BRISBANE WATER ESTUARY PROCESSES STUDY
CATCHMENT MODELLING - MUSIC
APPENDIX B

Report Prepared for

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Cardno Lawson Treloar Pty Ltd

ABN 55 001 882 873

Level 2, 910 Pacific Highway

Gordon New South Wales

2072 Australia

Telephone: 02 9499 3000

Facsimile: 02 9499 3033

International: +61 2 9499 3000

cltnsw@cardno.com.au

www.cardno.com.au

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		Name	**Initials**	**Name**	**Initials**
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EXECUTIVE SUMMARY

The Brisbane Water Estuary is fed by a number of tributaries, including Erina Creek and Narara Creek. These tributaries generate pollutants which are transported into the Estuary. The processes that affect the quantity and concentration of these pollutants is a complex process, and is dependent on a number of factors.

A computer model (MUSIC) was established to replicate these catchment processes. This computer model incorporates various catchment parameters such as land use, impervious area, rainfall and soil properties. The model was established for the entire Brisbane Water Estuary Catchment, which is an area of approximately 16,500ha. For the purposes of the modelling, the catchment was discretinised into 233 sub-catchments.

The MUSIC model was validated against both quantity (flows) and quality (concentrations) information. Flows were generated via an independent hydrological model (XP-RAFTS), and compared with those from the MUSIC model. Observed water quality concentrations were also available for a number of locations. These concentrations were compared with the MUSIC model results.

The MUSIC model was run for representative wet, dry and average rainfall years. Specific rainfall years were chosen that represented wet, dry and average rainfall years over a recorded period of up to 80 years.

As would be expected, the results of the modelling show a significant increase in pollutant load generated from the sub-catchments during a wet year, when compared to an average rainfall year. For the total Brisbane Water Catchment, there is an approximate 85% increase in pollutant load during a wet year, when compared to that of an average rainfall year. This compares with a 35% decrease in pollutant load during a dry year, when compared to an average rainfall year.

The Narara Creek catchment represents the largest proportion of pollutant load delivered to Brisbane Water. This is a function of both its proportionally larger sub-catchment area, as well as the land-use within the sub-catchment. The Erina Creek catchment, by comparison, produces approximately half the pollutant load of the Narara Creek catchment.


Lower Reaches of Erina Creek


Upper Reaches of Narara Creek

The smaller sub-catchments of the Brisbane Water Estuary, which discharge directly to Estuary, represent approximately 40% of the total pollutant load entering the estuary.

The Kincumber Creek catchment has the highest pollutant intensity (pollutant load per hectare) of the major sub-catchments within Brisbane Water. This primarily is a function of the mixture of industrial and residential land-uses in this area.


Kincumber Creek

B. CATCHMENT MODELLING

B.1 DATA SOURCES

There are numerous data sources that have been used in the establishment of the MUSIC water quality model for Brisbane Water.

Rainfall data was obtained from both Manly Hydraulics Laboratory (MHL) and the Bureau of Meteorology (BoM). For more details on the information obtained, please refer to Section B.1.1.

- Evaporation data was obtained from the BoM for the Peats Ridge Gauge.
- The BoM *Climatic Atlas of Australia – Evapotranspiration* (2003) was used in the estimation of the potential evapotranspiration for the catchment.
- Aerial photographs of the majority of the catchment in digital format were obtained from Council.
- Water quality sampling data for the catchment was obtained from Council, from Council's water quality database. This contained historically collected water quality information from a variety of sources.
- GIS layers obtained from Council which include 2 metre contour information, hydrological sub-catchment break-down, pipe layouts, major waterways, cadastre and Council zoning areas.

B.1.1 Climate Information

Rain Gauges

Rainfall information was obtained from MHL and BoM. Table B.1 shows the gauges that were used in the assessment of the Brisbane Water Catchment. These gauges were selected based on their proximity to the catchment and their period of operation. Their locations are shown in Figure B.1 and the details relating to each gauge are presented in Table B.1.

Table B.1 Rainfall Gauges

Gauge	Gauge ID	Operator	Type	Data Available
Woy Woy	61318	BoM	Daily	1/12/1964 – 29/2/2004
Gosford North	61319	BoM	Daily	1/12/1971 – 23/3/2004
Marlow Creek	61354	BoM	Daily	1/1/1986 – 28/2/2002
Avoca Beach	61294	BoM	Daily	1/5/1970 – 29/2/2004
Gosford (Narara)	61087	BoM	Daily	1/7/1917 – 23/3/2004
Peats Ridge	61351	BoM	Pluvio	1/11/1996 – 6/4/2003
Wyoming	None	MHL	Pluvio	1/7/1993 – 31/12/2003
Narara	None	MHL	Pluvio	1/7/1993 – 31/12/2003
Lisarow	None	MHL	Pluvio	1/7/1993 – 31/12/2003
Kincumber	None	MHL	Pluvio	1/7/1993 – 31/12/2003

Long Term Analysis of Rainfall Data

The daily historical data from Woy Woy, Gosford (Narara) and Avoca Beach were used to determine long term annual rainfall loads. These daily rainfall gauges had both a reasonable length of record and a good spatial coverage of the catchment. These were then used to determine years of average (50 percentile), dry (lower 10 percentile) and wet (upper 10 percentile) rainfall.

