Warringah Non-Urban Lands Study Stage 2: Impacts on Water Quality of Narrabeen Lagoon

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	Synopsis:	This report outlines expected pollutant load increases and suitable BMP's and BPP's that would be required to be implemented for two development scenarios in the western catchment of Narrabeen Lagoon to prevent further degradation of water quality. The outcomes are extrapolated to two other catchments within the Warringah Council area.

REVISION/CHECKING HISTORY

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1 INTRODUCTION

In response to the increasing demand for residential land within the Northern Beaches area, Warringah Council commissioned a study to, amongst other objectives, determine the environmental carrying capacity of non urban land within Warringah Council Area (PPK, 2000). This study, known as Stage 1 of the Non Urban Lands Study (NULS), determined a number of areas within the western catchment of Narrabeen Lagoon that may be suitable for increased development densities, as shown in **Figure 1.1**.

The Narrabeen Lagoon Estuary Processes Study (WBM, 2001) identified that water quality within Narrabeen Lagoon was dominated by catchment runoff. This was particularly the case in the western basin, where tidal flushing is poorest, resulting in near eutrophic conditions. Further uncontrolled development within the catchment would inevitably increase these nutrient loads, resulting in further degradation of water quality in the western basin.

This investigation, recommended in Stage 1 if the NULS, aims to determine the water quality controls required within the areas identified as suitable for development, such that the water quality within Narrabeen Lagoon will not be further degraded, or will in fact be improved.

The scope of this study is to:

1. Rerun the existing AQUALM model that was set up as part of the Estuary Processes Study for Narrabeen Lagoon, to include the development scenarios proposed in Stage One of the Non-Urban Lands Study (NULS) and for a greater development density of 15 dwellings per hectare;

2. Identify and outline various stormwater design solutions that are feasible based on site constraints to maintain or enhance water quality in the western basin of Narrabeen Lagoon;

3. Prepare comprehensive analysis of construction and maintenance costs of the proposed stormwater design solutions over a fifty year period;

4. Provide a written form of a cost-benefit analysis that identifies the costs (impacts) on Narrabeen Lagoon and to Council to maintain the devices against the benefits of additional land being available for development; and

5. Extrapolate the above results to the Middle Harbour and Cowan Creek catchments of Narrabeen Lagoon and develop a similar cost-benefit analysis.

Item 1, above, was carried out by Lawson and Treloar. The remaining components of the study were completed by WBM Oceanics Australia.

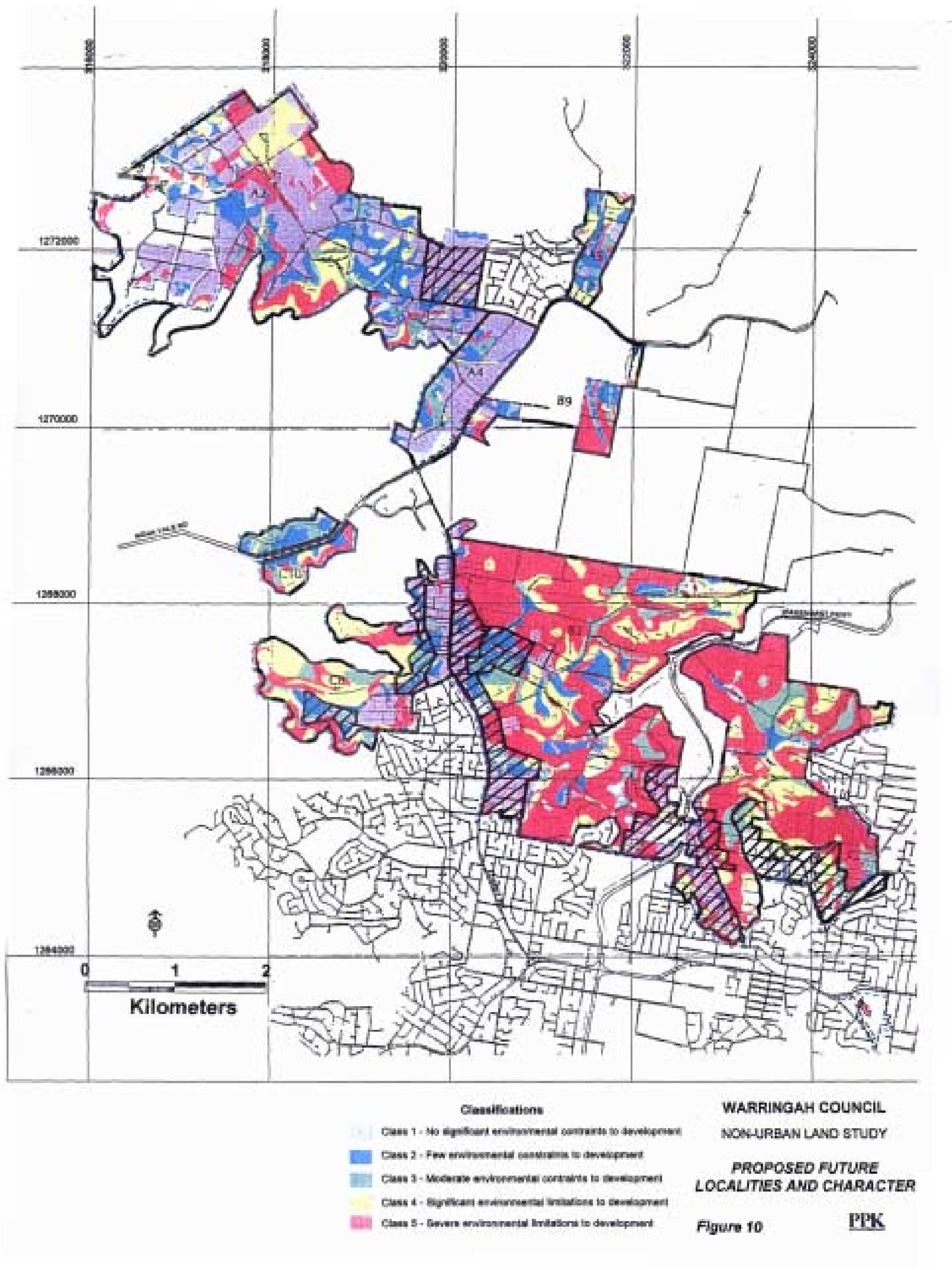


Figure 1.1 Proposed development areas – Stage 1 NULS (PPK, 2000)

2 AQUALM MODELLING

2.1 Narrabeen Lagoon as a Case Study

The Narrabeen Lagoon Estuary Processes Study, prepared by WBM Oceanics with assistance from Lawson and Treloar and Brown & Root Services (WBM Oceanics, 2001), involved the establishment of a catchment model of the entire catchment of Narrabeen Lagoon to a significant level of detail and accounts for land use, soil types, the existing drainage system and existing stormwater quality improvement devices (SQIDs).

As outlined in the Non-Urban Land Study (NULS) (PPK, 2000), to the west and the south-west of the Lagoon, 2,500 ha of the catchment was zoned Non-Urban 1(a1) under the 1985 Warringah LEP and is currently designated as B2 Oxford Falls Valley pursuant to the 2000 Warringah LEP.

The study considers that the primary threat to water quality in the catchment is urban development. The study outlines that further development of the catchment will need to be of a density and type consistent with the environmental capability of the land and will require appropriate management controls to ensure no significant impact on the Lagoon.

Thus, given the availability of a detailed model, the consideration of Narrabeen Lagoon as a case study was deemed appropriate as a means by which an assessment of the impacts of a change in landuse within the area might be made. The findings of the assessment of Narrabeen Lagoon have then been interpreted in consideration of other non-urban lands within the Middle Harbour and Cowan Creek catchments.

2.2 Modelling Objectives

The objectives of this section of the assessment are to:

- review the adequacy of the modelling undertaken for Narrabeen Lagoon for the purposes of this study through literature review and other desktop assessments;
- implement any changes required in the model to reflect the scenario's outlined;
- use the model to assess the land capability in terms of appropriate lot densities and the constraints of the environment (including the receiving waters) for Narrabeen Lagoon, Middle Harbour and Cowan Creek;
- make recommendations as to whether development at prescribed densities will cause unsatisfactory environmental degradation; and
- make recommendations as to the sustainable level of development, including appropriate lot densities.

2.3 Overview of Development Scenarios

2.3.1 Scenarios

The NULS (PPK, 2000) identified four areas for urban residential and rural residential development within the Oxford Falls Valley (identified as area B2 in the LEP, 2000) draining to Narrabeen Lagoon. These are outlined in **Table 2.1**. In addition to this, the table also contains the densities prescribed by the State Government applied to those same areas. Other areas identified that drain to other receiving waters are also shown in this table for completeness as well as reference later in this report.

There are two scenarios to be considered for their impact:

Scenario 1 - areas highlighted in Table 2.1 for potential release with density recommendations listed within the NULS (PPK, 2000) characterised by a predominance in rural residential areas and one urban residential area.

Scenario 2 - areas highlighted in Table 2.1 for potential release listed within the NULS (PPK, 2000) with density recommendations characterised by the State release rate of 15 dwellings per hectare.

The areas outlined in **Table 2.1** are shown in **Figure 2.1**.

2.3.2 Assumptions Derived from Existing Council Policies

Rural Residential Densities - Scenario 1

Minimum lot densities within the LEP (2000) vary from locality to locality. Actual densities relate to a minimum lot area for subdivisions, which are:

- Locality A2 1 dwg/2 ha
- Locality A4 1 dwg/2 ha
- Locality A5 1 dwg/2 ha
- Locality B2 1 dwg/20 ha
- Locality B9 1 dwg/20 ha
- Locality C8 1 dwg/20 ha
- Locality C10 1 dwg/20 ha.

For this assessment, the average lot density in the rural residential areas for Scenario 1 is assumed as 1 lot per 2 hectares as prescribed by the NULS (PPK, 2000).

Urban Residential Densities - Scenario 1 and 2

Within the category of urban residential development there are density variations with low density being referred to by the NULS (PPK, 2000) as being 600m^2 (i.e. 16.7 lots per ha) and medium density as being 450m^2 (i.e. 22.2 lots per ha). Thus the adopted 15 lots per ha as prescribed by the Department of Urban Affairs and Planning (DUAP) is slightly less than the 'low' density definition.

Sewerage Management in Rural Residential Areas

It is understood that lots of 2 ha or greater are not required to have sewer connections whilst lots less than 2 ha are required to be connected to sewer. For this assessment, all rural residential areas are assumed not to be connected to the sewer and therefore have some type of on-site sewage management system.

Impervious Fraction of Various Land Use Types

Council's current policy is to ensure at least 40% of surfaces are pervious for urban residential development and it is assumed that 95% of surfaces are pervious for rural residential development. Council also has a comprehensive on-site detention policy to manage the issue of increase in peak flow levels as a resulting from urban development.

Number of Dwellings on Each Lot

It is assumed that each lot contains only one residence whether the lot be rural residential or urban residential.

Table 2.1 Proposed Release Areas and Density Details

Locality	Catchment**	Council Identifier	Area	NULS RECOMM. (PPK, 2000) Density and Land Use Type	STATE RELEASE RATE(DUAP) Density and Land Use Type	Estimated Number of Dwellings for Scenario's		Estimated Population*	
				Scenario 1	Scenario 2	NULS Scen. 1	DUAP Scen 2	NULS Scen. 1	DUAP Scen 2
Immediately adjacent Forest Way	Narrabeen Lagoon	Part of Area - B2	65 ha	15 dwg/ha Urban Residential	15 dwg/ha Urban Residential	975	975	2700	2700
Morgan Road area (near Forest Way)	Narrabeen Lagoon	Part of area - B2	25 ha	1 dwg/2ha Rural Residential	15 dwg/ha Urban Residential	25	375	70	1050
Either side of Wakehurst Parkway	Narrabeen Lagoon	Part of area - B2	92 ha	1 dwg/2 ha Rural Residential	15 dwg/ha Urban Residential	92	1380	258	3864
Adjacent Red Hill	Narrabeen Lagoon	Part of area - B2	58 ha	1 dwg/2 ha Rural Residential	15 dwg/ha Urban Residential	58	870	162	2436
Terrey Hills/Duffys Forest	Cowan	Part of Area - A2	38 ha	1 dwg/2 ha Rural Residential	15 dwg/ha Urban Res. 1 dwg/2 ha Rural Res.	38	570	106	1500
Belrose North	Middle Harbour	Part of Area - C8	100 ha 45 ha	1 dwg /20ha 1 dwg /20ha Both Rural Residential	1 dwg /20 ha Rural Res. 1 dwg /2 ha over 45 ha Urban Residential	23	675	65	1890

- Population calculated from an estimated occupation rate of 2.8 (PPK, 2000)
- dwg - dwelling
- **Narrabeen Lagoon Catchment modelled only and conclusions drawn in latter parts of this report are inferred from Narrabeen Lagoon model results.

