Water Sensitive Urban Design Solutions for Catchments above Wetlands

Overview Report

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Hunter & Central Coast
Regional Environmental
Management Strategy

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Water Sensitive Urban Design Solutions for Catchments Above Wetlands

DOCUMENT SERIES:

Overview Report

Appendix A: Wetlands Classification Scheme

Appendix B: Catchment Hydrologic Indices and Urban Water Management Performance Objectives

Appendix C: A Procedure for Determining Catchment Stormwater Management Objectives

Appendix D: Planning Mechanisms

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1 INTRODUCTION

Ecological Engineering was commissioned by the Councils of the Lower Hunter and Central Coast (Hunter Council Inc.) to develop a NSW-wide methodology for determining urban stormwater management objectives and to investigate Water Sensitive Urban Design (WSUD) solutions for urban developments in catchments above wetlands.

Wetlands are among the most variable and productive types of ecosystems. They are dynamic, transitional environments that link terrestrial and aquatic ecosystems and are consequently highly variable in their nature. Being the interface between land and water, they are home and are hosts to numerous species, from phytoplankton to macroinvertebrates to birds and mammals.

State Environmental Planning Policy No. 14—Coastal Wetlands (SEPP 14) has been developed to ensure that coastal wetlands are preserved and protected. Under the Policy, land clearing, levee construction, drainage work or filling within a mapped wetland area requires development consent. However, the Policy is limited as it only relates to 'coastal wetlands' and to development *within* mapped wetland areas.

Natural wetland systems downstream of catchments undergoing urbanisation are subject to a range of environmental stresses bought about by activities outside the wetland boundaries. Most significantly urbanisation leads to changes in wetlands hydrology and the introduction of higher pollution loads from urban stormwater.

Consideration of the merits of urban development in a catchment upstream of natural wetlands is a complex one and involves a range of environmental and socio-economic factors. The guidelines developed from this investigation should not be viewed as promoting urban development. It is likely that some hydrological and water quality impacts on natural wetlands will result from catchment urbanisation even with adoption of current best practice methods for amerliorating environmental stresses.

The guidelines are designed to assist in the protection of biotic communities associated with wetlands, in situations where urban development in a catchment upstream of a natural wetland is to proceed. These guidelines are based on recognising and conserving the distinctive features of supporting hydrology and water quality of natural wetlands and deriving stormwater management objectives to guide urban development and lessen the impact of urban development on these wetlands. The guidelines developed through this project will include a method for specifying total catchment hydrological and water quality improvement performance and selecting from the available suite of WSUD techniques to achieve this performance.

The project has been developed in four components, which are appendices to this report namely:

1. Development of a simple wetland classification to enable practitioners to undertake field identification of wetlands to be managed. 17 wetland types were classified with the supporting hydrology described (Appendix A).

2. Formulation of water management objectives for catchments above the 17 wetland types based on quantification of their supporting hydrological characteristics (Appendix B).

3. Procedure for determining stormwater quality objectives for catchments above the 17 wetland types (Appendix C).

4. Development of a range of state planning recommendations and local planning provisions to assist councils implement the water management objectives recommended in this study (Appendix D).

This report synthesises the studies and directs readers to relevant appendices throughout.

2 NATURAL WETLANDS

Wetlands are highly variable in their nature and are significant transitional environments that link terrestrial and aquatic ecosystems.

The effective functioning of wetlands depends on the extent to which the wetland natural functions are impacted on or impeded. The main elements of wetland function are determined by hydrology, the physical and chemical properties of the substratum, biotic components and organic matter accumulation and decay. The interactions between these elements are complex and a shift or change in one element has the potential to modify many others. A simplified conceptual model of the relationships between various elements of wetland function, and potential threats from urban development, is illustrated in Figure 1.

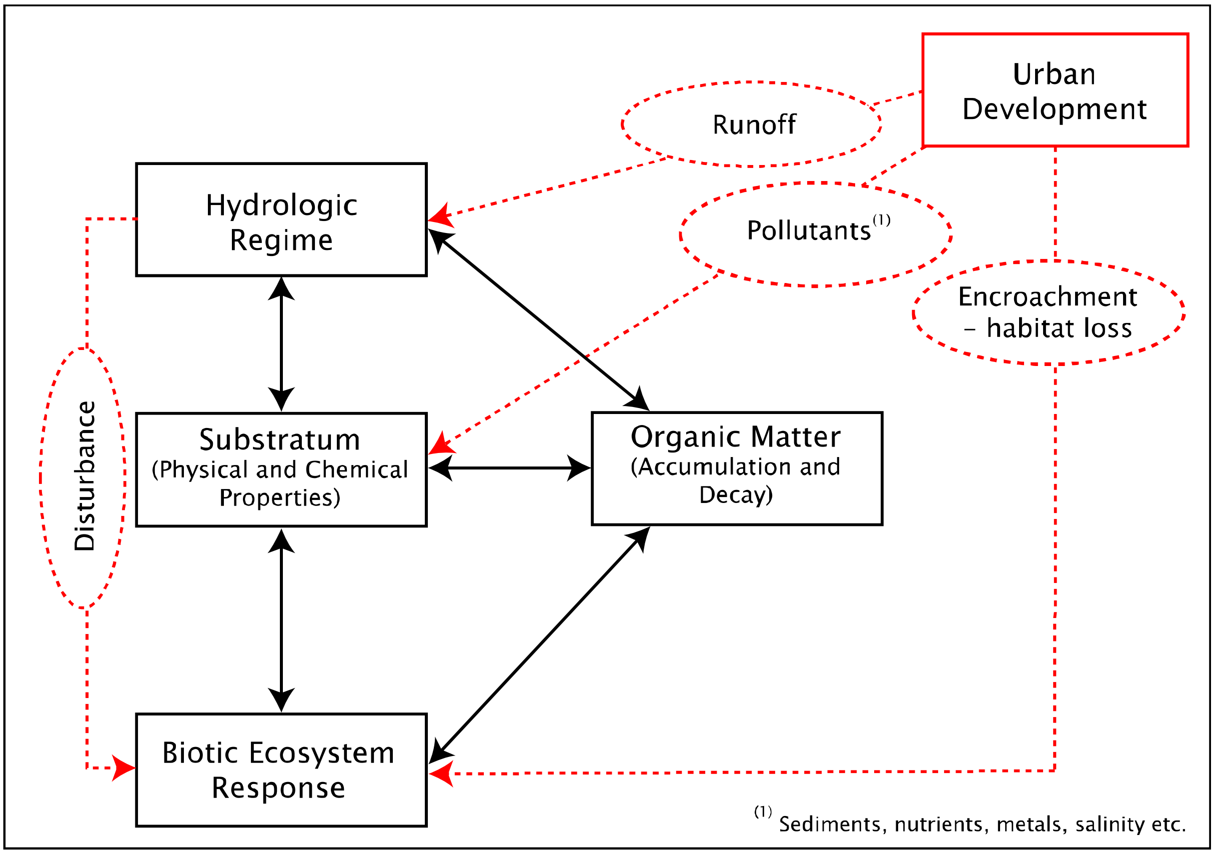


Figure 1 - Conceptual model of wetland function indicating potential threats from urban development to the natural function of wetlands (after Breen 1992)

The hydrologic regime of wetlands determines the depth, frequency, duration and temporal pattern of flooding and drying. These features inturn influence the characteristics of the substratum, while the wetting and drying pattern influences both the physical (e.g. gas diffusion) and chemical (e.g. redox) characteristics of the substratum.

2.1 Threats to wetlands from urban development

The threats to wetland function are complex and alterations to natural cycles and processes, as a result of urbanisation, can impact on physical, chemical and biological attributes of a wetland system. The mains threats from urban development to wetland function are related to:

- alterations to hydrology – volume of runoff into a wetland typically increases as a result of urbanisation, which impacts on the inundation patterns.
- physical disturbances as a result of altered hydrology – direct flood damage on vegetation, erosion and/or deposition of substratum, changes to substratum particle size distribution and changes to inflow and/or outflow patterns.
- alterations to the chemical and physical properties of the substratum – linked to changes in the water quantity and quality, altering parameters such as pH, redox potential, dissolved oxygen, nutrients, toxicants and suspended solids. The physical properties of the substratum can be altered in terms of sediment deposition and changes in sediment particle size distribution.
- direct encroachment on biotic ecosystems – land clearing, filling and artificial drainage directly encroach on wetland and result in and contribute to alterations of these systems.

Urban development has the following impacts on a wetland system:

- redistribution and loss of vegetation communities,
- deterioration of both water and sediment quality within the wetland,
- deterioration of water quality and modification of water volume flowing out of the wetland, and
- loss of individual species and biodiversity or changes to species composition.

The extent to which an impact affects natural wetland function is highly variable and related to the severity of the impact and the type of wetland present. The severity of the impact on the wetland will determine the degree to which wetland services (e.g. ecosystem and biodiversity services) will be impeded. Significant changes to ecosystem structure can consequently disturb and impede ecosystem function. However, if changes to the structure and vegetation composition of an individual wetland are subtle, the ability of the wetland to function can be preserved. Determining the threshold of structural change – for both biodiversity and ecosystem function – presents a challenge.

As the wetland function is also related to the type of wetland it is necessary to correctly classify the wetland type to ensure that potential threats, and subsequent impacts, can be appropriately managed by establishing water management objectives for urban developments discharging to these wetlands.

This methodology has been developed for broad-scale use and it is beyond the scope to consider individual threatened species within each geographic region or wetland class. Nevertheless, the methodology serves to protect the vegetation communities associated with the various wetland types that have been identified. Protection of community diversity indirectly protects much of the species diversity associated with that community.

2.2 Wetland Classification

A simplified wetland classification scheme has been developed to enable practitioners to undertake field identification on the types of wetlands. The classification system has been developed following an extensive review of the strengths and weaknesses of other classification schemes (Appendix A). The hierarchical classification scheme developed for this project is based on:

- dominant vegetation
- dominant substratum
- water chemistry
- typical life forms

The scheme has been devised in such a way that knowledge of these four factors alone will be sufficient to classify a wetland. Recognizing that wide-ranging and long-term information is often limited, the classification scheme only necessitates a site inspection, with each of these four components being able to be determined in the field. Further information on this process is contained in Appendix A.

Vegetation has been used as the primary determinant for the classification because it is relatively easily observed compared with other parameters and to a large degree, vegetation responds to and expresses the environmental conditions of wetlands. Similarly, characteristics of the dominant substratum and water chemistry can be easily ascertained. A sample of soil, deemed typical of the wetland, should be examined to determine its structure, composition and organic matter content. The salinity and pH of water can be tested in the field using appropriate equipment (e.g. pH meter, electrical conductivity meter).

Where simple field meters are not available, first-hand field observations of vegetation can be used to broadly determine salinity by assessing the salt tolerance of the species present, in particular, the presence of either salt sensitive or salt tolerant species. If necessary, the likely pH range can also be estimated through observations of catchment geology, water colour and salinity. For example, low pH can be expected when the presence of humic acids are observed, causing a brown colouration in the water. Higher pH levels would be expected in limestone-rich catchments.

Considerations of the range of wetland types typical in New South Wales led to the classification of 17 general wetland types. Table 1 presents the 17 wetlands types, with a broad description of their supporting hydrology, including the inundation water type (freshwater, saline or marine), frequency of drying, inundation depth, duration of drying and inundation regularity for each type of wetland. Further detail on wetland classification and wetland hydrology are contained in Appendix A and B respectively.

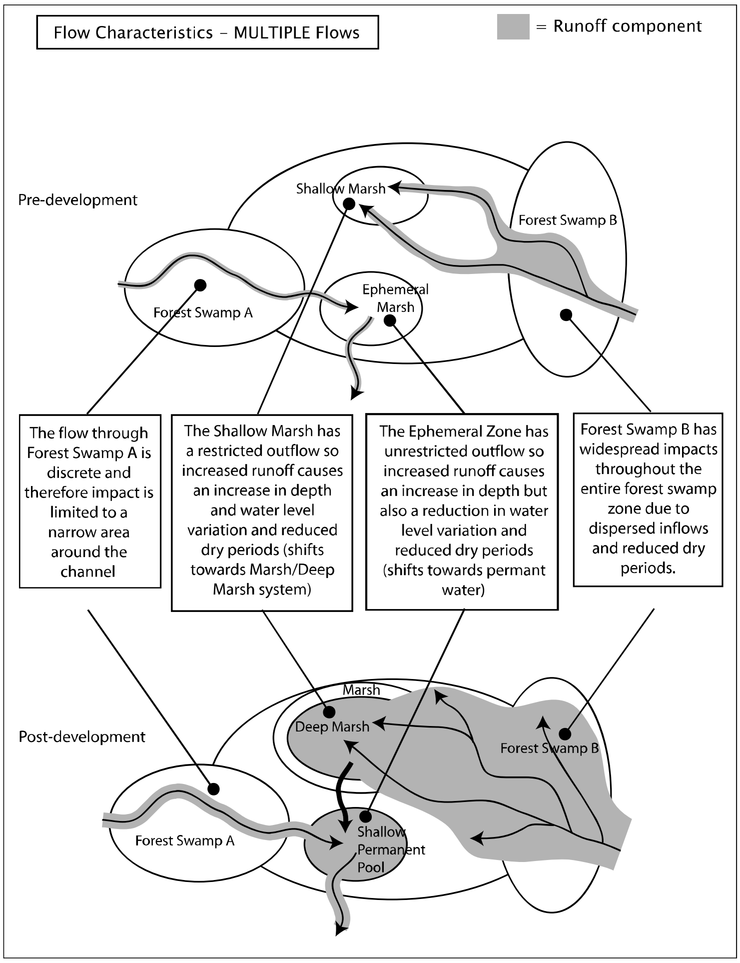
Table 1 - Wetland category and hydrologic variable matrix

Wetland Category	Inundation Water (Typical)	Inundation Regularity	Inundation Depth (m)	Duration of Drying	Frequency of Drying/Exposure (once/unit)
1. Coastal Flats	Marine	High	0 – 4+	0 – 12 hours	12 – 24 hours
2. Inland Flats	Saline	Low	0 – 1+	1 – many years	1– many years
3. Bogs	Rainwater	High	0 – 0.1+ (saturated)	1 – 2 months	1 – 3 years
4. Deep Marsh	Freshwater	High	0.3 – 0.6+ (–2.0+)	1 – 4 months	1.5 – 3 years
5. Fen	Freshwater	High	0 – 0.6+	1 – 6 months	1.5 – 3 years
6. Shallow Marsh	Freshwater	Low–Medium	0 – 0.3	3 – 6 months	3 – 6 months
7. Salt Marsh	Marine	Medium–High	0 – 0.3	1 day – 1 month	1 day – 6 months
8. Seagrass Beds	Marine	High	0+ – 10+	0 – 6 hours	≥ 6 months
9. Deep Salt Pans	Saline	Low	0 – 2	2 – many years	1 – 2+ years
10. Deep Open Water	Freshwater	Medium	1 – 2+	1 – 6 months	3 – 5 years
11. Shallow Open Water	Freshwater	Low	0.5 – 1.5	3 – 6 months	0.5 – 2 years
12. Wet Heath	Rainwater	High	0 (saturated)	3 – 6 months	3 – 6 months
13. Mangrove	Marine	High	0 – 1.5+	6 – 12 hours	6 – 12 hours
14. Scrub Swamp	Freshwater	Low	0 – 0.3	6 – 9 months+	6 – 9 months
15. Forest Swamp – Wet	Freshwater	High	0 – 2.0+	2 – 6 months	1 – 3+ years
16. Forest Swamp – Ephemeral	Freshwater	Medium	0 – 1.0+	4 – 8 months	annually
17. Forest Swamp – Dry	Freshwater	Low	0 – 0.2+	8 – 12+ months	annually

See Appendix A for Glossary of Terms

2.3 Management of Mosaic Wetlands

Some wetland areas, particularly when large in size, will consist of several classes of wetland. For example, the Porters Creek wetland (Wyong) has areas of deep marsh, shallow marsh, scrub swamp and several forest swamp classes. The classification system can be used to identify the wetland type/s that are most threatened within the wetland mosaic. Initially, all wetland types within the area are classified and the percentage of each determined. For example, 15 % deep marsh, 25 % shallow marsh, and 60 % scrub swamp. The threats to the wetland from the urban development are also identified. Using this information, the most threatened wetland type/s within the wetland area can be identified. A dominant supporting hydrology for the wetland as a whole will then be selected based on the most threatened wetland type/s within the area. Appendix A of this study illustrates the steps taken in choosing the appropriate supporting hydrology for large mosaic wetlands using this system, as highlighted in Figure 2.



The flow through Forest Swamp A is discrete and therefore impact is limited to a narrow area around the channel

The Shallow Marsh has a restricted outflow so increased runoff causes an increase in depth and water level variation and reduced dry periods (shifts towards Marsh/Deep Marsh system)

The Ephemeral Zone has unrestricted outflow so increased runoff causes an increase in depth but also a reduction in water level variation and reduced dry periods (shifts towards permant water)

Forest Swamp B has widespread impacts throughout the entire forest swamp zone due to dispersed inflows and reduced dry periods.

Figure 2 - A conceptual diagram of a mosaic wetland illustrating a variety of potential impacts from increased frequent flow runoff volume on various wetland types within the mosaic.

3 URBAN WATER MANAGEMENT OBJECTIVES FOR CATCHMENTS UPSTREAM OF NATURAL WETLANDS

Un-controlled urbanisation typically results in changes to both runoff quality and quantity. To minimise these impacts both hydrological and water quality objectives are proposed for catchment above natural wetlands. WSUD interventions directed at hydrologic management and pollutant reduction are inter-related. By achieving appropriate hydrologic control many of the hydrologic related water quality impacts that are likely to occur in wetlands, such as un-seasonal waterlogging and release of in-situ soil nutrients, will be addressed. Furthermore, urban stormwater pollutants will be removed through WSUD solutions adopted to preserve pre-development hydrologic characteristics. Initiatives to treat that component of stormwater runoff that is discharged to the wetland would further reduce stormwater pollutants loads.

3.1 Hydrologic Management Objectives for Natural Wetlands

Hydrologic regime wetlands can be quantified statistically by a number of hydrologic indices. These indices help define the characteristics of wetland drying and wetland hydrology and provide the basis for defining management objectives for protecting wetlands from adverse impacts of catchment urbanisation. Following review and consideration of a number of possible hydrologic indices for drying and flooding hydrology in wetland systems, three have been recommended, ie.

Drying Hydrology	1. Dry season flow duration frequency curves
	2. Low flow spell frequency curves
Flooding Hydrology	1. Annual high flow duration frequency curves

Flow duration frequency curves representing maximum flow and minimum flow conditions were considered to provide the principal hydrologic index for wetland flooding and drying hydrology respectively. Flood (instantaneous peak flow) frequency curves, while relevant, were considered less appropriate as the inherent detention storages associated with natural wetlands can often modify the significance of their effects in supporting key wetland functions.

Table 2 lists the recommended hydrologic performance objectives for urban developments upstream of natural wetlands. More information on hydrological performance is contained in Appendix B.

Table 2 - Hydrologic Management Objectives for Natural Wetlands

Wetland Category	Flooding Hydrology	Drying Hydrology		Reference Duration
	High Flow Duration Frequency Curve	Low Flow Duration Frequency Curve	Low Flow Spell Frequency	
1. Coastal Flats	✓			7 days
2. Inland Flats	✓	Isolate wetland from upstream catchment		30 to 60 days
3. Bogs	✓	✓	✓	30 to 60 days
4. Deep Marsh		✓	✓	30 to 60 days
5. Fen	✓	✓	✓	30 to 60 days
6. Shallow Marsh		✓	✓	60 days
7. Salt Marsh	✓	✓	✓	7 days
8. Seagrass Beds	✓			7 days
9. Deep Salt Pans	✓	Isolate wetland from upstream catchment		30 to 60 days
10. Deep Open Water	No hydrologic management objectives required			
11. Shallow Open Water		✓	✓	60 days
12. Wet Heath		✓	✓	60 days
13. Mangrove	✓			7 days
14. Scrub Swamp	✓	✓*	✓*	60 days
15. Forest Swamp – Wet		✓	✓	60 days
16. Forest Swamp – Ephemeral		✓	✓	60 days
17. Forest Swamp – Dry	✓	✓*	✓*	60 days

* For development along the fringe of wetland with Overland Flow Flooding Pathways (see Appendix B - Section 2.1) only. Note that reference to “fringe of wetland” simply related to areas that do not have a well defined conveyance pathway for stormwater into the wetland and are not meant to have any scientific definition of what the margin or fringe of a wetland is.

3.2 Water Quality Management Objectives for Natural Wetlands

Wetlands occur in a wide range of environments (Sainty & Jacobs 2003). As a result, the supporting water quality of wetlands varies considerably and due to the insufficient data available on the range of wetland types, the ANZECC (2000) guidelines provide no guidelines for wetlands in South-Eastern Australia.

In general water quality supporting various wetland types is related to the position of a wetland in the terrain. Upland wetlands (eg. bogs) or wetlands with limited catchments (wet heaths) tend to be adapted to very good water quality (low nutrient) conditions. Lowland wetlands (deep marshes, wet swamps) typically have large catchments and tend to regulate the supply of water and materials (sediment, nutrients, etc.) to downstream environments. As a result these systems tend to be adapted to poorer water quality (high nutrient) conditions. Some wetland types are very good at processing and utilising nutrients. With regard to the water quality protection of wetlands downstream from urban development the following approach is recommended:

- As a default all stormwater is treated to current “best practice” standards - Load reductions of 80% for total suspended solids, and 45% for nitrogen and phosphorus.
- For wetlands where interim water quality trigger values can be estimated, these values should be used in the protocol proposed in ARQ (2003) for determining sustainable loads from a catchment.
- For wetlands where interim water quality trigger values can not be estimated (Fen, Wet Heath, Scrub Swamp, Ephemeral Swamp Forest and Dry Swamp Forest) 50 %tiles for wet weather flows should not exceed:
    - 0.06 mg/L for Total Phosphorus
    - 1.0 mg/L for Total Nitrogen

  (These are concentrations are background concentrations that can be achieved by an appropriately designed stormwater treatment wetland at present but may be further reduced as new and better stormwater best management practices become available)
- Through the application of appropriate hydrologic controls on stormwater runoff to ephemeral wetlands, a high level of water quality control is also achieved, as such un-seasonal waterlogging and release of in-situ soil nutrients, will be addressed.

