 51% and 79% of the TP and TSS loads, respectively, between the two sites.

These extremely high reductions in constituent loads contradict expectations that loads would increase in the downstream direction during a significant flow event, though deposition may occur in smaller flows. Flow travel times between the sites are in the range of 12 – 18 hours, based on the difference in the timing of flow peaks. This is not thought to provide a sufficiently long residence time for such reductions in flow to occur. By comparison, constructed wetlands which are highly optimised for stormwater treatment typically have a guideline residence time of 72 hours or more to achieve 45% reduction in TP and TN load, and 80% for TSS. Therefore, the load reductions which are indicated by the water quality monitoring data appear to be unrealistic for the event flow conditions, and suggest that there are unknown issues behind either the flow data or the water quality data which affect their reliability.

A review of the flow gauging curves (Appendix C) and records for Stations 212280 and 2122801 indicate that the flows occurring during the events selected for the constituent generation model calibration are well within the envelope of gaugings for those sites. Further, a comparison of mean annual discharges in Table 10 with the upstream catchment areas indicates a similar mean unit area discharge of approximately 80ML/km^2 for each gauge. This suggests that there are no gross errors in the flow data, and therefore indicates that the issue may be in the water quality data.

The water quality data, at least for the 1992 and 1993 events (Event 2/4 and Event 3/5, respectively) is therefore not considered reliable for water quality calibration, and may warrant a review of the water quality monitoring and analysis procedures be undertaken to identify the reasons for these inconsistencies in the data.

5.3.2 Effluent Quality and Dry Weather Water Quality

Further analysis of the water quality data was undertaken by comparing the STP effluent quality with the water quality sample data at site E206 (The Crags, 7km downstream of the STP outflow point), to assess the consistency of the data. Constituent concentrations are compared in Table 15 on days when water quality data is available for both the effluent and in-stream flows. Daily discharges are also included. The Reduction Factor is equal to (effluent concentration ÷ gauge concentration) and represents an apparent dilution factor.

Table 15 Comparison of Effluent Quality and Dry Weather Water Quality

	Discharge (ML/d)		TN (mg/L)			TP (mg/L)		
	Effluent	Gauge	Effluent	Gauge	Reduction Factor	Effluent	Gauge	Reduction Factor
25/09/2007	3.357	4.65	6.26	0.6	10.4	0.133	0.02	6.7
20/11/2007	2.214	3.804	7.33	0.8	9.2	0.11	0.01	11
15/01/2008	1.511	3.662	6.55	1.0	6.6	0.152	0.04	3.8

It can be seen from the tabulated data that apparent dilution of the effluent TN and TP occurs at a factor of 4 – 11 between the STP outfall and The Crags. However, comparison of the daily discharges indicates that flows only increase by a factor of 1.4 – 2.4, which means that there is insufficient flow to achieve the dilution ratios suggested by the Reduction Factor values.

Potential reasons for the data inconsistencies include:

- Natural removal of the TN and TP by biogeochemical processes – however, there is only a short (7km) distance between the outfall and The Crags. Assuming a slow flow velocity of 0.2m/s, this translates to an approximately 10 hour flow travel time, which is considered too short a residence time to achieve up to 90% reduction in TN and TP. Therefore, natural removal is an unlikely reason for the data inconsistencies.
- Suspect in-stream water quality data – as previously highlighted in Section 5.3.1 there are inconsistencies in the in-stream water quality data which have not been explained to date from review of the available data.
- Suspect flow data at low flows – SCA officers mentioned that there may be issues with the gauge data at low flows, however, further clarification could not be obtained during the duration of this study.
- Effluent quality data not representative of average daily conditions – the STP effluent stream may have, on average over a day, lower constituent concentrations than those suggested by the available data due to diurnal cycles in STP flows. The effluent quality samples may be taken at the peak of the cycle for licensing purposes. The STP engineers could not be contacted to confirm this hypothesis.

Further investigation is required to ascertain the cause of this data issue.

5.4 Running the Constituent Generation Model

The model was run using constituent EMC and DWC values selected from Fletcher et. al. (2004), which provides a comprehensive compilation of EMC/DWC data from around Australia and worldwide. Catchment-specific data is not available for the various FUs. The EMC/DWC values are summarised in Table 16. While there is scope to vary the EMC/DWC values within each FU type according to soil facet, this was not undertaken as a part of this assessment due to an absence of suitable runoff water quality data for validating these enhancements.

The STP was represented in the model as a dummy FU with a nominal surface area of 1,000m^2. The EMCs and DWCs were set at the same value for each

constituent. The adopted EMC/DWC values are as per the average effluent constituent concentrations summarised in Table 6. The pre-2001 and post-2001 (2007-08) concentrations were adopted for the corresponding simulation periods to represent the pre- and post-upgrade STP.

5.4.1 Event Load Comparisons

The results from the constituent generation modelling are shown in Table 17 as an event load-based comparison. The loads are calculated based on the model predicted daily flows and constituent concentrations and compared to the calculated observed loads.

The modelled and observed event discharges for each event are also summarised in Table 17. It can be seen that the modelled and observed event discharge volumes typically differ markedly from each other for individual events, which significantly influences the event load estimates. This is attributed to the event discharge volumes not being accurately predicted for specific flow events. Additionally, the EMCs represent the typical event constituent concentration over a range of events, and may not characterise the concentrations for specific events.

The data in Table 17 is also presented in the column graphs in Figure 19 and Figure 20.

Table 16 Adopted EMC and DWC Values

FU	Landuse Description	TSS (mg/L)		TP (mg/L)		TN (mg/L)	
		EMC	DWC	EMC	DWC	EMC	DWC
Cleared	Rural	50	3.4	0.15	0.025	2	0.4
Horticulture	Agriculture	100	3.4	0.5	0.025	3	0.6
Intensive Animal Production	Agriculture	100	3.4	0.5	0.025	3	0.6
Rural Residential	Rural	30	3	0.1	0.04	0.7	0.4
Transport and other Corridors	Roads	90	6.1	0.5	0.04	1	0.6
Urban Sewered	Urban	70	6.1	0.1	0.04	1	0.6
Urban Unsewered	Assumed similar to rural	30	3.4	0.1	0.04	0.7	0.4
Vegetated	Forest	10	2	0.03	0.01	0.4	0.08

EMC/DWC values were selected with guidance from Fletcher et. al. (2004) and tend to be in the “low” range.

Table 17 Observed and Predicted Constituent Loads for Selected Events

Event Number	Event Duration	Event Discharge (ML)		Observed Load (kg)			Predicted Load (kg) estimated from Predicted Flows			Predicted Load (kg) estimated from Predicted Flows as % of Observed Load		
		Observed	Predicted	TN	TP	TSS	TN	TP	TSS	TN	TP	TSS
Site E210 Nattai River at Smallwoods Crossing (The Causeway)												
1	10 – 12/6/1991	41,448	42,894	56,793	1,693	42,870,498	29,412	2,781	844,051	-48%	64%	-98%
2	5 – 9/12/1992	1,348	682	905	86	-	968	170	30,563	7%	99%	-
3	14 – 18/9/1993	815	313	1,507	147	15,038	492	105	14,263	-67%	-28%	-5%
Site E206 Nattai River at The Crags												
4	4 – 7/12/1992	825	424	2,707	1,059	425,243	693	128	22,970	-74%	-88%	-95%
5	13 – 15/9/1993	576	237	1,360	297	73,095	459	103	14,035	-66%	-65%	-81%
6	2 – 3/6/2006	89	136	152	13	4,111	215	26	9,016	42%	106%	119%
7	11 – 12/2/2007	524	1,012	730	60	-	1,398	140	50,528	92%	131%	-

Figure 19 Observed and predicted low and load comparison, Event 1, Site E210 (Smallwoods Crossing)