2.4 Literature Review and Data Compilation

2.4.1 Background to Literature Review - Quantity and Quality

In general, to assess the load of pollutants being transported from an area there are two key aspects:

- the volume of runoff (generally related to the pervious/impervious fraction of an area), and
- the pollutant event mean concentration (EMC) or pollutant export/loading rate (generally related to the land use of an area).

The relationship with lot density of both the volume of runoff and EMC are also reviewed and discussed.

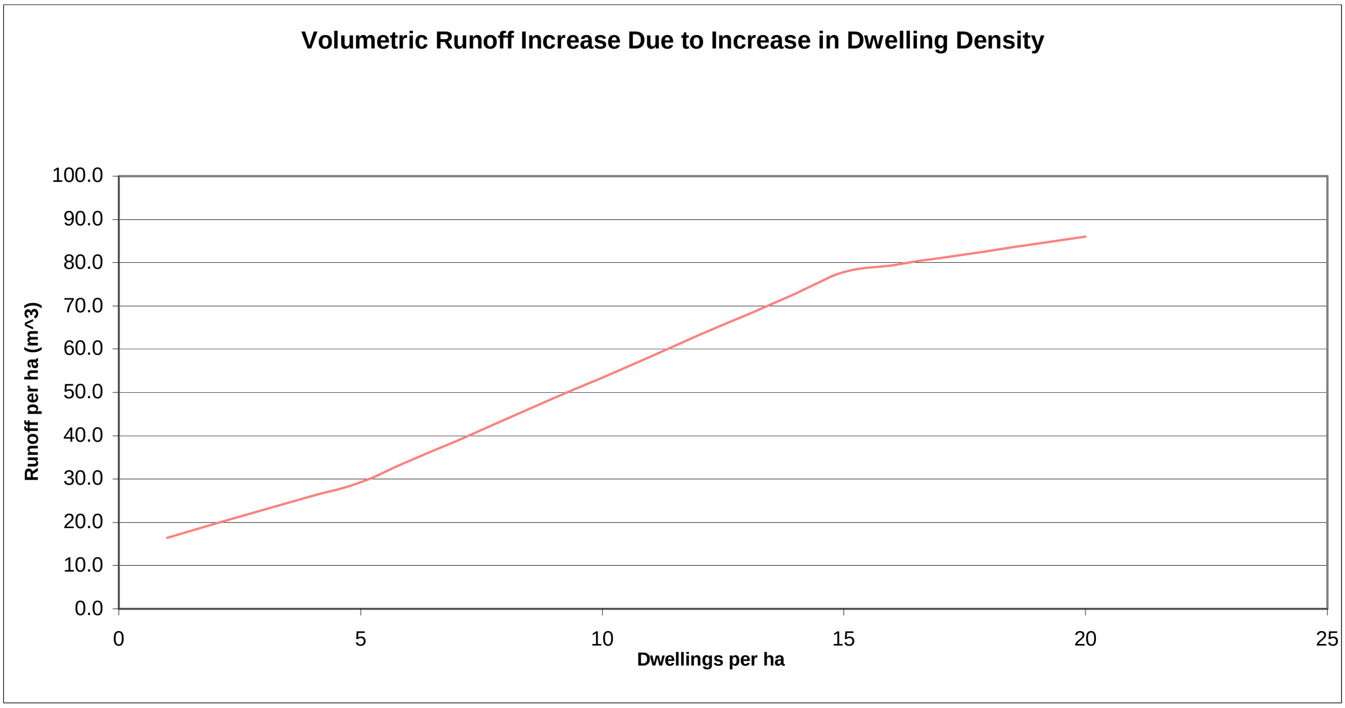
Volume of Runoff

A significant factor in the coupling of pollutant load and concentration is the calculation of runoff. The proportion of runoff is generally related to the impervious fraction of the area.

A simple relationship which can be quantified is that between impervious area and the volume of runoff. Lot density will affect the amount of pervious area.

To demonstrate this simple relationship, a plot of the increase in lot density for a fixed impervious area on each lot (an area of 400 m^2 impervious on each lot was assumed up to 15 lots per hectare and then 60% of the lot size impervious for lots greater than this value) versus the increase in the volume of runoff is shown as **Figure 2.2** for a 1 hour storm of 10 mm/hr intensity. This assumes no water sensitive urban design features are incorporated into a development. Volumetric runoff coefficients for pervious and impervious areas were adopted from assessments of data reported in EPA (1997).

Figure 2.2 Simple relationship between lot density and increase in runoff volume for a single rainfall event



Event Mean Concentration/Pollutant Export Rate

The other significant factor utilised is known as the Event Mean Concentration (EMC) for each pollutant type (e.g. Total Nitrogen, Total Phosphorus etc), which can be used to represent all of the processes occurring to contribute to the load of pollutant in the flow. The EMC is applied to the runoff calculated to determine pollutant loads and concentrations on an event basis. Loads are often reported as a total annual load (e.g. kg/year) or a annual load per unit area (e.g. kg/ha/year). A simple loading rate per land use can also be used as a more broad approach to the assessment of likely pollutant export rate.

The EMC and the annual pollutant export rates are known to be related directly to land use but relationships for each pollutant type are not well quantified and other influencing factors can play a part in the overall observed pollutant loads and concentrations. In catchment modelling, the EMC for various pollutant types is set as a specific value for each land use and these can generally be broadly categorised in a similar manner to land zonings such as:

- residential
- rural residential
- commercial
- industrial
- parks
- bushland

- specific uses where data is available or reasonable assumptions can be made (such as rubbish tips, schools, hospitals, golf courses etc).

Note that the influence of local roads is assumed within each land use types. Where significant portions of road are within a catchment then these can be assessed as separate areas.

Pollutant export rates have been reported in a number of documents as a single value or a range of values. For example, Brisbane City Council (2000) reports assumed pollutant export rates to be those shown in **Table 2.2** below. These are presented as a guide to demonstrate the difference between land uses of export rates.

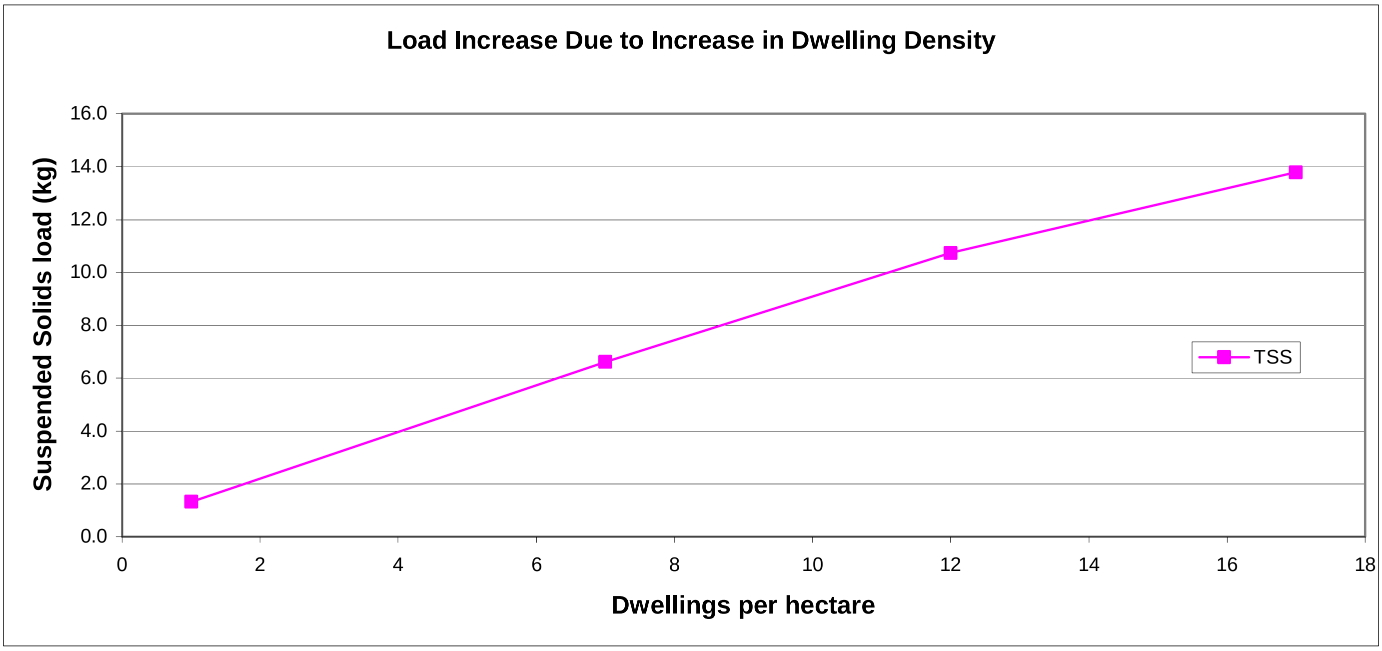
Table 2.2: Example Pollutant Export Rates (Brisbane City Council, 2000)

Land Use Type	Total Nitrogen (kg/ha/yr)	Total Phosphorus (kg/ha/yr)	Suspended Solids (kg/ha/yr)
Open Space and Parks	0.99	0.1	100
Rural Residential	4.10	0.68	150
Urban Residential	7.00	1.48	670

The relationship between lot density and EMC within each broad land use type is even more difficult to quantify and while values can be presented to reflect possible variations, there is limited Australian data to support these assumptions. A detailed search of literature was undertaken to identify any data or relationships developed in this regard.

Literature uncovered is described in detail in **Section 2.4.2**, however, to demonstrate the relationship between lot density and the associated increase in load, data uncovered in the literature review was applied to the same runoff event shown in **Figure 2.2** to generate a simple relationship between lot density and the increase in pollutant load. This approach utilised EMC's for varying levels of imperviousness from data collected for the City of Austin, Texas (1990). This is shown in **Figure 2.3**.

Figure 2.3 Simple Relationship between Lot Density and Increase in Suspended Solids Load for an Urban Residential Area



2.4.2 Literature Specific to Relating Lot Density and Pollutant Loads

A review of literature using a variety of sources including libraries, conference proceedings and journal articles was undertaken to assess existing literature regarding the relationships between residential lot density and pollutant export for both urban and non-urban areas.

Overall, there was very limited literature that relates specifically to the subject of lot density and pollutant export. Relevant documents were identified as outlined in **Table 2.3**.

Table 2.3: Relevant Literature Relating Lot Density and Pollutant Export

Jeliffe (1997)	An Australian method developed to estimate likely export of pollutants from unsewered developments (e.g. rural residential areas) with varying lot densities. Considered the use of the AQUALM-XP model. The method involves setting a target water quality objective for runoff as well as having information on the soil permeability, slopes, type of on-site sewage disposal system. Only a method is provided rather than any actual data.
Schueler (1987)	A US publication with calculated rates of pollutant export using the 'Simplified Method' for varying land use types and impervious cover and lot densities.
Environmental and Conservation Services Department (1990)	A US publication from the City of Austin, Texas, reporting results from a monitoring program of a number of urban residential sites of varying proportions of imperviousness to evaluate the presence of a first flush phenomena. General trend indicates an increase in imperviousness results in an increase in pollutant load and concentration however there is scatter in the data indicating other factors play a role. See **Table 2.4** for data.

NSW EPA (1997)	A NSW publication reporting differing pollutant export rates for differing land use types (listed as either urban or natural), but not specifically related to the lot density of an area.

Since the only reference that is based on actual data is that from the Environmental and Conservation Services Department (1990), this data has been utilised in the consideration of the Warringah case.

To draw some conclusions with these real data on the effect of the change of lot density of an area, an average area of 400 m^2 impervious on each lot was assumed up to 15 lots per hectare and then 60% of the lot size impervious for lots greater than this value, producing the first three columns in Table 2.4. An assumption was made to account for other impervious areas within the area (such as roads and footpaths) which is likely to produce conservative results. These were then coupled with the findings from the City of Austin, Texas for correlation with EMC's. This is shown in **Table 2.4**.

These data show no real trends between imperviousness (and therefore the assumed density differences) and EMC. For example, with the proportion of imperviousness increasing from 5% to 77%, where it would be expected (from simple trends calculated such as that shown in **Figure 2.3**) that the concentrations would generally increase, that the concentrations are low with low proportions of imperviousness but then peak, or plateau, at some mid-range of imperviousness. Specifically, the nitrogen species show a peak in the results at a fraction of 30% impervious but then lower at greater proportions of imperviousness (up to 70%). These observed trends, from a single site in conditions likely to be quite different to those of the Narrabeen Lagoon catchment make it difficult to draw conclusions about appropriate values to adopt for this study.