More detailed information on a possible procedure for determining water quality objectives for urban development upstream of wetlands is contained in Appendix C.

4 DESIGN PROCESS FOR THE APPLICATION OF HYDROLOGIC OBJECTIVES

WSUD of new urban developments and release areas typically seeks to achieve water quality objectives of 80% reduction of TSS and 45% reduction of TN and TP. Urban developments upstream of wetlands should seek to achieve these water quality objectives for that component of stormwater runoff that is discharged into wetlands in addition to the hydrologic performance objectives necessary to support wetland ecology, so as to minimise the impact of urbanisation on these wetlands.

To assist councils in the application of these hydrologic performance objectives, a design process has been developed and is detailed in Appendix B. The design process demonstrates the application of the methodology for computing hydrologic indices that sets the baseline for the hydrologic performance objectives required to preserve the supporting wetland hydrology and to examine possible WSUD solutions to match post-development hydrologic indices to baseline indices.

Defining the baseline hydrologic indices involves continuous hydrologic modelling or analysis of historical streamflow data. The key steps in the design process are:

1. Selection and calibration (if data is available) of catchment hydrological model or obtain relevant long-term streamflow data for statistical analysis. A data length (either simulated or observed) of 15 to 20 years is desirable.

2. Identify the most suitable classification for the wetland to be protected and select the appropriate hydrologic performance objective(s).

3. Define the baseline hydrologic indices from the data simulated or observed (Step 1), ie. undertake the required flow duration frequency analysis and, if appropriate, the dry flow spell analysis as discussed in Section 3.

4. Define, through hydrologic modelling, the changes in hydrological behaviour as the result of proposed urban development in the catchment and compare the post-development hydrologic indices against the baseline indices for either wetland flooding or drying conditions.

5. Identify WSUD measures that have the capabilities to manage the hydrologic conditions of the proposed development to meet the hydrologic performance objectives established in Step 3.

5 WSUD Solutions for Urban Developments upstream of Wetlands

WSUD strategies associated with new developments and redevelopments in catchment upstream of natural wetlands needs to include methods for preserving the pre-development drying hydrology and/or flooding hydrology characteristics in order to protect the ecology of these wetlands. There are a range of WSUD elements that can be adopted to preserve pre-development hydrology of these catchments, with the majority of them based on functions of:

- infiltration
- rainwater and stormwater harvesting, storage and reuse
- flow diversion

Table 3 outlines the range of WSUD elements appropriate at the allotment, subdivision or regional scale. These elements need to be seen in the context of the local environment, and be based on assessment of the local environment's capability, as for example, infiltration may not be appropriate in areas of high groundwater or sodic soils.

Table 3 - WSUD elements for differing scales of urban developments above Wetlands

Allotment ↔	*Subdivision* ↔	*Regional elements*
Allotment density	Development density	Public open space
Site coverage (fraction imperviousness)	Site coverage (fraction imperviousness) – provision of POS	
On-site infiltration	Precinct infiltration	
Rain gardens/ local wetlands	Plantation and sporting fields	Plantation and sporting fields
On-site detention	Retarding basins	Retarding basins
Rainwater tanks for in house reuse	Wetlands and ponds for storage and open space watering	Wetlands and ponds for storage and open space watering
	Flow diversion	Flow diversion

The application of preferred WSUD strategies for urban developments upstream of natural wetlands should be undertaken as a holistic planning approach by councils to optimise approaches linked with integrated water management strategies which may include opportunities such as regional stormwater harvesting and wastewater reuse. This is discussed in some detailed in Appendix B. Once a natural wetland has been classified and its water management objectives identified, as per the design process to determine the hydrologic performance objectives (Section 4), a holistic planning approach by council should relate to the whole catchment(s) draining to the wetland and include:

- adoption of appropriate local planning provisions through both LEPs and DCPs,
- development of and linkages to regional planning mechanisms such as structure plans, integrated water cycle management plans and masterplans, and
- local implementation of WSUD elements.

These strategies are outlined further within the following sections.

5.1 Local Planning Provisions

Whilst planning controls relevant specifically to wetland areas are important in minimising urban encroachment on wetlands (eg SEPP 14), attention must also be given to development within the catchment areas draining to these wetlands. Councils can utilise a variety of planning mechanisms to allow for the adoption of water management objectives within wetland catchment areas, so as to protect the ecological values and functioning of these wetland systems. These include LEP provisions which provide the rationale for planning controls, such as zoning and overlay controls, and detailed provisions contained in development control plans.

DCPs can formally specify hydrological objectives for wetland catchment areas, as outlined in Section 3 above, thereby requiring these matters to be taken into account in the assessment of development applications. In doing so it is also important to provide a cross-reference to relevant technical documents for the implementation of WSUD elements, to provide a firm technical basis for adopted objectives and standards. The determination and application of appropriate LEP and DCP provisions to meet these objectives is detailed in Appendix D.

5.2 Planning for Urban Development in Catchments above Wetlands

Urban development within a wetland catchment should accommodate the water management objectives by considering a holistic approach utilising the full range of available planning tools. Where a catchment has already been subject to significant development, land acquisition may be required to achieve the objectives and should be considered in a more strategic context, with longer term objectives that are considerate of the existing development pattern. Nonetheless, the same planning tools apply. Appropriate planning tools include:

- Strategic policy planning to define the appropriate values to be retained or installed and to weigh up the competing interests of social, environmental, economic and legislative requirements.

- Structure planning is concerned with integrated planning concepts that guide the implementation of subregional-scale projects such as urban release corridors, and typically summarises the proposed settlement pattern and urban structure. Structure plans should therefore address any necessary subregional strategies for achieving hydrological objectives for wetland catchment areas. Relevant matters that need to be addressed include development density, open space networks, subregional water infrastructure systems, and broad WSUD principles.

- Integrated water cycle plans should be prepared by each local water utility in NSW, with the primary objective of providing sustainable urban water services. Local water authorities need to determine how regional water supply, wastewater and stormwater systems and reuse schemes may assist achieving hydrological and water quality objectives

- Master planning is concerned with integrated planning concepts that guide the implementation of major development projects at the neighbourhood or precinct-scale, such as redevelopment areas or new housing estates. Master plans should therefore address any necessary precinct-level strategies for achieving hydrological and water quality objectives for wetland catchment areas.

- A WSUD strategy aims to optimise and integrate stormwater, potable mains water supply and wastewater within a given urban development or release area. A WSUD strategy evaluates a number of factors including the development scenarios and site constraints to identify appropriate WSUD elements to meet relevant site water objectives. The WSUD strategy needs to be consistent with the local water authority's IWCMP.

5.3 Local Implementation of WSUD Solutions

As shown in Table 3 there are a range of WSUD solutions which can be applied to meet established water management objectives for development upstream of natural wetlands and to mimic the pre-development drying hydrology for typical scenarios of catchment urbanisation. At a range of spatial scales these include:

- Localised (on-site) initiatives include provision of rainwater tanks for harvesting of rainwater for in-house and open space watering/toilets. As an example, within the Wyong area the use of rainwater tanks sized to comply with BASIX requirements will normally be sufficient to preserve the pre-development 7-day and 14-day low flow duration frequency curves.

- Regional Ponds – storage of catchment runoff in regional ponds and lakes and reuse for irrigation of Public Open Space (POS) or plantations.
- Increasing dwelling density through multi-unit development can preserve the pre-development drying hydrology through a combination of increasing in-house water demand relative to the available roof area for harvesting rainwater and larger opportunities for open space watering (while maintaining an overall whole-of-catchment development density) through clustering of development around a network of irrigated public open space.
- Possible investigation of the exportation of water to industry or other water users outside the catchment, within a regional IWCM strategy.
- Treatment of stormwater runoff from urban development to meet best practice stormwater quality objectives (ie. 80% reduction in mean annual TSS load and 45% reduction in mean annual nutrient (TP and TN) loads).

The integration of these WSUD solutions into new developments and redevelopments can be suited to a range of catchments above wetlands. However, their effective implementation requires councils to adopt the appropriate hydrologic objectives within their local planning instruments. Therefore an effective and strategic local and regional planning framework is essential.

Once the framework has been established councils can direct developments to meet the objectives both on-site and as a component of s94 contributions plans. The installation of WSUD solutions requires careful consideration of funding and responsibilities for ongoing operation and maintenance. More information on these areas can be found in the DEC document Managing Urban Stormwater: Urban Design (DEC in press).

5.4 Example of planning for Wetland Protection – Porters Creek

An example of the use of planning instruments to implement WSUD so as to meet hydrological objectives for catchments above wetlands is given by Porters Creek. This site was used as a case study for determining the hydrological and water quality objectives for this study (Appendix B).

The Warnervale/Wyong land release zone lies within the drainage catchment of the Porters Creek Wetland (one of the largest freshwater wetlands on the NSW coast) and other sensitive terrestrial and aquatic ecosystems (including sensitive Wallum Froglet habitat). The following is a summary of findings which indicates the importance of careful management of the water cycle in the wetland's catchment:

- Porter's Creek Wetland has been identified as a combination 'Paperbark / Casuarina Wet Forest' and 'Low Paperbark Swamp Forest' with an isolated patch of 'Reed, Sedge & Herb Wetland'. The wetland is particularly sensitive to the 'drying' frequency during the summer months and the water management is to *preserving the 'hydrologic signature' of summer minimum 30-day average flow duration and the low flow spell frequency characteristics at 'pre-development' levels.* At present the wetland is under threat as a result of the significant urban development occurring in its catchment and the associated change in hydrologic behaviour.

- Conceptual water balance models established to test the possible WSUD options for delivering on the water management objective indicate that: significant water 'loss' must occur to deliver hydrologic objectives for Porter's Creek Wetland and additional 'loss' or reuse must occur over-and-above that to meet the requirements of BASIX. Examples of how this ***additional 'loss'*** can be achieved are:

  - development in Porters Creek Wetland catchment should include 20% of the urbanised area set aside for irrigated plantation; and

  - stormwater harvesting at a regional scale for reuse either within or external to the catchment.

Consideration must therefore be given to the regional collection, storage and reuse or 'loss' of harvested stormwater through the Warnervale/Wyong region to protect the Porters Creek Wetland and other valuable ecosystems.

By achieving appropriate hydrologic control many of the hydrologic related water quality impacts that are likely to occur in wetlands, such as un-seasonal waterlogging and release of in-situ soil nutrients, will be addressed). Furthermore, urban stormwater pollutants will be removed through WSUD solutions adopted to preserve pre-development hydrologic characteristics. For example, in preserving the 30-day drying hydrology of the Porters Creek Wetland, a reduction in stormwater volume associated with measures directed at meeting hydrologic management objectives is of the order of 20% of the mean annual runoff volume. Initiatives to treat that component of stormwater runoff that is discharged to the wetland to current best practice objectives would further reduce stormwater pollutant loads by 80% of

TSS and 45% of nutrients, thus giving an overall mean annual TSS and nutrient load reductions of 84% and 56% respectively.

These WSUD elements can only be holistically implemented through a broad combination of requirements of land use zoning under councils LEP provisions, adoption of hydrological objectives through councils DCP provisions, the development of regional integrated water cycle management plans which take into account the hydrological needs of Porters Creek and identifies potential reuse demands, and masterplans which adhere to the principles and targets required for their development in the catchment. Once these processes have been established, WSUD elements such as reuse, open space irrigation, and detention, such as those discussed in the next section, can be implemented.

6 KNOWLEDGE GAPS AND UNCERTAINTIES

This project has been designed to allow councils to apply the wetland classifcation system with a knowledge of dominant vegetation, water chemistry, dominant substratum, and typical life forms. Despite the ease of use of the classification scheme it does require a base understanding of these elements to apply the system.

The hydrological nature of wetlands has been deliberately excluded from the classification scheme. Being water-dependent, hydrology is a driving force and can distinguish between types of wetlands. However, despite the importance of hydrological regimes, there are a number of impediments with their use; hydrological information may not be readily available; quantifying hydrology may require input from an expert; and/or the natural hydrology of the region may have been previously altered by human activity. Therefore, a scheme that precludes the need for hydrological data to classify a wetland is preferable. However, for the long-term management of wetlands hydrological information is crucial.

This project develops generic water quality performance objectives for urban developments upstream of natural wetlands. While there are inherent uncertainties introduced into the methodology when trying to generalise, the main knowledge gap pertaining to the establishment of urban water management objectives in these catchments is access to reliable water quality data of natural wetlands. While there does exist a large body of monitoring undertaken by a number of groups, access to the data is extremely difficult, and while these programs provide good local information they are often transient, lacking in scientific rigour and/or not well reported and managed. Further, while discrete monitoring was identified as a key data source for this project, the data has not been readily available. To overcome this issue it is recommended that there be a well coordinated and comprehensive program of field monitoring of ambient water quality in natural wetlands.

While the planning mechanisms developed to implement the water management objectives recommended in this study were directed at councils, there was a range of recommendations aimed at state government and state government planning instruments. It needs to be acknowledged that the ability of this project to influence state government to implement these recommendations is limited.

7 CONCLUSIONS

Catchment urbanisation leads to changes in the catchment hydrology that can affect the environmental value (and ecosystem health) of natural wetlands in urban environments. A simplified wetland classification procedure has been developed to enable practitioners to undertake field identification on the types of wetlands within their region. 17 different wetland types determined by their supporting hydrology were identified in the classification scheme.

Hydrologic management objectives have been established to mitigate the impact of catchment urbanisation on the ecology of natural wetlands and are aimed at preserving the critical characteristics of the supporting hydrology of these wetland systems. WSUD strategies associated with land development in catchment upstream of natural wetlands need to include methods for preserving the pre-development drying hydrology and/or flooding hydrology characteristics in order to protect the ecology of these wetlands.

It is suggested that there are a range of WSUD elements that can be applied to meet the required water quality and hydrologic objectives that have been established by this project. Attainment of the best practice water quality objectives is now standard industry practice for new urban developments. Similarly WSUD elements coupled with effective masterplanning can be applied within new development release areas to attain hydrologic objectives. The hydrologic objectives are reasonable and attainable and not beyond the industry to deliver. Examples of these elements have been suggested and are further detailed in Appendix B.

However, it is only through effective strategic planning and the translation of the hydrologic objectives into councils planning instruments that these objectives will be delivered by developers, and the protection of natural wetlands from the typical impacts of urban development can be amelorated.

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APPENDIX A: WATER SENSITIVE URBAN DESIGN SOLUTIONS FOR CATCHMENTS ABOVE WETLANDS – WETLAND CLASSIFICATION SCHEME

APPENDIX B: WATER SENSITIVE URBAN DESIGN SOLUTIONS FOR CATCHMENTS ABOVE WETLANDS – CATCHMENT HYDROLOGIC INDICES AND PERFORMANCE OBJECTIVES FOR DEVELOPMENTS

APPENDIX C: WATER SENSITIVE URBAN DESIGN SOLUTIONS FOR CATCHMENTS ABOVE WETLANDS – A PROCEDURE FOR DETERMINING CATCHMENT STORMWATER QUALITY OBJECTIVES

APPENDIX D: WATER SENSITIVE URBAN DESIGN SOLUTIONS FOR CATCHMENTS ABOVE WETLANDS – PLANNING MECHANISMS

Water Sensitive Urban Design Solutions for Catchments above Wetlands

Appendix A: Wetlands Classification Scheme

May 2007

Hunter & Central Coast
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Water Sensitive Urban Design Solutions for Catchments Above Wetlands

DOCUMENT SERIES:

Overview Report

Appendix A: Wetlands Classification Scheme

Appendix B: Catchment Hydrologic Indices and Urban Water Management Performance Objectives

Appendix C: A Procedure for Determining Catchment Stormwater Management Objectives

Appendix D: Planning Mechanisms

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1 INTRODUCTION

Ecological Engineering Pty Ltd was commissioned by the Hunter Councils to investigate Water Sensitive Urban design (WSUD) solutions for catchments above wetlands. The project will form part of the Lower Hunter & Central Coast Regional Environmental Management Strategy (LHCCREMS), and joint venture of the seven Councils that comprise the Lower Hunter and Central Coast Region – Cessnock, Maitland, Port Stephens, Newcastle, Lake Macquarie, Wyong and Gosford.

For the purposes of this study, a wetland is considered to be 'downstream' of urbanisation if it receives drainage from the urban area. The wetland may also be located in an already urbanised catchment and be exposed to other urban impacts such as edge effects, filling and weed invasions. One of the notable environmental stressors to a wetland receiving drainage from urban catchment is alteration to the water regime. It is well established that catchment urbanisation can bring about significant changes to the hydrology in, and associated increased pollutant export from, catchments. Hydrologic and hydrodynamic characteristics that can affect the environmental value (and ecosystem health) of natural wetlands in urban environments include the *hydrologic regime*[1], flood frequency and flow-duration responses to catchment urbanisation. Often the "drying" frequency is as important as the inundation frequency in preserving the inherent values of natural wetlands.

The hydrologic and hydrodynamic characteristics of a natural wetland system are altered differently, as its catchment is urbanised, and it is essential that specific management objectives be formulated (as part of development conditions) to protect the values of downstream wetlands. It is envisaged that the types (e.g. ephemeral systems, marsh systems, hybrid systems etc.) and locations (e.g. geological setting, groundwater influence etc.) of wetlands will require different catchment management responses. This project is directed at establishing water management (i.e. water quality and hydrology) objectives for developments upstream of natural wetland systems.

Rather than focusing on larger-scale water cycle management, which is typical of most WSUD planning instruments, this project will concentrate on the finer resolution dynamics that are important to wetlands.

The tasks for the project include:

1. Adopt or develop a wetland classification system

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[1] *Hydrologic Regime* describes the probabilistic temporal distribution of inundation depth in a water body

2. Derive and describe a generic supporting hydrology
3. Adopt/derive a target inflow water quality for each wetland classification
4. Undertake hypothetical case studies
5. Field-based case study - Porter Creek Wetland
6. Formulate a planning response

Addressing the first task, this report documents the development and characteristics of a wetland classification scheme.

2 OVERVIEW

A variety of classification schemes were reviewed in formulating the scheme presented in this report. It was determined that there was a need to derive a classification scheme that can be used without the need for in-depth research and comprehensive hydrologic data. Importance was also placed on the need to derive a scheme specific enough to distinguish between important wetland types and their characteristic supporting hydrology.

The classification scheme is designed for use by individuals with some knowledge/experience of wetlands and natural resource management. However, an important aspect of the system is that it does not depend on input of expert knowledge for quantifying hydrology and assessing long-term hydrologic data (which is not always available). The scheme is designed to allow assessment of the four main factors for classifying wetlands to be accomplished in a site visit. Some additional desktop research may be of assistance in gathering supportive/interpretive information such as geomorphology and flow characteristics.

On a broad scale, this classification scheme is designed to enable identification of the appropriate supporting hydrology and water quality parameters for each wetland type. This information can then be utilised to inform management decisions with regard to urban development in catchments above wetlands.

This scheme is designed to assist in the protection of biotic communities associated with wetlands by recognising and conserving the distinctive features of supporting hydrology and water quality. It is beyond the scope of this project to provide for individual species protection. Provisions have been made within this scheme to allow classification and management of large mosaic wetlands. In some circumstances this scheme can be used to classify degraded wetlands, this is however, dependent on the degree of degradation and the existence of remnant vegetation.

3 THE VALUE OF WETLANDS

Wetlands are among the most variable and productive types of ecosystems. They are dynamic, transitional environments that link terrestrial and aquatic ecosystems and are consequently highly variable in their nature. Being the interface between land and water, they are home and are hosts to numerous species, from phytoplankton to macroinvertebrates to birds and mammals.

Wetlands are highly valuable to humans and are of crucial importance to the natural world. As a consequence, the anthropogenic concept of *value* of natural environments tends to have either a conservation or exploitation focus depending on the philosophy of the human assessor. In less developed human communities there tends to be a tense balance between these values. However, in developed communities these values are often in clear conflict. Table 1 lists a number of common values of wetlands and illustrates the distinction between conservation and exploitation in terms of human values.

Table 1 - Wetland Values

Conservation	Exploitation
Plant and animal habitat	Fisheries and aquaculture
Biological diversity	Forestry and plant harvesting
Water quality regulation	Agriculture
Water quantity regulation	Wastewater and stormwater disposal sites
Climate – peat (carbon sink for global warming)	Land for urban development
Ecosystem services (processing and regulation of energy and materials)	
Cultural heritage	
Tourism and recreation	
Educations	
Value to science	

Exploitative uses are readily quantifiable and benefit private individuals and many wetlands have often been exploited to the detriment of the natural value of wetlands. The skewed incentive structure that favours the exploitative aspects of wetland use over the public good conservation aspects has resulted in the destruction of more than half of Australia's wetlands since European settlement (Bennett 1997). Many factors threaten wetland environments, but alteration of the natural water regime as a result of exploitative uses, such as those listed in Table 1, is perhaps the largest cause of wetland degradation.

The value of wetland conservation is gaining appreciation throughout the world at the regional, state and international level. The international Ramsar Convention in 1971 (see

Section 3) helped to trigger much of the drive that wetland conservation receives today. The work that the Hunter Councils are undertaking to protect their wetlands is one such example. The “WSUD solutions for catchments above wetlands” strategy has been developed in recognition of the inherent value of wetlands and recognition of the impact of urban development on wetlands.

3.1 Wetland Function

Fundamental to the inherent value of wetlands are the functions and services they provide. The ability of a wetland to provide these services, such as the ecosystem and biodiversity services outlined in the following sections, depends on the extent to which wetland natural function is protected or impeded. The main elements of wetland function are determined by hydrology, the physical and chemical properties of the substratum, biotic components and organic matter accumulation and decay. The interactions between these elements are complex and a shift or change in one element has the potential to modify many others. A simplified conceptual model of the relationships between various elements of wetland function, and potential threats from urban development, is illustrated in Figure 1.