To determine this statistical information, the plotting position method (as specified in AR&R, Book IV) was used. This method is commonly used in analysis of annual flood series, but is also sufficient for annual rainfall series. The plotting method was checked by assuming the annual data had a standard normal distribution. The results of this analysis agreed well with that of the plotting position method.

A number of the records had data missing. A recorded year was not included in the analysis if it had a total missing record of greater than one month.

Table B.2 shows the results of this analysis. It shows the year of record and corresponding annual rainfall depth for the average, wet and dry years for the three gauges. The average value shown gives an indicative value. The pluviometer data obtained covers the period from 1993 onwards. The average value was used to determine years from this record that represent dry, wet and average years.

Table B.2 Analysis of Rainfall Data

Station	Top 10%		50%		Bottom 10%	
	Rainfall (mm)	Year	Rainfall (mm)	Year	Rainfall (mm)	Year
Gosford (Narara)	1743	1931	1265	1946	909	1939
Avoca	1876	1988	1292	1981	998	1991
Woy Woy	1790	1989	1164	1986	811	1979
Average	**1803**		**1240**		**906**	

Pluviometer Data for MUSIC

Of the pluviometer data available, the MHL gauges are the closest to the catchment. The Peats Ridge data was not use due to its distance from the catchment.

Table B.3 shows the annual rainfall recorded at each gauge. Values with 'na' are years in which there are a significant number of missing records, and hence do not provide a reasonable representation of annual rainfall.

Table B.3 Analysis of Pluviometer Data

Year	MHL Pluvio Gauge (mm)				BoM Daily Gauge (mm)		
	Kincumber	Lisarow	Narara	Wyoming	Avoca	Woy Woy	Gosford (Narara)
1994	955	1141.5	1023.5	908.5	981.9	914.6	1036.9
1995	1111.5	1280.5	1232	1188.5	na	1159.8	1311.3
1996	1073	943.5	986	1084	na	1121.2	1192
1997	1187.5	1108.5	na	969.5	981	1004.6	1404.3
1998	1700.5	na	1581	na	1604.2	1604.6	1937.3
1999	1488	1321	1552	1357	1669.6	1448.2	1571.4
2000	844.5	859	857.5	777	na	738.3	1082.9
2001	1309.5	na	1311.5	na	1185	1126.8	1403.1
2002	832	767	1320	918	1229.6	1114.5	1084.4
2003	1197.5	1207	1292.5	1023.5	1350	1100.3	1282.2

There are some spatial variations in the data, as would be expected. Each MUSIC model can only accommodate one rainfall input, and therefore representative rainfall needs to be applied to the model as the entire catchment was included in one model file. The chosen gauge depends upon the modelling period.

From the above information, the years 1998, 2000 and 2003 were chosen as representative of a wet, dry and average rainfall respectively (Table B.4). The gauge used to represent the catchment is also shown. Gauges were chosen if they represented an average rainfall for the catchment for the period and also if they contained a minimal number of missing records for the chosen period.

Table B.4 Representative Rainfall Years

Type	Percentile	Year	Gauge
Average	50%	2003	Lisarow
Wet	Upper 10%	1998	Kincumber
Dry	Lower 10%	2000	Narara

Evapotranspiration

Daily evaporation data was available at the Peats Ridge gauge from 10 March 1981 through to 23 March 2004. This data was converted to monthly data, and the average for the period was determined. These averages were then compared to monthly areal potential evapotranspiration, taken from the *Climatic Atlas of Australia* (BOM, 2003). Table B.5 shows this comparison.

Table B.5 Comparison of Potential Evaporation with Areal Potential Evapotranspiration

Month	Peats Ridge Potential Evaporation (mm)	Monthly Areal Potential Evapotranspiration (mm)
January	143	179
February	116	142
March	101	139
April	76	91
May	57	57
June	48	44
July	53	47
August	77	62
September	103	89
October	127	130
November	132	153
December	148	164
Annual	**1113**	**1297**

The purpose of this comparison is to establish factors for the conversion of potential evaporation data into potential evapotranspiration data. However, the above comparison shows periods in which the potential evaporation is higher than that of the potential evapotranspiration.

Due to this inconsistency, and due to the distance of the Peats Ridge gauge from the catchment, the monthly areal potential evapotranspiration rates from the *Climatic Atlas of Australia* (BOM, 2003) were adopted representative of the catchment.

B.1.2 Water Quality Data

Validation data was available from Council's water quality database. MUSIC is capable of modelling total nitrogen (TN), total phosphorous (TP) and total suspended solids (TSS).

Of the data within Council's water quality database, only TN was sampled, with no data available on TP or TSS. Turbidity was sampled at a number of sites, and this was used as an indicator of TSS. Higher turbidities are generally associated with higher TSS.