Table 2.4 Correlation with Lot Sizes and EMCs using data from the USA Considering a 1 ha area with a dwelling area assumed of between 400-500 m^2

Dwelling/ha	Lot size (m^2)	Percent of hectare impervious	Pollutant EMC's - City of Austin (mg/L)			
			BOD (mg/L)	NO_2+NO_3 (mg/L)	PO_4 (mg/L)	TSS (mg/L)
1	10000	5%	9	0.15	0.04	80
7	1429	30%	9	1.1	0.18	170
12	833	50%	9	0.35	0.18	170
14	714	77%	9	0.35	0.18	170

2.4.3 Review of Existing Lot Sizes of Existing Areas within Narrabeen Lagoon Catchment

Since the literature review did not uncover any conclusive trends, the validity of the adoption of the parameters derived for the local area for new development was assessed by considering lot sizes in the existing catchment area.

The cadastral boundaries GIS layer and the aerial photographs for Warringah Council were assessed for existing lot density within the Narrabeen Lagoon catchment in the south-western areas (such as

Cromer, Narrabeen and Frenchs Forest). A random sample of 50 lots was chosen as representative of the existing urban residential density.

The results of the assessment are outlined in **Table 2.5**.

Table 2.5 Average Lot Size from Random Sample of 50 Lots in Urbanised Areas

Statistical Measure	Lot Size (m^2)	Equivalent Lots per ha
Average Lot Size	726.3	13.8
Min Lot Size	421.5	23.7
Max Lot Size	1831	5.5
Standard Deviation	241.4	NA

The results in **Table 2.5** indicate that there is quite a range in the lot sizes (400 - 1800 m^2) in the existing residential areas. Overall, the average lot size of ~ 730 m^2 equating to a lot density of 13.8 lots per hectare is slightly lower than the 15 lots per ha required by a portion of Scenario 1 and Scenario 2.

However, the available data reported in **Section 2.4.2 (Table 2.4)** indicates limited variance in the pollutant EMC as it relates to impervious area. Since the lot sizes in the existing developed areas are of a similar magnitude to the proposed urban areas, it is assumed that the adoption of the AQUALM parameters derived for the urban areas within the Narrabeen Lagoon catchment for the Estuary Processes Study (WBM, 2001) are valid for the proposed urban development in both scenarios.

2.4.4 Literature Review of Urban Densities

Literature was sought to compare the lot sizes derived as outlined above in **Section 2.4.3** with other data collected for urban areas in Sydney for the purposes of determining whether results could be compared with other areas of Sydney.

George et al (1996) assessed 144 release areas ranging from 15 - 200 ha, which were developed between 1971 and 1992. This investigation found that the average lot size for the Sydney metropolitan area to be 618 m^2 corresponding to a density of 16.2 lots per hectare. In addition to this data, the proportions of each type of land use within an urban residential area were also assessed along with the proportion of impervious land. The averages are:

- 56% residential 40% impervious
- 19% roads 75% impervious
- 14% open space 5% impervious
- 11% special use 60% impervious.

This gives an overall proportion of 44% impervious area.

Other more specific areas assessed include an average lot size for Blacktown to be 588 m^2 corresponding to 17 lots per ha and an average lot size for Baulkham Hills to be 1075 m^2 corresponding to 9.3 lots per ha.

This data indicate that whilst 60% imperviousness may be allowed for in the design case, the impervious fraction of existing residential areas is likely to be an overall 44%. This means that the runoff volume from the newly developed urban residential areas may be higher than that of the existing areas and the use of the same hydrological parameters for the two areas may produce non-conservative results. However, the impervious fraction of the newly developed urban residential areas assumes the entire development area to be developed with no open space included in the land release. Given these uncertainties, the use of the same hydrological parameters is considered to be reasonable.

2.4.5 Conclusions

The main conclusions drawn from the results of the literature review are:

- the relationship between increase in impervious area and increase in the volume of runoff is clear. The implications for this assessment are that with a greater lot density in an area, a greater volume of runoff will be generated. Thus Scenario 2 will result in an increase in total runoff volume as compared to Scenario 1.

- the relationship between pollutant load and land use type has been demonstrated for other catchments (**Table 2.2**) but not specifically for the Narrabeen Lagoon catchment, given the scarcity of data and specific studies showing statistically valid trends for the local area, however general trends, such as those shown in **Figure 2.3,** show that with increased imperviousness there is an increase in load. This occurs even if the trends in EMC are not well documented since the increase in the impervious area will result in the volume of runoff increasing. As such, this means that land use types with greater impervious areas will generate more pollutant loads than others.

- for the urban residential case, adopting the same runoff coefficients and pollutant export relationships within the AQUALM model as those derived for the surrounding catchment areas (such as Cromer, Frenchs Forest) as part of the Estuary Processes Study (WBM, 2001) is reasonable given similar lot densities to those proposed was found for these areas

- for the rural residential case, adopting the same runoff coefficients and pollutant export relationships within the AQUALM model as those derived for the surrounding rural catchment areas is reasonable in the absence of published data to suggest otherwise.

Given the uncertainties in the available data, it is concluded that the parameters adopted for the areas to be developed should generally be the same as those values adopted for other established urban residential areas with the Narrabeen Lagoon catchment for both runoff and pollutants.

2.5 Modelling

The modelling tasks for this assessment included:

- a review of the existing model for application for this project;

- consider the model parameters to be adopted for the two scenario's based on the data and literature described in **Section 2.4**;

- establishing the model for the two scenarios; and

- production of results and a discussion of those results.

The recommendations from the modelling are presented in **Section 2.6**, which include preliminary design parameters for the assessment of water sensitive urban design options (including stormwater quality improvement devices).

2.5.1 Overview of Existing Model

The Narrabeen Lagoon Estuary Processes Study (WBM, 2001) involved the modelling of the entire catchment using AQUALM-XP Version (XP Software, 1995). This model uses a daily water balance to route runoff from catchments to the Lagoon, coupled with a pollutant export function to determine loads and concentrations of specified pollutants. The model was run using a daily timestep for an average year of rainfall (1995) considering four scenarios:

- Existing catchment conditions;

- Pre-European catchment conditions (i.e. assuming all areas as bushland);

- Developed catchment of areas identified in the NULS (PPK, 2000) but assuming similar urban densities to other existing developed areas within the catchment (somewhat similar to Scenario 2 described in **Section 2.2** of this report); and

- Completely developed assuming all areas not developed converted to urban residential except for National Park areas with similar urban densities to other existing developed areas within the catchment.

The parameters modelled included Total Nitrogen (TN), Total Phosphorous (TP) and Suspended Solids (SS). Further details regarding the establishment of the model can be found in the Narrabeen Lagoon Estuary Processes Study report (WBM, 2001).

General details include:

- **Existing land use** was determined from the 1985 Local Environment Plan (LEP) for Warringah along with aerial photography. Land uses in the catchment range from bushland areas to urban and include rural, rural residential, major roads and parks.

- **Proposed land uses** were determined by considering the future proposed developments from strategic planning documents from Warringah Council. The proposed areas lie within Oxford Falls and Oxford Heights area identified within the NULS (PPK, 2000) (a total of 275 ha with a conservative assumption for residential development of the entire area).

- **Model Schematisation** involves a series of nodes and links routing flow from catchments into the various creeks or directly into the Lagoon (for the foreshore catchments). The catchment was divided into 212 sub-catchments. Flow into the Lagoon is represented by a series of nodes at fixed points around the Lagoon edge, generally at the location of a stormwater pipe discharge.

- **Pollutant loads** were attributed to surface flow only.

- **Event mean concentration** approach was used for pollutant export estimation - this assumes that an unlimited supply of constituents is available on the catchment surface - a conservative approach that will over-estimate the pollutant loads and concentrations exported from the catchment.

- **Model calibration** was loosely undertaken by checking results to be reasonable against available data, firstly for stream flow and secondly stream water quality. Since the model is a daily flow model, it is less suitable for flows in the higher range (that is, for conditions worse than minor flooding conditions). To capture the dominant conditions within the model, the parameters were adjusted to suit the general range of conditions, with peak flows of large events not being simulated as well. This is considered acceptable given the duration of the simulations and the likelihood that the majority of the constituent loads delivered to the Lagoon system would occur during the lower, more frequent events. A similar approach to the check of the pollutant export aspects of the model was conducted by comparing the modelled concentrations with those measured within the Warriewood Valley.

2.5.2 Model Setup for the Two Scenarios Identified for NULS Stage 2

The model was updated to reflect better information on the boundaries of the proposed development areas and rerun for the existing case and then altered from the existing case to consider the two scenarios. Details of the model setup on an area basis can be found in **Tables 2.6** to **2.9** below for the four separate areas under consideration. Comparisons of the model areas and the reported areas are provided to demonstrate the model detail, and discrepancies are described where they occur.

Note that the areas for development fall within the Middle Creek and South Creek catchments of Narrabeen Lagoon, which discharge to the western basin of the Lagoon.

Table 2.6 Immediately adjacent Forest Way (Area B2)

Scenario	Model SC Identifier	Tributary	Area (ha)	Bushland (ha)	Rural Residential (ha)	Urban (ha)	Major Roads (ha)	Other
Existing	M8	Middle Ck	167.91	93.39	66.21	4.02	4.30	0
Existing	D13	Deep Ck	113.62	103.35	10.27			0
Existing	D14	Deep Ck	116.71	105.95	10.76			0
Scenario 1	M8	Middle Ck	167.91	81.08	19.30	63.24	4.30	0
Scenario 1	D13	Deep Ck	113.62	103.32	5.74	4.56		0
Scenario 1	D14	Deep Ck	116.71	105.95	6.90	3.86		0
Difference						+67.64*		
Scenario 2	M8	Middle Ck	167.91	81.08	19.30	63.24	4.30	0
Scenario 2	D13	Deep Ck	113.62	103.32	5.74	4.56		0
Scenario 2	D14	Deep Ck	116.71	105.95	6.90	3.86		0
Difference						+67.64*		

Scenario 1: 15 dwgs/ha Scenario 2: 15 dwgs/ha

*NULS reports a value of 65 ha instead of 67.64 ha. Measurement errors and map rectification likely to be the cause and inclusion of road areas in the bulk assessment. Some portions of this area proposed under the NULS were found not to be included in the detailed catchment map of the area at present and fall within the Middle Harbour catchment (approximately 5.5 ha). An arbitrary boundary has been assumed between this area and the area defined as being the 'Morgan Road Area (near Forest Way)' that gives appropriate proportions of land.

Model SC Identifier - Model Sub-Catchment Identifier.

Table 2.7 Morgan Road area (near Forest Way)

Scenario	Model SC Identifier	Tributary	Area (ha)	Bushland (ha)	Rural Residential (ha)	Urban (ha)	Major Roads (ha)	Other
Existing	M10	Middle Ck	30.02		23.84	5.10	1.09	0
Existing	M11	Middle Ck	36.12	8.08	3.78	24.26		0
Scenario 1	M10	Middle Ck	30.02		23.84	5.10	1.09	0
Scenario 1	M11	Middle Ck	36.12	6.55	5.31	24.26		0
Difference					+1.53			
Scenario 2	M10	Middle Ck	30.02		2.00	26.94	1.09	0
Scenario 2	M11	Middle Ck	36.12	5.79		30.33		0
Difference						+27.91*		

Scenario 1: 1 dwg/2 ha Scenario 2: 15 dwgs/ha

*NULS reports a value of 25 ha instead of 27.91 ha. Measurement errors and map rectification likely to be the cause and inclusion of road areas in the bulk assessment. An arbitrary boundary has been assumed between this area and the area defined as being the area known as 'Immediately Adjacent to Forest Way' to give appropriate proportions of land.

Table 2.8 Either side of Wakehurst Parkway

Scenario	Model SC Identifier	Tributary	Area (ha)	Bushland (ha)	Rural Residential (ha)	Urban (ha)	Major Roads (ha)	Other
Existing	M12	Middle Ck	61.90	56.59		3.44	1.87	0
Existing	M13	Middle Ck	59.00	20.59	38.41			0
Existing	M14	Middle Ck	65.23	40.93	17.98	1.64	1.75	3.0
Existing	M16	Middle Ck	36.62	18.60	7.08	7.24	1.11	2.59
Existing	M33	Middle Ck	28.07	6.52	21.55			
Scenario 1	M12	Middle Ck	61.90	52.15	4.44	3.44	1.87	0
Scenario 1	M13	Middle Ck	59.00	20.59	38.41			0
Scenario 1	M14	Middle Ck	65.23	22.13	36.78	1.64	1.75	0
Scenario 1	M16	Middle Ck	36.62	18.60	7.08	7.24	1.11	2.59
Scenario 1	M33	Middle Ck	28.07	6.52	21.55			
Difference					+23.24			
Scenario 2	M12	Middle Ck	61.90	52.15		7.88	1.87	0
Scenario 2	M13	Middle Ck	59.00	20.59	15.21	23.2		0
Scenario 2	M14	Middle Ck	65.23	22.13	3.68	37.67	1.75	0
Scenario 2	M16	Middle Ck	36.62	18.60		16.91	1.11	0
Scenario 2	M33	Middle Ck	28.07	6.52		21.55		
Difference						+94.9		

Scenario 1: 1 dwg/2 ha Scenario 2: 15 dwgs/ha

*NULS reports a value of 92 ha instead of 94.9 ha. . Measurement errors and map rectification likely to be the cause and inclusion of road areas in the bulk assessment. 'Other' areas are unrelated existing land uses that will not change within the catchments such as major roads.