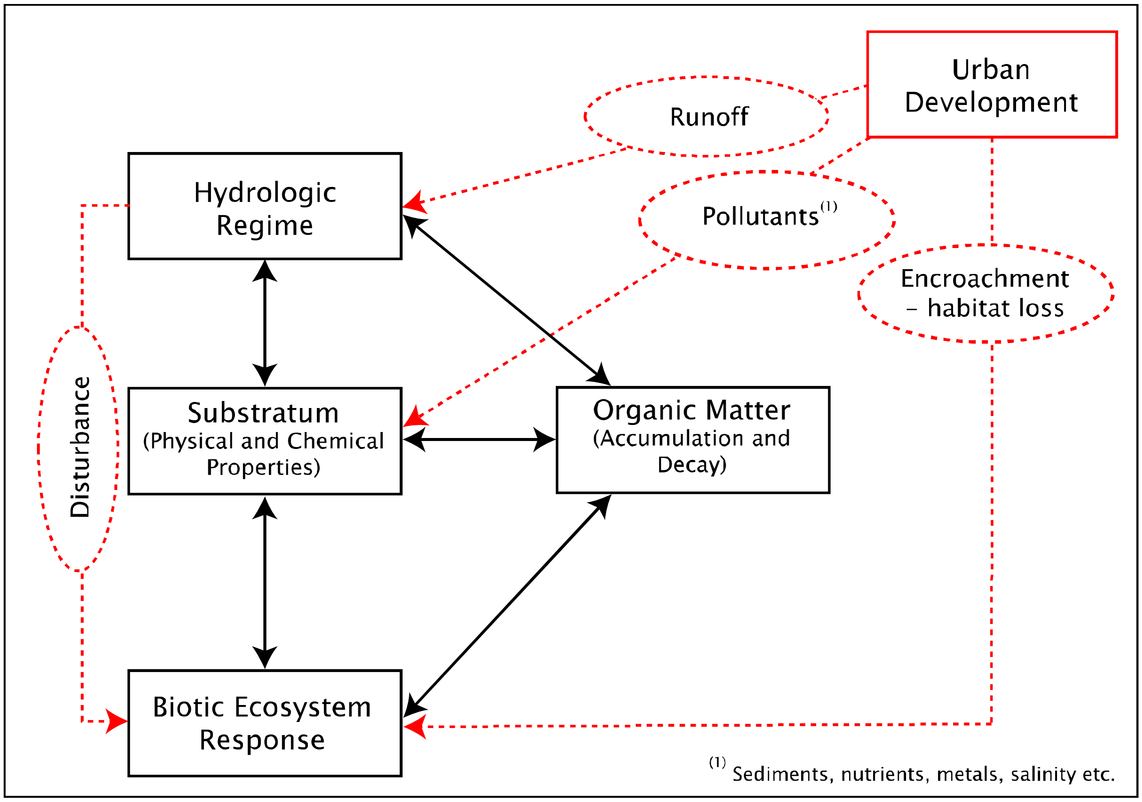


Figure 1 - Conceptual model of wetland function indicating potential threats from urban development to the natural function of wetlands (after Breen 1992)

The hydrologic regime of wetlands determines the depth, frequency, duration and temporal pattern of flooding and drying. These features of the hydrologic regime influence the characteristics of the substratum. The wetting and drying pattern influences both the physical (e.g. gas diffusion) and chemical (e.g. redox) characteristics of the substratum. For example, wet conditions tend to result in:

- decreased oxygen supply to the substratum,
- chemically reducing conditions,
- decreased rates and completeness of organic matter decomposition, and
- increased organic matter content of the substratum.

Dry conditions tend to result in:

- increased oxygen supply to the substratum,
- chemically oxidising conditions,
- increased rates and completeness of organic matter decomposition, and
- decreased organic matter content of the substratum.

As well as inundation frequency and duration, *the frequency and duration of drying* is an important feature of wetland function. The frequency and duration of dry periods will determine to the degree to which the above processes occur (e.g. re-oxygenation of the substratum and increased decomposition of organic matter)

The combination of hydrologic regime and substratum characteristics in turn selects for a particular range of plants. For example, wetland plants need to be able to tolerate periods of wetting and low sediment oxygen supply. The differing abilities of plants to tolerate such conditions results in plants that are adapted to different positions in a wetland gradient, from dry to permanently wet. The resulting vegetation community in turn provides habitat for fauna. Wetland vegetation also has a feedback effect on sediment conditions by providing a supply of organic matter. The organic matter content of substratum influences the water holding capacity of sediments and can influence physical and chemical conditions. On a macro scale, vegetation provides a resistance to flow and determines the flow pattern of water movement through the wetlands. From the interactive wetland model illustrated in Figure 1, it can be seen that the nature and extent of a wetland can be expected to change both spatially and temporally with changes in catchment landuse and climate.

Another important factor that facilitates the selects of a particular range of plant species in a wetland is the salinity gradient. The salinity gradient is an additional species selection factor to hydrology (depth and frequency of inundation gradient) but is strongly linked to it due to the influence it can exert on salinity concentrations (e.g. freshwater flooding).

Salt tolerant vegetation includes a variety of grasses, reeds, sedges and shrubs (Knight and Duke 2003). Halophytes (salt-loving plants) have developed various methods of avoidance, tolerance and excretion. Adaptations such as pneumatophores (breathing-roots) and salt excretions from leaves, along with the effects of competitive exclusion, have resulted in plant species and communities that exist along a salinity gradient from brackish (many salt marsh species, *Phragmites*) to moderate (mangrove species) to marine (seagrasses) (Grosshans and Kenkel 1997).

The cycles of freshwater inundation are often important for many of these salt tolerant species, which thrive in freshwater, and exist in saline environment due to competitive exclusion (Grosshans and Kenkel 1997). The impacts of urbanisation can impact on plants across the entire salinity gradient. Plants that exist in predominantly freshwater environments can be negatively impacted as a result of increasing salinity concentrations that are characteristic of runoff from an urban catchment. Alternatively, increases in runoff volume can result in saline environments becoming more brackish and therefore salt tolerant species are outcompeted by freshwater or brackish species (Knight and Dale 2003).

3.2 What requires protection

As urban areas expand and pressure from development continues to increase, it is difficult to preserve wetlands in their natural state so tradeoffs are often made. To ensure that the tradeoffs are well-informed and well-reasoned, wetland values must be prioritized; the attributes of wetlands that give the highest value in terms of conservation should be protected. Prioritizing the values of wetlands will guide conservation and management objectives, which are crucial for effective management. Of all of the values of wetlands, ecosystem function (which in turn provides ecosystem services) and biodiversity are perhaps the most important.

3.3 Ecosystem function and structure, and ecosystem services

In relation to wetlands, on a basic level, ecosystem function includes the trapping and exchange of energy, the cycling and flux of materials and the regulation of flows. Basic ecosystem function also incorporates the exchange of materials between organisms and the physical environment, and the flux of materials and energy between adjoining systems.

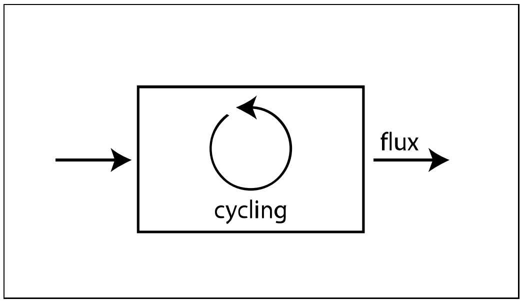


Figure 2. Conceptual model of cycling and flux

These mechanisms are important for provision of broader functions including nutrient processing, trophic cycle provision, buffering of high flows, improvement of water quality, provision of habitat, and so on.

Ecosystem function is typically correlated with ecosystem structure. The main structural factor in wetlands that can be altered by humans is the vegetation. Vegetation communities provide habitat and resources for other biota and possess a wide variety of functional attributes. Significant changes to this ecosystem structure can disturb and impede ecosystem function.

Ecosystem functions are often more robust and can be preserved even if ecosystem structure has been degraded, but the extent to which the structure can be altered needs to be identified. Although changes to ecosystem structure may not disturb ecosystem function, changing the type and composition of vegetation may severely impact local biodiversity, especially in regard to rare or endangered species.

This natural functioning of ecosystems (the interactions among and between biotic and abiotic constituents) also provides ecosystem services to people (Ecosystem Services Project 2004). Ecosystem services are the social, cultural, spiritual, lifestyle, intellectual and economic benefits gained directly from the natural function of ecosystems. These benefits (ecosystem services) include factors such as, the maintenance of soil fertility, climate regulation, insect pest control and provision of shade and shelter. The World Resources Institute estimated that ecosystem services contribute over $30 trillion to the global economy per annum, but their value still fails to gain recognition in economic frameworks (Brown et al. 2000).

A specific example of an ecosystem service might be the natural ability of a wetland to provide habitat for the predators of agricultural pests or to provide cultural, spiritual or educational values within the urban environment. Few ecosystems are as effective in this regard, in the urban environment, as wetlands. Although self-sustaining under natural conditions, the ability of ecosystems to continue to provide such services is hampered by broad-scale changes to land and water management practices within the catchment.

A greater understanding of ecosystem services can also guide the development of technology that is both advanced and ecologically sustainable. Ecological technology, such as water sensitive urban design (WSUD), often tries to imitate the processes and functions of ecosystem services. For example, bioretention systems, widely used as a water quality improvement measures in WSUD, mimic natural water filtration processes achieved by soil and catchment vegetation.

3.4 Biodiversity

Biodiversity refers to the variety of all life forms in an environment – the different plants, animals and microorganisms, their genes and the ecosystems of which they are a part. The term biodiversity encompasses the diversity within and between species, the diversity of ecosystems and the ecological complexes of ecosystems that provide our natural capital (EPA 1999; EA 2001; EA 2003).

Biodiversity underpins the structure and function of ecosystems and is fundamental to the sustainability of the world's natural resources (EA 2001). An ecosystem with high biological diversity is resilient to disturbance and has capacity to cope with environmental change (Brown et al. 2000). As the number of species and the genetic diversity within individual species diminishes, a community will become more susceptible to disease and will be less productive (Brown et al. 2000). Although all species are important, the loss of a keystone species in particular can fundamentally alter the organisation and integrity of an ecosystem.

As well as being crucial for ecosystem health, biodiversity provides numerous benefits to humans. Some of the direct benefits that humans receive include livelihoods based on ecotourism, resources for the pharmaceuticals industry and genetic material for crop and livestock breeding.

To ensure that ecosystems remain healthy and the services that they provide are maintained, it is essential to maintain and encourage high biodiversity. Biodiversity provides ecosystems with an insurance policy, as highly diverse communities are resilient and resistant to ecological and environmental change. It is particularly important when the rate of environmental change is fast, such as climate change. It can be assumed that high biodiversity ensures a high level of redundancy and that there will always be species able to adapt or be pre-adapted to any changed conditions. Biodiversity should also be preserved for its inherent value, as well as for the value it provides humans.

Changes to the structure of an ecosystem can alter biodiversity, which can consequently impede ecosystem function and may cause the loss of species. Some changes to the structure of an ecosystem are acceptable, so long as the ability of the wetland to function remains, but care must be taken to ensure that biodiversity remains high. Determining the threshold of structural change – for both biodiversity and ecosystem function – presents a challenge.

3.5 Threats to wetlands from urban development

The potential threats to wetland function discussed below are not exhaustive. Complex interactions and alterations to natural cycles and processes, as a result of urbanization, can result in a wide variety of changes to a naturally functioning system. These threats can impact on physical, chemical and biological attributes of a wetland system.

Threats to wetland function result, primarily, from:

- alterations to hydrology
- physical disturbances as a result of altered hydrology
- alterations to the chemical and physical properties of the substratum (in particular, changes to the wetting and drying pattern)
- direct encroachment on biotic ecosystems

Alterations to hydrology can occur at various levels. The volume of runoff into a wetland can be increased or decreased, although it is typically increased as a result of urbanisation. The frequency and duration of drying can also be altered (i.e. changes to inundation patterns). Groundwater recharge or discharge may be impeded by changes to re-charge zones.

Physical disturbances as a result of altered hydrology can occur in terms of direct flood damage on vegetation, erosion and/or deposition of substratum, changes to substratum particle size distribution and changes to inflow and/or outflow patterns.

Alterations to the chemical and physical properties of the substratum can also be linked to changes in the quantity and quality of the overlying water. The substratum and overlying water can both be subject to changes in parameters such as pH, redox potential, dissolved oxygen, nutrients, toxicants and suspended solids. The physical properties of the substratum can be altered in terms of sediment removal and deposition (typically deposition) and changes in sediment particle size distribution.

Direct encroachment of urban development on biotic ecosystems results in and contributes to alterations of the elements listed above. Land clearing, filling and artificial drainage are typical practices that directly encroach on wetland systems.

These threats from urban development can have the following impacts within a wetland system:

- redistribution and loss of vegetation communities,
- deterioration of both water and sediment quality within the wetland,
- deterioration of water quality and modification of water volume flowing out of the wetland, and
- loss of individual species and biodiversity or changes to species composition.

The extent to which an impact affects natural wetland function is highly variable and related to the severity of the impact and the type of wetland present. The severity of the impact on the wetland will determine the degree to which the provision of services (e.g. ecosystem and biodiversity services) by that wetland will be impeded. To this end it is necessary to correctly classify the wetland type to ensure that potential threats, and subsequent impacts, can be ascertained and managed by establishing an appropriate supporting hydrology.

3.5 A suggested hierarchy of attributes that need protection

A hierarchy of attributes can be constructed to help guide the prioritization of management initiative to protect wetland values. It is suggested that wetland attributes, or values, could be priorities as follows:

1. Wetlands as natural landscape or physiographic features need to be protected.
2. Wetland function needs to be protected. For example, the ability of a wetland to process and cycle energy and materials needs to be maintained. This is fundamental to the support of a structurally diverse community.
3. The macro-structure of the wetland needs to be protected. For example, attributes that would cause a wetland to be classified as shallow marsh, deep marsh, etc. need to be preserved as an important precursor to the preservation of ecosystem function. This may be achieved but still result in a change in community structure.
4. The environmental conditions for rare and endangered communities (wetland structure) need to be protected.
5. The habitat conditions for rare and endangered species (plants and animals) need to be protected.

This is an ecological hierarchy with each level supporting the next (i.e. the protection of wetlands as natural landscape features inherently protects species and habitats associated with the wetland). However, it is clear in some circumstances that the protection of individual taxa may become a priority.

4 WETLAND CLASSIFICATION

Like many ecosystems, it is difficult to define what a wetland actually is. Wetlands are particularly hard to define as they are essentially transitional between truly aquatic and terrestrial ecosystems. The large number and wide variety of wetland definitions and classification schemes indicate this complexity.

Wetlands are inherently difficult to define for a number of reasons, the major one being that many of them are sometimes flooded and, at other times dry. Some common attributes that make wetlands difficult to define are listed below.

1. Wetlands do not have precise borders that can be readily mapped, so there is unavoidable imprecision.

2. Wetland boundaries are not constant but shift seasonally or in response to long climatic cycles as inundation varies.

3. Wetlands are dynamic and are subject to rapid changes, so data from multiple years and seasons is required.

4. The nature and types of wetlands varies throughout the world in response to different geographic and climatic characteristics.

5. There is a tradeoff between a broad classification scheme that encompasses a wide area and a more specific scheme that relates to a particular geographic area. A classification that is too general will have little use for management purposes. However, if it too specific, a scheme cannot be applied to other areas, leading to multiple disjointed classification systems.

6. Factors used to identify wetlands, like edaphic and vegetative characteristics (i.e. hydric soils and hydrophytes), are often correlated so offer a circular definition.

Rather than having multiple classification schemes that essentially duplicate each other, it is more efficient to have a unified scheme that provides an integrated approach to wetland classification throughout the world. Such a scheme was developed at the International Convention on Wetlands held in Ramsar, Iran in 1971. The scheme developed at the Ramsar

Convention is valuable in that it is not geographically specific so provides a common understanding of the term and types of wetlands that occur throughout the world. To encompass the broad range and diversity of wetland systems in the world though, specificity was sacrificed. Although accepted by over 70 countries, the classification and definition provided by the Ramsar Convention is too broad and its acceptance and utility is questioned. The wide breadth of the definition has meant that the definition is of little use for management purposes.

Reflecting the inadequacies of the Ramsar Classification System, alternative classification systems have been developed. These systems are more specific – some relate to a local area (e.g. Wyong, NSW – Winning and Duncan 2001), some to a particular geographic region (e.g. Victoria, Australia – Corrick and Norman 1980) and others apply to a whole country (e.g. USA – Cowardin *et al* 1979) – and are therefore more useful for management purposes. As a consequence, many different classification systems are used throughout the world. In Australia, for example, wetland inventory and classification has been conducted largely at the state level. Without integrated classification schemes, it is not possible to formulate national or international databases of wetland types and condition. As a result, holistic assessment and management is not feasible.

Whilst there is no overarching understanding of what constitutes a wetland, all share the notion that a wetland undergoes periods of both wetting and drying, and that the saturation of the wetland substratum is the dominant factor that determines the type and composition of wetland vegetation, which is the dominant structural element of most wetlands.

4.1 Factors that can be used to classify wetlands

Existing classification systems have used numerous factors as the basis for distinguishing between types of wetland ecosystems (Pressey & Adam 1995). In NSW, for example, wetlands have generally been divided according to broad geographic areas. Further to these major groupings, Goodrick (1983) and Pressey and Harris (1988) divided NSW wetlands based on vegetation. Winning (1988) then followed by breaking the state into major physiogeographic regions and classifying distinct wetland types according to hydrology and geomorphology. Riley et al. (1984) based their classification scheme, which is the most detailed classification system in NSW, on geomorphology. Goodrick (1970) classified coastal wetlands based on vegetation and water regime.

Numerous factors can be used to classify wetlands, as illustrated in Table 2. Some factors offer greater utility than others, as they can be readily surveyed in the field, on topographic maps or in aerial photographs. The nature of the study and background information available will often make one approach more feasible. For example, if hydrological data has not been gathered, classifying a wetland based on its physicochemical and biological characteristics is likely to be more efficient.

Table 2 - Range of biotic and abiotic factors that can be used to classify wetland types

Type of Factor				
Physical	**Hydrological**	**Geomorphologic**	**Chemical**	**Biological**
· Terrain · Geography · Substratum type · Substratum composition · Climate	· Inundation frequency · Inundation depth · Inundation duration · Inundation regularity · Water source	· Basin shape · Basin size · Position in catchment	· pH · Nutrient status · Salinity · Soil chemistry · Water chemistry	· Vegetation composition · Vegetation life form · Fauna

5 DEFINITION OF A WETLAND

Numerous classification systems have been reviewed prior to the development of the classification scheme adopted in this report. The utility of each of the schemes and the various factors that distinguish between wetland types were assessed. Table 3 illustrates the type of analysis undertaken. It shows the main characteristics of a subset of classification schemes that are designed for application at different geographic scales. Refer to the References (Section 11) for a complete list of classification schemes reviewed. In light of our assessment, a classification scheme has been developed, as described below.

Table 3 - Main characteristics of a subset of classification schemes reviewed

Source	Geographic scale	Levels	Chief determinant	Secondary determinants	Classes	Comments
Breen 1990	General	4	Water source	Vegetation; substrate; water chemistry	–	Review; too broad to be a useful.
Ramsar 1971	Global scale	3	Marine/coastal; inland; human-made	Hydrologic regime; size; geomorphology	42	Widely accepted but limited use; too broad.
Cowardin *et al.* 1979	National – USA	5	Geomorphic origin; broad hydrology; substrate type	Vegetation	>28	Too many groups; some lack distinction.
Corrick and Norman 1980; Corrick 1981, 1982	State – Victoria	8	Water type, depth and permanence	Dominant vegetation life form	28	
NSW DLWC (DLWC 2000)	State – NSW	3	Geographic region	Water source; general description	18	
Winning and Duncan 2001	Local – Wyong LGA	–			–	Identifies wetlands of conservation value.

The definition of a wetland used in this report is based on the definition developed by Cowardin *et al.* (1979). Wetlands are defined as lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water (<2.0 metres). Wetlands must have one or more of the following characteristics:

1. at least periodically, the land supports predominantly hydrophytes;
2. the substratum is predominantly undrained hydric soils; and
3. the substratum is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year.

The upland limit for a wetland is defined as the boundary between:

- land that has predominantly hydrophytic cover and land that has mesophytic or xerophytic cover;
- soil that is mostly hydric and soil that is mostly non-hydric; or
- land and that is flooded or saturated at some time each year and land that is not (Cowardin *et al*. 1979).

6 CLASSIFICATION SCHEME DEVELOPED FOR THIS REPORT

In formulating the classification scheme used in this report, a wide range of existing classification schemes were reviewed (see References). The strengths and weaknesses of the schemes were assessed and the relative merits of each were incorporated into the developed scheme. Although there was no specific intention to devise a new classification scheme, none of the existing schemes were deemed suitable for the task at hand in terms of scope, detail and utility.

To validate and test the scheme that has been developed, it was compared to a range of other classification schemes. The classes and types of wetlands were verified against existing schemes to ensure that no types of wetlands were omitted. Categories from existing schemes were hypothetically aligned with classes in the developed scheme. For example, the subcategories 'salt pan, salt meadow and salt flats' of Corrick and Norman's (1980) 'Semi-permanent Saline Wetlands' fit into the Inland Flats category in our scheme, and the Ramsar (1971) 'Inter-tidal marshes' (Category H) into Salt Marsh.

The hierarchical classification scheme developed for this report is based on:

1. dominant vegetation;
2. dominant substratum;
3. water chemistry; and
4. typical life forms.

The scheme has been devised in such a way that knowledge of these four factors alone will be sufficient to classify a wetland. Recognizing that wide-ranging and long-term information is often limited, the classification scheme only necessitates a site inspection. Each of these four components can be determined in the field.