Table B.6 shows a selection of sites available for validation of the MUSIC model. They were chosen based on their length of operation and their location. Sampling sites within the estuary would be exposed to processes outside of the modelling scope of MUSIC, and are modelled within the 3D model of Brisbane Water. Therefore, only sites within the tributaries of Brisbane Water, such as Narara Creek, were chosen here.

Table B.6 Water Quality Sites Used for Calibration

Music Node	Site ID	Operation		TN	TSS
		Start	End		
W_GosfordO1	00026 - Station 8 Lower Narara Creek	10/02/1996	8/06/1999	Y	Y
NararaO1	00027 - Upper Narara Creek	8/02/1997	8/06/1999	Y	Y
ChertseyO2	00079 - Erina Creek Entrance	30/08/1999	25/06/2002	Y	Y
ChertseyO2	00028 - Station 9 Lower Erina Creek	10/02/1996	8/06/1999	Y	Y
ClarenceO1	00029 - Station 9A Upper Erina Creek	8/02/1997	8/06/1999	Y	Y
Kincumber_CkO2	00030 - Kincumber Creek	10/02/1996	8/06/1999	Y	N
Kincumber_CkO1	00080 - Kincumber Creek Entrance	30/08/1999	25/06/2002	Y	N
W_InletO8	00039 - Woy Woy Tip Laxton	14/09/1998	8/06/1999	Y	N
WWCreekO1	00037 - Woy Woy Creek Laxton	5/11/1997	8/06/1999	Y	Y
W_InletO1	00082 - Woy Woy Creek Cheng	30/08/1999	28/05/2002	Y	Y
Umina2	00035 - Upper Ettalong Creek Laxton	8/02/1997	8/06/1999	Y	Y
UminaO1	00036 - Lower Ettalong Creek Laxton	8/02/1997	8/06/1999	Y	Y
EmpireO1	00031 - Cockle Creek Laxton	10/02/1996	8/06/1999	Y	Y
EmpireO5	00081 - Cockle Creek Cheng	30/08/1999	25/06/2002	Y	Y

B.1.3 Catchment Properties

Sub-Catchments

The Brisbane Water Catchment was initially broken up into sub-catchments based on hydrological considerations. The Council GIS layer of sub-catchments was used as a template for the catchment delineation.

These hydrological catchments were then divided up based on their land use (such as forest, rural, etc). This was determined from zoning information and aerials photographs provided by Council. Ground truthing was also conducted to ensure relevance of the land types assumed.

The catchment layout is shown in Figure B.2 and sub-catchments for modelling are shown in Figures B.3-8. Table B.19 (at the conclusion of this Appendix) shows the area of each of these catchments, as well as the assumed impervious percentage and land use type. Figure B.9 visually summarises the land uses assumed for the catchment.

There are a number of tributaries that enter Brisbane Water. Six major tributaries are shown in Table B.7, along with the land use percentages assumed. These tributaries are shown in Figure B.10.

Table B.7 Land Uses within Major Tributaries

Tributary	Total Area (ha)	Impervious Percentage (%)	Forest Percentage (%)	Rural/ Parkland Percentage (%)	Residential Percentage (%)	Commercial Percentage (%)	Industrial Percentage (%)	Percentage of Other (%)
Upper Narara Creek	2811	14.6	52.4	24.3	17.0	0.0	2.8	3.4
Lower Narara Creek	4656	19.2	51.0	18.4	20.4	1.2	6.0	3.1
Upper Erina Creek	1926	5.0	50.5	49.5	0.0	0.0	0.0	0.0
Lower Erina Creek	3252	11.9	43.6	35.7	14.2	0.0	2.6	3.9
Kincumber Creek	484	25.9	29.0	18.1	41.6	0.0	2.9	8.3
Woy Woy Creek	588	8.4	84.6	0.0	0.0	0.0	0.0	15.4
Coorumbine Creek	361	23.4	55.3	12.2	16.6	0.0	13.6	2.4
Ettalong Creek	780	26.0	46.5	0.0	53.5	0.0	0.0	0.0

Soil Parameters

MUSIC allows for the input of a number of soil parameters. These parameters describe a number of different characteristics of the pervious soil areas, including:

- Groundwater flow rate and recharge
- Soil storage available
- The rate at which the soil can absorb water (infiltration rate).

As there is insufficient data to properly describe the individual soil characteristics of each sub-catchment, a catchment wide average is used. These were based on recommendations in the MUSIC Manual (CRCCH, 2003), soil maps (Chapman et al (1983) and Murphy & Tille (1993)) and were also modified as a part of the validation process.

Following discussions with Council, the Woy Woy peninsula was identified as having sandy soils, with a high infiltration capacity. Based on this information, the soil parameters in the MUSIC model were modified in this area.

Two sub-surface storages are modelled within the MUSIC model, the soil storage and the groundwater storage. Tables B.8 and B.9 show the parameters assumed for both of these storages, for the whole Brisbane Water catchment as well as for the Woy Woy peninsula.