Table 2.9 Adjacent Red Hill

Scenario	Model SC Identifier	Tributary	Area (ha)	Bushland (ha)	Rural Residential (ha)	Urban (ha)	Major Roads (ha)	Other
Existing	S13	South Ck	131.98	121.34		10.64		0
Existing	S16	South Ck	40.40	30.63		9.78		0
Existing	S18	South Ck	8.49	7.99		0.5		0
Scenario 1	S13	South Ck	131.98	84.30	47.68			0
Scenario 1	S16	South Ck	40.40	14.71	25.7			0
Scenario 1	S18	South Ck	8.49		8.49			0
Difference					+60.95			
Scenario 2	S13	South Ck	131.98	84.30		47.68		0
Scenario 2	S16	South Ck	40.40	14.71		25.7		0
Scenario 2	S18	South Ck	8.49			8.49		0
Difference						+ 60.95		

Scenario 1: 1 dwg/2 ha Scenario 2: 15 dwgs/ha

*NULS reports a value of 58 ha instead of 60.95 ha. . Measurement errors and map rectification likely to be the cause and inclusion of road areas in the bulk assessment.

2.5.3 Results

Results of the modelling for an average rainfall year with respect to the loads and volume of runoff delivered to the Lagoon from Middle Creek are shown in **Table 2.10**. Given the uncertainty in the modelling and the assumptions adopted in the modelling approach (e.g. an unlimited supply of pollutant exists on the surface of the catchment is available for export), use of the values as 'exact' reports of load and concentration is not recommended. These results are likely to be in the correct order of magnitude but are indicative only and are likely to be conservative due to the assumptions in the modelling. In the case of concentrations, whilst they are the appropriate order of magnitude, these are the least reliable results and are provided as an indication only; the load results and the runoff volume details are more reliable. This is in keeping with the load-based philosophy for the loading of the Western Basin and Narrabeen Lagoon. The relative difference in loads is the important aspect to consider between the Existing case, Scenario 1 and Scenario 2.

Table 2.10 Estimated Annual Loads for an Average Year of Constituents Delivered to the Lagoon by Middle Creek- Difference between Existing and Scenario 1 and Scenario 2*

Whole Catchment	Runoff	SS		TN		TP	
	(ML)	Load (tonne)	Peak Conc.	Load (kg)	Peak Conc.	Load (kg)	Peak Conc.
Middle Creek Existing	7700	950	340	4890	1.7	1160	0.40
Middle Creek Scenario 1	8000	1050	340	5490	1.7	1240	0.40
Total Increase Scenario 1	**300**	**100**	**0**	**600**	**0.0**	**80**	**0.00**
% Increase	**3.9%**	**10.5%**	**-**	**12.3%**	**-**	**6.9%**	**-**
Middle Creek Existing	7700	950	340	4890	1.7	1160	0.40
Middle Creek Scenario 2	8300	1200	340	6340	1.7	1300	0.40
Total Increase Scenario 2	**600**	**250**	**0**	**1450**	**0.0**	**140**	**0.00**
% Increase	**7.8%**	**26.3%**	**-**	**29.7%**	**-**	**12.1%**	**-**

* The results for these scenarios are 'worst case' as it has been assumed that no controls would be implemented as part of the development.

The results show the present load rates of Middle Creek contributing to the western basin to be in the expected order of magnitude and the increase of the loads due to either Scenario 1 or Scenario 2 is also within expected bounds.

The results indicate that uncontrolled development will have an impact on the downstream receiving waters. In terms of runoff volume, an increase in the volume of runoff to Middle Creek of 300 ML per year may have some minor impacts in terms of Lagoon flooding. However, the total volume of stormwater delivered to the Lagoon is of the order of 30,000 ML (WBM, 2001) in an average year and thus comparatively, this is a small increase (0.1%). Whilst not considered as part of this investigation, the increase in peak flow during runoff events is likely to have some impact on stream erosion downstream.

The increase in sediment load is likely to contribute in a minor way to the progradation of the deltas observed at the outlet of Middle and South Creeks and an increase in turbidity in the Lagoon.

The increase in nutrient load of 600 - 1450 kg/yr can be compared against the total load of Nitrogen delivered to the Lagoon by stormwater, which is of the order of 21,500 kg/yr. This represents an increase of the order of 3 - 7% on the total stormwater load for the two Scenarios.

2.5.4 Translation of Results to Environmental Impacts for Narrabeen Lagoon

The overall impact as shown in **Table 2.10** and described in **Section 2.5.3** is an increase in the volume of flow and the load of pollutants delivered to the Lagoon. Scenario 2 results in an increase in loading to the Lagoon that is double the increase in loading for Scenario 1. This means that if the land use was to change to urban with no controls (Scenario 2) the result would be an increase in load which is double that for an uncontrolled rural residential development (Scenario 1).

A 10% increase on the existing load from the catchment of nitrogen and phosphorous is likely to have a substantial impact on the western basin. Given that elevated sedimentation rates and poor tidal flushing in the western basin of Narrabeen Lagoon (WBM, 2001), any increase in pollutant loads will only serve to further degrade the water quality and increase sedimentation.

However, since no such uncontrolled development is likely to occur given the planning and development controls instituted by Council, the results are indicative only.

2.5.5 Implication of Results for Non-Urban Lands within Middle Harbour and Cowan Creek Catchments

The Stormwater Management Plans for both Cowan Creek (Webb McKeown & Associates, 1999) and Middle Harbour (Willing and Partners, 1999) were reviewed in the preparation of this document. The Middle Harbour Plan indicated that whilst various objectives were listed for the tributaries associated with the area under consideration (Bare Creek and Frenchs Creek), no water quality data were available for these creeks. Similarly, the Cowan Creek Plan indicated that no data were available for the tributaries associated with the area under consideration (Kierans Creek and Neverfail Gully).

For the cases of the non-urban lands in these alternative catchments, it is important to note that the same approach applied to Narrabeen Lagoon may not be suitable. This is related to the fact that the existing catchment exports are likely to be degrading the receiving waters they drain to.

The existing condition of the areas proposed for redevelopment for Middle Harbour are similar to the existing conditions for those areas identified for Narrabeen Lagoon and Cowan Creek. Details are provided in **Table 2.11** on the preliminary assessment of land use proportions adopted for the areas.

Table 2.11 Preliminary Land Use Proportions for Cowan Creek and Middle Harbour Localities

LEP Area	Scenario	Tributary	Area Identified (ha)	Bushland (ha)	Rural Residential (ha)	Urban (ha)	Other (ha)
A2	Existing	Cowan Creek	45	-	45	-	-
A2	Scenario 1	Cowan Creek	45	-	45	-	-
A2	Difference				0		
A2	Scenario 2	Cowan Creek	45			45	
A2	Difference					+45	
C8	Existing	Middle Harbour	38	27	11	-	
C8	Scenario 1	Middle Harbour	38	-	38	-	-
C8	Difference			-	+27	-	-
C8	Scenario 2	Middle Harbour	38	-	-	38	-
C8	Difference					+38	

For Cowan Creek, the existing land use consists of a rural residential area (at a density of 1 dwelling per 2 hectares). The release of the land for rural residential development at a rate of 1 dwelling per 1 hectare (Scenario 1) will not result in a significant change in land use for Scenario 1. The rationale behind this assumption relates to the small increase in proportion of imperviousness overall being within the tolerances of the modelling process. For example, assuming dwellings are constructed with an impervious area of 400 m^2 (previously used as the assumed size of a dwelling, the other impervious areas on a rural residential lot are assumed to be minimal). If the existing rate of release, of 1 dwelling per 2 hectares is applied then the proportion of impervious land is 2%. If the rate increases to 1 dwelling per 1 hectare, the proportion of impervious land increases to only 4%. These increases are considered to be small.

Preliminary model runs were undertaken by adopting the same parameters for these areas as for the closest subcatchments within the Narrabeen Lagoon catchment. The results are shown in **Tables 2.12 and 2.13**. These results should be used with caution and the same discussion outlined in **Section 2.5.3** of this report applies to the results presented here.

Table 2.12 Preliminary Results of AQUALM Modelling for Cowan Creek*

Area for Release	Runoff	SS		TN		TP	
	(ML)	Load (tonne)	Peak Conc.	Load (kg)	Peak Conc.	Load (kg)	Peak Conc.
45 ha in Area A2 - Existing	291	12.6	150	170	2.0	51.0	0.59
Scenario 1	291	12.6	150	170	2.0	51.0	0.59
Total Increase Scenario 1	**0**	**0**	**0**	**0**	**0**	**0**	**0**
% Increase	**0**	**0**	**0**	**0**	**0**	**0**	**0**
45 ha in Area A2 - Existing	291	12.6	150	170	2.0	51.0	0.59
Scenario 2	401	87	300	576	2.0	87.0	0.59
Total Increase Scenario 2	**110**	**74.4**	**150**	**406**	**0**	**36**	**0**
% Increase	**37.8%**	**590%**	**100%**	**238%**	**0%**	**71%**	**0%**

* The results for these scenario's are 'worst case' as it has been assumed that no controls would be implemented as part of the development.

Table 2.13 Preliminary Results of AQUALM Modelling for Middle Harbour*

Area for Release	Runoff	SS		TN		TP	
	(ML)	Load (tonne)	Peak Conc.	Load (kg)	Peak Conc.	Load (kg)	Peak Conc.
38 ha in Area C8 - Existing	168	5	130	56	1.8	16	0.51
Scenario 1	280	14	150	182	2	54	0.59
Total Increase Scenario 1	**112**	**9**	**20**	**126**	**0.2**	**38**	**0.08**
% Increase	**67%**	**180%**	**15%**	**225%**	**11%**	**238%**	**16%**
38 ha in Area C8 - Existing	168	5	130	56	1.8	16	0.51
Scenario 2	375	82	300	539	2	82	0.51
Total Increase Scenario 2	**207**	**77**	**170**	**483**	**0.2**	**66**	**0**
% Increase	**123%**	**1540%**	**131%**	**427%**	**11%**	**413%**	**0%**

* The results for these scenario's are 'worst case' as it has been assumed that no controls would be implemented as part of the development.

Results listed in **Table 2.12** indicates that the complete change of land use will result in a considerable change in the pollutant loads.

In simple terms, a significant impact of uncontrolled urban development would be observed in both of these catchments as a result of Scenario 2 over Scenario 1.

Given the impact that existing loads are having on the creeks, a more suitable approach may be to consider the impact of setting a downstream water quality objective and back calculating the appropriate load that can be released to ensure this objective is met.

2.6 Recommendations from Modelling

Any development within a catchment, regardless of the density, will have some impact on the receiving waters. Given that the receiving waters are generally under significant pressure already (as outlined in the Stormwater Management Plans for Cowan Creek - Webb McKeown & Associates, 2000 and Middle Harbour - Willing and Partners, 2000 as well as the Narrabeen Lagoon Estuary Processes Study - WBM, 2001), the overall goal for any development should be a zero net impact on the receiving waters through the application of appropriate controls to ensure the pollutant loads do not exceed the present (refer **Section 4**). These controls will vary depending on the land use type and should generally be 'at source'. This approach is often used to assess developments which are distant from the receiving water. In some cases, where lands are degraded at present or have an existing land use which is likely to be more polluting than the proposed land use, an objective for the water quality in the receiving waters may be a more suitable approach. At present, the tools available for modelling of the Warringah system do not support this second approach.

Adopting purely economic considerations, the pragmatic approach from a developers perspective is likely to be the assessment of whether a development is viable in an economic sense given the level of controls required. There is likely to be some critical threshold of development, beyond which it is not economically viable to sell the lots to gain an appropriate rate of return as well as implement all the required water quantity and quality controls required to ensure a zero net impact. Thus, even if a density for development is set for an area, the rate of return may constrain development of that area.