The hydrological nature of wetlands has been deliberately excluded from the classification scheme. Being water-dependent, hydrology is a driving force and can distinguish between types of wetlands. However, despite the importance of hydrological regimes, there are a number of impediments with their use; hydrological information may not be readily available; quantifying hydrology may require input from an expert; and/or the natural hydrology of the region may have been previously altered by human activity. Therefore, a scheme that precludes the need for hydrological data to classify a wetland is preferable. However, for the long-term management of wetlands hydrological information is crucial.

Vegetation has been used as the primary determinant for the classification because:

- vegetation is relatively easily observed compared with other parameters;
- many plant taxa can be identified with minimum training and may not necessitate an expert biologist (although expert botanical information is desirable);
- life forms are recognizable on remote sensing products;
- to a large degree, vegetation responds to and expresses the environmental conditions of wetlands;
- in many circumstances, it is the vegetation that is the object of management, often through hydrologic manipulation (Cowardin *et al*. 1979; Winning and Duncan 2001).

Similarly, characteristics of the dominant substratum and water chemistry can be easily ascertained. A sample of soil, deemed typical of the wetland, should be examined to determine its structure, composition and organic matter content. The salinity and pH of water can be tested in the field using appropriate equipment (e.g. pH meter, electrical conductivity meter) or from first-hand field observation.

Table 4 presents the draft structure of the hierarchical classification. Like other hierarchical keys, the steps of the classification process follow the order of the table from left to right; the dominant type of vegetation is to be determined first, followed by dominant substratum, water chemistry, and typical plant form. Appendix 2 provides the definitions of the terms used in the classification process.

Although the classification can be completed without knowledge of the water regime, information about the water regime can be useful to ascertain the derived classifications. The water regime of each type of wetland is quantified in more detail in Table 5. Table 5 documents the typical inundation water, frequency of drying, inundation depth, duration of drying and inundation regularity for each type of wetland.

This system could potentially be used to classify degraded wetlands if sufficient remnant vegetation was present (see Section 9.2 – Degraded Wetlands)

Each of the different wetland classes are described in more detail in Appendix 2. After classifying each wetland with the key (Table 4), the classification results should be checked by comparing a given wetland with its description provided in the text. The description of each type of wetland includes:

- Hierarchical identification;
- Definition;

- Location;
- Vegetation;
- Substratum;
- Water chemistry;
- Hydrology;
- Significance;
- Management issues; and
- Australian example.

Not all of the 17 wetland types included in the classification scheme will occur in the Lower Hunter and Central Coast Region. However, the scheme encompasses all of the major types of wetlands so will be applicable and can be used throughout NSW and Australia.

Table 4 - Hierarchical structure of the wetland classification scheme

Dominant Vegetation	Dominant Substratum	Water Chemistry	Typical plant forms		Name	Water Regime
Algae	Mineral/ organic	Marine	May support benthic algae	1	**Coastal Flats**	Tidal
	Mineral	Saline	May support algae	2	**Inland Flats**	Ephemeral/ seasonal
Herbaceous Angiosperms	Peat	Fresh/Acid /Coloured	Mosses/ sedges	3	**Bogs**	Saturated – impeded drainage; permanent/ seasonal
	Organic	Fresh	Large emergent macrophytes	4	**Deep Marsh**	Permanent
	Organic/ Mineral	Fresh	Emergent macrophytes	5	**Fen**	Groundwater saturated/ seasonal – permanent
	Mineral	Fresh	Emergent macrophytes	6	**Shallow Marsh**	Ephemeral/ seasonal
	Organic/ Mineral	Marine/ Saline	Emergent macrophytes, some shrubs	7	**Salt Marsh**	Tidal/ seasonal/ ephemeral
	Organic	Marine	Submerged macrophytes	8	**Seagrass beds**	Permanent/ tidal
	Organic	Saline	Submerged macrophytes	9	**Deep Salt Pans**	Permanent
	Organic	Fresh	Submerged macrophytes	10	**Deep Open Water**	Permanent
	Mineral/ organic	Fresh	Submerged macrophytes	11	**Shallow Open Water**	Ephemeral/ seasonal
Woody Angiosperms	Peat / Organic /Mineral	Fresh / Acid / Coloured	Shrubs	12	**Wet Heath**	Saturated / ephemeral – seasonal
	Organic	Marine	Trees	13	**Mangrove**	Tidal
	Mineral	Fresh	Shrubs	14	**Scrub Swamp**	Ephemeral/ seasonal
	Organic/ Mineral	Fresh	Trees	15	**Forest Swamp – Wet**	Ephemeral/ seasonal
	Mineral/ Organic	Fresh	Trees	16	**Forest Swamp – Ephemeral**	Ephemeral
	Mineral	Fresh	Trees	17	**Forest Swamp – Dry**	Irregular

Table 5 - Wetland category and hydrologic variable matrix

Wetland Category	Inundation Water (Typical)	Inundation Regularity	Inundation Depth (m)	Duration of drying	Frequency of Drying/Exposure (once/unit)
1. Coastal Flats	Marine	High	0 – 4+	0 – 12 hours	0 – 12 hours
2. Inland Flats	Saline	Low	0 – 1+	1 – many years	1– many years
3. Bogs	Rainwater	High	0 – 0.1+ (saturated)	1 – 2 months	1 – 3 years
4. Deep Marsh	Freshwater	High	0.3 – 0.6+	1 – 4 months	1.5 – 3 years
5. Fen	Freshwater	High	0 – 0.6+	1 – 6 months	1.5 – 3 years
6. Shallow Marsh	Freshwater	Low–Medium	0 – 0.3	3 – 6 months	3 – 6 months
7. Salt Marsh	Marine	Medium–High	0 – 0.3	1 day – 1 month	1 day – 6 months
8. Seagrass Beds	Marine	High	0+ – 10+	0 – 6 hours	≥ 6 months
9. Deep Salt Pans	Saline	Low	0 – 2	2 – many years	1 – 2+ years
10. Deep Open Water	Freshwater	Medium	1 – 2+	1 – 6 months	3 – 5 years
11. Shallow Open Water	Freshwater	Low	0.5 – 1.5	3 – 6 months	0.5 – 2 years
12. Wet Heath	Rainwater (Freshwater)	High	0 (saturated)	3 – 6 months	3 – 6 months
13. Mangrove	Marine	High	0 – 1.5+	6 – 12 hours	6 – 12 hours
14. Scrub Swamp	Freshwater	Low	0 – 0.3	6 – 9+ months	6 – 9 months
15. Forest Swamp – Wet	Freshwater	High	0 – 2+	2 – 6 months	1 – 3+ years
16. Forest Swamp – Ephemeral	Freshwater	Medium	0 – 1+	4 – 8 months	annually
17. Forest Swamp – Dry	Freshwater	Low	0 – 0.2+	8 – 12+ months	annually

7 APPLICATION OF THE CLASSIFICATION SYSTEM

This classification system was developed as a tool for use on a broad geographic scale. Accounting for the complexity and diversity of wetlands the descriptions have been designed to encompass a range of characteristics for each wetland type while still providing distinct classes.

7.1 Mosaics

Some wetland areas, particularly when large in size, will consist of several classes of wetland. For example, the Porters Creek wetland (Wyong) has areas of deep marsh, shallow marsh, scrub swamp and several forest swamp classes. This classification system can be used to identify the wetland type/s that are most threatened within the wetland mosaic.

Initially, all wetland types within the area are classified and the percentage of each determined. For example, 15 % deep marsh, 25 % shallow marsh, and 60 % scrub swamp. The threats to the wetland from the urban development are also identified. Using this information, the most threatened wetland type/s within the wetland area can be identified. A dominant supporting hydrology for the wetland as a whole will then be selected based on the most threatened wetland type/s within the area. Figure 3, below, illustrates the steps taken in choosing the appropriate supporting hydrology for large mosaic wetlands using this system.

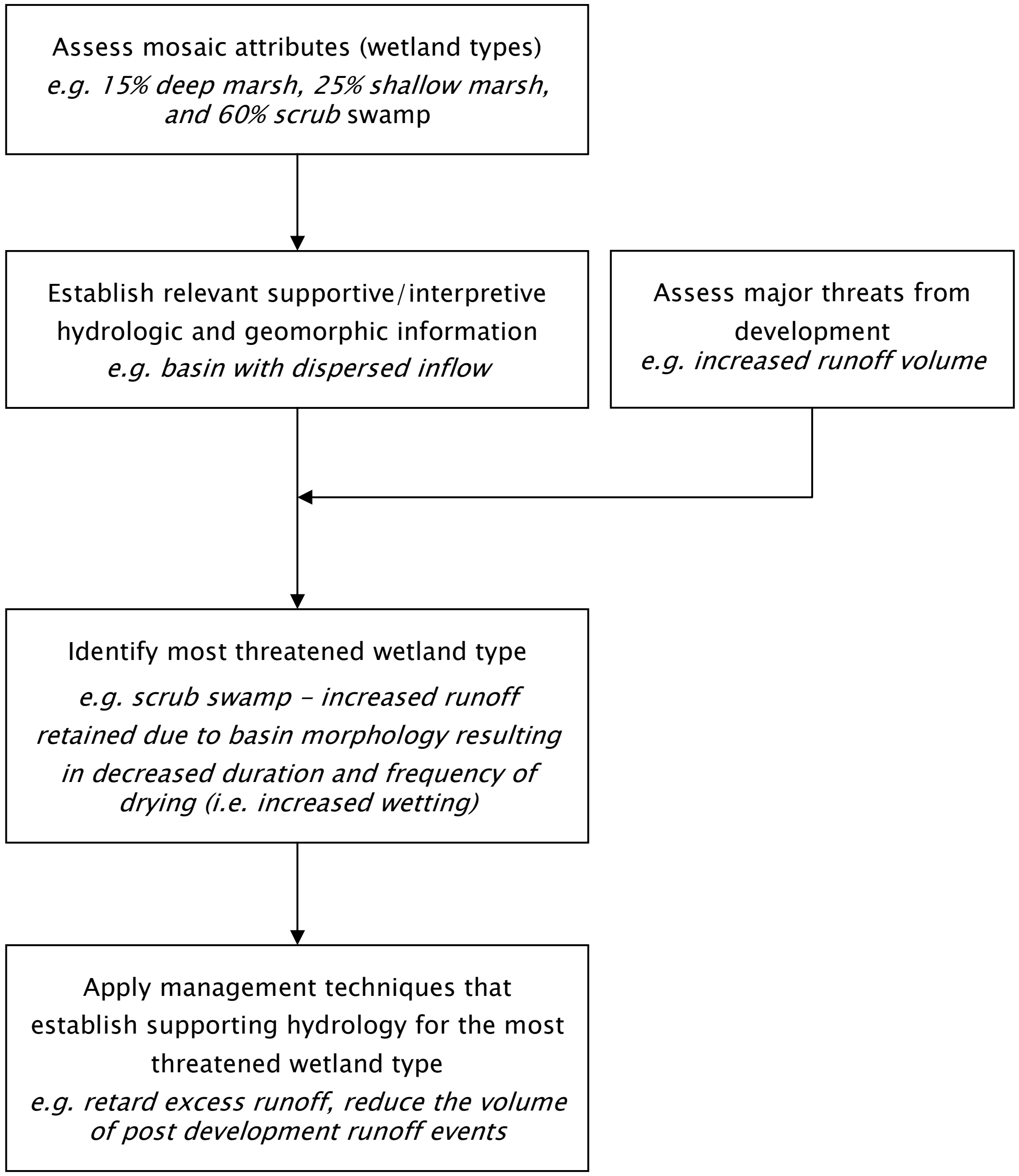


Figure 3 - Flow chart outlining the application of the classification system to a large mosaic wetland

7.2 Supportive/Interpretive Information

To ensure that specificity is achieved, in relation to applying the appropriate supporting hydrology for each individual wetland, supporting information on the hydrology and geomorphology of the wetland can be utilised. This information assists in determining what the most appropriate remediation techniques will be and to ensure the appropriate supporting hydrology (hydrologic regime) is applied to each wetland.

The supporting, or interpretive, information may include:

- *Geomorphology* – e.g. floodplain, upland, basin, billabong, old river channel
- *Inflow and Outflow Characteristics* – e.g. discrete, dispersed, restricted, unrestricted, multiple inlets/outlets

Some examples of how this supporting/interpretive information assists in determining the degree of impact a threat, such as an increase in runoff volume, has on a particular wetland type are illustrated below in simplified diagrams (Figures 4 to 7).

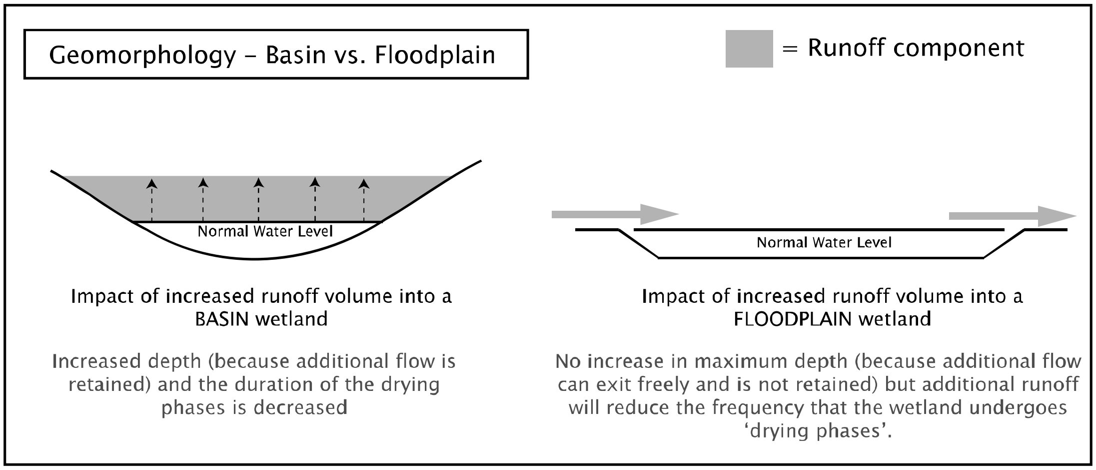
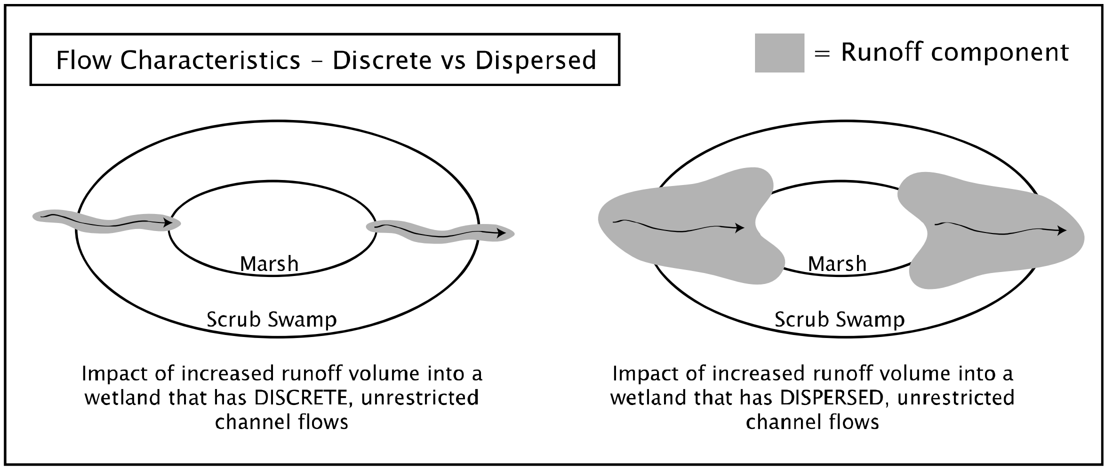


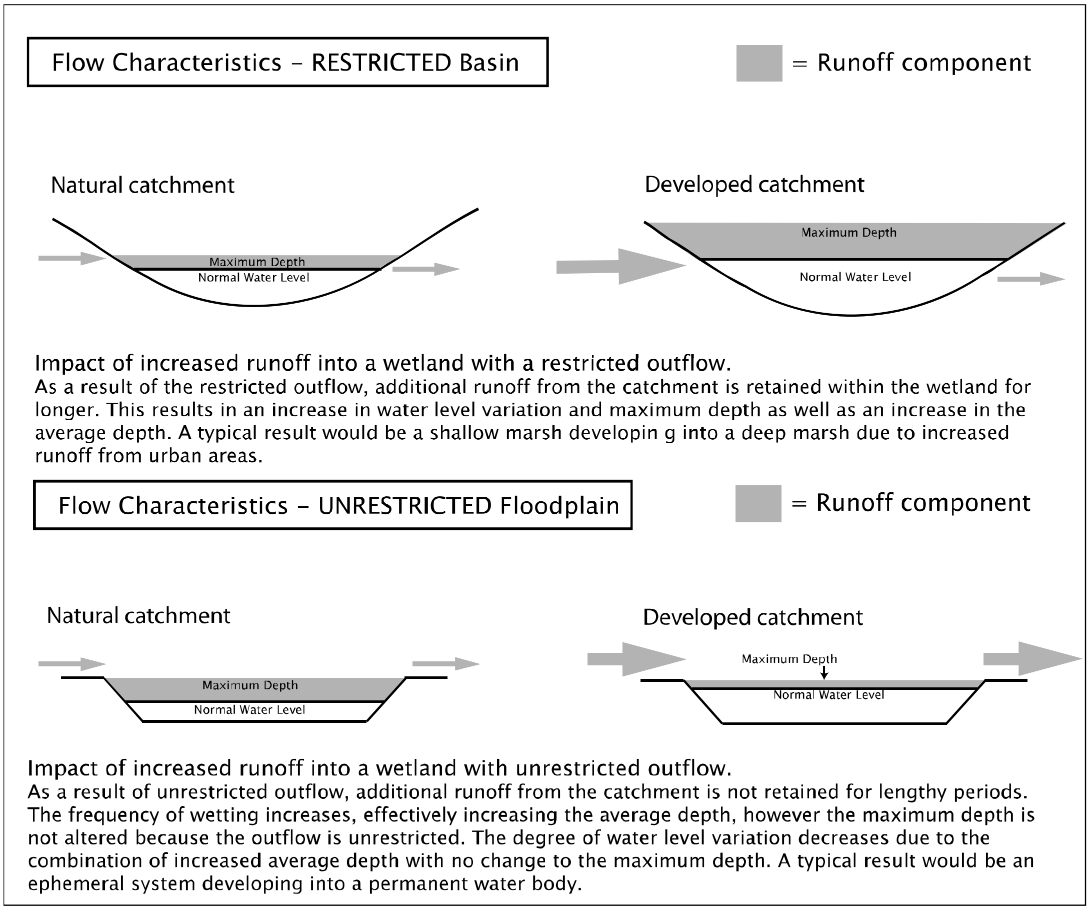
Figure 4 - Effect of geomorphology (basin vs. floodplain) on the impact of increased runoff volume



Impact of increased runoff volume into a wetland that has DISCRETE, unrestricted channel flows

Impact of increased runoff volume into a wetland that has DISPERSED, unrestricted channel flows

Figure 5 - Effect of discrete and dispersed flow on the impact of increased runoff volume



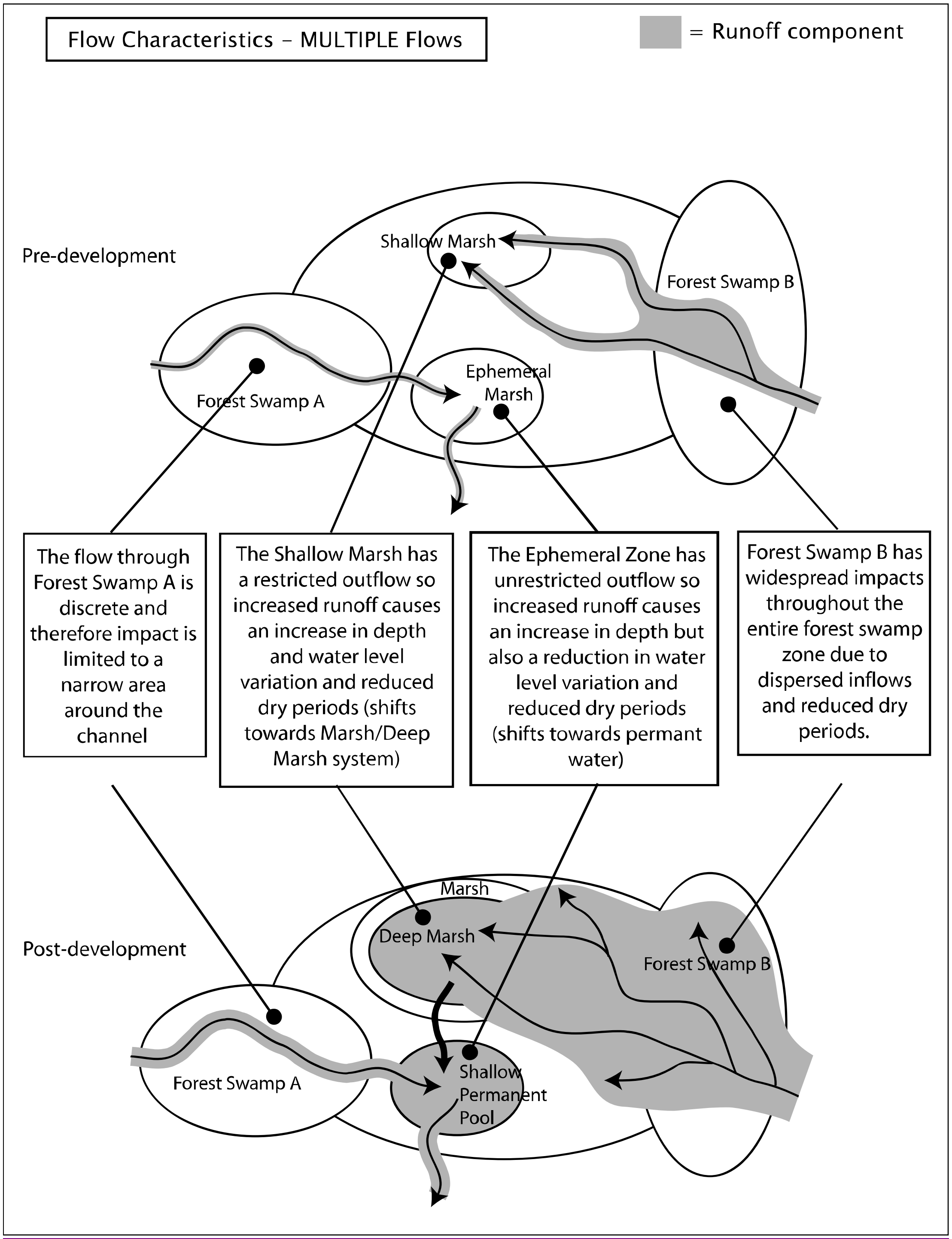
Impact of increased runoff into a wetland with a restricted outflow.