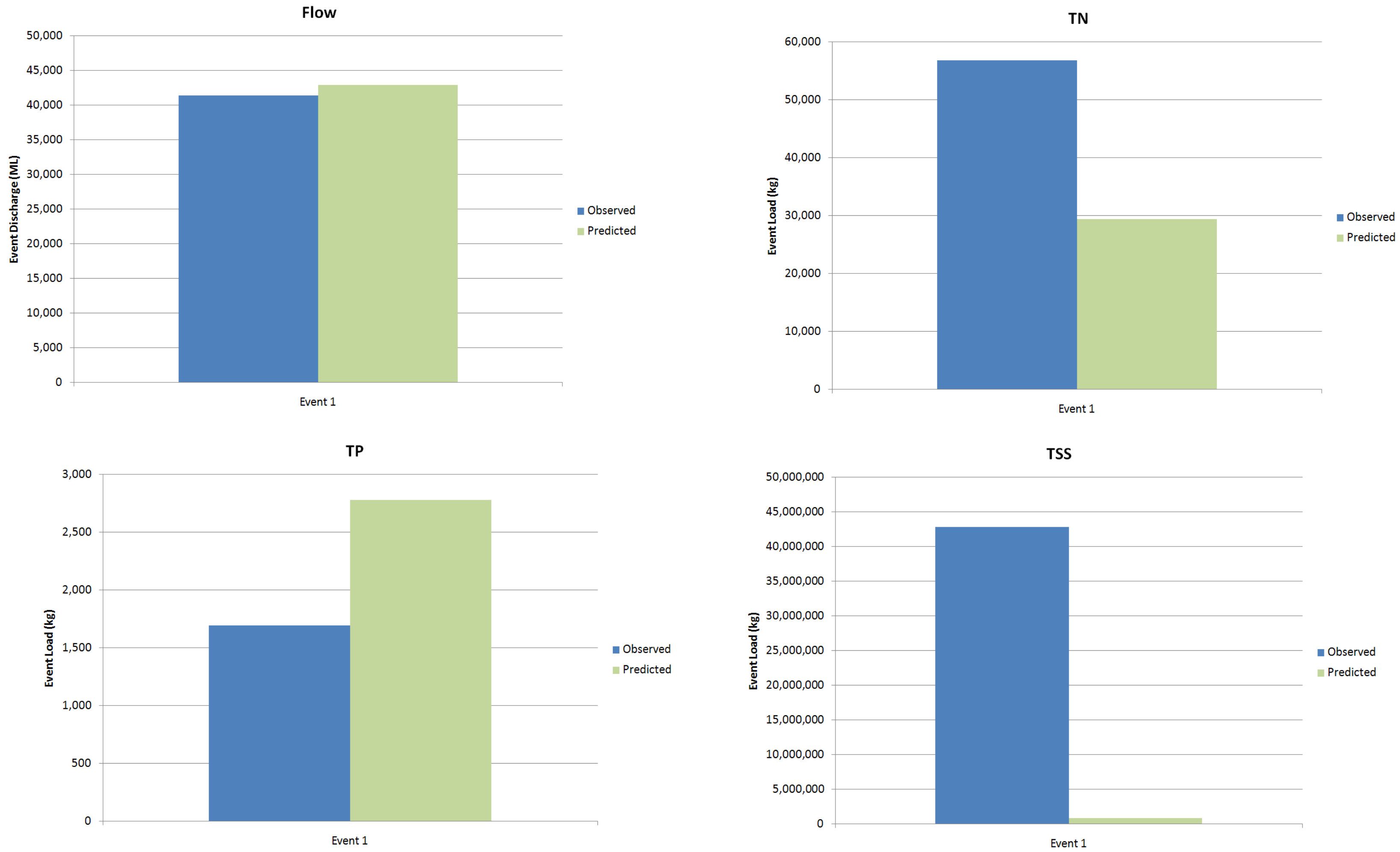
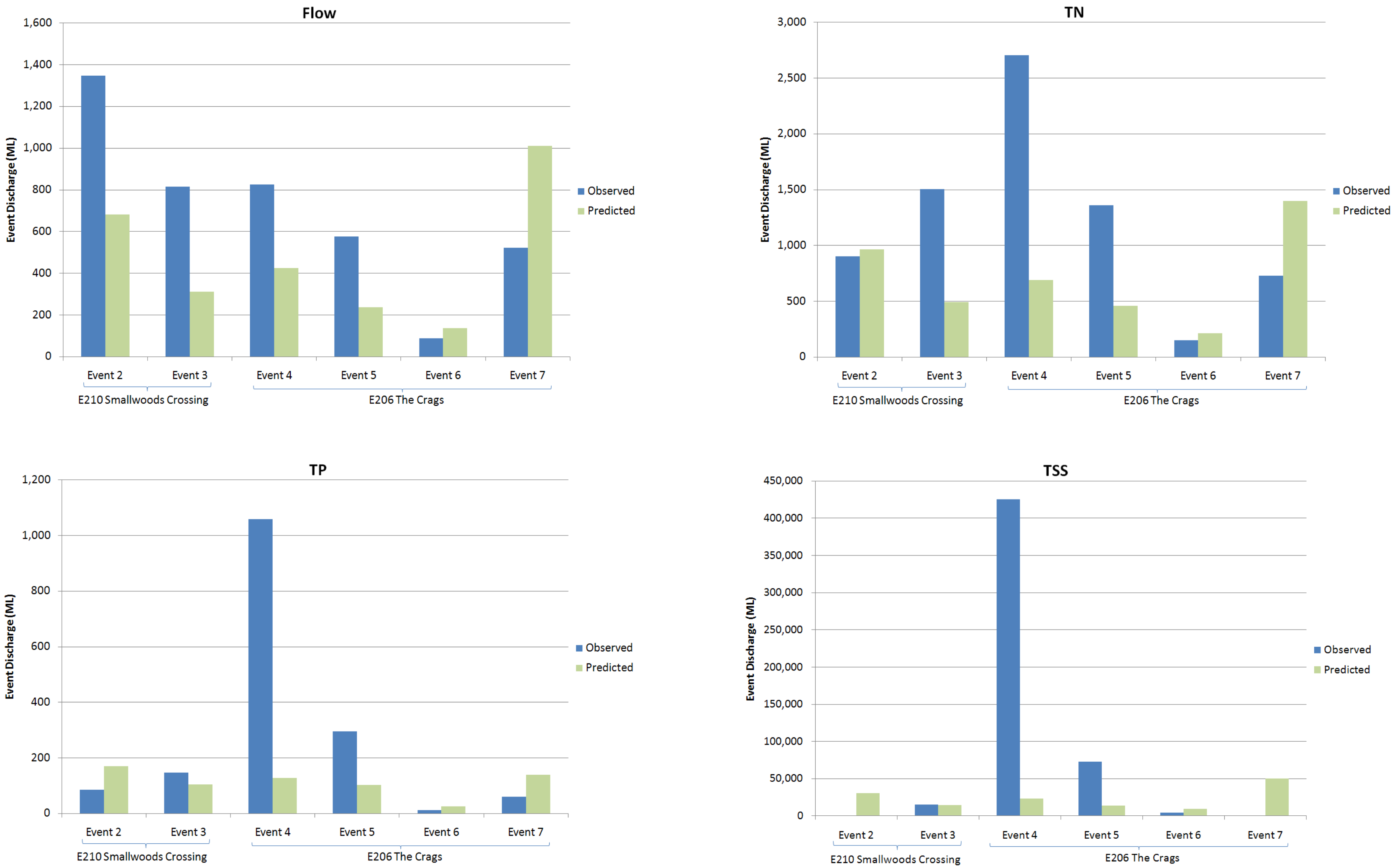


Figure 20 Observed and predicted low and load comparison, Events 2 – 7, Site E210 (Smallwoods Crossing) and Site E206 (The Crags)



The loads calculated from the predicted flows for the calibration events are typically significantly different from the observed loads (up to +/- 130%) due to the error introduced by the error in the daily and event discharges, since load = flow x concentration. A satisfactory predicted event load should be within +/- 50% of the observed load, and is a criterion which has been adopted in similar Source Catchments projects (Waters & Webb, 2007). It is concluded that the model, while reasonably representing hydrologic conditions on monthly or yearly scales, is unable to predict daily discharges or specific event discharges accurately, and this unreliability is transferred to the water quality component of the model. However, it is still necessary to run the model at a daily time step to represent the temporal variability in flows and pollutant generation at this scale, which can then be aggregated to monthly and longer time scales.

At this stage, the model is not considered to be fully calibrated due to issues concerned with inconsistent in-stream water quality and STP effluent quality data which could not be resolved during the course of this application project. As previously mentioned in Section 5.3.1 the water quality data suggests a significant and unrealistic loss of observed constituent load between sites E206 and E210 for the 1992 flow event (Event 2 and 4) and the 1993 event (Event 3 and 5). This potentially indicates erroneously low sample constituent concentrations from site E210 which could be contributing to the high difference between observed and predicted loads. Further investigation is required to confirm whether this is the case.

5.4.2 Dry Weather Period Results

A review of the time series of predicted constituent concentrations indicates that the in-stream constituent concentrations at some locations decrease during a flow event. An example is shown for site E206 in Table 18. This is due to the dry weather constituent concentrations being dominated by high concentrations in the STP effluent, which are subsequently diluted by runoff from the catchment. Analysis of the in-stream water quality data suggests that this is an actual phenomenon, particularly for the pre-STP upgrade period. The post-STP upgrade water quality exhibits this behaviour only for TN, which remains relatively high in this period.

Table 18 Example of Modelled Constituent Concentrations being "Diluted"

Date	Discharge (ML/d)	Concentration (mg/L)		
		TSS	TP	TN
7/11/2000	6.6	40	3.21	11.4
8/11/2000	8.6	38	3.47	12.4
9/11/2000	4.9	30	4.30	15.2
10/11/2000	4.2	23	5.04	17.8
11/11/2000	4.8	28	4.53	16.0
12/11/2000	18.1	51	1.54	5.7
13/11/2000	65.8	56	0.99	3.8
14/11/2000	202.5	52	0.46	2.3
15/11/2000	436.6	52	0.42	2.1
16/11/2000	225.9	49	0.43	2.1
17/11/2000	104.9	48	0.50	2.3
18/11/2000	81.6	45	0.56	2.5
19/11/2000	48.1	41	0.71	2.9
20/11/2000	24.5	32	0.87	3.4
21/11/2000	22.0	25	1.11	4.2
22/11/2000	16.3	17	1.30	4.8
23/11/2000	14.9	12	1.48	5.4

* High flow period highlighted.

Table 19 Average Dry and Wet Weather Constituent Concentrations at Site E206

	Constituent	Wet Weather Concentration (mg/L)	Dry Weather Concentration (mg/L)
Pre-STP Upgrade	TN	2.4	2.6
	TP	0.52	0.71
	TSS	182	44
Post-STP Upgrade	TN	1.4	1.3
	TP	0.09	0.06
	TSS	34	8

5.5 Limitations of the EMC/DWC Approach

The available in-stream event flow and water quality data indicates that flow events are typically quite "flashy", characterised by a sharp peak in flow as a result of the catchment terrain and typically short storm behaviour. Additionally, constituent concentrations and trends in concentrations appear to be highly variable, both between storm events and during individual storm events. The EMC/DWC approach assumes a single concentration for each constituent in the catchment quick flow for all events, hence the trends in the data are ignored and care needs to be taken when selecting an EMC in order to best represent constituent generation for all events.

A more appropriate approach where sufficient data is available over a long period may be to apply a power function model for constituent generation, assuming the runoff constituent concentrations are exponentially related to the flow. There is evidence for such a relationship in the observed water quality, however, the limited data set across the full range of flow magnitudes did not make this possible.

Given the high variability of constituent concentrations and loads between events, it may be more appropriate to compare long term differences in loads rather than focussing on event loads. Comparison of event loads would be undertaken as a sanity check on whether the model is predicting loads to the correct order of magnitude.

5.6 Summary of the Constituent Generation Modelling

The constituent generation model in the Nattai River Source Catchments model is considered to be partially calibrated based on 2006 and 2007 event data from site E206 (The Crags). Additional suitable water quality data is needed for site E210 to fully calibrate the model.

The 2006 and 2007 events are considered to have the best available data for calibration that other identified events, due to greater certainty in the STP discharge and effluent quality data post-2001. The remaining identified flow events with water quality data occur in the 1990s when no STP data is available, although the in-stream water quality data suggests discharges (possibly sewer overflows) with very high concentrations of TN and TP preceding the peak of a catchment flow event.