2.6.1 Scenario 1 Recommendations

The rural residential development results in an increase in the pollutant loads and concentrations and these increases require mitigation such that the development has a zero net impact on the receiving waters. **Table 2.14** outlines the increases in the volume of runoff and the increases in the pollutant loads and concentrations on an annual basis that will occur as a result of the Scenario 1 development case. If development is to proceed then controls for these areas will need to be sized accordingly to treat these pollutant loads and concentrations and reduce these volumes of flow via retention techniques (such as stormwater reuse or infiltration).

The results in **Table 2.14** are presented on a subcatchment basis, as the control of additional loads is best managed on a local or 'at source' basis. It is recommended that, as a minimum, any control implemented be located at the catchment outlet (offline from the main tributary).

The management of the areas earmarked for rural residential development could be also served by considering an alternative method than that used in this assessment. A method similar to that developed by Jeliffe (1997) could be used, which would provide an assessment of appropriate lot densities for these areas. However, this would involve taking an different philosophy in terms of concentration control over load control and is more appropriate for areas directly adjacent to main watercourses as opposed to the type of areas considered within this study located in the upper catchment areas. This approach also requires detailed consideration of all the other contributing areas to establish their effects on the downstream concentration. Overall the approach adopted in this study is consistent with the approach advocated by the NSW EPA and thus is considered to be a Best Practice approach.

Table 2.14 Design Annual Runoff Volume, Pollutant Loads and Concentrations Increases on Existing Case for Device Design for Part Urban/Part Rural Residential Case - Scenario 1

Development Area	Sub Catchment	Runoff	SS		TN		TP	
		(ML)	Load (tonne)	Peak Conc.	Load (kg)	Peak Conc.	Load (kg)	Peak Conc.
Immediately adjacent Forest Way	M8	200	109	0	615	0.00	59.9	0.00
Immediately adjacent Forest Way	D13	12	9	110	44	0.20	3.2	0.00
Immediately adjacent Forest Way	D14	10	7	100	37	0.20	2.7	0.00
Morgan Road area	M10	0	0	0	0	0.00	0.0	0.00
Morgan Road area	M11	10	1	0	10	0.00	3.4	0.00
Either side of Wakehurst Parkway	M12	14	2	0	13	0.00	4.0	0.00
Either side of Wakehurst Parkway	M13	0	0	0	0	0.00	0.0	0.00
Either side of Wakehurst Parkway	M14	70	6	0	77	0.00	23.1	0.00
Either side of Wakehurst Parkway	M16	0	0	0	0	0.00	0.0	0.00
Either side of Wakehurst Parkway	M33	0	0	0	0	0.00	0.0	0.00
Adjacent Red Hill	S13	114	9	0	111	0.10	34.0	0.13
Adjacent Red Hill	S16	49	4	0	48	0.10	14.6	0.08
Adjacent Red Hill	S18	22	2	0	23	0.20	6.8	0.26

Table 2.14 indicates that the total load for treatment from the four development areas ranges considerably from catchment to catchment and is dependent on the difference between the loading from the current land use. It should be noted that for zero net impact these loads would be the

minimum for treatment. However, should the opportunity arise, offset of loads into the Western Basin through treating a greater load than that listed would be encouraged.

For the case of Cowan Creek and Middle Harbour, the relevance of adopting the same approach is arguable (as outlined in **Section 2.5.5**). If the approach is adopted, then the loads to be catered for are outlined in **Section 2.5.5**.

2.6.2 Scenario 2 Recommendations

Full urban residential development of the areas identified also results in an increase in the pollutant loads and concentrations. In the same way as Scenario 1, these increases require mitigation such that the development has a zero net impact on the receiving waters. **Table 2.15** outlines the increases in the volume of runoff and the increases in the pollutant loads and concentrations on an annual basis that will occur as a result of the Scenario 2 development case. Accordingly, if urban development is to proceed then controls for these areas will need to be sized to treat these pollutant loads and concentrations and reduce these volumes of flow via retention techniques (such as stormwater reuse or infiltration).

Table 2.15 Design Annual Runoff Volume, Pollutant Loads and Concentrations Increases on Existing Case for Device Design for Urban Rural Residential Case - Scenario 2

Development Area	Sub Catchment	Runoff Inc. (ML)	SS Increase		TN Increase		TP Increase	
			Annual Load (tonne)	Peak Conc.	Annual Load (kg)	Peak Conc.	Annual Load (kg)	Peak Conc.
Immediately adjacent Forest Way	M8	200	109	0	615	0.0	59.9	0.00
Immediately adjacent Forest Way	D13	12	9	110	44	0.2	3.2	0.00
Immediately adjacent Forest Way	D14	10	7	100	37	0.2	2.7	0.00
Morgan Road area	M10	55	37	70	207	0.0	15.8	0.00
Morgan Road area	M11	25	12	10	70	0.0	7.5	0.00
Either side of Wakehurst Parkway	M12	26	9	0	55	0.0	8.2	0.00
Either side of Wakehurst Parkway	M13	59	42	140	220	0.1	15.9	0.00
Either side of Wakehurst Parkway	M14	153	61	10	371	0.0	47.2	0.00
Either side of Wakehurst Parkway	M16	10	10	30	34	0.0	2.4	0.00
Either side of Wakehurst Parkway	M33	54	36	150	193	0.1	15.7	0.00
Adjacent Red Hill	S13	212	69	30	458	0.2	68.8	0.02
Adjacent Red Hill	S16	91	30	10	198	0.1	29.6	0.01
Adjacent Red Hill	S18	46	15	50	99	0.2	14.9	0.04

As for **Table 2.14**, **Table 2.15** indicates that the total load for treatment from the four development areas ranges considerably from catchment to catchment and is dependent on the difference between the loading from the current land use. As for Scenario 1, it should be noted that for zero net impact these loads would be the minimum for treatment. However, should the opportunity arise, offset of loads into the Western Basin through treating a greater load than that listed would be encouraged.

Similarly for Scenario 1, for the case of Cowan Creek and Middle Harbour, the relevance of adopting the same approach is arguable (as outlined in **Section 2.5.5**). If the approach is adopted, then the loads to be catered for are outlined in **Section 2.5.5**.

2.6.3 General Recommendations

For greater confidence in the model results it is recommended that detailed monitoring be undertaken to better ascertain the parameters to be adopted for modelling. Nonetheless, the results of the modelling carried out to date provide a good indication of the needs for future development within the Warringah shire.

It is recommended that monitoring sites be chosen in the areas of interest to better determine the current loads from the existing land use. It is recommended that monitoring also be undertaken in areas similar to those outlined in this report that have already been developed (e.g. areas such as the Peppercorn Ridge Estate at Oxford Heights) to consider the loads generated from these areas in the post-developed condition. Monitoring sites must be specific to a single land use and lot density in order to provide meaningful results to feedback into the modelling and multiple sites are required in order to cover a range of land uses as well as lot densities.

Given the absence of local data, the results presented in this report must be heavily qualified.

Should either Scenario 1 or Scenario 2 proceed, possible staging of the release to minimise the overall disturbance within the Narrabeen Lagoon catchment should be considered in the following order:

- Release Area 1 - Morgan Road area (given it is the least overall area to be developed and thus could be considered a pilot area for implementation of Water Sensitive Urban Design techniques)
- Release Area 2 - Red Hill (the next least area, draining to a separate tributary - South Creek)
- Release Area 3 - Forest Way
- Release Area 4 - Wakehurst Parkway Area (the largest release area).

3 IDENTIFICATION OF STORMWATER DESIGN SOLUTIONS

3.1 Site Constraints

A large number of Stormwater Best Management Practices (BMP's) are available for the treatment of urban runoff to varying degrees. Many of these BMP's are, however, constrained in some way by site conditions, such as permeability of the soil, availability of land and the grade of the site. In order to determine suitable Stormwater BMP's that can effectively treat stormwater, the site constraints of the land identified in Stage 1 of the NULS need to be determined.

Review of available literature, including the Stage 1 NULS report and Soil Landscape Maps, has identified the following site constraints:

1. Steep slopes of around 20-25% including large rock outcrops with vertical faces;

2. Shallow, highly erodable sandy soils underlaid by Hawkesbury Sandstone; and

3. High soil permeability.

The above constraints limit the construction of Stormwater BMP's that depend on the following conditions:

- Large above ground storages as the steep slopes and shallow sandy soils inhibit the construction of embankments;

- Large overland flow devices as the steep slopes generate high flow velocities creating potential hazard to the public. The high flow velocities would also create a high erosion potential;

- Detention of stormwater for extended periods such as constructed wetland as the high infiltration capacity of the soil would drain the BMP;

- Significant excavation due to the shallow soils, which are generally less than 50cm deep.

It is recognised that other localised site constraints may also be present within the study area including elevated groundwater levels and space limitation etc. These constraints do not, however, dominate the study area and therefore, they have not been considered when determining suitable BMP's.

3.2 Treatment Trains

As no single BMP treats all stormwater pollutants, BMP's may need to be placed in series to capture the full range of target pollutants that are contained in urban runoff. Treatment trains offer a number of advantages when treating urban stormwater as follows:

1. They often provide a more economical solution to stormwater treatment as a number of smaller BMP's may be less expensive than one large BMP;

2. They can potentially reduce the maintenance frequency of BMP's as pollutants that are not targeted by a certain BMP do not impact on its performance. For example a wetland requires less de-silting when a sediment trap is placed upstream;

3. Cost savings may be made when disposing of the collected materials as the different elements of the treatment train collect different pollutants. For example litter that is collected at source in say in-pit litter baskets can be easily separated for recycling, however, if this litter is captured in a GPT then it is often disposed of in landfill as it is mixed with the captured sediment.

For the reasons above, it is becoming more accepted that treatment trains offer far better stormwater quality management than the traditional approaches, which involves construction of large end-of-pipe devices.

Treatment trains also encourage the use of source controls to limit the pollutant load in stormwater at source. This is of particular importance in the study area, as end-of-pipe devices are constructed in downstream waterways to treat large catchment areas. This requires polluted stormwater to flow through numerous tributaries before being treated, therefore, degrading the minor tributaries through which it flows.

3.3 Available BMPs

To enable simplicity in reporting, the BMPs that have been listed in this report represent what are considered as the core BMPs. A number of variations on core BMPs exist, which are growing rapidly due to the growing community concern regarding stormwater quality issues.

Table 3.1 identifies a series of common Stormwater BMPs that have been effectively implemented within Australia. These BMP's have been divided as follows:

- **Lot Scale** – BMP's that are constructed on a lot-lot basis for the treatment of stormwater;
- **Neighbourhood Scale** – BMP's that are constructed to serve a small number of residential street blocks; and
- **Suburb Scale** – Large scale BMP's constructed to treat runoff from large areas.

Some devices that have been listed in **Table 3.1** have been included in two or more categories as they have the potential to be implemented at more than one scale. For example small scale grass swales can be constructed on a lot-by-lot scale to convey roof runoff to the street drainage system, this increases infiltration and adsorption of pollutants. Grass swales can also be effective on a neighbourhood scale where they are constructed along the roadside in lieu of a traditional kerb and gutter system to treat and convey direct road runoff before discharge to a downstream waterway.

Table 3.1 also identifies the BMP's that are limited by the site constraints as outlined in Section 3.1 and the target pollutants of each of the devices. From this table a series of devices on each of the scales can be selected.

Table 3.1 BMP's selection matrix

BMP	Site Constraints: Steep Topography	Shallow Erodable Soils	High Soil Permeability	Target Pollutants: SS	TN	TP
Lot Scale						
Rainwater Tanks	-	-	-	●	●	●
On-Site Detention Tanks	-	Low	-	●		
Infiltration Trenches	Low	Low	-	●	●	●
Filter Strips	Mod	Low	-	●	●	●
Grass Swales	Mod	Low	-	●	●	●
Neighbourhood Scale						
Grass Swales	Mod	Low	-	●	●	●
Filter Strips	Mod	Low	-	●	●	●
Sand Filters	Mod	Mod	-	●		
Infiltration Basins	Mod	Low	-	●	●	●
Proprietary Devices	Low	Low	-	●		
Sediment Traps	Low	Mod	-	●		
Constructed Wetlands	Mod	Mod	Mod	●	●	●
Suburb Scale						
Gross Pollutant Traps	Low	Low	-	●		
Proprietary Devices	Low	Low	-	●		
Constructed Wetlands	High	Mod	High	●	●	●
Dry/Wet Detention Basins	Mod	Mod	High	●	●	●

Low, Mod, High – Indicates the degree of impact from the particular site constraint ie high signifies a severe constraint that may make the BMP unable to be constructed

● Denotes Target Pollutant

3.4 Preferred BMPs

Based on the site constraints and other considerations such as cost effectiveness and maintenance issues, BMP's for each of the scales in **Table 3.1** have been selected as being most appropriate for the study location. Detailed descriptions of the preferred BMP's are provided below.