As a result of the restricted outflow, additional runoff from the catchment is retained within the wetland for longer. This results in an increase in water level variation and maximum depth as well as an increase in the average depth. A typical result would be a shallow marsh developin g into a deep marsh due to increased runoff from urban areas.

Impact of increased runoff into a wetland with unrestricted outflow.

As a result of unrestricted outflow, additional runoff from the catchment is not retained for lengthy periods. The frequency of wetting increases, effectively increasing the average depth, however the maximum depth is not altered because the outflow is unrestricted. The degree of water level variation decreases due to the combination of increased average depth with no change to the maximum depth. A typical result would be an ephemeral system developing into a permanent water body.

Figure 6 - Effect of restricted and unrestricted flow on the impact of increased runoff volume, before and after development



The flow through Forest Swamp A is discrete and therefore impact is limited to a narrow area around the channel

The Shallow Marsh has a restricted outflow so increased runoff causes an increase in depth and water level variation and reduced dry periods (shifts towards Marsh/Deep Marsh system)

The Ephemeral Zone has unrestricted outflow so increased runoff causes an increase in depth but also a reduction in water level variation and reduced dry periods (shifts towards permant water)

Forest Swamp B has widespread impacts throughout the entire forest swamp zone due to dispersed inflows and reduced dry periods.

Figure 7 - A conceptual diagram of a mosaic wetland illustrating a variety of potential impacts from increased frequent flow runoff volume on various wetland types within the mosaic

7.3 Dominant Hydrologic Pathway

Hydrologic regime is a major factor responsible for the differences between wetlands. Table 5 is an attempt to quantify a series of hydrologic variables that can distinguish between wetlands. However, these variables contain no information on the dominant hydrologic pathway responsible for delivering water to wetlands. Water can be delivered to wetlands via a range of pathways, as illustrated in Figure 8. The principal pathways (hydrology types) are:

1. Flooding as a result of over-bank flows from a channelised catchment (an inside-out flood pattern)

   (e.g. inland flats, some shallow and deep marshes, some swamp forests)

2. Flooding or saturation as a result of diffuse drainage from a poorly or non-channelised local catchment (diffuse flood pattern)

   (e.g. some shallow or deep marshes, some wet heath, scrub swamp)

3. Flooding or saturation as a result of groundwater expression

   (e.g. fen)

4. Flooding or saturation as a result of direct rainfall

   (e.g. bog

Impacts of urbanisation on wetlands can vary, depending on which of the hydrologic pathways, or hydrology types, (outlined above) is the dominant pathway delivering water to the wetland.

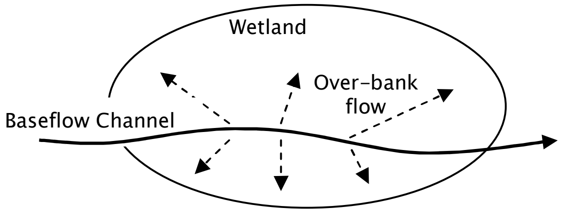
For wetlands with type 1 hydrology that are regularly wet, it is important to protect their drying hydrology (i.e. to ensure their relief from the stress of inundation is preserved and that they continue to have an adequate drying phase). For wetlands with type 1 hydrology that are regularly dry, it is important to protect their flood hydrology (i.e. ensure they continue to get an adequate pattern of inundation) as well as their drying hydrology (i.e. their drying phase is preserved).

For wetlands with type 2 hydrology it is important that the diffuse pattern of inflow, such as localised runoff from the fringe areas of the wetland, is maintained and their drying hydrology is preserved (i.e. they continue to have an adequate drying phase). Wetlands with type 2 hydrology are very sensitive to the introduction of point source inflows typical of conventional urban development.

For wetlands with type 3 hydrology, it is important to protect the drying hydrology (i.e. ensure the duration of the drying phase is not increased). This largely has to do with preserving adequate infiltration in recharge zones. This is complicated by the size and proximity of the groundwater catchment.

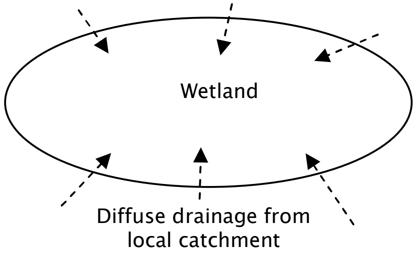
Wetlands with type 4 hydrology need to be completely isolated from any developed catchment runoff.

Hydrologic Pathway Type 1



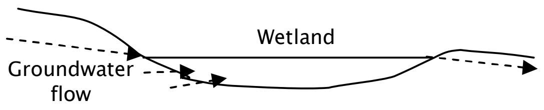
Over-bank flows provides pathway for delivery of water to wetland

Hydrologic Pathway Type 2



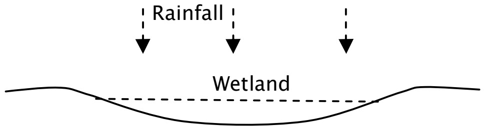
Diffuse drainage from local catchment delivers water to wetland

Hydrologic Pathway Type 3



Groundwater expression delivers water to wetland

Hydrologic Pathway Type 4



Direct rainfall delivers water to wetland

Figure 8 - Illustrations of the four dominant hydrologic pathways (hydrology types) delivering water to wetlands

8 WETLAND CATEGORY AND HYDROLOGIC VARIABLES

8.1 Inundation Water

This term describes the dominant source and quality of water for the wetland:

- Marine – coastal saltwater (tidal)
- Saline – inland saltwater
- Rainwater – water entering the wetland as direct rainfall
- Freshwater – non-saltwater water entering the wetland as either surface runoff or groundwater

8.2 Inundation Regularity

This term is a qualitative assessment of the predictability of the water source.

8.3 Inundation Depth

This term is a simple estimate of the typical water depth range for each of the selected wetland categories. Inundation depth can vary widely depending on climatic conditions. This term is intended to include the depths that may be experienced on time scales relevant to the biological responses of plants (i.e. does not cover depths that may be experienced during major floods).

8.4 Duration of Drying

This term is an estimate of the period of time during any one “drying episode” the wetland sediments are exposed. The duration of drying may be short (hours) and highly regular (tidal coastal flats) or long (many years) and highly irregular (arid inland flats). For drying periods greater than a month some aeration of the sediments can be expected. Aeration of the sediments is an important factor in reducing the stress on plants growing in anoxic environments like flooded sediments.

8.5 Frequency of Drying

This term is an estimate of how frequently the sediments of particular wetland categories experience a drying episode. The wetting and drying sequence can be a highly variable feature of a wetland. The frequency of wetting and drying brings both water supply and the physiological stress of flooding on the wetting cycle and the release of flood stress and potential water stress (drought) on the drying cycle.

8.6 Hydrologic Regime

The hydrologic regime of a wetland is a feature determined by a combination of the frequency and duration of drying and the depth and predictability of inundation. The combination of these factors results in a “wetness gradient”. Plants have adapted to various ranges within this wetness gradient and, as a result, wetlands with different hydrologic regimes typically supporting different vegetation types.

9 LIMITATIONS OF THE CLASSIFICATION SYSTEM

9.1 Biodiversity

As discussed previously, maintaining a diverse biotic system is important for the long-term survival of a wetland system. However due to the nature of this classification system, developed for broad-scale use, it is beyond its scope to incorporate considerations for individual threatened species within each particular geographic region or wetland class. Further to this, rare and threatened species lists are not static documents and require regular update. A thorough flora and fauna survey of the area would be required if rare and threatened species were thought to exist within a particular region or wetland.

This classification system does, however, serve to protect the vegetation communities associated with the various wetland types that have been identified. Protection of community diversity indirectly protects much of the species diversity associated with that community.

9.2 Degraded Wetlands

This classification system is designed to protect existing wetlands downstream of potential urban development. As a result, the dominant vegetation, water chemistry, substratum and dominant plant forms in natural systems are used to classify the wetland type. In a severely degraded wetland these elements would likely be absent and therefore a detailed topographic analysis and access to long-term hydrologic records would be required to determine the wetland type that existed previously. Expert knowledge and analysis would be required for each individual degraded wetland and is beyond the scope of this classification system.

In degraded wetlands where there is remnant vegetation present this classification system could possibly be used to determine the wetland type that existed previously. Remnant vegetation can be classified and assumptions made, based on the type of remnant vegetation, as to the type of wetland and supporting hydrology that existed prior to degradation.

10 KNOWLEDGE GAPS AND UNCERTAINTIES

This classification system attempts to group and describe the major wetland types that will occur in many areas throughout the State. However such a broad approach will always miss particular wetland types or mosaic systems in any particular region or location. In particular the relationship between a wetland type and supporting hydrology for any specific wetland can be very difficult to describe in a broad classification scheme. For example while the relationship between wetland hydrology and wetland vegetation is well known in the generic sense, this relationship is poorly understood for most specific wetland types. The quantification presented in this report is simply based on our best estimates and needs to be confirmed through field studies and research. Similarly the importance of any changes to supporting hydrology for any specific wetland has to be considered with respect to the hydrologic type (ie. pattern of inflow) and the geomorphology of the wetland basin. Such factors are difficult to incorporate into a generic classification system without creating a large number of categories, which starts to decrease the utility of the system.

The general relationship between wetland hydrology and specific wetland classes (and vegetation types, eg marshes, swamps, etc.) needs quantification based on specific field studies. Such studies need to relate hydrographic time series, topographic survey, and vegetation spatial distributions.

11 CONCLUSION

The classification scheme developed for this report should enable the classification of different types of wetland within the Lower Hunter and Central Coast Region. The scheme has been designed to enable easy adaptation for use throughout NSW and Australia as it encompasses all of the major types of wetlands. After a detailed hydrologic analysis, WSUD solutions for Lower Hunter and Central Coast catchments above wetlands will ultimately be developed in accordance with these 17 wetland classification types.

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APPENDIX 1 DESCRIPTION OF WETLAND TYPES

1. Coastal Flats

Hierarchical identification

Algae → Mineral/Organic → Marine → May support benthic algae

Definition

Coastal flats are areas of soft substratum found in the intertidal region along the coast. These wetlands have no vegetation as such, except for benthic algae and cyanobacteria (NSW Fisheries 2004).

Coastal flats include the flats associated with marine embayments, estuaries and lagoons, as well as intertidal mudflats and sandflats. The classification does not include areas that are external to the land mass, like coral reefs, beaches or intertidal platforms.

Although coastal flats can be affected by flows from rivers, they are tidal and therefore the inundation water is marine. Being tidal, most coastal flats are inundated daily corresponding to the high tide. Some coastal flats may not always be flooded daily as the tidal range changes as the tides alternate from spring (large tidal range) to neap tides (small tidal range).

Location

Coastal flats are located along the sea-land boundary. They extend inshore as far as the zone of tidal influence, so can include flats associated with coastal estuaries, for example.

Vegetation

Due to the action of waves and tides, and the marked changes in salinity and water depth each day, vascular (higher) plants do not inhabit coastal flats. Benthic algae and cyanobacteria (blue-green algae) are the dominant type of vegetation found on coastal flats. Benthic algae grow attached to the surface of various substrata, including rocks, snags and sediment particles.

The filamentous algae *Lamprothamnium*, which is tolerant of salinities up to 150,000 mg/L (seawater is typically 35,000 mg/L), may occur in coastal flats along with species of cyanobacteria.

Substratum

The soft substratum of coastal flats is generally sand or silt but varies in particle size and organic matter content. Areas with finer sediment particles and a high organic load are commonly referred to as ‘mud flats’.

The sediment may be derived from marine sediment or be fluvial deposits from coastal rivers.

Water chemistry

Coastal flats are essentially marine in terms of their inundation water. Although based around the salinity levels of the sea, salinity will vary depending on the amount of evaporation, whether freshwater flows over the flats, the timing of the freshwater flows (if any) relative to the tides, and the drainage regime (e.g. whether the flats are free-draining or restricted).

Hydrology

The hydrologic regime of coastal flats is defined as tidal. Coastal flats are frequently inundated and exposed. In the most part, the water regime of coastal flats has a regularity that reflects the daily movement of the tides so water depth differs depending on the time of day. Minimum depth will depend on the tidal range which will alternate between spring and neap tides. Spring tides represent the maximum tidal range, whereas neap tides have the minimum tidal range. Wetlands typically vary between mesotidal and macrotidal. Mesotidal areas have a tidal range between 2 metres and 4 metres. Tidal action and wave activity are the most influential hydrologic factors in mesotidal areas. Macrotidal coastal areas have a tidal range greater than 4 metres. In these areas, like the north-west coast of Western Australia for example, tidal currents are the dominant influence.

The duration of inundation varies with distance from the sea. Areas close to the low tide mark will be inundated for the longest periods of time, possibly up to 12 hours with exposure only at low tide.

Hydrologic characteristics

Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Marine	0 – 12 hours	0 – 4+	0 – 12 hours	High

Significance

Coastal flats support a very diverse benthic (bottom-dwelling) community. Algae and cyanobacteria provide food and shelter for smaller fish and aquatic animals, which in turn provide food for many larger fish species such as flathead, flounder and whiting (NSW Fisheries 2004).

Management Issues

- River regulation alters the natural flooding pattern of rivers and may result in destruction of river mouths and reduced tidal action.

- Waterbird habitat. Australia has obligations under the China Australia Migratory Bird Agreement (CAMBA) and the Japan Australia Migratory Bird Agreement (JAMBA) agreements to conserve waterbird habitat represented by coastal flats.

Australian example

- The geographically small mudflats in Western Port Bay, Victoria.
- The large intertidal mudflats in Roebuck Bay, Western Australia.

2. Inland Flats

Hierarchical identification

Algae → Mineral → Saline → May support benthic algae

Definition

Inland flats are similar to coastal flats, with the main distinction being their geographic location and the associated influence of the sea. Whereas coastal flats are characterized by tidal inundation, the hydrologic regime of inland flats is either ombrotrophic (atmospheric) or minerotrophic – with water sourced from rainfall, groundwater or surface water. Such systems may be depressions with little catchment (rainfall), shallow windows into saline groundwater, or terminal or semi-terminal depressions in a surface drainage system.

By definition, inland flats occur in all areas that are not near the coast, but they predominantly occur in semi-arid and arid regions. Evaporation in these regions is typically high, so the wetlands tend to be saline.

Location

Inland flats generally occur in arid areas, like the alluvial sandplains and dunefields of western NSW. They occur in a variety of geomorphic situations, including (Goodrick 1984):

- Terminal playas (lakes) of major streams.
- Clay pans and lakes of old drainage systems often located in dune fields and sand plains. The drainage systems are partly or completely occluded.
- Clay pans that are located in dune fields and sand plains and receive local runoff.

Vegetation

Most inland flats are high in salinity and are dry for the majority of time, so vegetation is generally restricted to algae and cyanobacteria (blue-green algae) that grow after flooding. The filamentous algae *Lamprothamnium*, which is tolerant of salinities up to 150,000 mg/L (seawater it typically 35,000 mg/L), may occur along with species of cyanobacteria.

In some inland flats, salt tolerant *Ruppia* species (Sea tassel) may grow. Saltbushes, bluebushes, copperburs and samphire may occur around the fringes of an inland flat wetlands.

Substratum

Inland flats have mineral substratum, as the small amount of organic matter that is received decomposes relatively quickly. Due to the high evaporation rates in semi-arid regions, chemical precipitates (evaporites) are deposited on the soil surface. The least soluble salts (magnesium and calcium carbonates) precipitate first, followed by sodium and potassium sulphates. Lastly, and in the centre of the pan, sodium and potassium chlorides and magnesium sulphate are deposited.

Water chemistry

The water chemistry of inland wetlands depends on the season and hydrologic characteristics. Wetlands in arid regions typically have high rates of evaporation and, as a result, they are characteristically saline. Seasonal evaporation rates and inflows typically influence the duration of inundation and the salinity of inland wetlands and therefore these factors are highly variable (Goodrick 1984).

Hydrology

Inland flats generally rely on local and regional runoff for inundation, although some wetlands may also be fed by groundwater (e.g. from surrounding dune systems). The duration of inundation is typically determined by the size of the inflows and the seasonal evaporation rates (Goodrick 1984). Most inland flats exist in arid and semi-arid areas, so commonly undergo extended dry periods.

Hydrologic characteristics

Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Saline	1- many years	0 - 1+	1 - many years	Low

Significance

When flooded, many of the large salt lakes and playas found in north-western NSW support large waterbird populations. As a result, these areas are highly valuable for the conservation of waterbirds (DLWC 2000).

Current land management practices do not interfere with the flooding and drying cycles of these wetlands. Due to the unaltered state of their hydrologic regime, this wetland type is considered to be one of the most well represented, in its natural state (DLWC 2000).

Management issues

- Grazing is a common occurrence in inland flats, and the hooves of the livestock may destroy soil structure and increase the probability of erosion - fluvial erosion will be limited but topsoil can be transported by wind (aeolian erosion).

- Feral animals, such as pigs, goats and foxes, threaten both the flora and fauna of inland flats.

- Extraction, or other alterations, to groundwater storages may threaten the natural hydrology of wetlands that typically experience natural interactions with groundwater.

- Waterbird habitat for breeding and feeding.

Australian example

- Lake Eyre, Northern Territory.

3. Bogs

Hierarchical identification

Herbaceous angiosperms → Peat → Fresh/coloured/acidic → Mosses/sedges

Definition

Bogs typically form in basins with impeded drainage but a limited catchment, resulting in an area of wet spongy peat consisting chiefly of mosses and small herbs. Bogs frequently occur in highlands or other cool regions where decomposition rates are low. The pH of a bog is typically low, so they are often very acidic. As decomposition rates are low, bogs tend to be oligotrophic (nutrient deficient) (Gore 1983).

Location

Bogs may occur at any elevation, but they are most common in sub-alpine regions (>1000 metres above sea level). Being primarily fed by precipitation, bogs do not occur in river floodplains or valleys.

Vegetation

Bogs are dominated by small herbs that can tolerate saturated conditions. Mosses requiring moist wet habitat conditions are ideally suited to the wet and spongy bog environments. Consequently, *Sphagnum* mosses are characteristic of most bog wetlands.

Substratum

One of the most distinctive characteristics of bogs is their peat substratum. Peat is classified as an organic soil because it contains greater than 12-20% organic matter (Hammer 1991). Organic soils can be further sub-divided on the basis of the degree of decomposition of the organic matter (Mitsch & Gosselink 1993). As opposed to muck that is poorly structured and well decomposed, peat is well structured and organic matter is only partially decomposed. Peat consequently is fibrous and it typically forms in acidic conditions.

Hydrology

Bogs are ombrotrophic so receive water that falls directly on them as rain or snow. Bogs have impeded drainage so their soil is typically saturated. Bogs may have permanent surface water as well, or may only pond on a seasonal basis corresponding to periods of rainfall.

Hydrologic characteristics

Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Rainwater	1 – 3 years	0 – 0.1+ (saturated)	1 – 2 months	High

Significance

Bogs are unique habitats and are populated with organisms that are adapted to the unusual conditions. With the loss or reduction in bog wetlands, there will also be a loss or reduction in biodiversity. Unlike other habitats, there are few environments that offer similar conditions to bogs, so alternative refugia and environmental retreats are limited, making biodiversity loss even more likely. The globally threatened corroboree frog, *Pseudophryne corroboree*, is one such example.

Management Issues

- Peat mining and extraction
- Feral animals
- Weed invasion
- Biodiversity
- Fire
- Grazing
- Habitat for fauna
- Scientific research – Due to the slow rates of decomposition, organic matter is more likely to stay intact and can be used for carbon dating and pollen analysis (palaeontology), providing information on climatic and ecological change.

Australian example

- Ginini Flats, located near Mount Ginini, Namadgi National Park, in the upper reaches of the Cotter River catchment. The site is about 40 km southwest of Canberra, and is a good example of a *Sphagnum* bog at its northern limit in the Australian Alps. The site provides an important breeding ground for the globally threatened corroboree frog, *Pseudophryne corroboree* (Wetlands International 2004).
- Great Dividing Range, Victoria.

4. Deep Marsh

Hierarchical identification

Herbaceous angiosperms → Organic → Fresh → Large emergent macrophytes

Definition

Deep marsh wetlands have deep and, for the most part, permanent surface water and are dominated by large emergent macrophytes, like reeds. The substratum has a high content of organic matter due to almost permanent inundation. Water is sourced from local rainfall, upstream catchments and occasionally some groundwater. The water is typically fresh, but can become brackish periodically.

Location

Deep marshes are usually located in relatively deep channels or depressions in the floodplains of major rivers. They occur most extensively at the end of river systems.

Vegetation

Deep marshes are dominated by large emergent vegetation. The macrophytes, like reeds and rushes, occur in dense stands often growing to a height of 1.5 metres. One species may dominate a marsh system, such as *Typha* species or *Phragmites australis*.

Substratum

As opposed to the frequent drying cycles experienced by shallow marshes, deep water marshes are inundated for the majority of the time. Due to the predominantly anaerobic conditions in permanently inundated systems, decomposition is slower. Slow decomposition results in substratum with an organic content greater than 12 – 20% and is therefore defined as organic. The higher organic content of deep water marshes can distinguish them from shallow marshes that generally have mineral substratum.

Water chemistry

Being sourced primarily from rivers and local precipitation, deep marshes have freshwater, but can become brackish periodically.