There are other issues with the in-stream water quality data for the events in the 1990s (particularly 1992 and 1993 events) which cause these events to be unsuitable for calibration, namely the unrealistically high reduction in constituent event loads between site E206 and site E210. Additionally, there are inconsistencies between the STP effluent quality data and the in-stream water quality data at site E206 which are unresolved.

In order for future progress to be made with the development of the constituent generation modelling for the Nattai River, it is recommended that:

- New event water quality data be collected at both sites E206 (The Crags) and E210 (Smallwoods Crossing) well sampled across individual events and also covering a events that range in magnitude. Instantaneous flow data is also required to accompany event sampling. This is preferred over attempting to resolve the inconsistencies with the existing data, since the limited amount of information may not reveal the causes of these issues;
- Clarification should be sought from Braemar STP operators regarding the effluent quality data which is provided, specifically whether constituent concentrations are peak values during the diurnal cycle and how daily-averaged values may be derived from the reported data.
- At this stage the variability in the soil facet across each FU has been utilised only for varying the hydrologic response of each area. Future work could include scaling of the EMC/DWC values based on soil facet (which considers soil type and terrain) or gully density spatial data provided sufficient data was available to support any assumptions.

6 Conclusions

A Source Catchments model has been successfully developed and calibrated to represent hydrological processes in the Nattai River catchment. The model has been calibrated and validated to two streamflow gauges located in the upper and lower catchment over a simulation period of 1975 – 2008.The calibration and validation periods are relatively dry and wet periods, respectively, and hence the model is considered to be calibrated over a range of climatic conditions.

Predicted total discharge volumes over the period of record are within -10% and +1% of observed discharge volumes at the upper and lower gauges, respectively, and predicted annual discharges are typically within +/- 30% of observed discharges. The statistics describing the fit of the daily and monthly predicted flows, including R^2 and Nash-Sutcliffe coefficient of efficiency "E", are high (> 0.8).

The model has also been configured to represent constituent generation in the catchment. Constituents of interest include TN, TP and TSS. The EMC/DWC model has been adopted as the constituent generation model. Some data on effluent quality from Mittagong/Braemar STP is available and hence the STP is included as a major point source of pollutants in the catchment.

The model has not been fully calibrated to the available event water quality data at this stage. Differences between observed and predicted event constituent loads for the calibration events are typically large, as a result of poor estimates of event discharge volumes for specific events. The Source Catchments model, while reasonably representing hydrologic conditions on monthly or yearly scales, is unable to predict daily discharges or specific event discharges accurately, and this unreliability is transferred to the water quality component of the model. It may therefore be more appropriate to compare long term differences in loads rather than focussing on event loads.

Suitable and reliable water quality data is also limited in availability and a lack of data at the lower gauge prevented a catchment-wide calibration of the constituent generation model. Further investigation is needed to determine the reasons for the inconsistencies in the data. Additional information on the STP effluent data is also required given the inconsistency between the STP and in-stream water quality data.

To further enhance the water quality component of the Nattai River Source Catchments model, it is recommended that new event water quality data be collected at both the upper and lower gauges, ensuring that instantaneous flow data is collected at the same time to enable constituent loads to be calculated. This is preferred over attempting to resolve the inconsistencies in the water quality data for historic events, as this may not lead to a conclusive outcome.

At this stage the variability in the soil facet across each FU has been utilised only for varying the hydrologic response of each area. Future work could include scaling of the EMC/DWC values based on soil facet (which considers soil type and terrain) or gully density spatial data.

In summary, the Nattai River catchment Source Catchments model provides indicative estimates of flow generated within the Nattai Catchment. Additional

water quality data is required to improve the models reliability as a predictor of constituent loads generated in the catchment and delivered to its receiving waters. Further refinement and calibration of the constituent generation component of the model should consider the adoption of a power function model to predict constituent concentrations as being exponentially related to flow, and/or focus on validating long term predicted constituent loads rather than on shorter term event loads. This is given the high variability in water quality between individual flow events. To date, the model has been configured to represent catchment hydrology and predicts discharge volumes to satisfactory accuracy, and could be considered as a flow yields model.

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Appendix A Soil Facet and Functional Unit Areas

Table A.1 Preliminary Functional Unit Areas and Soil Facet Composition

FU1 Cleared			FU2 Horticulture			FU3 Intensive Animal Production			FU4 Rural Residential			FU5 Transport / Other Corridors			FU6 Urban Sewered			FU7 Urban Unsewered			FU8 Vegetated		
Soil Facet	Area m^2		Soil Facet	Area m^2		Soil Facet	Area m^2		Soil Facet	Area m^2		Soil Facet	Area m^2		Soil Facet	Area m^2		Soil Facet	Area m^2		Soil Facet	Area m^2	
ERlm1	17,648,196	42%	ERlm1	326,211	30%	ERlm1	94,386	60%	ERlm1	3,443,862	36%	ERlm1	1,124,642	37%	ERlm1	3,454,472	52%	ERht2	1,466,845	24%	ERnt1	121,144,853	32%
ERlm2	6,835,975	16%	ERht2	255,268	24%	ERlm2	34,329	22%	ERht2	1,887,599	20%	ERht2	737,041	24%	ERlm2	1,312,973	20%	ERlm1	1,401,343	23%	COhw2	60,667,589	16%
REsf1	4,220,911	10%	REsf1	126,099	12%	ERav3	17,112	11%	REsf1	1,669,610	18%	ERlm2	397,340	13%	ERht2	1,145,800	17%	REsf1	1,177,603	19%	COha2	47,331,699	13%
ERht2	2,809,460	7%	ERlm2	123,500	11%	REgq1	6,160	4%	ERlm2	679,524	7%	ERht1	171,740	6%	ERht1	534,641	8%	ERht1	634,103	10%	ERht2	22,316,563	6%
ERav1	1,581,397	4%	SWsfb1	101,436	9%	ERav2	5,272	3%	ALmk1	552,962	6%	REsf1	112,127	4%	ALmk1	101,064	2%	ERlm2	594,772	10%	ERmf2	22,094,008	6%
ERnt1	1,005,749	2%	ERav2	68,042	6%	ALcx2	0	0%	SWsfb1	507,652	5%	ERht3	84,413	3%	REsf1	51,383	1%	COmma1	176,871	3%	ERht1	17,420,624	5%
ERht1	972,847	2%	ERht3	39,250	4%	ALmk1	0	0%	ERht1	296,365	3%	COhw2	60,918	2%	COha2	20,203	0%	ERav2	151,579	3%	COhw3	15,967,106	4%
ALmk1	877,788	2%	COpn1	19,633	2%	COha1	0	0%	ERht3	162,626	2%	COpn1	48,780	2%	COmma1	17,881	0%	ERav1	117,245	2%	COhwa1	15,620,293	4%
ERav4	857,985	2%	ERav1	11,175	1%	COha2	0	0%	ERnt1	128,555	1%	COha2	44,358	1%	COpn1	15,047	0%	ERnt1	81,786	1%	REsf1	11,495,792	3%
COpn1	796,809	2%	ERht1	7,705	1%	COhw1	0	0%	COpn1	106,263	1%	ERnt1	42,265	1%	COpn3	13,927	0%	ALmk1	66,608	1%	COhw1	6,605,181	2%
ERmm3	622,481	1%	ERnt1	6,943	1%	COhw2	0	0%	COmma1	20,858	0%	ERmm4	38,676	1%	COha1	8,674	0%	ERht3	38,162	1%	COha1	6,099,301	2%
ERmm2	578,081	1%	ALcx2	0	0%	COhw3	0	0%	ERav1	20,376	0%	ERmm3	35,025	1%	ERnt1	7,217	0%	SWsfb1	33,635	1%	ERlm1	6,046,588	2%
ERht3	545,490	1%	ALmk1	0	0%	COhwa1	0	0%	REgq1	19,705	0%	COha1	28,202	1%	ERht3	2,546	0%	ERav3	24,483	0%	ERmf4	4,341,980	1%
ERav2	511,084	1%	COha1	0	0%	COkh1	0	0%	COpn3	14,016	0%	ALmk1	26,057	1%	ALcx2	0	0%	COha1	22,137	0%	ERht3	4,255,498	1%
ERmf2	458,272	1%	COha2	0	0%	COkh2	0	0%	ERmm2	4,803	0%	ERav1	25,561	1%	COhw1	0	0%	ERav4	21,379	0%	ALcx2	3,361,852	1%
COpn3	261,692	1%	COhw1	0	0%	COmma1	0	0%	ERmm1	4,223	0%	SWsfb1	24,211	1%	COhw2	0	0%	ERmm4	14,112	0%	ERlm2	1,781,512	0%
COhw2	256,281	1%	COhw2	0	0%	COpn1	0	0%	ALcx2	0	0%	COmma1	14,394	0%	COhw3	0	0%	ERmm2	12,050	0%	ERmf1	1,294,485	0%
REgq1	235,070	1%	COhw3	0	0%	COpn3	0	0%	COha1	0	0%	COhw3	10,899	0%	COhwa1	0	0%	DTxx1	11,228	0%	ERmm2	1,180,694	0%
ERmm1	219,772	1%	COhwa1	0	0%	DTxx1	0	0%	COha2	0	0%	COpn3	5,963	0%	COkh1	0	0%	REgq1	4,349	0%	ERmm3	1,116,630	0%
ERmm4	208,811	0%	COkh1	0	0%	ERav1	0	0%	COhw1	0	0%	ERav3	5,867	0%	COkh2	0	0%	COhw2	4,033	0%	SWes1	1,063,296	0%
ERav3	174,810	0%	COkh2	0	0%	ERav4	0	0%	COhw2	0	0%	COhw1	5,603	0%	DTxx1	0	0%	COpn1	3,715	0%	COpn1	941,696	0%
COha2	170,538	0%	COmma1	0	0%	ERht1	0	0%	COhw3	0	0%	REgq1	5,008	0%	ERav1	0	0%	COha2	1,827	0%	COmma1	898,625	0%
SWsfb1	153,768	0%	COpn3	0	0%	ERht2	0	0%	COhwa1	0	0%	ERav2	4,055	0%	ERav2	0	0%	ERmm3	958	0%	ERmm4	765,940	0%
COkh2	115,616	0%	DTxx1	0	0%	ERht3	0	0%	COkh1	0	0%	ERav4	796	0%	ERav3	0	0%	COpn3	776	0%	ERav4	539,694	0%
COha1	92,492	0%	ERav3	0	0%	ERmf1	0	0%	COkh2	0	0%	ALcx2	0	0%	ERav4	0	0%	ALcx2	0	0%	COkh2	529,928	0%
ALcx2	64,735	0%	ERav4	0	0%	ERmf2	0	0%	DTxx1	0	0%	COhwa1	0	0%	ERmf1	0	0%	COhw1	0	0%	COpn3	371,104	0%
COhwa1	55,063	0%	ERmf1	0	0%	ERmf4	0	0%	ERav2	0	0%	COkh1	0	0%	ERmf2	0	0%	COhw3	0	0%	ALmk1	328,309	0%
ERmf1	50,058	0%	ERmf2	0	0%	ERmm1	0	0%	ERav3	0	0%	COkh2	0	0%	ERmf4	0	0%	COhwa1	0	0%	COkh1	149,019	0%
COhw3	23,835	0%	ERmf4	0	0%	ERmm2	0	0%	ERav4	0	0%	DTxx1	0	0%	ERmm1	0	0%	COkh1	0	0%	REgq1	148,992	0%
SWss1	12,411	0%	ERmm1	0	0%	ERmm3	0	0%	ERmf1	0	0%	ERmf1	0	0%	ERmm2	0	0%	COkh2	0	0%	SWsfb1	121,921	0%
COhw1	10,392	0%	ERmm2	0	0%	ERmm4	0	0%	ERmf2	0	0%	ERmf2	0	0%	ERmm3	0	0%	ERmf1	0	0%	ERmm1	116,082	0%
COkh1	10,382	0%	ERmm3	0	0%	ERnt1	0	0%	ERmf4	0	0%	ERmf4	0	0%	ERmm4	0	0%	ERmf2	0	0%	ERav3	100,958	0%
COmma1	5,162	0%	ERmm4	0	0%	REsa1	0	0%	ERmm3	0	0%	ERmm1	0	0%	REgq1	0	0%	ERmf4	0	0%	ERav1	97,836	0%
ERmf4	860	0%	REgq1	0	0%	REsf1	0	0%	ERmm4	0	0%	ERmm2	0	0%	REsa1	0	0%	ERmm1	0	0%	ERav2	76,401	0%
DTxx1	632	0%	REsa1	0	0%	SWes1	0	0%	REsa1	0	0%	REsa1	0	0%	SWes1	0	0%	REsa1	0	0%	DTxx1	27,159	0%
REsa1	0	0%	SWes1	0	0%	SWsfb1	0	0%	SWes1	0	0%	SWes1	0	0%	SWsfb1	0	0%	SWes1	0	0%	SWss1	14,279	0%
SWes1	0	0%	SWss1	0	0%	SWss1	0	0%	SWss1	0	0%	SWss1	0	0%	SWss1	0	0%	SWss1	0	0%	REsa1	2,043	0%
Total Area	**42,444,903**			**1,085,262**			**157,259**			**9,519,001**			**3,053,939**			**6,685,829**			**6,061,598**			**376,435,529**	
% of Study Area	**10%**			**0%**			**0%**			**2%**			**1%**			**2%**			**1%**			**85%**	