3.4.1 Lot Scale BMP's

3.4.1.1 Rainwater Tanks

Rainwater tanks reduce the amount of runoff by collecting and storing roof runoff for reuse. A study recently undertaken by the University of Newcastle (Coombes et al, 2000) determined that the use of rainwater tanks on a lot-by-lot basis reduces Suspended Solids, Total Nitrogen and Total Phosphorus loads by 70%, 50% and 70% respectively when compared to traditional stormwater disposal techniques. This estimation was based on the use of a $10m^3$ tank (ie approx. 2.5m diameter x 2m high) per lot. The tanks can be installed with an orifice plate approximately mid way up the tank to provide for On-Site Detention storage, should it be required of particular developments. This eliminates the common concern that often no storage is available in the tank as it is full. The estimated cost for the installation of a rainwater tank is approximately $1,500, per lot. Once installed, little maintenance is required.

Additional to providing storage volume for OSD purposes, stored water can be used for secondary household purposes including irrigation, hot water, laundry and toilet flushing. Using the stored water not only provides additional storage volume at the commencement of the storm but also reduces the demand for potable water with an associated cost saving. Coombes et al 2001, estimated that for an average lot with a 10kL tank, a total annual cost saving of $22.56 with reduced mains use of 46% or 78kL per year was achieved, if the tank dedicated half of its storage volume to OSD storage. A schematic of a typical rainwater tank water supply system is shown in **Figure 3.1**.

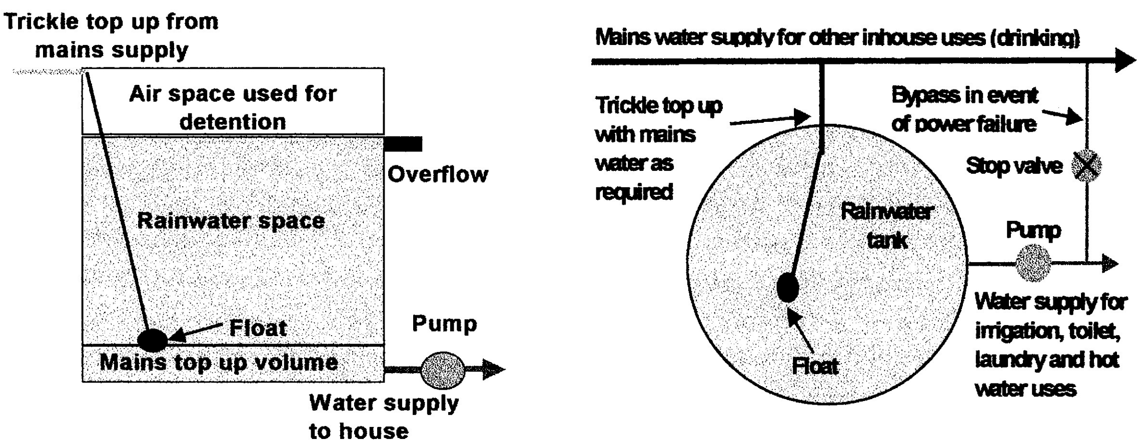


Figure 3.1 Schematic of typical rainwater tank supply system (Coombes et al, 2001)

3.4.1.2 Infiltration Trenches

Infiltration trenches also reduce the amount of runoff by infiltrating a significant proportion of the collected runoff but reductions in nutrient load are also achieved as they are adsorbed onto the underlying soil. Infiltration trenches are also quite versatile with various lot scale infiltration trench configurations available.

Infiltration trenches may be incorporated into a treatment train if overflows from rainwater tanks are conveyed to infiltration trenches along with lot runoff.

It is recognised that some sites may not be able to incorporate infiltration trenches due to rock being located on the surface. In such cases other measures such as swales or filter strips, which 'filter' stormwater through a vegetated area prior to being discharged, should be incorporated to promote infiltration of runoff.

The proposed cost per lot for installation of the proposed lot scale treatment has been estimated at $800 with ongoing maintenance costs being minimal (refer **Appendix A**).

3.4.2 Neighbourhood Scale BMP's

3.4.2.1 Grass Swales

As runoff generated from individual lots can potentially be treated at source, road runoff generated from roads is the primary source of stormwater that is required to be treated on the neighbourhood scale. Runoff from urban roads has been determined in numerous studies to contribute a significant proportion of the pollutant load in urban runoff.

The most cost effective method for the treatment of urban road runoff is through the use of Water Sensitive Urban Design (WSUD) techniques such as the provision of grassed swales instead of kerb and guttering to convey and treat/filter road runoff prior to discharge. Grassed swales promote infiltration of runoff but also provide a natural surface for pollutants such as oils and greases and heavy metals to bind too and be naturally broken down/assimilated, preventing them from entering downstream waterways.

Although site limitations such as steep topography provide some restriction to the use of grass swales these can be overcome be providing only short sections of grassed swale, which drain to stormwater pits to be piped. This ensures that large flows and hence high flow velocities are not conveyed by the swale while treatment of the stormwater is provided. **Figure 3.2** shows a typical grass swale used for the treatment of road runoff.

Figure 3.2 Typical roadside swale

The cost of constructing a water sensitive road runoff treatment system is difficult to estimate, however, a cost of approximately $16,000 per ha (of development) to construct grass swales has been assumed (refer **Appendix A**).

3.4.2.2 Constructed Wetlands

Grass swales on a neighbourhood scale offer a good first step in the treatment train of stormwater runoff, however, they would not be sufficient to treat runoff to a level consistent with the existing water quality. Neighbourhood scale constructed wetlands have been incorporated successfully into recent residential developments within the Warringah Council area.

As constructed wetlands, even on a neighbourhood scale, require significant quantities of both storage volume and planted area, some sites may not be suited and hence other measures will need to be taken. It is also important that a semi-permeant pool of water is contained within the wetland to prevent the drying out of aquatic plants. With the permeable nature of the soils this may require importing of impermeable fill material to prevent seepage from the wetland.

Constructed wetlands are typically expensive to construct with costs of neighbourhood scale wetlands (approx 200m^2 in size) ranging between $25,000-$35,000. Maintenance of wetlands is also quite expensive and is required generally on an annual basis, and annual costs typically of the order of 5% of the original construction cost.

3.4.2.3 Sediment Traps

Sediment Traps are another common BMP that have been constructed in the Warringah Council area. These sediment traps are often incorporated into detention basins that lower peak flows from the catchment to pre-developed levels. Where the site does not permit the construction of a wetland, a sediment trap provides an alternative. To operate effectively sediment traps do not necessarily require a large area, only a sufficient volume, therefore they can be deep and cover a small surface area, which is often the method of constructing open water retention structures on steep slopes.

Sediment traps do not, however, target nutrients and trap only the fraction of nutrient that is adsorbed onto fine sediments that are trapped.

Sediment traps are generally less expensive to construct than constructed wetlands due to the limited planting that is required. Typical costs for sediment traps on a neighbourhood scale (ie $200m^2$) are $20,000-$25,000. Maintenance of the sediment traps involves removing captured sediment, which is often performed on a three-monthly to annual basis, however, during the development phase of the catchment this may need to be performed more often as high sediment loads are expected.

3.4.3 Suburb Scale BMP's

3.4.3.1 Water Sensitive Urban Design

Site constraints generally limit the ability to construct large scale stormwater treatment BMP's as these BMP's generally require large, and flat areas, which unfortunately are not available within the proposed site. Some possible sites may be located along natural drainage lines at the base of the catchment, however, devices constructed along these drainage lines will be required to not only treat runoff from the proposed development area but other already established urban areas draining to the same location. There is also the issue of degradation of the natural drainage lines, which convey the untreated stormwater runoff to the suburb scale treatment device/s. Therefore, source control on a lot-by-lot and neighbourhood scale provides the most feasible BMP's for the effective treatment of stormwater pollutants.

A number of suburb scale BMP's such as proprietary devices and gross pollutant traps can generally be incorporated into the site, however, these devices are not specifically designed to removed the dissolved nutrient load and hence would only be effective in reducing the suspended solids load. Suburb scale devices are also expensive to construct and maintain, and as such, there is a general shift away from these devices in preference to less expensive source controls.

For the reasons outlined above, no specific suburb scale BMP's have been selected. Instead, the best approach to stormwater management on a suburb basis is to plan the proposed development in a water sensitive matter. This is known as a Best Planning Practice (BPP) and involves planning and designing a proposed subdivision to:

- Identify and set aside land from development to protect natural drainage lines, storage locations, remnant vegetation, recreation, cultural and environmental features and discharge points;
- Identify options for the reuse/conservation of water;
- Minimise road areas and encourage infiltration of road runoff;
- Locate lots that integrate with the drainage function of the open spaces and minimise lot sizes by reducing private open space areas to increase communal open space areas; and

- Integrate street scape design to reduce runoff and contain peak flows.

Figure 3.3 shows some typical WSUD techniques implement on a suburb scale.

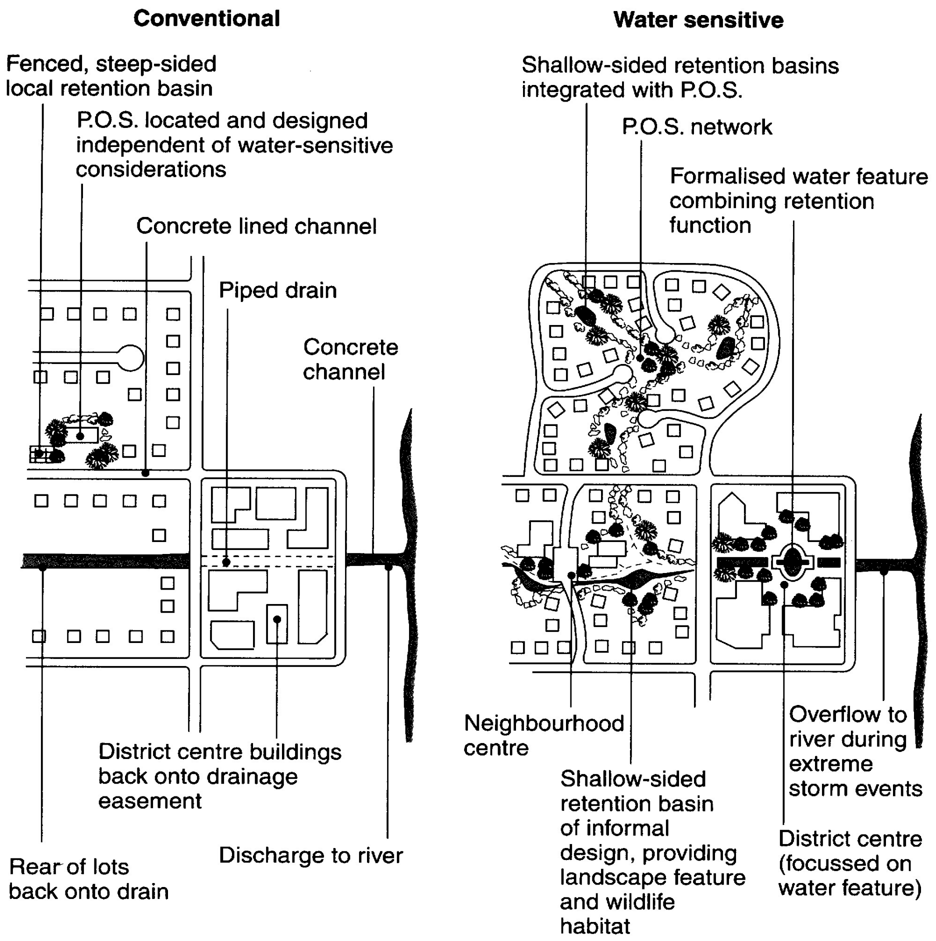


Figure 3.3 Water sensitive vs conventional urban lot layout (VicEPA, 1999)

This suburb scale WSUD methodology provides an opportunity to integrate the neighbourhood and lot scale BMP's recommended above. For example, constructed wetlands can be installed within open spaces set aside for natural drainage.

A study into the potential water quality benefits of WSUD for a residential subdivision in the Newcastle area (Coombes et al, 2000) determined that reductions of between 80 and 90% in the annual load of suspended solids, total nitrogen and total phosphorus was achievable.

Estimating the cost of designing and implementing water sensitive techniques on a suburb scale is difficult to estimate, however, an cost of $10,000 per hectare has been assumed.

3.5 Conclusions

The selected BMP's are all generally consistent with the principles of Water Sensitive Urban Design with no traditional stormwater BMP's being recommended based on site constraints or their limited treatment capabilities. There has been considerable discussion regarding the practically of WSUD techniques with only a few developments fully embracing the technology. This proposed urban development has the potential to be a show case development by incorporating a full suite of WSUD techniques from a lot to suburb scale, which optimises the reuse and treatment of stormwater and reduces pollutant loadings to the sensitive receiving waters of Narrabeen Lagoon.