Hydrology

The majority of water flowing into deep marsh wetlands comes from surrounding catchments, although local precipitation and groundwater may also be sources. Deep marshes develop where there is surplus water from rivers or in areas where the flow of a river is regulated creating weir pools. Deep marshes almost always have surface water, although the depth of the water may fluctuate depending on inflows and seasonal evaporation rates. In years of average or above average rainfall, deep marshes will usually have water to at least 0.5 metres deep. Reflecting the hydrologic regime of these wetlands, plants in deep marshes require long-term and/or regular inundation, but they can survive dry periods as long as they are not prolonged.

Hydrologic characteristics

Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Freshwater	1.5 – 3 years	0.3 – 0.6+	1 – 4 months	High

Significance

The dense stands of vegetation in deep marshes provide a sheltered habitat for waterbirds, like crakes, rails and reed warblers. Some of these wetlands, like those along the Murray River, are important breeding grounds for waterbirds, such as ibis and spoonbills.

Reed-dominated marshes have proved to be very efficient at treating and improving the quality of water. They effectively reduce nutrient and sediment loads, thereby increasing the quality of water received by downstream ecosystems.

Management Issues

- Waterbird habitat
- River regulation
- Grazing
- Fire
- Feral animals
- Water quality

Australian example

- The Macquarie Marshes and the Great Cumbungi Swamp occur at the end of major river systems – the Macquarie and Lachlan Rivers respectively.
- The Wanganella Swamp north of Deniliquin dominated by Cumbungi (Typha species) is an example of a deep marsh that is the result of regulated river flows. Channels are often controlled by herbicides or mechanical means.

5. Fen

Hierarchical identification

Herbaceous angiosperms → Organic → Fresh → Emergent macrophytes

Definition

Fens are similar to marshes in that they are dominated by emergent macrophytes, have freshwater, and their substratum is organic, particularly in the upper layers. Unlike marshes that principally receive water from local precipitation or catchments, fens are minerotrophic, receiving flows from groundwater. Fens are essentially windows into the groundwater, and they are usually covered wholly or partly with shallow water or are frequently inundated (Breen 1990).

Location

Being fed by groundwater, fens are found in low-lying areas and moist depressions.

Vegetation

Like marshes, fens are characterized by emergent macrophyte species, such as *Eleocharis* species and *Cyperus* species

Substratum

Fens have soil with greater than 12-20% organic matter content, and are thus classified as organic. Although the organic content of fen soils may be almost as high as peat, the organic matter is well decomposed, with little structure.

Water chemistry

The actual chemistry of the water and soil of fens vary widely, but tend to be less acidic than peat, and can even be alkaline. Fen soils are also more mineral-rich than peat. As groundwater is often rich in minerals, fens are typically eutrophic and have a plentiful supply of nutrients for plant growth. Consequently, they are generally very productive ecosystems.

Hydrology

Fens are influenced by water derived predominantly from outside their own immediate limits. Fens are predominantly dependent on groundwater, but may also receive runoff from local catchments. They are characteristically saturated with groundwater as they occur in areas that are windows into the water table. In the case of fluctuating water table levels, fens can be seasonally inundated or saturated, but can also be permanent.

Hydrologic characteristics				
Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Freshwater	1.5 – 3 years	0 – 0.6+	1 – 6 months	High

Significance

Like other wetlands, fens offer habitat and a feeding sites for waterbirds (i.e. ibis, herons, egrets, spoonbills and ducks) (Pressey 1981). A loss or reduction in fens has the potential to cause impact biodiversity.

Management Issues

- Grazing
- Groundwater extraction
- Draining
- Land reclamation
- Weed invasion

Australian example

- West coast of Tasmania.
- Lowlands (together with mangrove) along the north coast of the Australian mainland, Northern Territory.

6. Shallow Marsh

Hierarchical identification

Herbaceous angiosperms → Mineral → Fresh → Emergent macrophytes

Definition

Shallow marshes are dominated by emergent macrophytes, like rushes and sedges. Unlike deep marshes, they do not always have surface water, but their period of inundation is either seasonal or ephemeral. Although the maximum water depth of a shallow marsh may not be much less than that of a deep marsh, the mean water level is notably lower.

As shallow marshes are not always flooded, the substratum is chiefly mineral and has relatively little organic matter. Water is sourced from local rainfall, upstream catchments and occasionally some groundwater. The water in a shallow marsh is typically fresh.

Location

Shallow marshes occur in shallow depressions in floodplains and are often associated with riverine forests and woodlands.

Vegetation

Shallow marshes are dominated by emergent vegetation. These species are adapted to both wetting and drying, and must be able to cope with prolonged dry periods. Typical plant taxa include *Eleocharis* species, *Cyperus* species and *Juncus* species

Substratum

The substratum in shallow marshes is defined as mineral as it has an organic content less than 12-20%. Frequent aerobic conditions during the dry periods enable extensive decomposition, resulting in limited build up of organic matter.

Water chemistry

Being sourced primarily from rivers and local precipitation, shallow marshes have freshwater.

Hydrology

Most water in shallow marshes is sourced from rivers and their catchments. Water may only flow into shallow marsh wetlands after large rainfall events when the flow exceeds the capacity of the river channel. Consequently, the time of inundation is directly linked to the timing of rainfall events. In tropical and semi-tropical regions, rainfall is highly seasonal and flooding will therefore also be seasonal. In temperate regions, precipitation may be more ephemeral, particularly in drier inland areas, so flooding of a wetland can be irregular and difficult to predict. Depending on geographic location, some ephemeral wetlands will be inundated numerous times a year, whereas as others will be flooded once every few years.

Although the water can be deep (>0.5 metres) on occasions, the duration of inundation is limited and water will recede within a few hours to days. In general, the water depth is shallow (<0.3 metres) and water is usually semi-permanent, relying on seasonal or ephemeral flooding.

Hydrologic characteristics

Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Freshwater	3 – 6 months	0 – 0.3	3 – 6 months	Low-Medium

Significance

Shallow marshes provide sheltered habitat and breeding grounds for waterbirds and other biota. Marshes dominated by macrophytes have proved to be very efficient at treating and improving the quality of water. They effectively reduce the nutrient and sediment load of water.

Management Issues

- Waterbird habitat
- River regulation
- Grazing
- Fire
- Feral animals
- Water quality

Australian example

- Chittaway Bay and the mouth of Wallarah Creek near Charmhaven, NSW.

7. Salt Marsh

Hierarchical identification

Herbaceous angiosperms → Mineral/ organic → Marine/saline → Emergent macrophytes and some shrubs

Definition

Salt marshes may be coastal or inland systems. Coastal salt marshes are typically marine systems that occur at the upper levels of the intertidal zone and are influenced by the tides or salt spray. Coastal salt marshes are not inundated daily, but are flooded by larger tides and semi-permanent pools of brackish water (NSW Fisheries 2004). Inland saline systems may be influenced by the accumulation of salts from atmospheric deposition and weathering processes in endorheic systems.

Salt marsh communities are vegetated with herbs and some woody shrubs, and occur on either mineral or organic substratum.

Location

Salt marsh communities are found along tidal shorelines that are exposed to seawater or in inland saline areas. Coastal salt marshes mainly occur in the upper tidal zone of estuaries and mangrove wetlands, but often extend up coastal rivers as far as the tidal limit. Salt marshes survive in a niche created by hyper saline conditions that restrict both terrestrial species and even mangroves (Australian Wetlands 2004). Salt marshes are found in a wide range of climatic conditions from the arctic to the tropics.

Vegetation

Vegetation in a coastal salt marsh community often occurs in distinct zones. These zones correspond with frequency of inundation. A typical zonation pattern includes *Sarcocornia quinqueflora* (samphire), *Sporobolus virginicus* (salt couch) and *Juncus krausii* (salt rush) from the sea to the land (Goodrick 1983). *Casuarina glauca* (Swamp sheoak) may also be found growing towards the landward side of a salt marsh (e.g. on the margins of the wetland) (Jacobs and Brock 1993).

Other typical species found in salt marsh wetlands include chenopods, *Atriplex* species and other *Juncus* species. Woody plants, namely small shrubs, are found on the landward side of a salt marsh, as they are less tolerant of flooding than monocotyledons (grasses, rushes etc) (Etherington 1983).

Substratum

The substratum of salt marshes is either organic or mineral. The organic content is typically a surface layer that increases as inundation frequency increases.

Water chemistry

Salt marshes often have very high salinity levels. Occupying a niche that restricts terrestrial species and even mangroves, they are exposed to hyper saline conditions (Australian Wetlands 2004).

Hydrology

Marine systems have a tidal hydrologic regime, but they are not inundated daily. Occurring at the upper boundary of the intertidal zone, salt marshes are only flooded by larger tides (spring tides or king tides) and have a short inundation period. Spring tides occur once a fortnight and king tides occur twice a year, one during summer and one during winter.

Saline systems inland are irregularly inundated as a result of rainfall and runoff. These inland systems may be inundated for periods of weeks to months.

The period of inundation will vary depending on the geographic location of a wetland. Those that occur on the margin of a mangrove forest will be inundated almost daily, whereas those in more inland regions may be flooded only once a year or less. The inundation depth of salt marsh is relatively shallow and will generally not exceed 0.3 metres.

If located a distance from the coast, salt marshes may be ephemeral or seasonal, relying on rainfall or river flows for their semi-permanent pools of brackish water (NSW Fisheries 2004).

Hydrologic characteristics

Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Marine	1 day – 6 months	0 – 0.3	1 day – 1 month	Medium-high

Significance

Salt marshes provide habitat and shelter for plants and animals. Salt marshes are an important habitat for juveniles of some fish species, such as bream and mullet. Crabs are common in saltmarsh communities, and are a significant food source for bream and other carnivorous species. Some species, such as common galaxias (*Galaxias maculatus*), deposit their eggs in saltmarsh vegetation (NSW Fisheries 2004).

Salt marshes filter the runoff from surrounding areas, reducing the suspended solid and nutrients loads that enter the coastal receiving waters. They also act as visual screens along the shoreline.

Management Issues

- Sedimentation (from clearing and erosion) alters and degrades wetland habitat.
- Urban development (clearing of habitat, increased water pollution including elevated nutrient loads, stormwater runoff and pollution).
- Conservation objectives – Australia has obligations under JAMBA and CAMBA Agreements to conserve habitat for water birds, as well as for waders and fish.
- Recreation often occurs near salt marshes with subsequent impacts (e.g. fishing and boating).
- Pressure from agriculture and urban development.
- Land reclamation – as coastal salt marshes typically occur between the mean high tide and the king or maximum tide, many saltmarshes in Australia and many other parts of the world have been lost to land reclamation initiatives.

Australian example

- Cranagan Bay, Lake Macquarie foreshore, NSW.
- Tuggarah lake foreshore in NSW.
- Anglesea, Victoria.

8. Seagrass Beds

Hierarchical identification

Herbaceous angiosperms → Organic → Marine → Submerged macrophytes

Definition

Seagrass beds occur in areas subject to tidal flooding. Unlike mangroves or salt marshes, the vegetation of seagrass beds remains submerged even during low tides. Seagrass beds are found on organic soil, which often occurs as mudflats.

Location

Seagrass beds occur along tidal shorelines that are inundated with marine seawater. On the landward side, prolonged dry periods limit the range of seagrasses, and so they are replaced by mangrove or saltmarsh wetlands. Seagrasses generally occur in estuaries and shallow coastal waters with sandy or muddy bottoms.

As seagrasses need nutrients they are often located close to mangrove wetlands, and receive these nutrients when the seawater ebbs (tide goes out). Seagrasses also require good light, so only occur in areas where the water is clear. (EPA 2003).

Vegetation

Seagrass beds consist of small herbaceous plants. Similar in structure to terrestrial plants, these marine plants have tiny flowers and strap-like or oval leaves. They are most similar to lilies, and are quite different from seaweeds, which are algae.

Typical seagrass species include *Zostera capricorni* (eelgrass), *Halophila* species (paddleweed) and *Posidonia australis* (strapweed) (NSW Fisheries 2004).

Substratum

Seagrasses generally occur in soft substratum. Although mostly on mud, which has a higher organic matter content, seagrasses are also found on sand.

Water chemistry

Seagrasses occur in marine systems and are characteristically saline. Seagrass beds are usually free draining and connected directly to the sea, so they do not experience extreme fluctuations in salinity like some coastal systems, such as salt marshes. The salinity is therefore similar to the seawater, except at river mouths. Nevertheless, seagrasses are able to cope with different salinity levels and species vary in their salinity tolerance.

Hydrology

Seagrass beds are inundated daily by the tides. They cannot grow easily where they dry out at low tide. They thrive in shallow coastal waters where there is shelter (such as a sand bar) from drying winds, wave action and strong currents which could create turbulent muddy water.

Seagrasses are normally found in shallow water up to 10 metres deep. However, they can grow at depths of 32 metres and have been found in clear water at 68 metres in parts of Queensland (EPA 2003).

Hydrologic characteristics

Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Marine	≥ 6 months	0+ – 10+	0 – 6 hours	High

Significance

Seagrasses are very efficient at photosynthesizing and are highly productive. Seagrasses contribute organic matter to the food chain, and form the basis of a complex ecosystem supporting animals like dugong, green turtles, sea urchins and some fish. They provide habitat for seaweeds and filter-feeding animals like bryozoans, sponges, and hydroids as well as the eggs of ascidians (sea squirts) and molluscs (EPA 2003). They are valuable as nursery and shelter areas for many aquatic animals, including commercially and recreationally important fish, molluscs and crustaceans.

Like other estuarine vegetation, seagrasses remove nutrients from the water and facilitate sedimentation. They also baffle water currents, preventing erosion and stabilizing sand and mud banks.

Management Issues

- Nutrient enrichment and high level of suspended solids from urban, industrial and agricultural runoff threaten seagrass beds. The nutrients facilitate algal blooms which reduce light availability. Suspended sediment also blocks light, which is essential for photosynthesis.

- The loss or reduction in the extent of seagrass beds is problematic for other species that rely on them for food and habitat, like dugongs for example.

- Seagrasses can be physically damaged by repeated trawling and outboard motors. As seagrass beds rely on mangroves for their supply of nutrients, the destruction of mangrove wetlands may disrupt seagrass bed systems as well.

- The removal of sandbanks can expose the plants to sediment-stirring waves. With a higher fraction of suspended sediment, light availability will be reduced, and without the physical barrier of the sandbanks, the beds may drain and dry out at low tide.

Australian example

- Seagrass mudflats adjacent to mangrove wetlands in Western Port Bay, Victoria.

- Seagrass beds grow in the shallow waters of eastern and southern Hervey Bay, Queensland. Due to the reduction and loss of these beds and consequent reduction in dugong numbers, they are now protected by the Hervey Bay Marine Park.

9. Deep Salt Pans

Hierarchical identification

Herbaceous angiosperms → Organic → Saline → Submerged macrophytes

Definition

Deep salt pans are saline areas of open water. Although emergent macrophytes may grow around the edges of these wetlands, they are dominated by submerged macrophytes which grow beneath the water surface. The substratum is organic and is almost always saturated as these wetlands usually have permanent surface water.

Location

Deep salt pans occur near the coast and in inland areas. Their salt may be derived from past marine intrusions, from saline groundwater inflows, or from the accumulation of salts from atmospheric deposition and weathering processes in endorheic drainage systems.

Vegetation

Deep salt pans are dominated by submerged macrophytes that are adapted to saline conditions. These plants can tolerate a range of salinity levels due to the changes in salinity caused by freshwater inflows and evaporation.

Substratum

Deep salt pans are usually found on organic substratum. The high organic content of the substratum is a reflection of the fact they are almost permanently inundated. Without exposure to air, organic matter takes longer to decompose. Submerged macrophytes, as well as other organisms, also provide a constant supply of organic matter.

Water chemistry

The salinity of deep salt pans will vary depending on the timing and size of the inflows relative to seasonal evaporation rates. In the dry season, the salinity of these wetlands rises due to the loss of water by evaporation. After rain, the salinity of these wetlands decreases, sometime markedly.

Hydrology

Except during severe drought, deep salt pans are permanent water bodies, which can extend to depths greater than 2 metres. Water is usually sourced from local catchments or groundwater.

Hydrologic characteristics				
Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Saline	1 – 2+ years	0 – 2	2 – many years	Low

Significance

Like other types of wetlands, deep salt pans provide habitat for waterbirds and other biota.

Management Issues

- Disturbance around edges of pans by livestock
- Draining
- Diversion of catchment inflows

Australian example

- Volcanic plains around Colac, Victoria.

10. Deep Open Water

Hierarchical identification

Herbaceous angiosperms → Organic → Fresh → Submerged macrophytes

Definition

Deep open water wetlands have freshwater and are often located on the floodplain of large rivers. Although emergent macrophytes may grow around the edges of these wetlands, they are dominated by submerged macrophytes. The substratum is organic and is almost always saturated as these wetlands usually have permanent surface water. However, unlike ponds or lakes, deep open water wetlands dry out occasionally.

Location

Deep open water wetlands occur in depressions alongside large rivers or at the end of inland river systems. They occur in various forms including:

1. depressions on floodplains filled by overbank flooding;
2. billabongs (oxbow lakes) which are segments of an old river channel isolated from the main flow;
3. deflation basins (large rounded lakes) formed by wind erosion of alluvial sediments; and
4. large wetlands that occur at the end of a river or creek system.

Vegetation

Deep open water wetlands are dominated by submerged macrophytes that are adapted to freshwater and depths that may exceed 2 metres. The vegetation in these wetlands is adapted to occasional drying. Typical plants include *Myriophyllum* species, *Potamogeton* species and *Vallisneria gigantea*.

Substratum

Deep open water is usually found on organic substratum. The high organic content of the substratum is a reflection of the fact they are almost permanently inundated. Without exposure to air, organic matter takes longer to decompose. Submerged macrophytes, as well as other organisms, also provide a constant supply of organic matter.

Water chemistry

Deep open water wetlands that have freshwater differ from their saline counterparts (deep salt pans) in that they are completely flushed more regularly with runoff or, if endorheic, they are more recent geological features and have not had time to accumulate salt inputs.

Hydrology

Except during drought, deep open water wetlands have permanent surface water, which can extend to depths greater than 2 metres. Water is usually sourced from local catchments or groundwater. Their main source of water comes from the seasonal or intermittent flooding of rivers. Rainfall and local runoff may also replenish the wetland during inter-flood periods.

Hydrologic characteristics

Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Freshwater	3 - 5 years	1 - 2+	1 - 6 months	Medium

Significance

Deep open water wetlands provide important nursery areas for fish, as well as habitat for waterbirds and other biota. They also help to mitigate the impact of flood events.

Management Issues

- Disturbance around edges by livestock
- Draining
- Extraction of water
- Weed intrusions
- Salinity and rising groundwater tables are affecting wetlands in some areas
- Conservation of waterbird feeding habitat and nurseries for young fish
- Floodplain structures may isolate wetlands or divert flows into other areas
- River regulation

Australian example

- King Island and west coast of Tasmania.

11. Shallow Open Water

Hierarchical identification

Herbaceous angiosperms → Mineral/ organic → Fresh → Submerged macrophytes

Definition

Shallow open water wetlands have freshwater and are often located on the floodplains of large rivers. Although emergent macrophytes may grow around the edges of these wetlands, they are dominated by submerged macrophytes. The substratum is mineral or organic, reflecting the variable wetting and drying cycles of these wetlands.

Location

Like deep open water, shallow open water wetlands occur in depressions alongside rivers or at the end of inland river systems. Shallow open water locations differ from deep water ones in that the depressions may not be so deep, they may be further from the river channel (so receive less water and flooded less frequently), or may be associated with ephemeral creeks or creeks with smaller flows. They occur in various forms including:

1. depressions on floodplains filled by overbank flooding;
2. billabongs (oxbow lakes) which are segments of an old river channel isolated from the main flow;
3. deflation basins (large rounded lakes) formed by wind erosion of alluvial sediments; and
4. large wetlands that occur at the end of a river or creek system.

Vegetation

Shallow open water wetlands are dominated by submerged macrophytes that are adapted to freshwater and depths that rarely exceed 0.5 – 1.0 metres. The vegetation in these wetlands is adapted to frequent drying, so must be opportunistic and be able to colonise and establish rapidly after inundation. Typical plants include *Myriophyllum* species and *Potamogeton* species.

Substratum

Shallow open water is usually found on organic or mineral substratum. Areas with organic soils are those that are inundated more frequently and for longer periods of time than areas with mineral substratum.

Water chemistry

Shallow open water wetlands that have freshwater differ from their saline counterparts (salt marsh wetlands or inland flats) in that they are completely flushed more regularly with runoff or, if endorheic, they are more recent geological features and have not had time to accumulate salt inputs.

Hydrology

Shallow open water wetlands are flooded on an ephemeral or seasonal basis, and may remain dry for the majority of time. The water level can exceed 2.0 metres, but will not remain at this depth for a long period of time. If the average water level of these wetlands was taken over time, they would be shallow. Their main source of water is the seasonal or intermittent flooding of rivers. Rainfall, local runoff and groundwater may also replenish the wetland during inter-flood periods.

Hydrologic characteristics

Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Freshwater	0.5 – 2 years	0.5 – 1.5	3 – 6 months	Low

Significance

Shallow open water wetlands provide habitat for waterbirds and other biota. They also help to mitigate the impact of flood events.

Management Issues

- Land reclamation
- Disturbance around edges by livestock
- Draining
- Extraction of water
- Weed intrusions
- Salinity and rising groundwater tables
- Conservation of waterbird feeding habitat and nurseries for young fish
- Floodplain structures may isolate wetlands or divert flows into other areas
- River regulation

Australian example

- King Island and west coast of Tasmania.

12. Wet Heath

Hierarchical identification

Woody Angiosperms → Mineral/ organic /peat → Fresh/coloured/acidic → Shrubs

Definition

A wet heath is an area dominated by shrubs growing on substrata of variable composition that is regularly saturated, and only occasionally flooded. The substratum of wet heath can be mineral, organic or peat depending on the duration of saturation and the acidity of the interstitial water. Wet heaths resemble bogs in their water chemistry, but as the soil is not constantly saturated, they are able to support a more diverse flora including woody angiosperms.