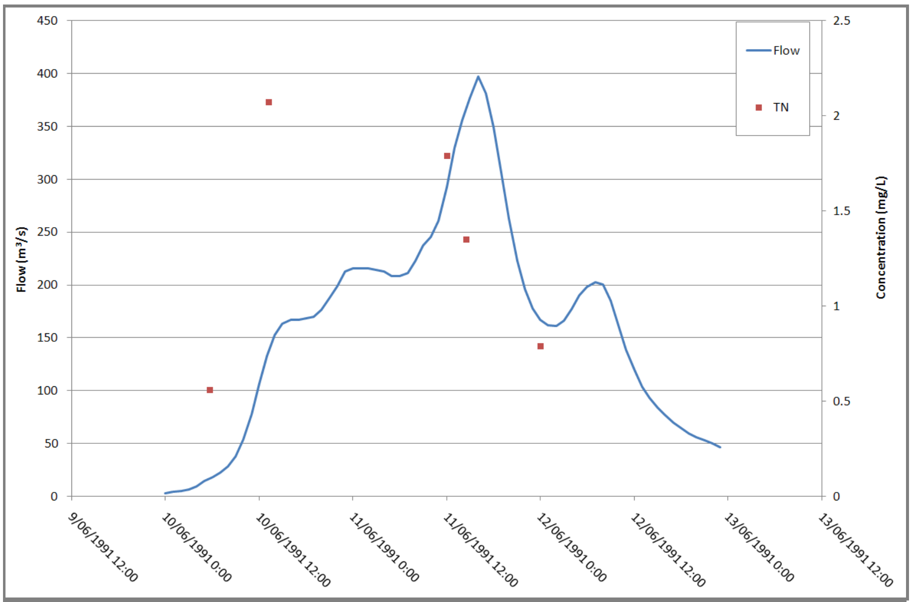
The preliminary FUs were sub-divided based on soil facet. FU2, FU3 and FU5 not sub-divided due to their small proportional area of the total catchment area. FU1, FU4, FU6 and FU7 were sub-divided into four sub-categories (three based on the top three soil facets and one lumped category for the remaining soil facets). FU8 was sub-divided into eight sub-categories.

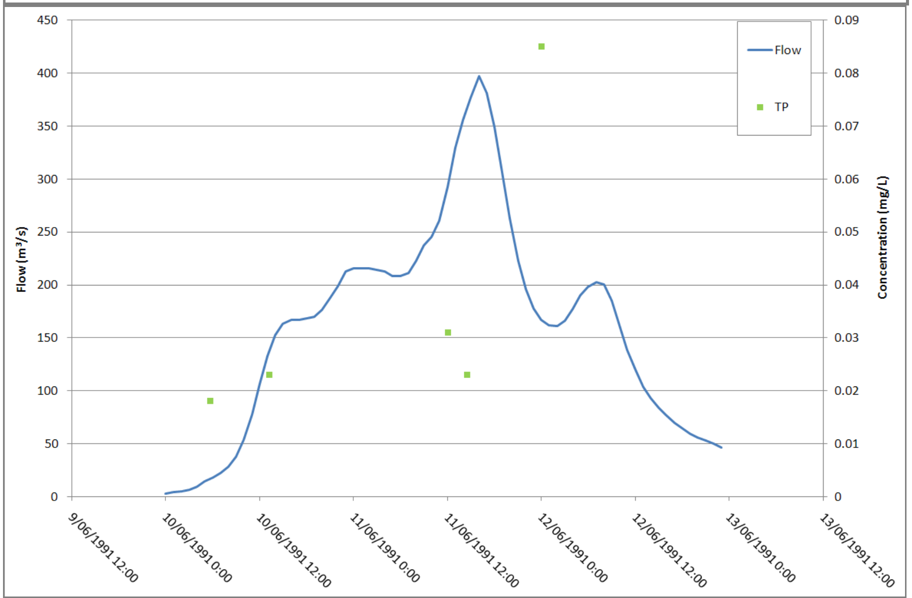
Colour-coding of soil facets in each land use FU denotes that soil facet is presented individually. Multiple soil facets with same colour indicate that these soils are grouped together due to similar characteristics. Uncoloured soil facets in each FU are grouped together.

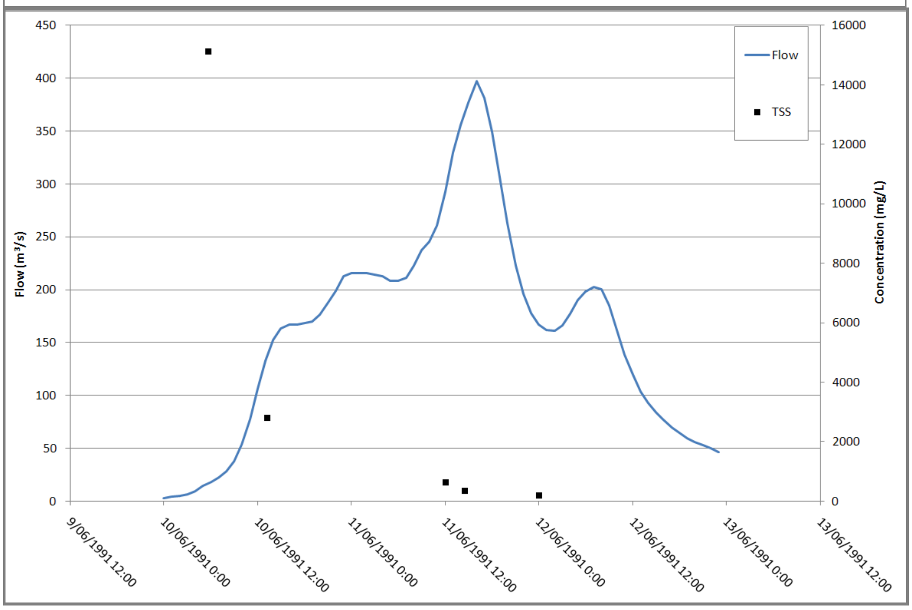
A total of 27 final FUs were created.