Table B.8 Soil Storage Parameters

Parameter	Catchment	Woy Woy
Soil Storage Capacity (mm)	200	300
Initial Storage (% of Capacity)	30	30
Field Capacity (mm)	150	150
Infiltration Capacity Coefficient – a	100	100
Infiltration Capacity Coefficient – b	2	2

Table B.9 Groundwater Storage Parameters

Parameter	Catchment	Woy Woy
Initial Depth (mm)	10	10
Daily Recharge Rate (%)	50	50
Daily Baseflow Rate (%)	5	10
Daily Deep Seepage Rate (%)	0	0

B.1.4 Water Quality Parameters

Water quality parameters were selected using ARQ (Engineers Australia, 2006). These were then typically adjusted within the one standard deviation bound of the data in ARQ as a part of the validation process with the historical water quality data.

The mean generation, rather than the stochastic generation function in MUSIC was used. The stochastic generation will randomly produce pollutant concentrations at each time step based on an input mean and standard deviation. This results in differing results each time the model is run. By comparison, the mean generation function will produce the specified mean concentration at each time step. The main reasons for using the mean generation options are:

- The mean generation option produces consistent results, which results in a more efficient validation of the model and reproducible design results.
- The large number of catchments defined in the model in part reduces the need for a stochastic generation, as this produces a more natural average.

Three types of pollutants can be modelled in MUSIC:

- Total Suspended Solids (TSS)
- Total Nitrogen (TN)
- Total Phosphorous (TP).

Table B.10 shows the runoff and baseflow mean pollutant concentrations assigned to the major catchment types within the model.

Table B.10 Adopted Runoff and Baseflow Mean Pollutant Concentrations

Catchment Type	Runoff Concentrations (mg/L)			Baseflow Concentrations (mg/L)		
	TSS	TN	TP	TSS	TN	TP
Residential	141	2.75	0.40	12.6	0.76	0.10
Rural	110	2.04	0.21	25.1	1.00	0.13
Forest	40.7	0.84	0.08	7.94	0.65	0.03
Commercial	158	2.40	0.29	12.6	2.09	0.15
Industrial	158	2.40	0.29	12.6	2.09	0.15
Quarry	257	2.00	0.20	12.6	2.00	0.15
Garbage Tip	200	3.89	0.54	25.1	3.89	0.13

B.1.5 Sewage Treatment Works

There are a number of sewage treatment plants within the catchment. These generally have a fairly constant daily outflow. This time series was added directly into the (3D) receiving water model.

B.1.6 Routing

The Muskingum-Cunge routing method was utilised in the MUSIC model. This method uses a lag time as well as a constant (theta), which will effectively change the time of travel depending on the quantity of flow.

Lag times were determined using the Kinematic Wave Equation (AR&R, 1999) as well as in-house equations that relate the slope of the channel with the velocity of the flow. Validation of the resulting hydrographs using the RAFTS model indicate that the lag times used are suitable.

B.2 MODEL VALIDATION

B.2.1 Validation with RAFTS

There are no stream gauges for the catchment. Only water level gauges exist, and these are within the estuary. These include Ettalong (212423), Wharf Street (212421) and Koolewong (212422). These are operated by MHL on behalf of DNR and are appropriate for use in comparing 3D modelling results, but not for MUSIC.

A simple RAFTS model was established so that the flows from the MUSIC model could be verified against a separate modelling system. Figure B.11 shows the RAFTS model layout. Only the major tributaries were modelled in RAFTS, namely Erina Creek, Narara Creek, Kincumber Creek and Woy Woy Creek.

These tributaries were broken up into a series of relatively large sub-catchments. Table B.11 shows the sub-catchment details used in the model.

Table B.11 RAFTS Sub-Catchment Details

Catchment	Area (ha)	Length (m)	Slope (%)	Impervious Area (ha)	Pervious Area (ha)
Narara	1430	5384	4.12	283	1148
Niagara	820	3984	0.75	216	604
Upper_Erin	1423	4090	2.69	112	1311
Lower_Erin	2138	6980	1.00	509	1629
Kincumber	484	2579	1.55	185	299
WoyWoy	588	2574	6.60	32	556
Gosford	2406	6402	0.62	617	1789

The links between these catchments were modelled using assumed channel sections and roughnesses in RAFTS.

RAFTS is an event based model. The model can be set up to accommodate various aspects such as baseflow, but for the purposes of this comparison, an initial/ continuing loss model was used. The inclusion of more parameters to model baseflow in RAFTS was considered unnecessary for comparative purposes. Two events were chosen in 1996:

- An event which covered 30/8/1996 to 2/9/1996. This event was a typical frequent high rainfall event for the catchment, approximately equivalent to a 2 year ARI event.
- An event which covered 1/5/1996 to 7/5/1996. This event was a typical low rainfall event for 1996.

The initial and continuing losses were assumed to be different for the two storms. The event that began on 30/8/1996 had a higher intensity and would be expected to have a lower evapotranspiration loss. As a result, the assumed continuing loss was less that that of the event starting 1/5/1996. There would be little runoff expected from the pervious areas, which include large forested areas, during a low rainfall event such as 1/5/1996. The assumed losses are shown in Table B.12.