Location

Wet heaths occur inland and near the coast. This vegetation can occur on both flat and sloping terrain. On flat terrain water is typically derived from rainfall with heathland developing in areas of impeded drainage. On sloping terrain water may be derived from both rainfall and shallow groundwater from an upslope catchment.

Vegetation

Wet heath wetlands have similar vegetation to bogs in that they are adapted to acidic conditions and soils with poor drainage. As the substratum is dry more frequently than bogs, wet heaths can support higher vegetation, including shrubs. The shrubs are usually small and stout in structure. Characteristic species of wet heath habitat include *Epacris impressa*, *Baumea juncea*, *Isolepis nodosa* and *Crinum pedunculatum*. Other species that can occur include *Olearia axillaris* (Coastal Daisy), *Helichrysum paralium* (Coast Beard Heath and Coast Everlasting), *Allocasuarina pusilla* (Dwarf Sheoak), *Leptospermum juniperinum* (Prickly Tea-tree), *Hakea sericea* (Bushy Needlewood), *Astroloma conostephioides* (Flame Heath), Silver Banksia and some *Gahnia* species (Saw-Sedge).

Substratum

Organic matter content in wet heath wetland is highly variable, so the substratum can range from mineral to organic to peat. Organic content increases with the duration of saturation and the acidity of the interstitial water. The acidity is derived from the breakdown of the pant organic matter and the accumulation of organic acids which are also responsible for the yellow-red- brown colour of the water.

Mineral substratum has less than 12-20% organic matter (Hammer 1991), whereas as organic and peat substratum has more. Peat will form in the more acidic waterlogged environments, as decomposition will be limited under these conditions, thus leaving a rich, fibrous soil.

Hydrology

Wet heaths are chiefly ombrotrophic so receive water that falls directly on them as rain or snow. They will also gain water from surplus river flows and possibly from shallow groundwater on sloping terrain. Wet heaths may often have impeded drainage so their soil can remain saturated. For the majority of the time wet heaths remain free from surface water although the substrata can be saturated.

Hydrologic characteristics

Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Rainwater (Freshwater)	3 – 6 months	0 (saturated)	3 – 6 months	High

Significance

Wet heath wetlands provide unique habitats and are populated with organisms that are adapted to the unusual conditions. With the loss or reduction in wet heath wetlands, there will also be a loss or reduction in biodiversity.

Management Issues

- Peat mining
- Biodiversity
- Fire
- Grazing
- Habitat for fauna
- Scientific research. – Due to the slow rates of decomposition, much organic matter can stay intact and be used for carbon dating and pollen analysis (paleontology). This can be used to provide information on climatic and ecological change

Australian example

- Cape Nelson State Park, Victoria.
- Hanging swamps in Blue Mountains, NSW.

13. Mangrove

Hierarchical identification

Woody Angiosperms → Organic → Marine → Trees

Definition

Mangrove wetlands occur in estuarine areas that are subject to tidal flooding. The mud-like soil contains a high content of organic matter, and the water is saline. Mangrove trees are the dominant plant form.

Location

Mangroves are found along tidal shorelines that are exposed to seawater and are inundated daily. Mangroves typically occur in estuarine areas, and can form extensive forests.

Vegetation

Mangroves are woody trees and shrubs that are flooded by seawater to a depth of at least 0.1 – 1.0 metres, on a daily basis. Mangrove forests in NSW are dominated by *Avicennia marina* (Grey Mangrove). In some areas, the smaller shrub-like *Aegiceras corniculatum* (River Mangrove) co-occurs with *A.marina*. *A.corniculatum* only occurs north of Batemans Bay whereas *A.marina* occurs along the entire NSW coast.

Substratum

Due to the high load of organic matter and detritus, the soils in mangrove wetlands are defined as organic. A wide variety of epilithic fauna and microorganisms are usually present.

Water chemistry

Mangroves have essentially marine water chemistry. Although predominantly influenced by the salinity levels of the seawater, salinity will vary depending on the amount of evaporation, whether freshwater flows through the mangroves, the timing of the freshwater flows (if any) relative to the tides, and the drainage regime (e.g. whether the mangroves are free-draining or restricted). The species found in mangrove communities will be suitably adapted to cope with such a salinity range.

Hydrology

Mangroves depend on daily inundation by water from the sea. Mangroves are found within the range of tidal influence and will be flooded twice a day. The flooding depth depends upon their position relative to the sea. Water usually reaches about 0.1-1 metre in depth, but can sometimes reach 1.5 metres. Although salt marshes also occur in NSW, mangroves are dominant where flooding of seawater occurs daily.

Hydrologic characteristics				
Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Marine	6 – 12 hours	0 – 1.5+	6 – 12 hours	High

Significance

Mangrove communities provide habitat and shelter for plants and animals. The forest floor is home to a large variety of benthic fauna, like molluscs and crabs. Numerous birds also use mangrove forests. For example, at Towra Point in Botany Bay, 176 bird species have been recorded, 30 of which are migratory species protected under international agreements between Japan and Australia (West *et al.* 1985).

Waterways in mangroves also provide important nursery areas for fish, including commercial species such as bream, flathead and mullet.

Leaf litter and other plant material from mangroves are an important food source for estuarine animals. It is estimated that one square kilometre of mangrove contributes about 600 tonnes of leaf litter to the detrital food web each year (West *et al.* 1985).

By filtering the runoff from surrounding areas, mangroves reduce the loads of suspended solids and nutrients entering the coastal receiving waters.

Mangroves also act as visual screens along the shoreline and a buffer for salt marsh wetlands (NSW Fisheries 2004).

Management Issues

- Sedimentation (from clearing and erosion)
- Urban development (habitat loss, increased water pollution)
- Commercial fishing
- Conservation objectives
- Recreation (e.g. fishing and boating)

Australian example

- Crangan Bay, Lake Macquarie foreshore, NSW.
- Western Port Bay, Victoria.

14. Scrub Swamp

Hierarchical identification

Woody Angiosperms → Mineral → Fresh → Shrubs

Definition

Scrub swamps have freshwater, a mineral substratum and are dominated by woody shrubs growing to about 3 metres in height. Scrub swamps are flooded on an ephemeral or seasonal basis. Occurring on inland floodplains, scrub swamp wetlands are filled by the surplus of flood flows. The scrub swamp classification includes basins that are dominated by woody shrubs, billabongs and other areas adjacent to a river channel, floodways and overflow systems.

Location

Scrub swamps can cover extensive areas of inland floodplains. Wetlands that are dominated by lignum are usually found at the end of a river system. They often occur in floodways that are extensively braided, but are also found in smaller depressions and billabongs closer to the river channel.

Vegetation

Scrubs swamps are dominated by woody shrubs, like *Muehlenbeckia* species (lignum), *Leptospermum* species (Tea trees) and some *Melaleuca* species (Paperbark). Vegetation grows to a height of 3 metres and often forms dense stands where there is regular inundation. Following flooding, the areas of shallow water and wet soil that exist between the shrubs are colonized by emergent macrophytes like *Cyperus* species (flat-sedges), *Eleocharis* species (spike-rushes), *Ludwigia* species (water primrose), *Marsilia* species (nardoo) and *Myriophyllum* species (knotweeds).

Substratum

Flooding is infrequent and there is limited organic material, so the substratum in a scrub swamp is mineral.

Water chemistry

As scrub swamps rely on rivers for water, they are freshwater systems.

Hydrology

Scrub swamps are flooded by surplus water from rivers, so have surface water on either a seasonal or ephemeral basis. Depending on the geographic region, climate, size of river and the distance of a wetland from the river, scrub swamps can be flooded once every one to two years or as irregularly as once every ten years.

Hydrologic characteristics				
Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Freshwater	6 – 9 months	0 – 0.3	6 – 9+ months	Low

Significance

Scrub swamp provides valuable breeding habitat for colonial waterbirds, like ibis and spoonbills, as well as for endangered waterbirds, like the freckled duck and other biota.

Scrub swamps provide extensive overflow areas so are important in terms of dissipating floodwaters from a catchment.

Management Issues

- Habitat clearance
- Draining (e.g. Pressure from agriculture and urbanization)
- Alteration of natural water regime (e.g. construction of floodplain structures which may exclude or impound floodwaters)
- Grazing
- Waterbird breeding
- Feral animals, like pigs and foxes, which cause land management problems

Australian example

Examples of scrub swamp dominated by lignum are found in the floodways and overflows of the:

- Paroo River, NSW.
- Warrego River, NSW.
- Lachlan River, NSW.
- Murrumbidgee River, NSW.

15. Forest Swamp – Wet

Hierarchical identification

Woody Angiosperms → Mineral/Organic → Fresh → Trees

Definition

Wet forest swamps have freshwater, a mineral/organic substratum and are dominated by woody trees growing to about 3 – 25 metres in height. Wet forest swamps are flooded on a regular or seasonal basis, generally occur on floodplains, and are typically dominated by *Melaleuca* species.

Location

Wet forest swamp wetlands occur along most of the coastal rivers and lagoons in eastern NSW. They typically occur in the floodplains of these rivers and the backwater areas of coastal lagoons.

Vegetation

Trees are the dominant type of vegetation in wet forest swamps. The trees will often grow to over 20 metres in height, but smaller stands may also merge into swamp scrub and wet heath. *Melaleuca quinquenervia* (Broad-leaf Paperbark) is typically the dominant species although *Melaleuca linariifolia* (Narrow-leaf Paperbark) may also be common. *Melaleuca ericifolia* (Swamp Paperbark) is variable species and may also occur in near permanent water at the interface with marshlands, or grade into wet heath or scrub swamp where the substratum is saturated for prolonged periods.

Most of the plants in the understorey of these wetlands can tolerate periodic inundation. Typical species in the understorey include sedges, rushes, spike-rushes and grasses, like *Baumea juncea* (Bare Twig-rush) and *Pseudoraphis spinescens* (Spiney Mudgrass).

Substratum

Flooding is frequent and drainage is restricted, resulting in accumulation of organic material, so a wet forest swamp has organic/mineral substratum.

Water chemistry

As forest swamps are largely inundated by surface water from either direct rainfall or rivers, they have freshwater.

Hydrology

Wet forest swamps are flooded by surplus water from rivers, so have surface water on either a seasonal or ephemeral basis. Depending on the geographic region, climate, local topography, size of river, and the distance of a wetland from the river, wet forest swamps are typically flooded annually and dry out for 2-6 month per year, but may not dry out every year.

Hydrologic characteristics				
Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Freshwater	1 - 3+ years	0 - 2+	2-6 months	High

Significance

Wet forest swamps provide valuable breeding habitat for colonial waterbirds, like ibis and spoonbills. Wet forest swamps also provide important winter feeding habitat for bats, birds and insects.

Wet forest swamps provide extensive overflow areas so are important in terms of dissipating floodwaters from a catchment.

Management Issues

- Habitat clearance
- Draining (e.g. Pressure from agriculture and urbanization)
- Alteration of natural water regime (e.g. construction of floodplain structures which may exclude or impound floodwaters)
- Grazing
- Waterbird feeding areas
- Feral animals (e.g. foxes)

Australian example

- Bulloo Overflow, NSW.
- Tuggerah Lake, NSW.

16. Forest Swamp – Ephemeral

Hierarchical identification

Woody Angiosperms → Mineral → Fresh → Trees

Definition

Ephemeral forest swamps have freshwater, a mineral substratum and are dominated by woody trees growing to about 5 – 25 metres in height. This forest swamp type is flooded on an ephemeral or seasonal basis. Occurring on inland or coastal floodplains, ephemeral forest swamp wetlands are inundated by either rainfall or flood flows and are typically dominated by *Melaleuca* and *Eucalyptus* species.

Location

Ephemeral forest swamp wetlands occur along most of the major coastal and inland rivers in Australia. They typically occur in the floodplains of these rivers. The dominant tree species of a forest swamp is largely determined by the geographic location. For example, floodplain swamp forest wetlands are common along the Murray River in southern NSW and northern Victoria, whereas mixed *Eucalyptus* and *Melaleuca* swamp forests are more common on coastal floodplains.

Vegetation

Trees are the dominant type of vegetation in forest swamps. The trees will often grow to over 20 metres in height. This wetland classification type includes *Eucalyptus camaldulensis* (River Red-gum) forests and coastal floodplain forests characterized by *Melaleuca linariifolia, Melaleuca sieberi*, *Melaleuca decora, Melaleuca stypheloides* and *Eucalyptus robusta*. *Eucalyptus camaldulensis* (River Red-gum) is often the dominant species in inland floodplain swamps.

Most of the plants in the understorey of these wetlands can tolerate periodic inundation. Typical species in the understorey include sedges, rushes, reeds and grasses (e.g. *Phragemites australis* and various *Juncus* species in River Red-gum forests, *Gahnia clarkei* and *Carex appressa*).

Substratum

Flooding is infrequent but drainage is restricted, resulting in some organic matter accumulation, so ephemeral forest swamps have mineral/organic substratum.

Water chemistry

As forest swamps are largely inundated by surface water from either direct rainfall or rivers, they have freshwater.

Hydrology

Ephemeral forest swamps are flooded by surplus water from rivers, so have surface water on either a seasonal or ephemeral basis. Depending on the geographic region, climate, size of river, and the distance of a wetland from the river, ephemeral forest swamps can be flooded once every one to two years, or once every ten years.

Hydrologic characteristics

Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Freshwater	annually	0 – 1+	4-6 months	Medium

Significance

Ephemeral forest swamps provide valuable breeding habitat for a wide range of fauna and represent an interface between terrestrial and aquatic systems.

Ephemeral forest swamps provide extensive overflow areas so are important in terms of dissipating floodwaters from a catchment.

Management Issues

- Habitat clearance
- Draining (e.g. Pressure from agriculture and urbanization)
- Alteration of natural water regime (e.g. construction of floodplain structures which may exclude or impound floodwaters)
- Grazing
- Waterbird breeding
- Feral animals (e.g. pigs and foxes)
- Forestry

Australian example

- Millewa Forest, NSW.
- Koondrook and Perricoota Forests, NSW.
- Werai Forest, NSW.

17. Forest Swamp – Dry

Hierarchical identification

Woody Angiosperms → Mineral → Fresh → Trees

Definition

Dry forest swamps have freshwater, a mineral substratum and are dominated by woody trees growing to about 5 – 25 metres in height. Dry forest swamps are flooded on an irregular basis but may be annually inundated or saturated as a result of rainfall and impeded drainage. Occurring on inland or coastal floodplains, dry forest swamp wetlands are inundated by either rainfall or flood flows and are typically dominated by *Eucalyptus* and *Melaleuca* species.

Location

Dry forest swamp wetlands occur along the floodplains most of the major inland rivers systems and edges of coastal floodplain rivers in Australia. The dominant tree species of a forest swamp is largely determined by the geographic location. For example Coolibah forest swamps usually occur in the north and west of NSW (e.g. Gwydir, Darling, Warrego, Paroo, Culgoa) (DLWC 2000), whereas coastal systems occur around the edge of riverine floodplains. This class tends to be more characteristic of sites of impeded drainage than flood inundation.

Vegetation

Trees are the dominant type of vegetation in forest swamps. The trees will often grow to over 20 metres in height. This wetland classification type includes inland swamp forests characterised by *Eucalyptus coolabahs* (coolibah) and *Eucalyptus largiflorens* (black box) and coastal systems characterised locally by a range of eucalypts and *Melaleuca* species (e.g. *Eucalyptus longifolia, Eucalyptus botryoides, Angophora costata, Melaleuca nodosa, Melaleuca sieberi, Melaleuca thymifolia*).

Most of the plants in the understorey of these wetlands can tolerate periodic inundation. Typical species in the understorey include sedges, rushes, and grasses, such as *Gahnia clarkei, Imperata cylindrical, Lepidosperma quadrangulatum* and *Juncus* species).

Substratum

Flooding is infrequent and there is limited organic material, so the substratum in dry forest swamps is mineral.

Water chemistry

Dry forest swamps are largely inundated by rainfall or surface water from rivers so they have freshwater.

Hydrology

Forest swamps are flooded by surplus water from rivers, so have surface water on either a seasonal or ephemeral basis. Depending on the geographic region, climate, size of river, and the distance of a wetland from the river, dry forest swamps can be flooded once every one to two years, or once every ten years.

Hydrologic characteristics

Inundation Water (Typical)	Frequency of Drying/ Exposure (once/unit)	Inundation Depth (m)	Duration of drying	Inundation Regularity
Freshwater	annually	0 – 0.2+	8–12+ months	Low

Significance

Dry forest swamp wetlands provide valuable breeding sites for waterbirds and provide habitat for a wide range of fauna. They represent an interface between terrestrial and aquatic systems.

Dry forest swamp wetlands provide extensive overflow areas so are important in terms of dissipating floodwaters from a catchment.

Management Issues

- Habitat clearance
- Draining (e.g. Pressure from agriculture and urbanization)
- Alteration of natural water regime (e.g. construction of floodplain structures which may exclude or impound floodwaters)
- Grazing
- Feral animals (e.g. pigs and foxes)
- Forestry

Australian example

- Outer margins of the Millewa Forest, NSW.
- Coolibah woodlands of the Gwydir Wetlands, NSW.
- Black Swamp and Coopers Swamp (basins of Delta Creek) , NSW.

APPENDIX 2 DEFINITION OF TERMS USED IN THE CLASSIFICATION SCHEME (TABLE 4) AND HYDROLOGIC VARIABLE MATRIX (TABLE 5)

Term	Definition
Dominant Vegetation	Dominant type of vegetation that forms the major structural element of vegetation
Algae	Wetland is generally devoid of vascular vegetation but some macroalgae, primarily benthic (bottom-dwelling) algae, may occur.
Herbaceous angiosperms	Describes seed-bearing plants that contain little permanent hard woody tissue. To survive waterlogging, wetland herbs contain cells which are largely filled with air, aerenchyma. Aerenchyma provide air spaces within plant tissues, enabling respiration. There are three types of herbs that can be distinguished by the response of their aerial parts after the growing season. Annual herbs totally die after the growing season. Seasonal perennials (biennials) and non-seasonal perennials are rhizomatous so have organs (e.g. bulbs, corms) that are modified to survive under the soil in unfavourable conditions even if their shoots die (Martin *et al.* 1996).
Woody angiosperms	Plants contain hard woody tissue, primarily in the trunk and branches. Woody vegetation includes shrubs and trees. Wood is the secondary xylem of dicotyledons (angiosperms) and conifers. It forms a dense growth during secondary thickening, thereby providing the mechanical support that enable shrubs and trees to grow to considerable heights. Like herbs, wood angiosperms contain aerenchyma. They also exhibit other adaptations that enable them to survive waterlogging, such as the pneumatophores of mangrove species and lenticels.
Dominant Substratum	Substratum refers to the material or object on which a sedentary organism (e.g. a plant) lives, grows or is attached. The substratum may provide nutrients for the organism or it may simply act as a physical support (Allaby 1994; Martin *et al.* 1996).
Mineral	Substratum primarily composed of and derived from rock or mineral soil. Mineral soils are typically derived from *in situ* weathered rocks or from aeolian or fluvial sediments. The main characteristic of mineral soils is that their composition generally reflects their basal origins and has not been significantly modified by the accumulation of organic material. The characteristics of a mineral soil are determined by the mineral rather than the organic content. Soils with less 12-20% organic matter (dry weight) being classified as mineral.

Organic	Soils containing greater than 12-20% organic matter are classified as organic (Hammer 1991). Organic soils can be further sub-divided on the basis of the degree of decomposition of the organic matter (Mitsch & Gosselink 1993). Well structured, partially decomposed (fibrous) organic matter is termed *peat* and typically forms in acidic environments. Poorly structured, well decomposed organic matter is sometimes termed *muck*, although in this document will simply be referred to as organic.
Peat	Peat is an organic soil or deposit that is well structured, partially decomposed (fibrous) organic matter. It typically forms in acidic environments. The acidic conditions are due to poor drainage and the accumulation of organic acids as a result of the partial breakdown of plant matter. Peat occurs where decomposition of organic matter is slow due to anaerobic conditions in the waterlogged soil. Decomposition is also limited by the acidic water characteristic of bogs, so plant structure remains resulting in black, highly structured peat. Decomposition of cellulose and hemicellulose is particularly slow for *Sphagnum* plants. *Sphagnum* plants are characteristic of areas with peat and are among the main peat-forming plants. Although the organic soil, or muck, found in fens is sometimes classified as peat due to its high organic content, it differs in its structure and chemistry so has been classified as organic soil in this report. Fen soils can be distinguished from bog peats by their relative lack of structure. In fens, the presence of calcium in the groundwater neutralises the acidity, which often leads to more complete breakdown of plant structure.
Water Chemistry	Chemical characteristics of the surface water in the wetland.
Fresh	Freshwater with low salinities (<1500 mg/L).
Marine	Saline water that is derived directly from the sea (approximately 35, 000 mg/L).
Saline	Inland salty water varying in concentration from brackish (1500 – 5000 mg/L) to hypersaline (> 150, 000 mg/L).
Coloured	Surface water is amber to brown in colour, due to tannins from dissolved organic matter derived from decomposing vegetation. Water clarity can still be high.
Acidic	Surface water has a pH below 6.