Appendix B Selected Water Quality Event Time Series Plots

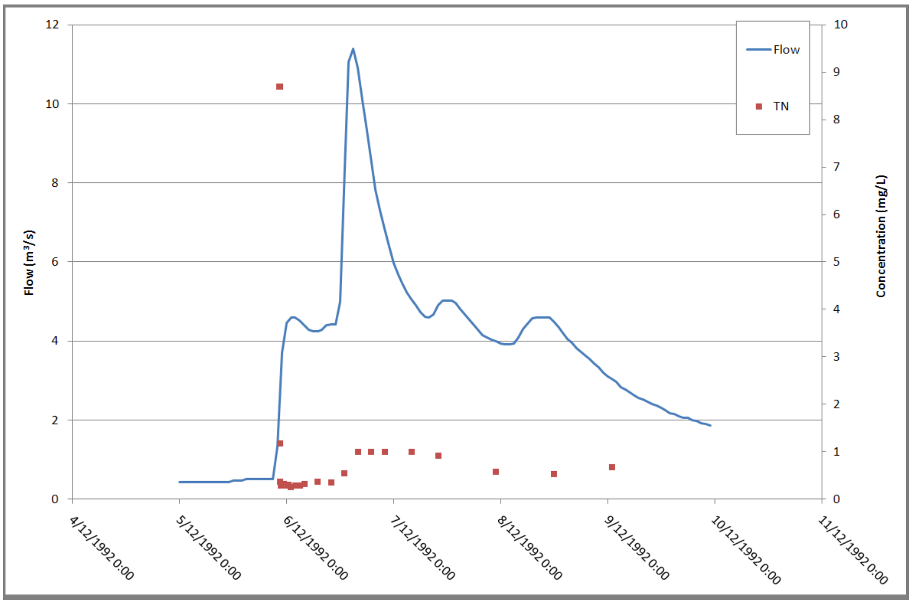
Event 1 Site E210: 10 – 12/6/1991

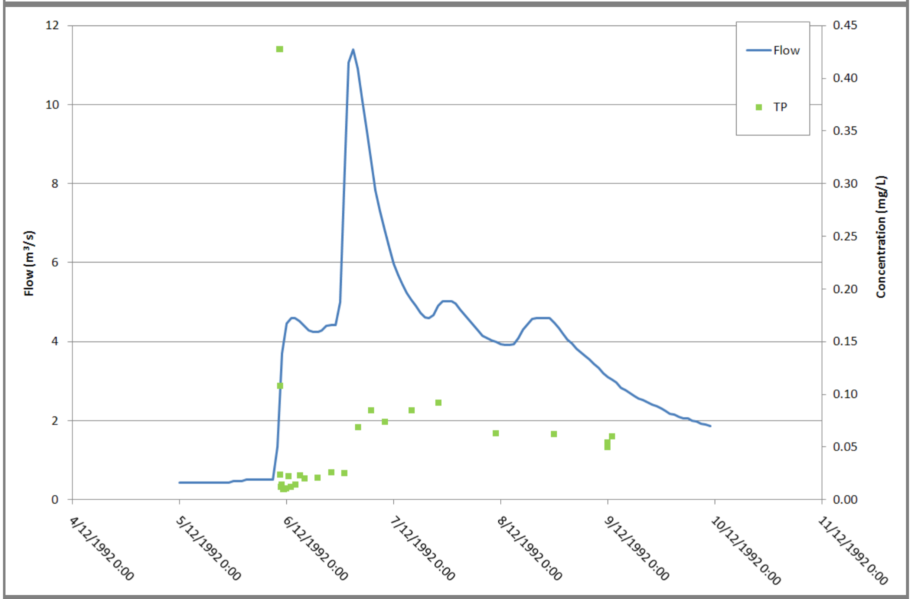


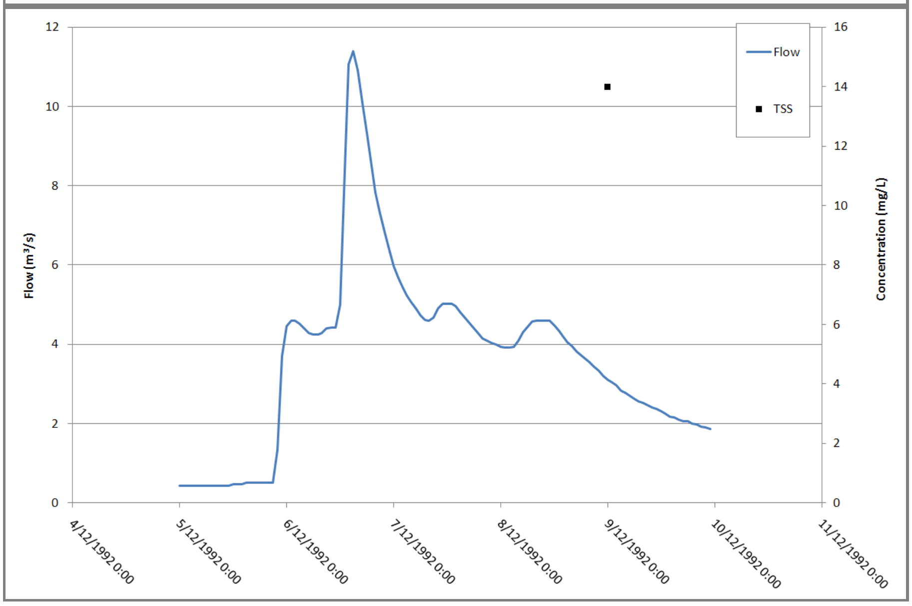




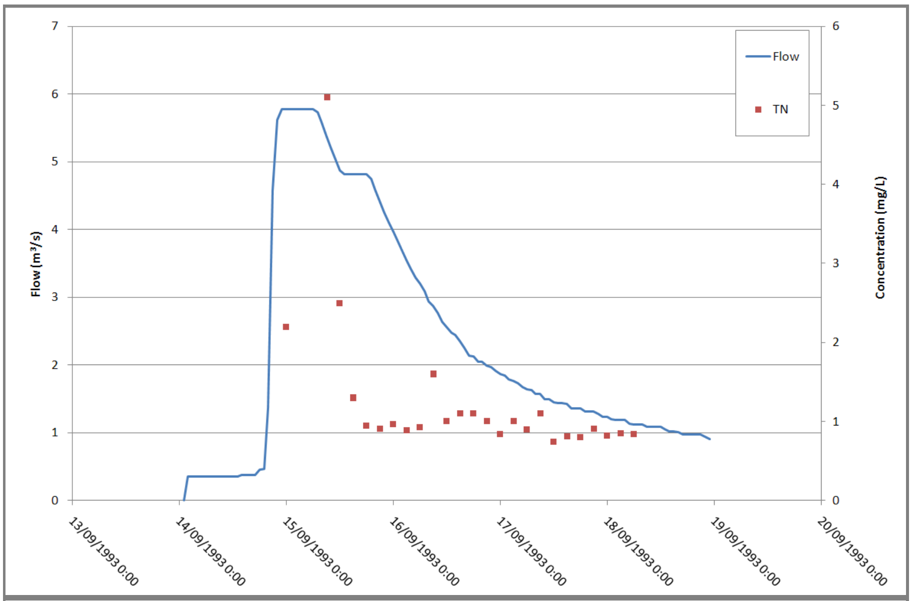
Event 2 Site E210: 5 – 9/12/1992

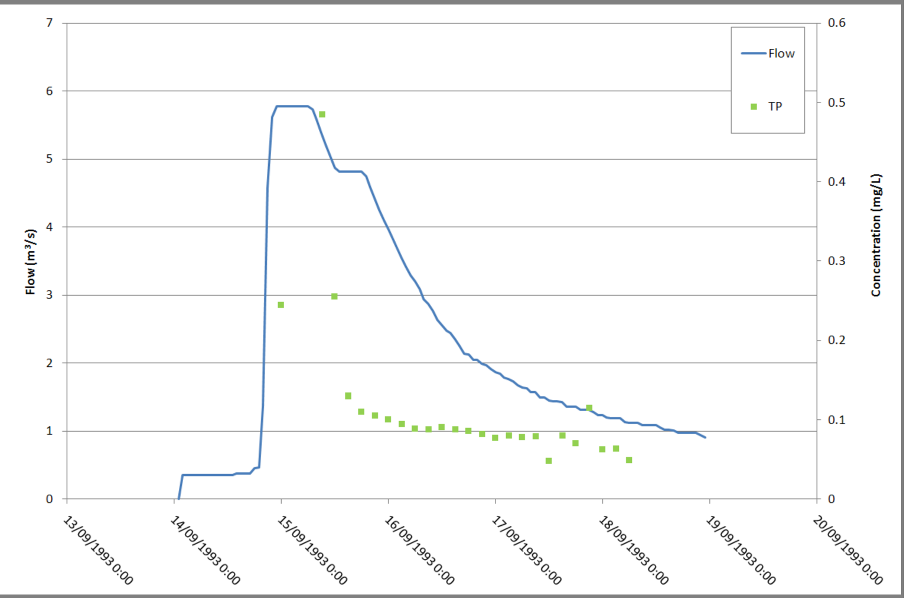


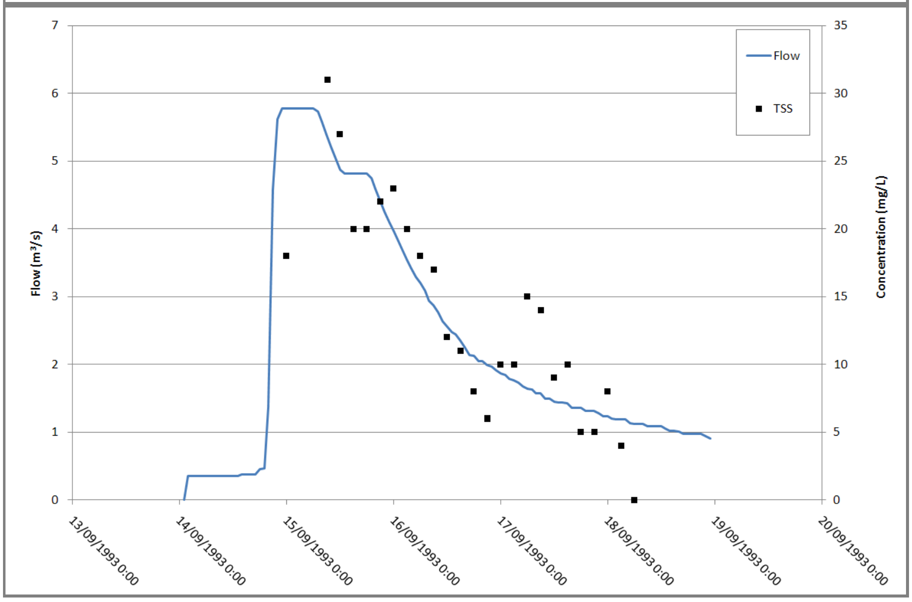




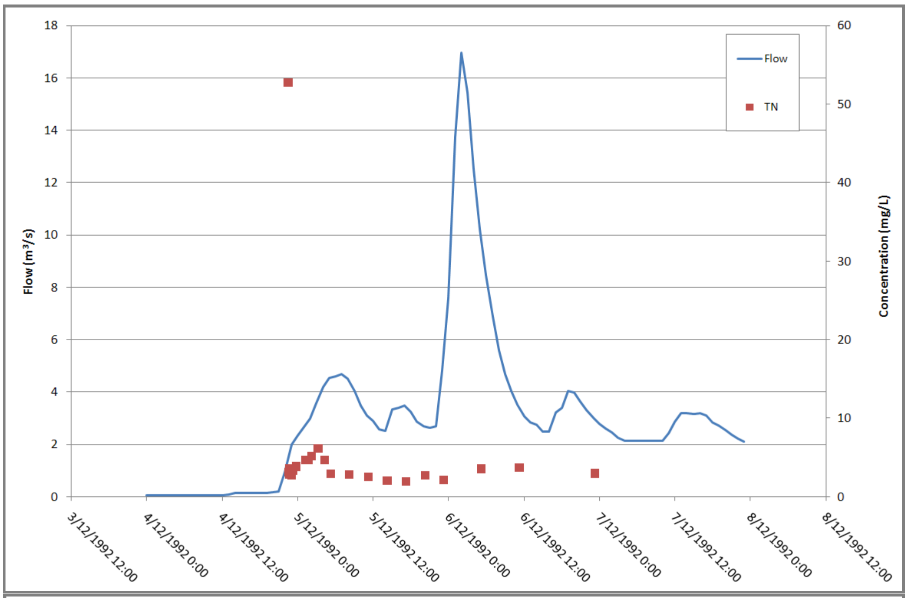