Analysis of the AQUALM modelling data was undertaken to identify the required removal efficiency of the BMP's and BPP's that will result in 'no net increase in pollutants entering Narrabeen Lagoon'. The results of this analysis are presented in **Table 3.2**.

Table 3.2 Pollutant removal required for no net increase to Narrabeen Lagoon

	Pollutant	Reduction required for no net increase to Narrabeen Lagoon
Scenario 1	Suspended Solids	38 %
	Total Nitrogen	42 %
	Total Phosphorus	28 %
Scenario 2	Suspended Solids	49 %
	Total Nitrogen	52 %
	Total Phosphorus	31 %

The results in **Table 3.2** identify the pollutant removal efficiency required of the two development scenarios so as to limit the pollutant loads from the existing catchment to their current levels. It is interesting to note that the Narrabeen Lagoon Estuary Process Study (WBM, 2001) determined that Total Nitrogen and Total Phosphorus loads have increased by 45 and 80 times since European settlement.

It is also important to note that the above required removal efficiencies reflect only the areas that have been determined to be physically suitable for development in Stage 1 of the NULS, not the entire catchment area. Should further areas be opened up for development within the Narrabeen Lagoon catchment area (other than those areas identified in the NULS-Stage 1), additional modelling would need to be undertaken to determine the extents to which development could take place without impacting on water quality in Narrabeen Lagoon.

To determine the expected removal rate of stormwater pollutants, estimates of each of the preferred BMP's removal efficiency of the pollutants have been determined, as shown in **Table 3.3**.

Table 3.3 Approximate pollutant removal efficiency of BMP's and BPP's

	Pollutant Removal Efficiency (%)		
BMP	**SS**	**TN**	**TP**
WSUD (BPP)	20	20	20
Rainwater Tanks (R/T)	30	10	10
Infiltration Trenches (I/T)	60	30	30
Grass Swales (G/S)	50	20	20
Sediment Traps (S/T)	40	20	20
Constructed Wetlands (C/W)	60	30	30

Comparison of **Table 3.3** with **Table 3.2** shows that no one BMP has sufficient removal efficiency to remove all the simulated pollutants to result in a no-net increase in pollutant load to Narrabeen Lagoon. This justifies both the use of a treatment train and the adoption of a WSUD approach, as traditional treatment methods generally only involve the construction of one large scale end-of-pipe device, which in this case, has been shown to be ineffective at achieving the desired pollutant removal.

The total expected removal efficiency of six selected treatment trains have been determined and are shown in **Table 3.4.** The removal efficiency of the treatment train has been estimated by assuming that the second BMP in the treatment train, reduces the total remaining pollutant load by its treatment efficiency. For example, two devices are in series that each removal 50% of the suspended sediment load. The first device removes 50% of the sediment load while the second device removes 50% of the remaining 50% of the load (which is 25% of the total load). Therefore, the total sediment load is reduced by 50% + 25% = 75%.

Table 3.4 Pollutant removal efficiency of various Treatment Trains

	Removal efficiency of treatment train (%)		
Treatment Train	***SS***	***TN***	***TP***
WSUD + R/T + I/T +G/S + C/W	96	72	72
WSUD + R/T + G/S + C/W	89	60	60
WSUD + R/T + C/W	78	50	50
R/T + G/S + C/W	86	50	50
WSUD + R/T + G/S	72	42	42
R/T + C/W	72	37	37

- Treatment trains suitable for development scenario 1 (refer Table 3.2)
- Treatment trains suitable for development scenario 1 & 2 (refer Table 3.2)

From **Table 3.4** it can seen that five of the selected treatment trains would reduce stormwater pollutants to maintain or enhance water quality within Narrabeen Lagoon for development Scenario 1, while only two treatment trains are suitable for development Scenario 2.

The sixth treatment train in Table 3.4, which incorporates rainwater tanks and constructed wetlands only, although meeting criteria for suspended solids and total phosphorus, would not satisfy the criteria for nitrogen, and hence would not be suitable for the proposed development.

Table 3.4 also shows that **some** land area, additional to that identified as being suitable in the NULS-Stage 1, can be developed without reducing existing water quality within Narrabeen Lagoon. This is shown in the maximum removal efficiency of Total Nitrogen (the limiting pollutant) being 72% while the required removal efficiency for Scenario 2 is 52%. Therefore, it would be possible to increase the development area and/or density without detrimental environmental impacts. This increased treatment would, however, have an additional cost, which is considered in **Section 4**.

4 COST BENEFIT ANALYSIS

To allow developers and Council to determine the life cycle cost of each of the BMP's and BPP's over a 50 year design period, the capital and maintenance costs for each of the BMP's and BPP's were estimated (refer **Tables 4.1** and **4.2)**. Costs have been presented as a total cost per additional lot that the land will be able to support for each of the development scenarios.

Table 4.1 Scenario 1 capital and 50 year maintenance costs

BMP	Construction Cost	Per	Total Capital Cost	Annual Maintenance Cost	50 yr Maintenance Cost	Total life Cycle Cost	Additional Lots	Total 50 yr Cost per Lot	Annual Cost per Lot
WSUD	$10,000.00	ha	$1,540,000			$1,540,000	1150	$1,339.13	$26.78
Rainwater Tanks	$1,500.00	Lot	$1,725,000		$1,725,000	$3,450,000	1150	$3,000.00	$60.00
Infiltration Trenches	$900.00	Lot	$1,035,000		$1,035,000	$2,070,000	1150	$1,800.00	$36.00
Grass Swales	$17,300.00	ha	$2,664,200	$133,210	$6,660,500	$9,324,700	1150	$8,108.43	$162.17
Constructed Wetlands	$34,500.00	ha	$2,656,500	$132,825	$6,641,250	$9,297,750	1150	$8,085.00	$161.70
Sediment Traps	$24,800.00	ha	$1,909,600	$95,480	$4,774,000	$6,683,600	1150	$5,811.83	$116.24

Total number of Lots 1150 Lots
Total developed area 154 ha
Assume:
1. Half catchment served by wetland and half by sediment trap
2. Maintenance of Rainwater Tanks and Infiltration Trenches assumes replacement once in 50 years

Table 4.2 Scenario 2 capital and 50 year maintenance costs

BMP	Construction Cost	Per	Total Capital Cost	Annual Maintenance Cost	50 yr Maintenance Cost	Total life Cycle Cost	Estimated Lot	Cost per Lot	Annual Cost per Lot
WSUD	$10,000.00	ha	$2,510,000	-	$0	$2,510,000	3600	$697.22	$13.94
Rainwater Tanks	$1,500.00	Lot	$5,400,000	-	$5,400,000	$10,800,000	3600	$3,000.00	$60.00
Infiltration Trenches	$900.00	Lot	$3,240,000	-	$3,240,000	$6,480,000	3600	$1,800.00	$36.00
Grass Swales	$17,300.00	ha	$4,342,300	$217,115	$10,855,750	$15,198,050	3600	$4,221.68	$84.43
Constructed Wetlands*	$34,500.00	ha	$4,329,750	$216,488	$10,824,375	$15,154,125	3600	$4,209.48	$84.19
Sediment Traps*	$24,800.00	ha	$3,112,400	$155,620	$7,781,000	$10,893,400	3600	$3,025.94	$60.52

Total number of Lots 3600 Lots
Total developed area 251 ha
Assume:

1. Half catchment served by wetland and half by sediment trap
2. Maintenance of Rainwater Tanks and Infiltration Trenches assumes replacement once in 50 years

Table 4.3 provides a cost comparison for each of the treatment trains detailed in **Table 3.4**. The costs in **Table 4.3** represent the total life costs on an annualised basis and include capital and maintenance costs. This is not annual maintenance costs incurred by Council, which will be discussed later.

Table 4.3 Annual life cycle cost per additional Lot for various Treatment Trains

	Removal efficiency of treatment train (%)			*Expected annual cost per additional Lot*
Treatment Train	***SS***	***TN***	***TP***	
1. WSUD + R/T + I/T +G/S + CW	96	72	72	Scenario 1 –$562.89 Scenario 2 –$339.09
2. WSUD + R/T + G/S + CW	89	60	60	Scenario 1 –$526.89 Scenario 2 –$303.09
3. WSUD + R/T + C/W	78	50	50	Scenario 1 –$364.72 Scenario 2 –$218.65
4. R/T + G/S + C/W	86	50	50	Scenario 1 –$500.11 Scenario 2 –$289.14
5. WSUD + R/T + G/S	72	42	42	Scenario 1 –$248.95 Scenario 2 –$158.38
6. R/T + C/W	72	37	37	Scenario 1 –$337.94 Scenario 2 –$204.71

- Preferred treatment train for development scenario 1
- Preferred treatment train for development scenario 2

From **Table 4.3** a treatment train can be selected for each of the development scenarios based on the expected pollutant removal efficiency and annual cost per additional lot that the land will support. The preferred treatment train for development Scenario 1 is option 5 (WSUD + rainwater tanks + grass swales) as it provides sufficient treatment to maintain water quality in Narrabeen Lagoon for least cost, whilst utilising environmentally sensitive technologies.

Option 2 (WSUD + rainwater tanks + grass swales + constructed wetlands) is the preferred treatment train for development Scenario 2 due to its cost savings over option 1 (the only other option that achieves the necessary pollutant removal efficiencies). Option 2 is also considered more favourable as infiltration techniques on a lot scale often fail due to a lack of maintenance and understanding of how the device operates by individual landowners.

Both options 2 and 5 also have other associated cost benefits, such as grass swales providing cost savings on the supply and installation of piped drainage systems to convey stormwater.

To assist in the comparison of traditional stormwater treatment techniques and WSUD, an estimated cost per person using traditional stormwater treatment measures has been prepared and is based on a standard piped drainage system and a large scale wetland/s for treatment. The total annual costs per additional person have been estimated at $406.49 and $211.64, respectively for Scenarios 1 and 2. These compare favourably for Scenario 1, but traditional stormwater treatment measures are somewhat less expensive than the WSUD measures adopted for Scenario 2, although as discussed in **Section 3**, the traditional stormwater treatment measure adopted does not treat stormwater to the desired degree and therefore, direct comparison is difficult.

Table 4.4 shows a summary cost-benefit analysis of the selected treatment trains.

Table 4.4 Summary cost-benefit analysis for development scenarios 1 & 2

Development Scenario	Capital and Environmental Costs	Benefits
Scenario 1	• Total life cycle cost of stormwater BMP's and BPP's over 50 years of $14,315,000 (refer **Table 4.1**), which equates to approximately $250 per annum per additional lot that the catchment can support. • Estimated annual maintenance costs of $120 per additional lot to be borne by Council	• Addition population capacity of 3,190 • Reduced demand for potable water estimated at 76ML per year • Reduced costs when compared to 'traditional' stormwater treatment measures, which is estimate to cost $400 per additional lot • No additional nutrient load and a reduction of approximately 90t/annum of suspended sediment load to Narrabeen Lagoon.
Scenario 2	• Total life cycle cost of stormwater BMP's and BPP's over 50 years of $54,556,000 (refer **Table 4.2**), which equates to approximately $300 per annum per additional lot that the catchment can support. • Estimated annual maintenance costs of $160 per additional lot to be borne by Council • Increased cost when compared to 'traditional' stormwater treatment measures, which is estimated to cost $210 per additional lot. However, traditional methods do not treat stormwater to the desired level.	• Additional population capacity of 10,050 • Reduced demand for potable water estimated at 248ML per year • Reductions of 208t/annum, 238kg/annum and 138kg/annum of SS, TN and TP respectively to Narrabeen Lagoon.

5 EXTRAPOLATION OF RESULTS TO MIDDLE HARBOUR AND COWAN CREEK CATCHMENTS

Non-urban land areas within the Warringah Shire, which drain to Middle Harbour and Cowan Creek, were also considered during Stage 1 of the NULS (PPK, 2000). Although these sites are located in different catchments, some site characteristics are similar to those identified for the land draining to Narrabeen Lagoon and hence similar site constraints exist for possible BMP's and BPP's to be constructed to serve the land areas.

Based on the similar features of the site, the results for this study undertaken for the Narrabeen catchment can be extrapolated directly to these additional areas located outside the Narrabeen Lagoon catchment based on the proposed developed area and capital and maintenance costs estimated for the Narrabeen Lagoon catchment areas. As little is known about the water quality processes within these waterways, it is difficult to quantify actual impacts in terms of environmental degradation to the catchment waterways. Nonetheless estimates can be made on the increases of pollutants expected from the proposed development within these catchments based on the proposed development area and lot density.