Table B.12 RAFTS Assumed Initial and Continuing Losses

Storm	Impervious		Pervious	
	Initial (mm)	Continuing (mm/hr)	Initial (mm)	Continuing (mm/hr)
30/8/1996	1	0	20	3
1/5/1996	1	1	20	5

The RAFTS results for the rainfall event starting 30/8/1996 compare well in most cases compared with that of the MUSIC results. The rainfall event starting on the 1/5/1996 does not compare as well, but is considered reasonable. The results for these two events, at selected locations, are shown in Figure B.12 and Figure B.13.

Some differences occur in the August 1996 event between the MUSIC model and the RAFTS model. The main differences occur at Woy Woy Creek and in the upper reaches of Erina Creek. Both of these areas are defined by large pervious areas, comprising mainly of forest or rural areas. This rainfall event is an "embedded" event, (ie. with preceding rainfall). In the MUSIC model, the soil store would be relatively saturated and runoff would occur relatively quickly. By comparison, the RAFTS model is still subject to losses which would result in less runoff than the MUSIC model. Additionally, the RAFTS model creates a differently shaped hydrograph for pervious areas, which results in a longer, flatter shaped hydrograph.

The discrepancy resulting in the rainfall event starting on 1/5/1996 is suspected to be in the modelling procedure used. The RAFTS model was set up as an event based model, with initial and continuing losses, and no baseflow. The rainfall starting 1/5/1996 is actually a number of smaller rainfall bursts, with dry periods in between. These dry periods would result in variable losses in MUSIC, as water in the soil store is lost to evapotranspiration and delayed due to baseflow. These losses cannot be accounted for in an initial/ continuing loss model.

The high initial/continuing pervious losses used in the RAFTS model result in a large proportion of the flow being sourced from impervious areas. This produces the peaky nature of the hydrographs from RAFTS. The peaky nature of the hydrographs does not appear consistent with what would generally be expected.

A closer inspection of the cumulative volume of the flow at MUSIC node W_GosfordO1 (corresponding to RAFTS node 'Gosford') indicates that the actual volume of runoff from the RAFTS model is greater than that of the MUSIC model (see Figure B.14 and Table B.14). This would be due to the MUSIC model having storage capabilities, which are not accounted for in the RAFTS initial/ continuing loss model.

Table B.13 shows the peak flows recorded in MUSIC versus those recorded in RAFTS.

Table B.13 Comparison of Peak Flows from RAFTS and MUSIC (cubic metres/sec)

MUSIC Node	RAFTS Node	30/8/1996		1/5/1996	
		MUSIC	RAFTS	MUSIC	RAFTS
HyltonO1	Lower_Erin	96	101	5	23
ErinaO2	Upper_Erin	77	48	2	9
Kincumber_CkO1	Kincumber	27	30	4	13
WWCreekO1	WoyWoy	57	26	4	5
W_GosfordO1	Gosford	158	156	15	53
NiagaraO1	Niagara	41	45	6	19

Table B.14 Comparison of Volumes from RAFTS and MUSIC (cubic metres)

MUSIC Node	RAFTS Node	30/8/1996		1/5/1996	
		MUSIC	RAFTS	MUSIC	RAFTS
HyltonO1	Lower_Erin	2,405,636	2,987,027	286,594	1,059,618
ErinaO2	Upper_Erin	992,592	1,145,782	54,708	377,804
Kincumber_CkO1	Kincumber	410,142	466,029	96,396	188,336
WWCreekO1	WoyWoy	442,807	476,638	57,176	157,818
W_GosfordO1	Gosford	3,729,361	4,035,878	687,418	1,517,351
NiagaraO1	Niagara	678,166	739,233	145,941	279,374

In general, the MUSIC model appears to agree well with the RAFTS model. In summary, the discrepancies that occur between the two modelling systems is more likely to be a result of the RAFTS model, due to:

- The large, broad scale sub-catchments used in RAFTS, compared to the much smaller, detailed sub-catchments used in MUSIC.
- The initial/ continuing loss method being used in RAFTS.
- No evapotranspiration or baseflow.

B.2.2 Annual Volumetric Runoff Coefficients

Annual volumetric runoff coefficients were also determined for the period 1/1/1996 to 30/12/1997 (Table B.15). Where RAFTS provides a check of flows for event based scenarios, the use of the runoff coefficients provides a long time series analysis of the flow results. The runoff coefficients determined from the validation period are reasonable for the catchment type.

Table B.15 Annual Volumetric Runoff Coefficients for the Validation Period

Location	MUSIC Node	Annual Runoff Coefficient
Upper Narara	NararaO1	0.26
Lower Narara	W_GosfordO1	0.30
Upper Erina	ErinaO1	0.19
Lower Erina	HyltonO1	0.24
Kincumber Creek	Kincumber_CkO1	0.35
Woy Woy Creek	WWCreekO1	0.25
Ettalong Lagoon	UminaO1	0.35
Coorumbine Creek	FaganO5	0.33

B.3 VALIDATION WITH OBSERVED WATER QUALITY DATA

Based on the availability of the data, the period from 1/1/1996 through to 31/12/1997 was chosen to validate the MUSIC model. TN was the only available data for a direct validation of the model, while Turbidity was used to check the TSS values assumed.