Event 3 Site E210: 4 – 18/9/1993

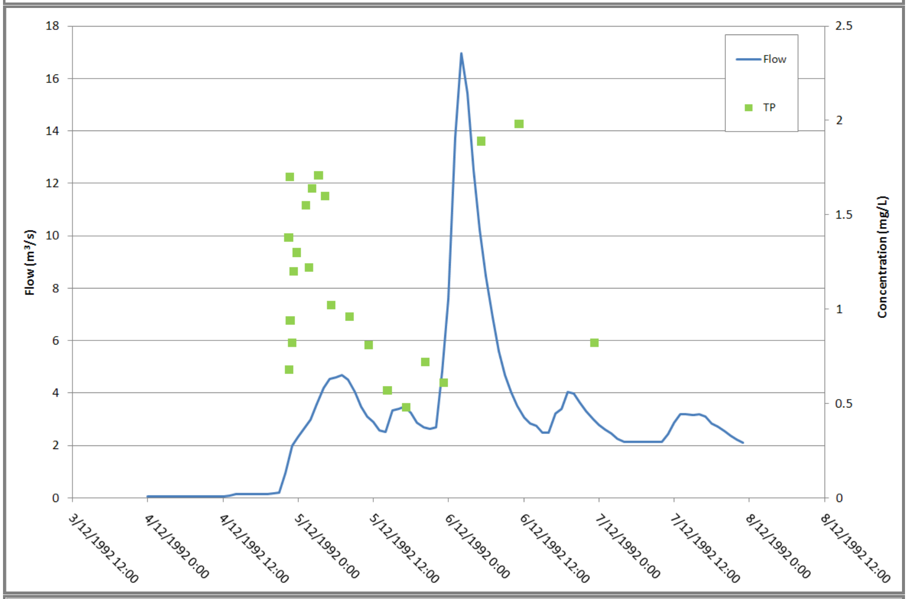


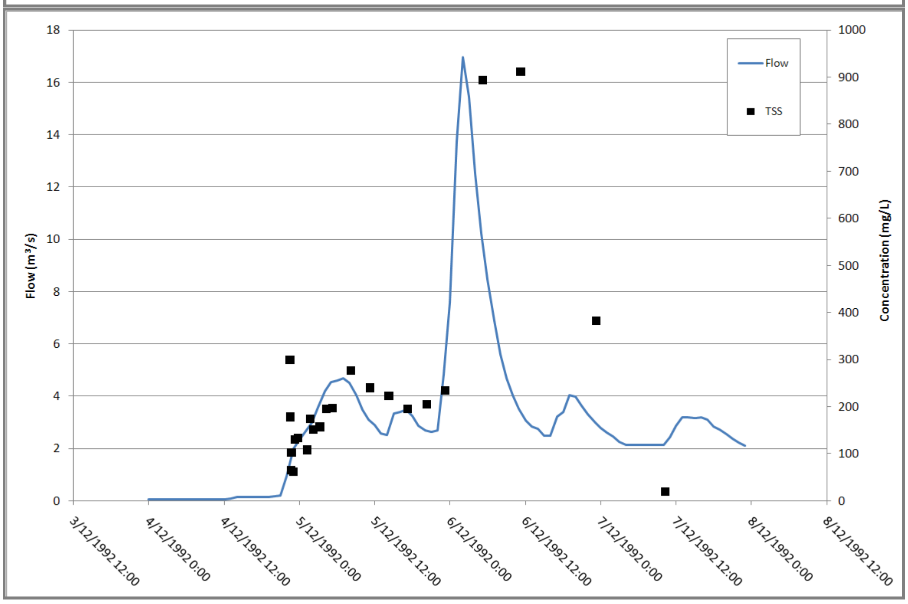




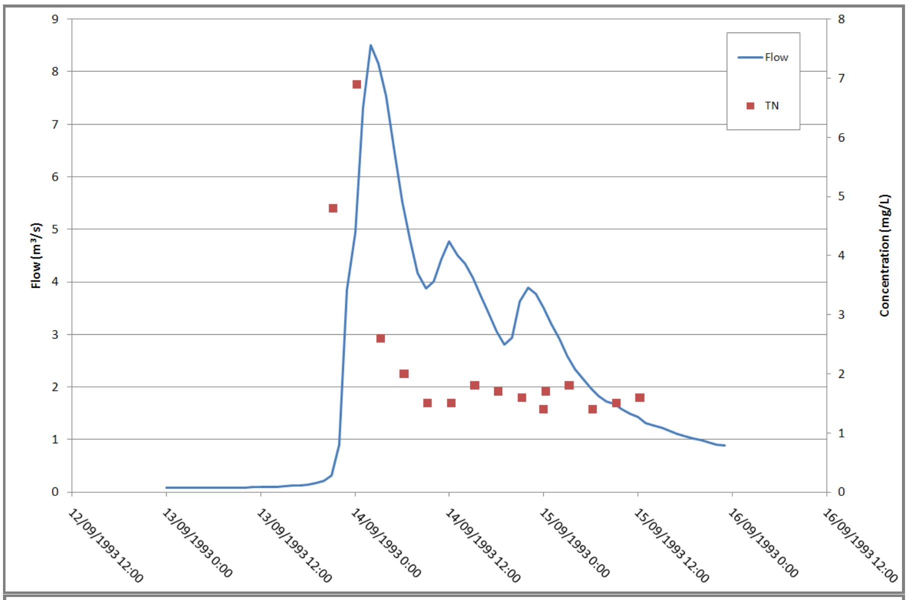
Event 4 Site E206: 4 – 7/12/1992

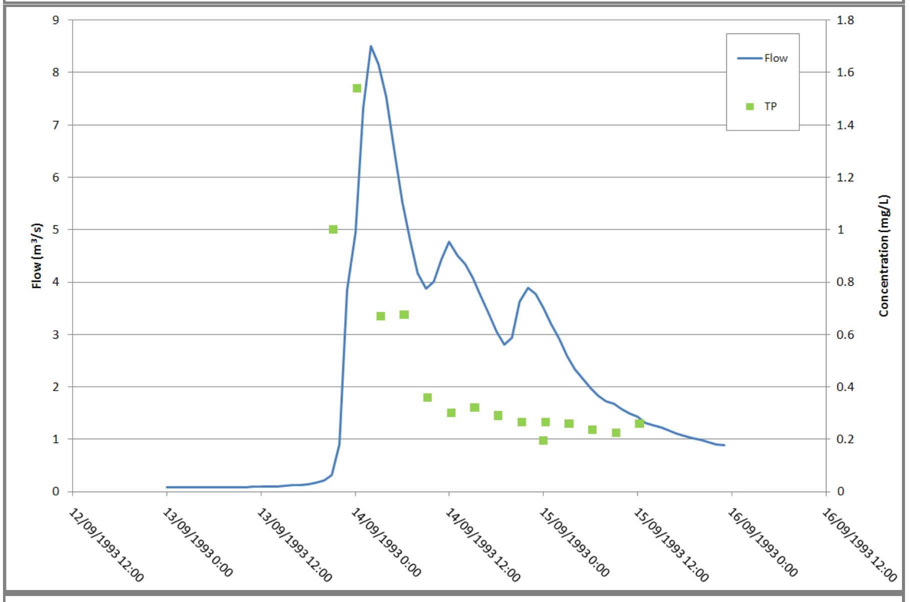


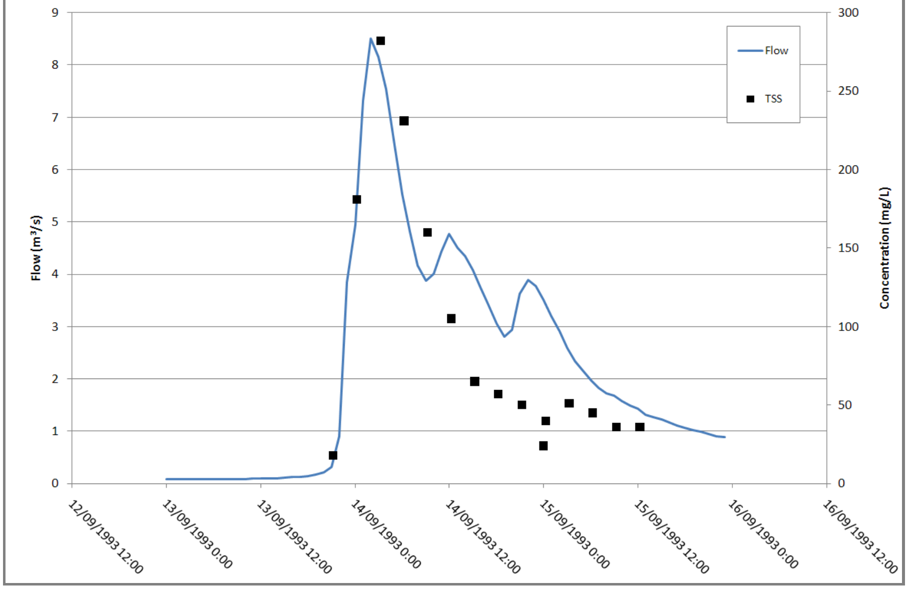




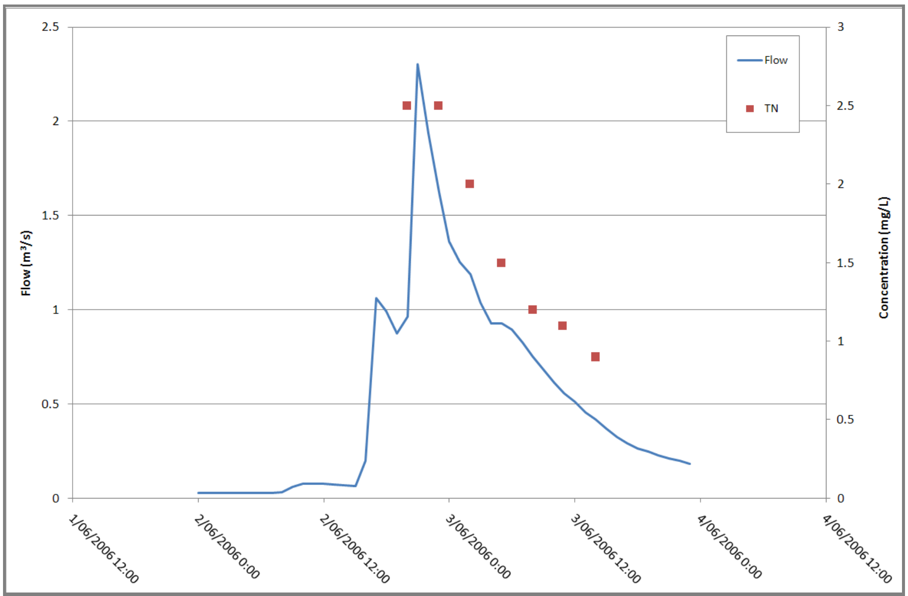
Event 5 Site E206: 13 – 15/9/1993

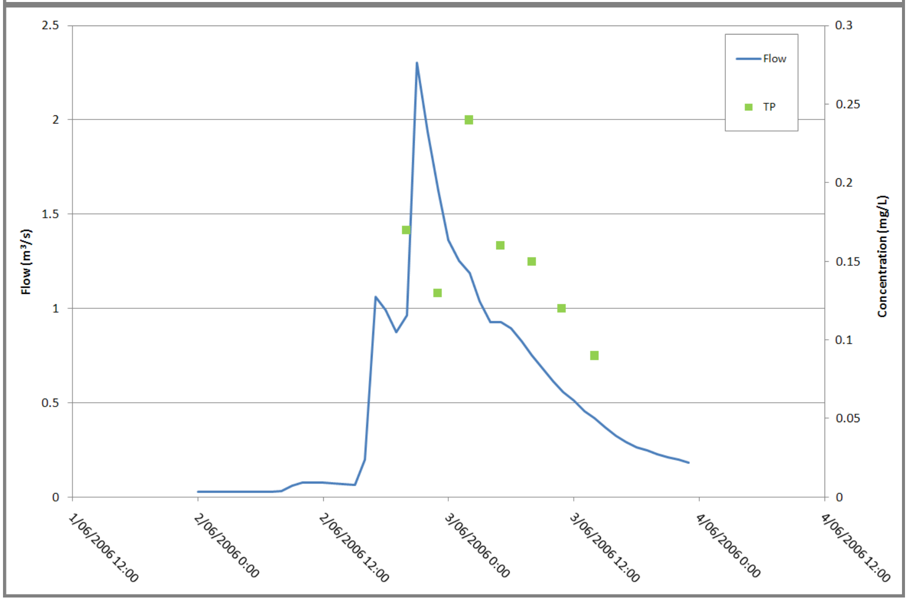


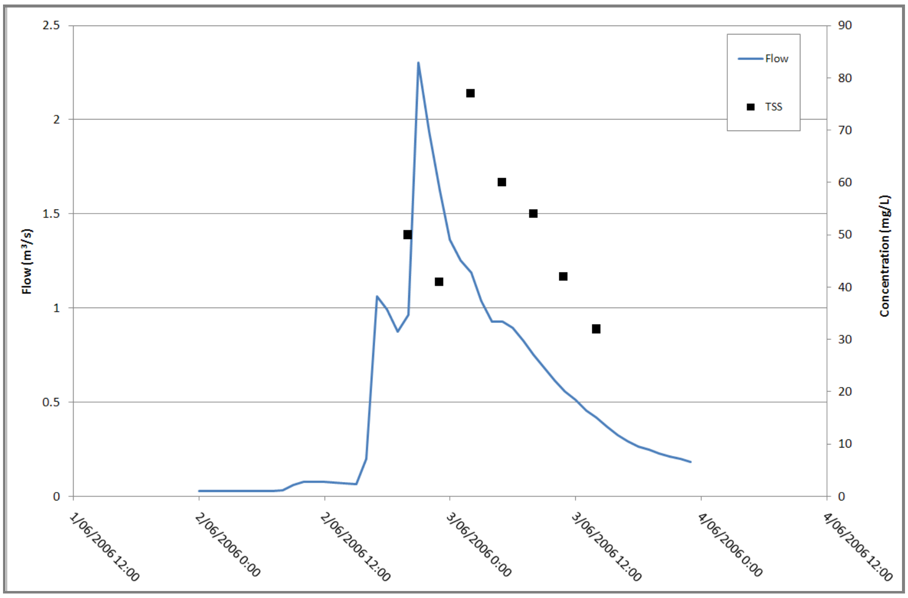