Pollutant load for each of the catchments were estimated using AQUALM-XP and are shown in **Table 5.1**.

Table 5.1 Pollutant loads for Cowan and Middle Harbour

	Pollutant Loads			Removal efficiency required (%)		
Catchment	**SS**	**TN**	**TP**	**SS**	**TN**	**TP**
Cowan						
Existing	12.6 t	170 kg	51 kg	-	-	-
Scenario 1	12.6 t	170 kg	51 kg	0	0	0
Scenario 2	87 t	576 kg	87 kg	86	71	42
Middle Harbour						
Existing	5 t	56 kg	16 kg			
Scenario 1	14 t	182 kg	54 kg	65	69	70
Scenario 2	82 t	539 kg	82 kg	94	90	80

The Cowan Scenario 1 results indicate a no net increase in pollutants from the site, due to the existing developed nature of the catchment. The insignificant increase in developed area results in an insignificant increase in pollutant load, and as such, no stormwater treatment is required for this development scenario. Scenario 2, however, requires BMP's and BPP's to be implemented to maintain or enhance stormwater runoff quality.

The Middle Harbour development scenarios also show that stormwater is required to be treated prior to discharge to maintain existing water quality within the catchment.

Based on the required pollutant removal efficiencies shown in **Table 5.1**, the most cost effective treatment trains have been selected and the life cycle cost determined in a similar method as was prepared for the Narrabeen Lagoon catchment areas. The following treatment trains (as shown in **Table 4.3**) were selected for each of the development scenarios:

- Cowan – Development Scenario 1 Non required
- Cowan – Development Scenario 2 Treatment Train 1
- Middle Harbour – Development Scenario 1 Treatment Train 1
- Middle Harbour – Development Scenario 2 Treatment Train 1 + extra treatment

Due to the existing large proportion of bushland in the Middle Harbour catchment, there is only a relatively small load of pollutants. Therefore, when considering the developed scenarios, high removal efficiencies are required and even when implementing Treatment Train 1 (the treatment train with the highest removal efficiency), development scenario 2 is unable to remove enough Total Nitrogen to reduce the levels to the 'adjusted existing' case. Therefore, incorporation of other treatment measures into the treatment train would need to be considered. Given the lengths required to ensure 'no net increase' in loads to Middle Harbour, Council may wish to reconsider the applicability for Scenario 2 development (ie 15 dwellings / ha). A lower density development could be treated by Treatment Train 1.

Table 5.2 shows the summary of cost-benefits for the Cowan and Middle harbour catchments with the life cycle cost sheets presented in **Appendix B**.

Table 5.2 Cost-benefit analysis for Cowan Creek and Middle Harbour catchments

Catchment / Development Scenario	Capital and Environmental Costs	Benefits
Cowan Creek - Scenario 1	• Total life cycle cost of stormwater BMP's and BPP's over 50 years of $0 as no stormwater controls are required to maintain existing pollutant loads.	• Addition population capacity of 106 • No additional pollutant load to the downstream catchment. • Reduced demand for potable water estimated at 2.6ML/yr
Cowan Creek - Scenario 2	• Total life cycle cost of stormwater BMP's and BPP's over 50 years of $9,360,000 which equates to approximately $315 per additional lot that the catchment can now support • Increased cost when compared to 'traditional' stormwater treatment measures, which is estimated to cost $77 per additional lot. However, traditional methods do not treat stormwater to the desired level.	• Additional population capacity of 1500 • Reduced demand for potable water estimated at 37ML/year • Reductions of 9t/annum, 8kg/annum and 26kg/annum of SS, TN and TP respectively below the existing pollutant load.
Middle Harbour - Scenario 1	• Total life cycle cost of stormwater BMP's and BPP's over 50 years of $4,820,000 which equates to approximately $4000 per additional person that the catchment can now support • Increased cost when compared to 'traditional' stormwater treatment measures, which is estimated to cost $1260 per additional lot. However, traditional methods do not treat stormwater to the desired level.	• Additional population capacity of 65 • Reduced demand for potable water estimated at 1.6ML/year • Reductions of 5t/annum, 5kg/annum and 1kg/annum of SS, TN and TP loads respectively.

Middle Harbour - Scenario 2	• Total life cycle cost of stormwater BMP's and BPP's over 50 years of $9,860,000 which equates to approximately $100 per additional person that the catchment can now support • Increase of 95kg/annum and 7kg/annum of TN and TP loads respectively. • Increased cost when compared to 'traditional' stormwater treatment measures, which is estimated to cost $60 per additional lot. However, traditional methods do not treat stormwater to the desired level.	• Additional population capacity of 1890 • Reduced demand for potable water estimated at 47ML/year • Reduction in costs associated with installation of a piped stormwater drainage system estimated at $74 000/ha or $2,812,000 over the total development area • Reduction of 2t/annum of SS load.

6 CONCLUSIONS

It has been determined that development of the areas identified as suitable from Stage 1 of the NULS (PPK, 2000), which drain to Narrabeen Lagoon, can be undertaken without a subsequent reduction in water quality in Narrabeen Lagoon, and in most cases as increase in water quality can be achieved.

Traditional treatment methodologies involving large end-of-pipe devices have been determined as unsuitable for stormwater treatment to the desired level. Therefore, to prevent detrimental effects associated with increased stormwater flows and pollutant loads, a treatment train has been suggested that incorporates a series of treatments on a lot and neighbourhood scale and incorporates the principles of Water Sensitive Urban Design (ie Best Planning Practice) on a suburb scale.

Treatment costs have been estimated at $250 and $300 per additional lot that the land can support for Scenarios 1 and 2 respectively. This compares with costs for traditional stormwater treatment measures of $400 and $210 for scenarios 1 and 2, however, the traditional approach does not treat stormwater to the desired level and as such direct comparison should not be made.

Maintenance costs for Council on an annual basis have also been calculated and total $120 for Scenario 1 and $160 for Scenario 2 per additional lot.

Additional benefits of the WSUD design were also identified including the reduced demand for potable water, as rainwater stored in tanks could be used for secondary household uses including watering, hot water and toilet flushing. It has been estimated that a reduction in potable water demand of 76ML/yr and 248ML/yr respectively for Scenario 1 and 2 is achievable.

Based on the existing condition of the catchments and there relative areas, it is recommended that if the land were to be opened for development that it be released in the following order:

- Release Area 1 - Morgan Road area (given it is the least overall area to be developed and thus could be considered a pilot area for implementation of Water Sensitive Urban Design techniques)
- Release Area 2 - Red Hill (the next least area, draining to a separate tributary - South Creek)
- Release Area 3 - Forest Way
- Release Area 4 - Wakehurst Parkway Area (the largest release area).

Extrapolation of the results for the Narrabeen Lagoon catchment into the Cowan and Middle Harbour catchments determined that a treatment train approach was required to provide a no net increase in pollutants entering the downstream waterways. However, development scenario 2 for the Middle Harbour catchment would require additional treatment to that identified in the treatment trains, or should be reconsidered for applicability to urban development (at 15 dwellings / ha). The cost of stormwater management per additional lot have also be estimated for these catchments and are shown in **Table 6.1**.

Table 6.1 Annual costs for stormwater management – Cowan and Middle Harbour

	Capital and Maintenance Cost $/lot/yr	Annual Maintenance Costs $/lot/yr
Cowan		
Scenario 1	$0	$0
Scenario 2	$320	$160
Middle Harbour		
Scenario 1	$4000	$2750
Scenario 2	$280	$130

The relatively high cost of development scenario 1 in the Middle Harbour catchment is attributed to the large area being utilised but only being sparsely populated. Although scenario 2 offers a far more economical development scenario it also contributes an increased Total Nitrogen load to the downstream catchment. Therefore, it is recommended that some alternative development scenario be determined to optimise both the cost and degree of stormwater treatment required.

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8 QUALIFICATIONS

The use of the XP-AQUALM model follows on from the use of this model established for and accepted by Council for the Narrabeen Lagoon Estuary Processes Study (WBM, 2001). The model was updated with additional information provided by Council on the non-urban lands for assessment.

The results presented rely on limited data presented in literature and caution is required when relying on results from overseas investigations. Thus, there is a definite need for monitoring as outlined in the recommendations of this report.

The AQUALM modelling has some limitations and readers should familiarise themselves with the modelling system in order to fully understand these limitations.

The model was prepared relying on :

- topographic data (2m LIC contours) supplied by Warringah Council for the Processes Study;
- stormwater infrastructure information supplied by Warringah Council for the Processes Study;
- cadastral boundaries supplied by Warringah Council for the Processes Study;
- aerial photography supplied by Warringah Council for the Processes Study;
- non urban land areas identified for assessment were those described in the Non-Urban Lands Study by PPK (2000) and digitised from available paper plans provided by Council.

The accuracy of the model is reliant on the accuracy of these inputs.

APPENDIX A: BMP, BPP COST ESTIMATES

APPENDIX B: COWAN AND MIDDLE HARBOUR LIFE CYCLE COSTS

Cowan Scenario 2

BMP	Construction Cost	Per	Total Capital Cost	Annual Maintenance Cost	50 yr Maintenance Cost	Total life Cycle Cost	Additional Lot	Total 50 yr Cost per Lot	Annual Cost per Lot
WSUD	$10,000.00	ha	$380,000			$380,000	570	$666.67	$13.33
Rainwater Tanks	$1,500.00	Lot	$855,000		$855,000	$1,710,000	570	$3,000.00	$60.00
Infiltration Trenches	$900.00	Lot	$513,000		$513,000	$1,026,000	570	$1,800.00	$36.00
Grass Swales	$17,300.00	ha	$657,400	$32,870	$1,643,500	$2,300,900	570	$4,036.67	$80.73
Constructed Wetlands	$34,500.00	ha	$655,500	$32,775	$1,638,750	$2,294,250	570	$4,025.00	$80.50
Sediment Traps	$24,800.00	ha	$471,200	$23,560	$1,178,000	$1,649,200	570	$2,893.33	$57.87

Total number of Lots 570 Lots
Total developed area 38 ha
Assume:
1. Half catchment served by wetland and half by sediment trap
2. Maintenance of Rainwater Tanks and Infiltration Trenches assumes replacement once in 50 years

Middle Harbour - Scenario 1

BMP	Construction Cost	Per	Total Capital Cost	Annual Maintenance Cost	50 yr Maintenance Cost	Total life Cycle Cost	Additional Lot	Total 50 yr Cost per Lot	Annual Cost per Lot
WSUD	$10,000.00	ha	$270,000			$270,000	23	$11,739.13	$234.78
Rainwater Tanks	$1,500.00	Lot	$34,500		$34,500	$69,000	23	$3,000.00	$60.00
Infiltration Trenches	$900.00	Lot	$20,700		$20,700	$41,400	23	$1,800.00	$36.00
Grass Swales	$17,300.00	ha	$467,100	$23,355	$1,167,750	$1,634,850	23	$71,080.43	$1,421.61
Constructed Wetlands	$34,500.00	ha	$465,750	$23,288	$1,164,375	$1,630,125	23	$70,875.00	$1,417.50
Sediment Traps	$24,800.00	ha	$334,800	$16,740	$837,000	$1,171,800	23	$50,947.83	$1,018.96

Total number of Lots 23 Lots
Total developed area 27 ha
Assume:

1. Half catchment served by wetland and half by sediment trap
2. Maintenace of Rainwater Tanks and Infiltration Trenches assumes replacement once in 50 years

Middle Harbour - Scenario 2

BMP	Construction Cost	Per	Total Capital Cost	Annual Maintenance Cost	50 yr Maintenance Cost	Total life Cycle Lot	Estimated Lots	Cost per Lot	Annual Cost per Lot
WSUD	$10,000.00	ha	$380,000	-	$0	$380,000	675	$562.96	$11.26
Rainwater Tanks	$1,500.00	Lot	$1,012,500	-	$1,012,500	$2,025,000	675	$3,000.00	$60.00
Infiltration Trenches	$900.00	Lot	$607,500	-	$607,500	$1,215,000	675	$1,800.00	$36.00
Grass Swales	$17,300.00	ha	$657,400	$32,870	$1,643,500	$2,300,900	675	$3,408.74	$68.17
Constructed Wetlands*	$34,500.00	ha	$655,500	$32,775	$1,638,750	$2,294,250	675	$3,398.89	$67.98
Sediment Traps*	$24,800.00	ha	$471,200	$23,560	$1,178,000	$1,649,200	675	$2,443.26	$48.87

Total number of Lots 675 Lots
Total developed area 38 ha
Assume:

1. Half catchment served by wetland and half by sediment trap
2. Maintenance of Rainwater Tanks and Infiltration Trenches assumes replacement once in 50 years