Figure B.15 shows the results of the modelling, compared with the sampled data. In general, the results compare well with the sampled data. Stormflow concentrations, however, do not directly correspond with the sampled data.

The database of data received from Council only specifies the date, and not the time, at which the samples were taken. When comparing the stormflow concentrations, this may mean that the samples were taken following the main part of the storm event.

Lower concentrations of TN during low flow periods were encountered at the lower ends of Narara Creek and Erina Creek in the sampled data. It is expected that this is due to the estuary processes that occur in these locations. This type of process is beyond the scope of the MUSIC model. However, stormflow concentrations, which provide the majority of the pollutant load, are similar to the MUSIC model results.

Analysis of the turbidity indicated that the TSS values from the model were in a similar range.

To ensure that a thorough validation of all the water quality parameters had taken place, a comparison of the total annual loads was made with annual load results from Sydney Water for TN, TP and TSS. Sydney Water (1993 & 1994), as a part of the *Clean Waterways Programme*, conducted sampling of a number of waterways within the Sydney and Wollongong areas. The annual loads from the MUSIC model were factored for area and compared with the sampling done by Sydney Water. In general, a good agreement was found with the results. Figure B.16, B.17 and B.18 show a comparison of these results.

B.4 RESULTS

Following the validation of the model, modelling of the representative rainfall years of 1995, 1998 and 2000 was undertaken. The annual loads from the major tributaries in the catchment are shown in Figures B.19, B.20 and B.21 for TSS, TN and TP respectively.

Tables B.16, B.17 and B.18 shows the Annual Loads and Annual Flows experienced under each of the representative years.

Table B.16 Annual Loads for Representative Wet Year (1998)

Location	Area (ha)	Annual Flow (ML/yr)	Runoff Coefficient	Annual Loads (kg/yr)		
				TSS	TP	TN
Upper Narara	2811	23500	0.53	1710000	3870	33900
Lower Narara	4565	40500	0.56	3170000	7380	62300
Upper Erina	1926	14700	0.48	801000	1790	18000
Lower Erina	3252	26300	0.51	1810000	4330	38100
Kincumber Creek	484	4440	0.58	432000	1110	8620
Woy Woy Creek	588	4840	0.52	319000	559	5640
Ettalong Lagoon, Umina	780	7190	0.58	601000	1690	12700
Coorumbine Creek	361	3260	0.57	274000	585	5070
Total Catchment	**16466**	**142000**	**0.55**	**10800000**	**27100**	**222000**

Table B. 17 Annual Loads for Representative Average Year (1995)

Location	Area (ha)	Annual Flow (ML/yr)	Runoff Coefficient	Annual Loads (kg/yr)		
				TSS	TP	TN
Upper Narara	2811	8920	0.20	831000	1810	15000
Lower Narara	4565	16800	0.23	1680000	3820	30600
Upper Erina	1926	4370	0.14	246000	541	5420
Lower Erina	3252	9310	0.18	774000	1860	15500
Kincumber Creek	484	2050	0.27	238000	604	4540
Woy Woy Creek	588	1760	0.19	167000	260	2470
Ettalong Lagoon, Umina	780	3350	0.27	348000	981	7080
Coorumbine Creek	361	1450	0.25	160000	329	2710
Total Catchment	**16466**	**58500**	**0.22**	**5660000**	**14000**	**109000**

Table B.18 Annual Loads for Representative Dry Year (2000)

Location	Area (ha)	Annual Flow (ML/yr)	Runoff Coefficient	Annual Loads (kg/yr)		
				TSS	TP	TN
Upper Narara	2811	4820	0.11	541000	1130	9140
Lower Narara	4565	9370	0.13	1100000	2420	19000
Upper Erina	1926	2100	0.07	157000	301	3010
Lower Erina	3252	4890	0.10	502000	1140	9300
Kincumber Creek	484	1190	0.16	155000	385	2860
Woy Woy Creek	588	938	0.10	108000	160	1450
Ettalong Lagoon, Umina	780	1930	0.16	230000	635	4510
Coorumbine Creek	361	828	0.15	104000	209	1690
Total Catchment	**16466**	**32500**	**0.12**	**3700000**	**8910**	**67600**

B.5 DISCUSSION

The annual loads presented above represent the main tributaries within the model. There are a number of smaller catchments which also drain into the Brisbane Water Estuary. Figure B.22 shows the proportion of annual TSS pollutant load that the major tributaries represent of the total TSS pollutant load. The proportions are similar for TN and TP. Note that the upper reaches of Narara and Erina Creek are not shown in this figure as they flow directly into the lower reaches.