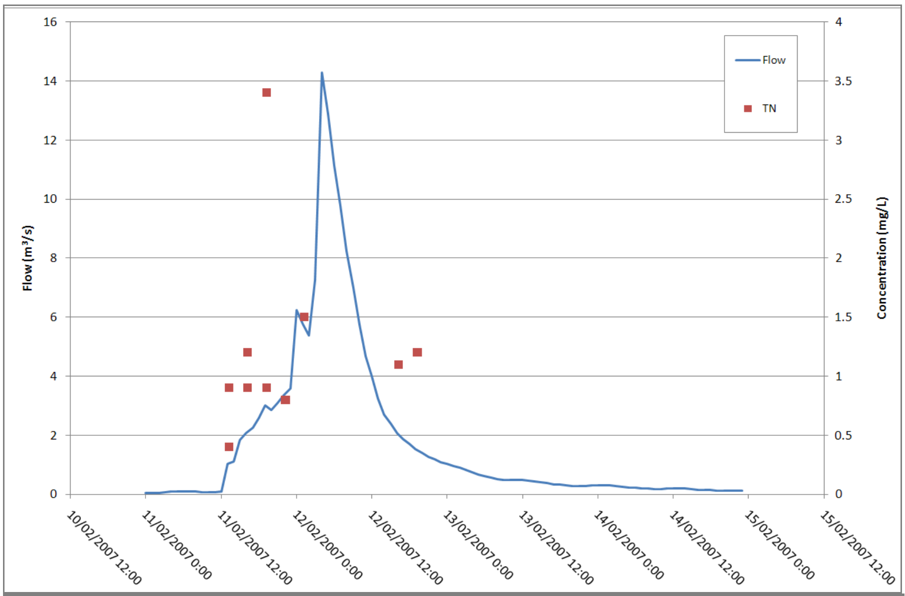
Event 6 Site E206: 2 – 3/6/2002

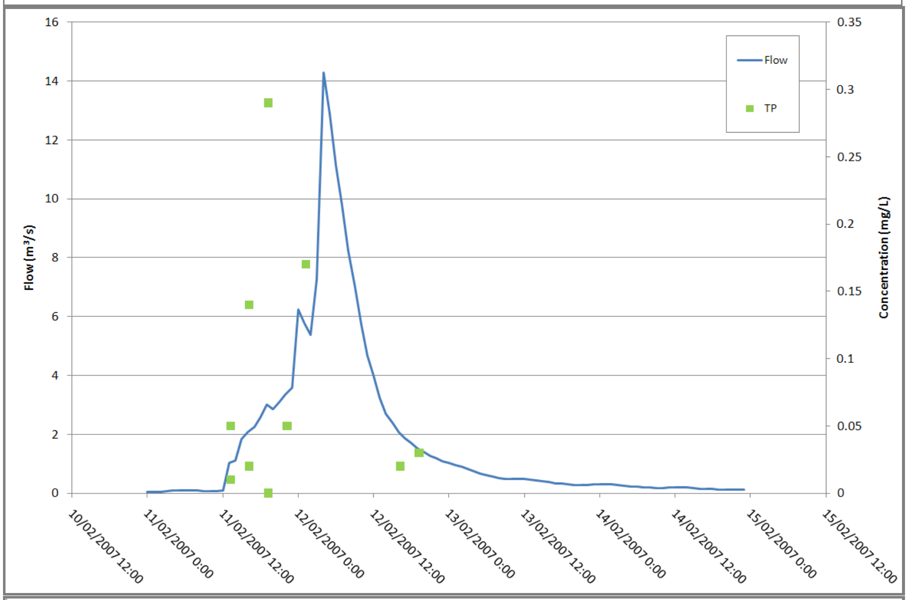


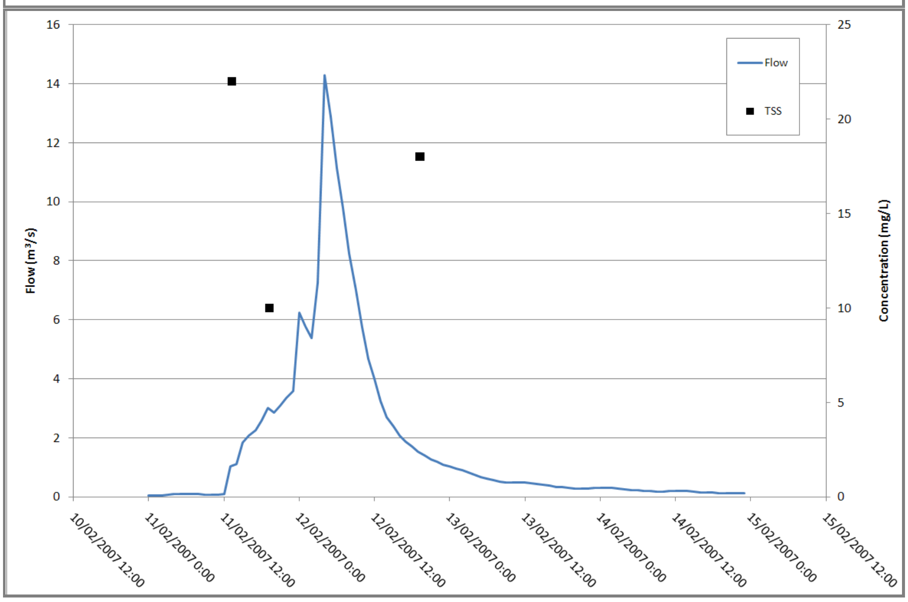



2.5
2
1.5
1
0.5
0
Flow (m³/s)
90
80
70
60
50
40
30
20
10
0
Concentration (mg/L)
Flow
TSS
1/06/2006 12:00
2/06/2006 0:00
2/06/2006 12:00
3/06/2006 0:00
3/06/2006 12:00
4/06/2006 0:00
4/06/2006 12:00

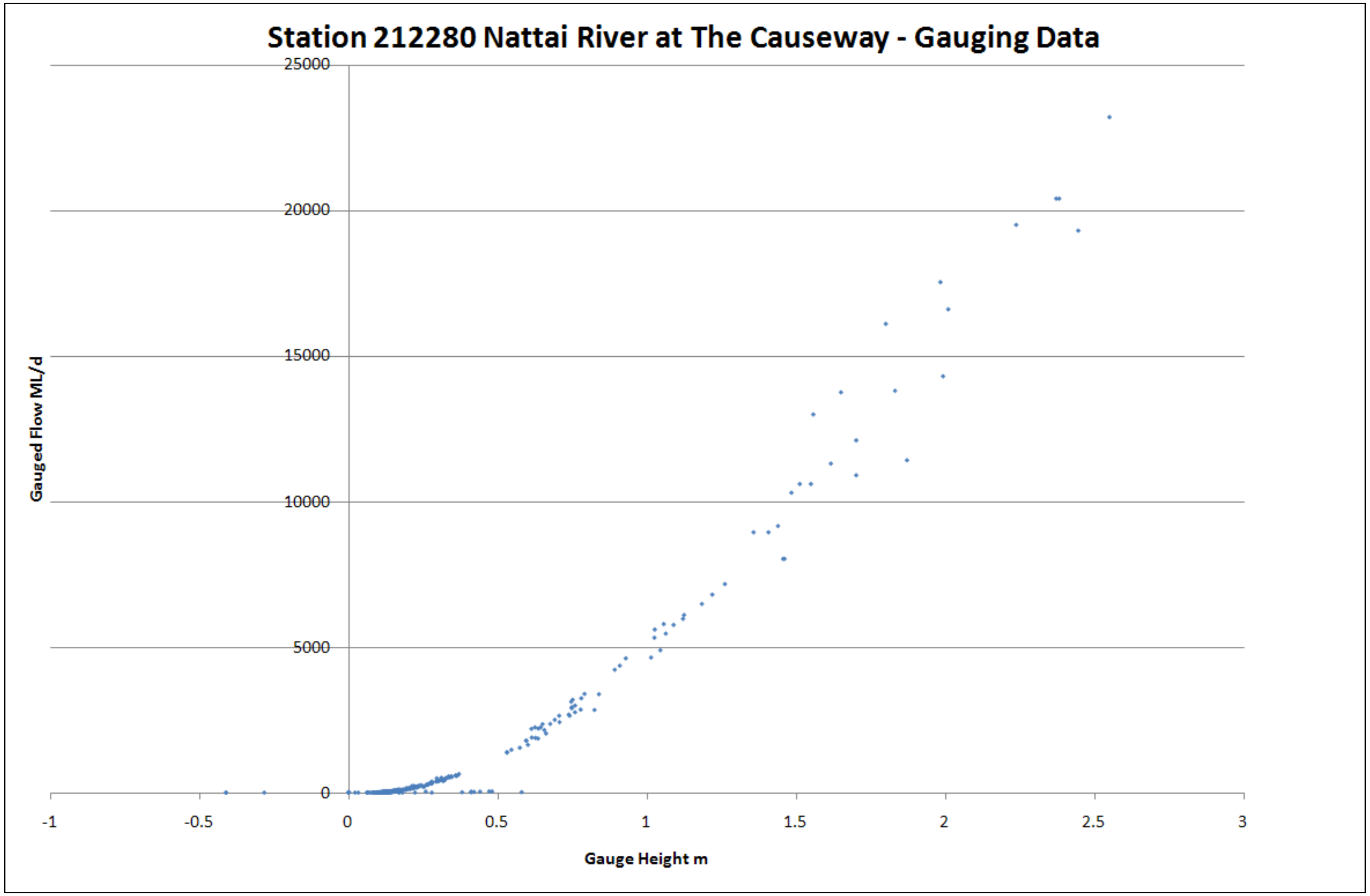