The Narara Creek catchment represents a large proportion of the contributing pollutant load to Brisbane Water. This is both a function of the area of this catchment, as well as the amount of development within the catchment. The Erina Creek catchment, by comparison, has an established urban area in the lower reaches, yet the upper reaches are largely rural and forested. As a result, Erina Creek catchment produces approximately half the pollutant loads of Narara Creek.

The smaller sub-catchments of the Brisbane Water Estuary represent approximately 40% of the total pollutant load that enters the estuary. A number of these sub-catchments are highly developed, water front land. This results in a higher proportion of impervious area, and hence a greater runoff and associated pollutant loads.

In terms of pollutant intensity, the Kincumber Creek catchment produces the greatest pollutant load per hectare than the other major tributaries of Brisbane Water. The Kincumber Creek catchment has a mixture of industrial and residential areas, all of which have high proportions of impervious area. Similarly, the Ettalong Lagoon catchment, with runoff sourced from some of the highly developed Woy Woy area, has a high pollutant intensity.

The pollutant loads from the Woy Woy Creek catchment and the Upper Erina Creek catchment are low when compared to the rest of the sub-catchments. Both of these catchments have low impervious areas, and as a result, a reduction in the runoff. Furthermore, the Woy Woy Creek catchment has a high proportion of forested area, which naturally has lower pollutant stormflow concentrations.

Table B.19 Sub-Catchment Details

Catchment	Classification	Area (ha)	Impervious Percentage
Fires1	Rural	207	5
Fires3	Forest	34	5
Fires4	Forest	307	5
Fires2	Forest	121	5
Matcham1	Rural	167	5
Matcham2	Forest	49	5
Matcham4	Forest	97	5
Matcham3	Forest	32	5
Erina_Ck4	Rural	250	5
Erina_Ck6	Forest	26	5
Erina_Ck7	Forest	101	5
Erina_Ck5	Forest	30	5
Erina_Ck2	Forest	174	5
Erina_Ck1	Rural	233	5
Erina_Ck3	Rural	95	5
Chetwynd1	Rural	169	5
Clarence6	Quarry	5	70
Clarence3	Forest	13	5
Tarragal_Glen2	Rural	40	5
Tarragal_Glen4	Forest	35	5
Tarragal_Glen3	Residential	128	40
Erina_Fair3	Industrial	30	80
Erina_Fair2	Forest	13	5
Erina_Fair4	Residential	12	40
Erina_Fair1	Industrial	32	90
Tarragal_Glen1	Residential	33	40
Nunn4	Forest	131	5
Nunn3	Residential	71	40
Nunn2	Rural	27	5
Nunn1	Industrial	15	80
Woodport1	Industrial	6	60
Woodport3	Residential	5	40
Woodport2	Rural	6	5
Clarence4	Residential	24	30
Clarence1	Residential	15	30
Clarence5	Forest	28	5
Clarence2	Forest	36	5
Chertsey2	Residential	59	40
Chertsey3	Rural	10	5
Chertsey1	Forest	60	5
Chertsey5	Rural	40	5
Chersey7	Residential	8	40
Hylton_Pk3	Forest	35	5
Hylton_Pk2	Residential	106	40
Hylton_Pk1	Rural	39	5
Chertsey4	Forest	68	5
Chertsey6	Forest	27	5
Narara9	Quarry	7	70

Catchment	Classification	Area (ha)	Impervious Percentage
Narara7	Road	62	90
Narara11	Other	13	70
Narara12	Rural	82	5
Narara4	Rural	85	5
Narara5	Residential	11	40
Niagara2	Forest	82	5
Niagara12	Forest	96	5
Niagara4	Forest	13	5
Niagara11	Rural	66	5
Niagara9	Residential	14	10
Niagara7	Residential	16	30
Niagara6	Forest	8	5
Lisarow1	Residential	10	40
Niagara10	Forest	21	5
Lisarow2	Rural	10	5
Lisarow3	Forest	19	5
Lisarow4	Rural	29	5
Lisarow6	Industrial	50	50
Lisarow5	Rural	25	5
Niagara8	Residential	8	40
Lisarow7	Industrial	16	70
Lisarow9	Forest	13	5
Lisarow8	Residential	26	30
Niagara3	Residential	187	40
Niagara5	Forest	17	5
Niagara1	Residential	93	40
Fountain4	Road	13	90
Fountian2	Residential	31	30
Narara3	Rural	47	5
Fountain1	Residential	83	30
Fountain3	Forest	346	5
Fountain5	Forest	28	5
Wyoming3	Forest	105	5
Narara2	Industrial	14	90
Wyoming2	Rural	7	5
Wyoming1	Residential	173	40
Wingello1	Residential	165	40
Wingello2	Forest	358	5
Brady3	Forest	81	5
Brady2	Residential	116	40
Brady1	Industrial	35	80
Narara1	Rural	54	5
W_Gosford10	Residential	31	40
W_Gosford8	Sewage	7	60
W_Gosford5	Rural	75	5
W_Gosford7	Forest	339	5
W_Gosford6	Industrial	164	90
W_Gosford2	Rural	37	5
W_Gosford4	Forest	17	5

Catchment	Classification	Area (ha)	Impervious Percentage
W_Gosford3	Commercial	56	80
Fagans6	Quarry	9	70
Fagans5	Residential	30	40
Fagans4	Rural	44	5
Fagans3	Forest	200	5
Fagans2	Residential	30	50
Fagans1	Industrial	49	80
Fagans7	Residential	102	40
Fagans8	Forest	104	5
W_Gosford1	Rural	26	5
W_Gosford9	Residential	26	40
Narara8	Rural	339	5
Narara6	Forest	793	5
Narara10	Forest	38	5
Green5	Forest	84	5
Green6	Garbage	22	30
Green3	Residential	128	40
Green2	Industrial	12	90
Green1	Forest	62	5
Green7	Residential	74	40
Green8	Forest	19	5
Egan2	Rural	60	5
Egan3	Residential	11	40
Egan4	Forest	251	5
Egan1	Forest	37	5
Kincumber9	Commercial	19	80
Kincumber3	Rural	45	5
Kincumber1	Forest	24	5
Kincumber8	Residential	26	40
Kincumber5	Residential	29	40
Kincumber6	Forest	81	5
Kincumber4	Industrial	14	90
Kincumber12	Sewage	29	60
Kincumber13	Residential	16	40
Kincumber14	Rural	71	5
Kincumber15	Forest	25	5
Kincumber17	Residential	15	40
Kincumber16	Forest	34	5
Kincumber18	Forest	14	5
Kincumber21	Rural	19	5
Kincumber20	Residential	36	40
Empire1	Residential	12	40
Empire6	Residential	34	35
Empire3	Rural	106	5
Empire2	Forest	85	5
Empire7	Forest	76	5
Empire5	Residential	39	30
Empire4	Forest	61	5
Empire11	Forest	65	5

Catchment	Classification	Area (ha)	Impervious Percentage
Empire10	Rural	45	5
Empire12	Forest	28	5
Empire13	Residential	18	40
Cockle2	Residential	62	40
Cockle3	Forest	12	5
Cockle1	Residential	29	40
Lintern2	Forest	36	5
Lintern1	Residential	33	40
Lintern3	Residential	21	40
Lintern4	Forest	9	5
Paddy3	Forest	12	5
Paddy2	Residential	14	40
Paddy1	Forest	15	5
Saratoga1	Residential	104	40
Saratoga2	Forest	14	5
Huberts1	Residential	66	40
Riley_Bay1	Forest	126	5
Huberts2	Residential	32	40
Huberts3	Forest	17	5
Hardy3	Rural	72	5
Hardy1	Residential	29	25
Hardy2	Forest	32	5
Hardy5	Forest	32	5
Hardy4	Residential	30	25
Box_Head1	Forest	92	5
Pearl2	Forest	323	5
Pearl1	Residential	83	30
Fagan10	Forest	12	5
Fagan9	Commercial	44	80
Gosford2	Commercial	79	80
Gosford1	Forest	28	5
Gosford3	Residential	46	40
Hylton_Pk4	Residential	10	40
Caroline2	Residential	91	40
Caroline1	Rural	15	5
Caroline3	Forest	38	5
Kincumber24	Residential	114	40
Kincumber23	Rural	43	5
Kincumber22	Garbage	11	30
Claire1	Residential	36	35
Claire2	Forest	13	5
Tascott2	Forest	32	5
Tascott1	Residential	32	30
Tascott4	Forest	155	5
Tascott3	Residential	51	30
Koolewong3	Forest	51	5
Koolewong1	Residential	52	35
Koolewong2	Forest	41	5
Woy5	Forest	23	5

Catchment	Classification	Area (ha)	Impervious Percentage
Woy1	Forest	309	5
Woy2	Forest	287	5
Woy3	Forest	117	5
Woy4	Residential	24	25
W_Inlet1	Forest	9	5
W_Inlet3	Forest	34	5
W_Inlet5	Forest	33	5
W_Inlet4	Residential	15	25
W_Inlet7	Other	15	60
W_inlet10	Garbage	29	30
W_inlet8	Sewage	10	60
W_Inlet9	Quarry	37	70
W_Inlet6	Forest	497	5
W_Inlet2	Residential	23	25
Kincumber25	Residential	58	40
Kincumber2	Residential	12	40
Kincumber26	Forest	35	5
Kincumber10	Forest	24	5
Empire9	Forest	150	5
Empire14	Forest	48	5
Empire15	Rural	54	5
Empire8	Rural	60	5
Pretty1	Residential	42	35
Pretty2	Forest	58	5
Woy_P3	Rural	42	5
Woy_P1	Residential	257	40
Woy_P2	Forest	50	5
Woy_P4	Residential	88	50
Woy_P5	Commercial	22	70
Woy_P6	Residential	66	50
Woy_P7	Residential	94	50
Woy_P8	Residential	116	50
Woy_P10	Residential	104	50
Woy_P9	Forest	44	5
Woy_P11	Residential	180	50
Woy_P12	Residential	180	50
Umina2	Forest	363	5
Umina1	Residential	237	40

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FIGURES