Event 7 Site E206: 11 – 12/2/2007

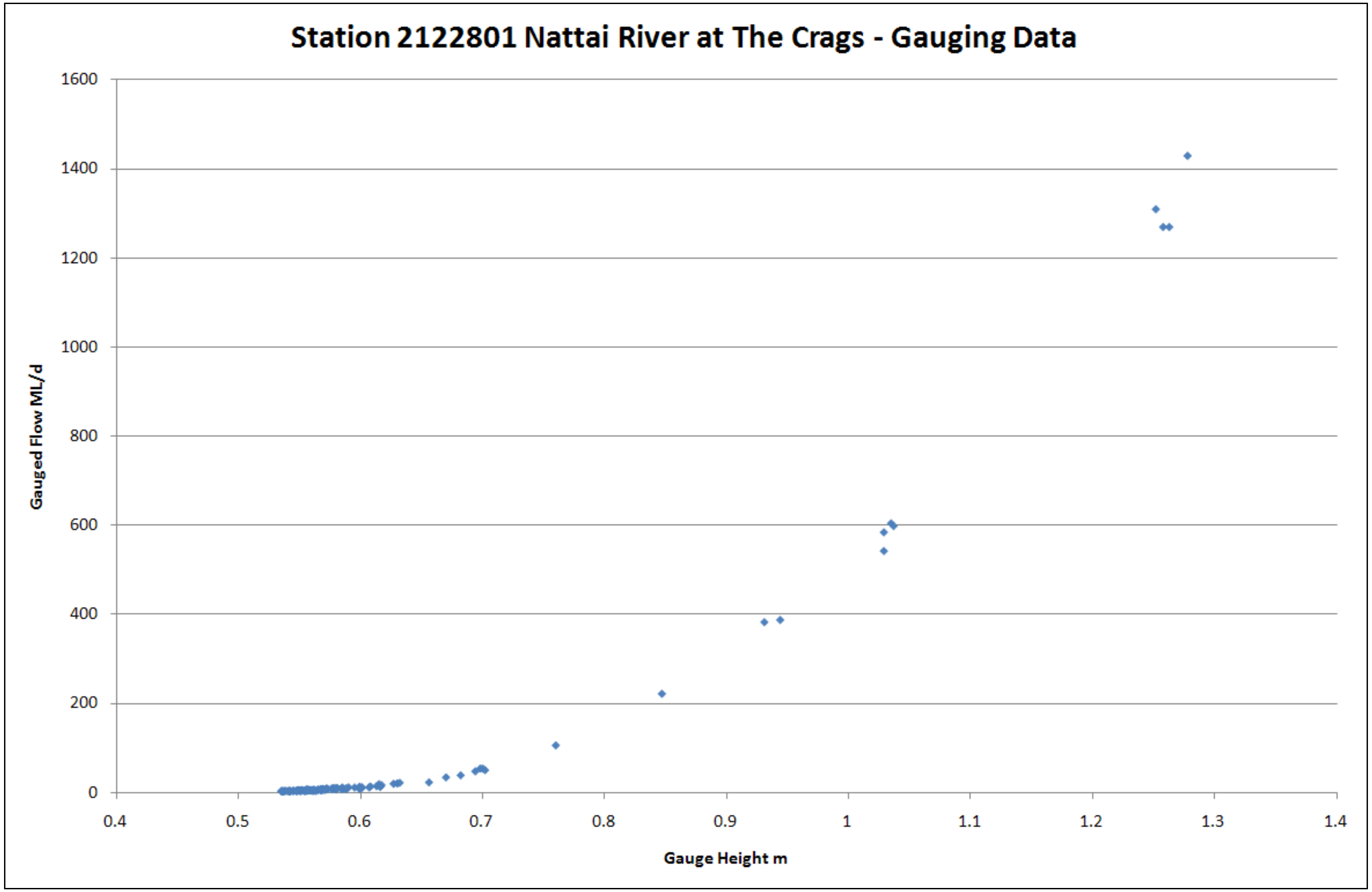






Appendix C Flow Gauging Curves


Station 212280 Nattai River at The Causeway - Gauging Data
25000
20000
15000
10000
5000
0
-1
-0.5
0
0.5
1
1.5
2
2.5
3
Gauged Flow ML/d
Gauge Height m


Station 2122801 Nattai River at The Crags - Gauging Data
Gauged Flow ML/d
1600
1400
1200
1000
800
600
400
200
0
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
Gauge Height m