Typical Plant Form	Type of plants that characterise the wetland.
Benthic algae	Algae are a group of unrelated simple organisms that live in aquatic or moist habitats. They are either unicellular or multicellular (ribbon-like, plate-like or filamentous) and contain chlorophyll, which enables them to photosynthesize. Benthic algae are an unrelated group of macroalgae that either grow through the substratum forming complex mats or attached to the substratum (where they can sometimes resemble submerged aquatic angiosperms (e.g. *Chara* species or *Nitella* species).
Seagrass	Seagrasses are small herbaceous plants. Similar in structure to terrestrial plants, these marine plants have tiny flowers and strap-like or oval leaves. They are most similar to lilies, and are quite different from seaweeds, which are algae. Seagrasses differ from algae as they produce flowers, fruit and seeds, whereas algae produce spores. They also have roots, leaves and rhizomes and seagrasses are vascular plants, so are able to transport nutrients and dissolved gases around the plant.
Mosses	Mosses, or Musci, are a type of bryophyte that are found in both damp and drier environments. A class of plants, *Sphagnum* plants, are characteristic of areas with peat
Submerged macrophytes	Aquatic plants that live submerged in water. Submerged macrophytes have adaptations that enable them to cope with the anaerobic conditions of submersion. Submerged macrophytes may be free floating or attached to the substratum.
Emergent macrophytes	Macrophytes are plants that live for all or part of their life with their roots submerged in water. Emergent macrophytes will typically have at least two-thirds of their shoots exposed to the air. Emergent macrophytes are typically monocotyledonous plants from families like Cyperaceae (sedges), Juncaceae (rushes) and Poaceae (grasses).
Shrubs	Woody plants that branch below or near the ground so that they have several main stems and do not have a visible trunk. Australian wetland shrubs are typically evergreen, although there may be some loss of foliage (senescence) in dry periods.
Trees	Woody plants with a single main stem (trunk) that is unbranched near the ground. Some trees do have multi-trunked forms though. Australian wetland trees are typically evergreen, although there may be some loss of foliage (senescence) in dry periods.

Water regime	Distinguishing feature of the hydrological characteristics.
Tidal	The water regime in a tidal wetland is determined by the periodic rise and fall of the earth's oceans. Water levels will correspond with the stage of the tide, which alternates between high and low twice in every 24 hours. The tidal range varies from a maximum during spring tides to a minimum during neap tides. Spring tides (high maximum and low minimum) occur about every two weeks when the moon is full or new. The tidal effect in wetlands is often damped and out of sequence with the driving tide.
Ephemeral	Wetland is inundated only after precipitation (rain), which makes the pattern of inundation highly variable. As flooding depends on periods of high rainfall, periods of inundation are stochastic and are not as regular or predictable as wetlands with a seasonal water regime. Ephemeral wetlands may be flooded more or less frequently than seasonal wetlands.
Seasonal	Unless the rainfall distribution is atypical, a wetland with a seasonal water regime will flood at around the same time each year (same season). Wetlands in northern Australia typically flood during the summer months (the 'wet' season), whereas wetlands in southern Australia will flood in the higher rainfall of the winter months.
Permanent	Wetland vegetation is almost always inundated by water, so that the water surface is easily seen. Wetlands with permanent water may still experience water level fluctuations due to periodic flooding and drying.
Saturated	The substratum of a wetland is almost always saturated. Surface water may not always be present in a wetland with a saturated water regime, but the substratum will remain waterlogged. Such wetlands typically occur in areas of impeded drainage (like bogs) or where they are a window into the groundwater.
Descriptors	Clarify descriptive terms used in classification scheme.
Deep	Remains inundated during years of average or above average rainfall. Under normal conditions, water depths will commonly exceed 0.5 metres, extending to 2.0 metres. Although wetlands can be deeper than 2 metres, most emergent macrophytes cannot grow in water that commonly exceeds 2.0 metres in depth.
Shallow	Semi-permanent; ephemeral or seasonal; although the water can be deep during intense floods, generally the water level would be relatively shallow (typically 0.2-0.3 metres).

Hydrologic indices	Indices used to define the hydrologic characteristics of wetland systems.
Inundation Water	Defines the water quality (salinity) of the main source of water inundating the wetland. This index has four basic groups, i.e. Rainwater, Freshwater (surface runoff), Saline Water and Marine Water.
Frequency of Drying/ Exposure	Defines the frequency that the wetland is subjected to periods of no or minimal inflows.
Inundation Depth	Defines the typical depth (or depth range) of inundation in wetlands.
Duration of Drying	Defines the typical duration that a wetland is subjected to no or minimal inflow. This index is often used in conjunction with the index for frequency of drying/exposure to define the natural frequency and duration in which wetlands are subjected to extended periods of drying. This index may also be correlated with the inundation regularity index.
Inundation Regularity	Defines the regularity (and predictability) of wetland inundation. The index range from High (e.g. dominant inundation source is daily/seasonal, related to water source from tidal or groundwater systems) to Low (e.g. dominant inundation source is stochastic, related to rainfall and surface runoff). A Medium Index indicates a system where the inundation is affected by both regular and stochastic water sources.

Water Sensitive Urban Design Solutions for Catchments above Wetlands

Appendix B: Catchment Hydrologic Indices and Urban Water Management Performance Objectives

May 2007

Hunter & Central Coast
Regional Environmental
Management Strategy

stormwater TRUST
A NSW Government initiative

HCC REMS

Water Sensitive Urban Design Solutions
for Catchments Above Wetlands

Document Series:

Overview Report
Appendix A: Wetlands Classification Scheme
Appendix B: Catchment Hydrologic Indices and Urban Water Management Performance Objectives
Appendix C: A Procedure for Determining Catchment Stormwater Management Objectives
Appendix D: Planning Mechanisms

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Definition of Terms

Water regime	Distinguishing feature of the hydrological characteristics.
Tidal	The water regime in a tidal wetland is determined by the periodic rise and fall of the earth's oceans. Water levels will correspond with the stage of the tide, which alternates between high and low twice in every 24 hours. The tidal range varies from a maximum during spring tides to a minimum during neap tides. Spring tides (high maximum and low minimum) occur about every two weeks when the moon is full or new. The tidal effect in wetlands is often damped and out of sequence with the driving tide.
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Inundation Depth	Defines the typical depth (or depth range) of inundation in wetlands.
Duration of Drying	Defines the typical duration in which a wetland is subjected to no or minimal inflow. This index is often used in conjunction with the index for frequency of drying/exposure to define the natural frequency and duration in which wetlands are subjected to extended periods of drying. This index may also be correlated with the inundation regularity index.
Inundation Regularity	Defines the regularity (and predictability) of wetland inundation. The index range from High (eg. dominant inundation source is daily/seasonal related to water source from tidal or groundwater systems) to Low (eg. dominant inundation source is stochastic related to rainfall and surface runoff). A Medium Index indicates a system where the inundation is affected by both regular and stochastic water sources.

1 INTRODUCTION

Natural wetland systems downstream of catchments undergoing urbanisation are subject to environmental stresses at a number of levels, most notably in significant changes to their hydrology and stormwater pollution. The adoption of Water Sensitive Urban Design (WSUD) practices in urban development is gaining prominence as a means of facilitating a more sustainable approach to urban water cycle management in urban environments. These practices include the treatment of urban stormwater for reduction in urban contaminants to current best practice standards. WSUD strategies for urban development cover a range of spatial scale, from implementation at an allotment scale to regional scales. Their appropriate combinations reflect site opportunities and constraints and are developed from a "whole-of-catchment" perspective. In some cases, the attenuation of peak discharges from frequent storm events is implemented to enable protection of aquatic habitats in natural waterways.

For catchments above natural wetlands, it may be necessary to address in more detail the hydrologic change associated with catchment urbanisation beyond that of flow attenuation. This project will concentrate on the finer resolution hydrological dynamics that are important to wetlands.

Hydrologic and hydrodynamic characteristics that can affect the environmental value (and ecosystem health) of natural wetlands in urban environments include the *hydrologic regime*[1], flood frequency, and flow-duration responses to catchment urbanisation. It is envisaged that the types (eg. ephemeral systems, marsh systems, hybrid systems etc.) and locations (eg. geological setting, groundwater influence etc.) of wetlands may require different catchment management responses.

To ensure that the methodology developed in this project is applicable throughout NSW, it will be necessary to accommodate a wide range of wetland types. One of the early project task involved developing a simplified wetland classification to enable practitioners to undertake field assessment on the types of wetlands being managed. The outcomes and recommendations from undertaking this task are reported in Appendix A. In developing the wetland classification model, it was considered desirable that limited hydrologic modelling is required in assigning the appropriate wetland type in practice and thus the classification proposed is primarily based on a number of dominant physical wetland characteristics, ie. vegetation, substratum, water chemistry, typical plant form. There are altogether 17

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[1] *Hydrologic Regime* describes the probabilistic temporal distribution of inundation depth in a water body

different wetland types in the classification method proposed and a broad description of the supporting hydrology of the 17 classifications of wetland is presented in Table 1.

A subsequent task following the development of wetland classification types and corresponding supporting hydrology was to quantify the hydrologic characteristics of these wetland supporting hydrology (described in Table 1) in a form which can be readily specified as conditions of development approval. It is envisaged that this could be undertaken using statistical measures. This report presents the methodology adopted in the investigation in defining a set of appropriate hydrologic indices that can describe the critical hydrologic characteristics of wetland supporting hydrology and concludes with recommendation on the appropriate index or indices for each of the 17 wetland classifications.

Table 1 - Wetland category and hydrologic variable matrix

Wetland Category	Inundation Water (Typical)	Inundation Regularity	Inundation Depth (m)	Duration of Drying	Frequency of Drying/Exposure (once/unit)
1. Coastal Flats	Marine	High	0 – 4+	0 – 12 hours	12 – 24 hours
2. Inland Flats	Saline	Low	0 – 1+	1 – many years	1– many years
3. Bogs	Rainwater	High	0 – 0.1+ (saturated)	1 – 2 months	1 – 3 years
4. Deep Marsh	Freshwater	High	0.3 – 0.6+ (–2.0+)	1 – 4 months	1.5 – 3 years
5. Fen	Freshwater	High	0 – 0.6+	1 – 6 months	1.5 – 3 years
6. Shallow Marsh	Freshwater	Low–Medium	0 – 0.3	3 – 6 months	3 – 6 months
7. Salt Marsh	Marine	Medium–High	0 – 0.3	1 day – 1 month	1 day – 6 months
8. Seagrass Beds	Marine	High	0+ – 10+	0 – 6 hours	≥ 6 months
9. Deep Salt Pans	Saline	Low	0 – 2	2 – many years	1 – 2+ years
10. Deep Open Water	Freshwater	Medium	1 – 2+	1 – 6 months	3 – 5 years
11. Shallow Open Water	Freshwater	Low	0.5 – 1.5	3 – 6 months	0.5 – 2 years
12. Wet Heath	Rainwater	High	0 (saturated)	3 – 6 months	3 – 6 months
13. Mangrove	Marine	High	0 – 1.5+	6 – 12 hours	6 – 12 hours
14. Scrub Swamp	Freshwater	Low	0 – 0.3	6 – 9 months+	6 – 9 months
15. Forest Swamp – Wet	Freshwater	High	0 – 2.0+	2 – 6 months	1 – 3+ years
16. Forest Swamp – Ephemeral	Freshwater	Medium	0 – 1.0+	4 – 8 months	annually
17. Forest Swamp – Dry	Freshwater	Low	0 – 0.2+	8 – 12+ months	annually

2 HYDROLOGIC REGIMES OF WETLANDS

The hydrologic regime of wetlands determines the depth, frequency, duration and temporal pattern of flooding and drying. These features of the hydrologic regime influence the characteristics of the substratum. The wetting and drying pattern influences both the physical (e.g. gas diffusion) and chemical (e.g. redox) characteristics of the substratum. For example, wet conditions tend to result in:

- decreased oxygen supply to the substratum,
- chemically reducing conditions,
- decreased rates and completeness of organic matter decomposition, and
- increased organic matter content of the substratum.

Dry conditions tend to result in:

- increased oxygen supply to the substratum,
- chemically oxidising conditions,
- increased rates and completeness of organic matter decomposition, and
- decreased organic matter content of the substratum.

As well as inundation frequency and duration, the frequency and duration of drying is an important feature of wetland function. The frequency and duration of dry periods will determine to what degree the above processes occur (e.g. re-oxygenation of the substratum and increased decomposition of organic matter)

2.1 Flow Hydrodynamics and Flooding Pathways

Natural wetland systems receive inflow by four means, ie. rain falling onto the wetland, surface flow discharged from upstream catchments, groundwater inflow and tidal flow from downstream marine systems. Apart from rainwater, water inflow to wetlands is by means of a conveyance system (one or a series of natural channels or broad low lying depressions) that distributes water to the wetland. The nature of the inflow pathways often defines the locations of different wetland types (in relation to the conveyance system) within a mosaic system. To illustrate this, consider a simplified scenario of a wetland receiving inflow from an external source (eg. freshwater from upstream catchment or marine water from downstream). The hydrologic regime of this wetland is defined by the frequency at which water breaks out of the conveyance channels or depression to flood adjoining areas.

Water can be delivered to wetlands via a range of flooding pathways as described in Table 2.

Table 2 - Wetland Flooding Pathways

Flooding Pathway	Flooding Pattern
Overbank Flow	Flooding as a result of over-bank flows from a distant channelised catchment (an inside-out flood pattern), eg. inland flats some shallow and deep marshes, some swamp forests
Overland Flow	Flooding or saturation as a result of diffuse drainage from a poorly or non-channelised local catchment (diffuse flood pattern), eg. some shallow or deep marshes, some wet heath, scrub swamp
Groundwater	Flooding or saturation as a result of groundwater expression, eg. fen
Rainfall Fed	Flooding or saturation as a result of direct rainfall, eg. bog

The hydrologic impacts of urbanisation on wetlands for the various hydrology types outlined above can vary but are generally associated with increased surface runoff (both in terms of volume and rate). For systems subjected to overbank flow flooding, it is important to protect the drying behaviour for wetlands that tend to be regularly wet (ie. to ensure their relief from the stress of inundation is preserved and that they continue to have an adequate drying phase). Similarly, for wetlands that are regularly dry it is important to ensure they continue to get an adequate pattern of inundation (ie. their flood hydrology is preserved) but also that their drying hydrology is also preserved (ie. their drying phase is preserved).

For wetlands with flooding pathway associated with overland flows, it is important that the diffuse pattern of inflow is maintained and their drying hydrology is preserved (ie. they continue to have an adequate drying phase). Wetlands with this form of flooding pathway are very sensitive to the introduction of point source inflows typical of conventional urban development and it may be necessary for hydraulic intervention measures such as diversion of stormwater runoff away from these systems to fully protect their supporting hydrology.

Wetlands that are predominantly inundated by groundwater inflow will need to be protected by preserving the drying phase pattern (ie. ensuring the duration of the drying phase is not increased by lowering groundwater table). The requirement to not reducing the rate of groundwater inflow to these systems may also be necessary and thus may restrict hydrologic management options to that associated with preserving adequate infiltration. However, the significance of such actions is complicated by the relative size and proximity of the groundwater catchment to the urban development.

Wetlands which have very small catchment area and their flooding pathway being predominantly associated with direct rainfall input simply need to be completely isolated from any developed catchment runoff.

2.2 Hydrologic Indices

Defining and quantifying the characteristics of wetland drying and wetland hydrology will provide the basis for defining management objectives for protecting wetlands from adverse impacts of catchment urbanisation. Following review and consideration of a number of possible hydrologic indices for drying and flooding hydrology in wetland systems, three have been recommended, ie.

Drying Hydrology	1. Dry season flow duration frequency curves
	2. Low flow spell frequency curves
Flooding Hydrology	1. Annual high flow duration frequency curves

Flow duration frequency curves representing maximum flow and minimum flow conditions were considered to provide the principal hydrologic index for wetland flooding and drying hydrology respectively. Flood (instantaneous peak flow) frequency curves, while relevant, were considered less appropriate as the inherent detention storages associated with natural wetlands can often modify the significance of the effects of catchment instantaneous peak flow characteristics in supporting key wetland functions.

2.2.1 Flow duration frequency curves

A flow duration frequency curve is one of the simplest and most informative means of showing flow characteristics of a stream (McMahon and Mein, 1986). It describes the relationship between the average flow of a given number of consecutive days (usually 1, 7, 14, 30 and 60 days) and its annual probability of exceedence.

Flow duration frequency curves are derived by examining recorded or synthesized streamflow data and defining either the maximum (flooding hydrology) or minimum (drying hydrology) average flow over 1, 7,14, 30 or 60 consecutive days for each year or selected critical period within each year (eg. the wet or dry season of the year). The average flow is computed as the moving average over the selected duration and the maximum or minimum value for each year (or selected critical period) selected for statistical analysis.

In the statistical analysis, the maximum or minimum average flows for the period analysed are expressed statistically by ranking them according to ascending order and plotting them in the form of annual frequency curves with the x-axis expressed as annual exceedence probability (AEP). A special case of a flow duration curve is the maximum instantaneous flow frequency curve commonly applied in flood frequency analysis as described in Australian Rainfall and Runoff – Book IV (Institution of Engineers Australia, 1997).

As is the case with flood frequency analysis, the flow duration curves could appear irregular but should always be monotonically decreasing. The irregularity is simply an artifact of the number of years of flow record from which the curves are derived.

It is recommended that:

- **some smoothing be applied to the derived flow duration curves to reflect a smooth monotonically decreasing curve form.**
- **in assessing compliance of post-development measures, a similarly pragmatic approach to smoothing of the post-development flow duration curves be applied.**

Selection of Critical Periods for Flow Duration Analysis

The selection of the critical periods within a given year for flow duration analysis of streamflow data depends on whether wetland flooding or drying hydrology is to be defined. For instance, wetland drying is influenced by both catchment hydrology (base flow magnitude, flow duration etc.) and meteorological (rainfall and evapotranspiration) patterns. Figure 1 shows the mean monthly rainfall and evapotranspiration recorded at Wyong and it is apparent that whilst monthly rainfall is generally higher in the summer/autumn period compared with the winter/spring period, monthly potential evapotranspiration is highest in the spring/summer period.

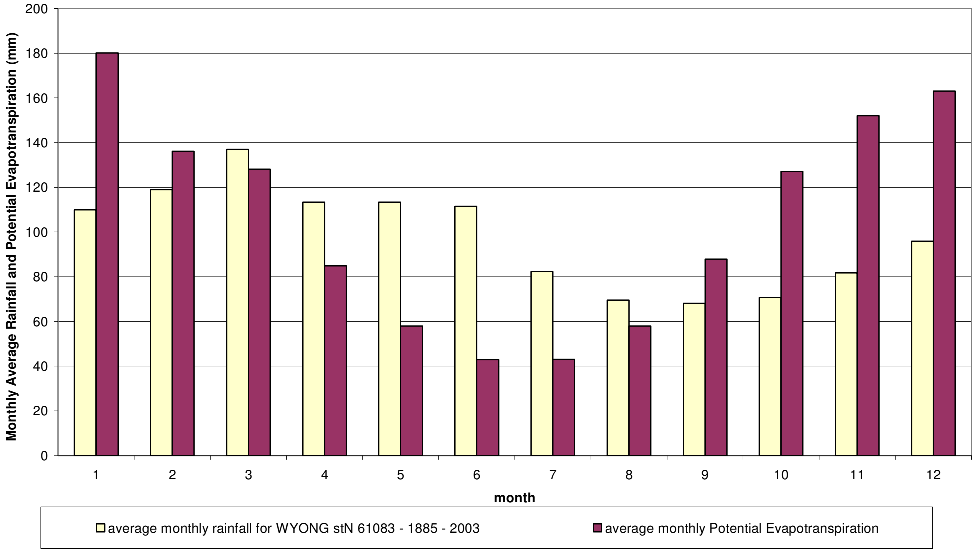

Figure 1 - Mean monthly rainfall and potential evapotranspiration - Wyong

(i) Drying Hydrology

Figure 2 plots the differences between Potential Evapotranspiration and Rainfall and shows the critical months for low flow duration analysis to define the drying hydrology of a wetland are thus considered to be between October and January (inclusive) where the difference between monthly mean potential evapotranspiration and rainfall are highest.

The low flow duration frequency analysis should be undertaken across a calendar year using a "water year" (July to June) for the months of October to January (inclusive).

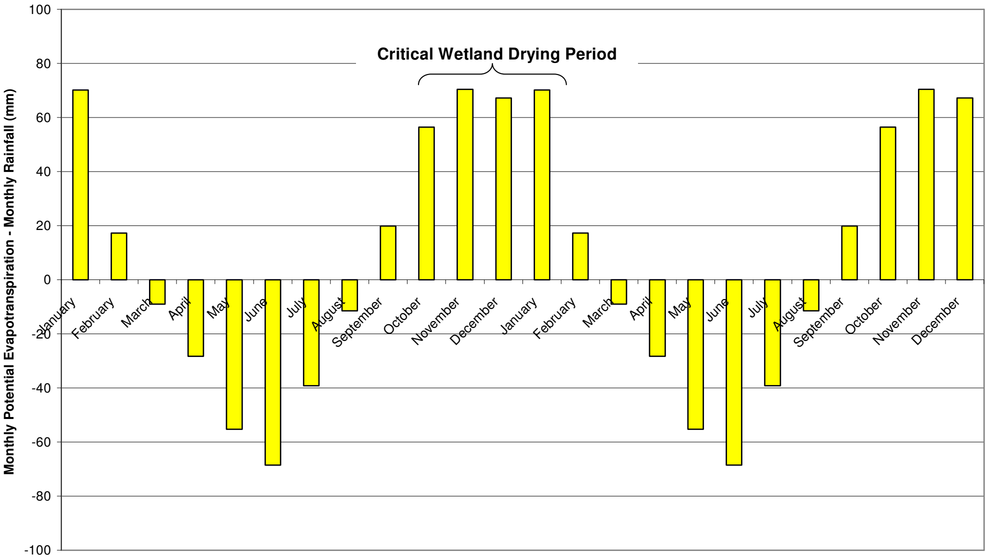

Figure 2 - Monthly PET minus Rainfall showing critical wetland drying period between the months of October and January

(ii) Flooding Hydrology

In defining the flooding hydrology, analysis will need to be undertaken to define the average maximum flow-duration curves. The influence of evapotranspiration on flooding in wetland is less significant and the deposition of organic matter and increasing wetness in substratum are the important occurrences associated with wetland flooding. Given this, there is no critical period for derivation of the high flow duration frequency curve and that it is less important when flooding occurs as long as it does at the appropriate frequency and duration.

Analysis of maximum flow duration characteristic to define the flood hydrology characteristics of natural wetland should be undertaken for all months in a calendar year (January to December).

Defining Representative Flow Duration Curves

Flow duration curves can only be reliably derived from analysis of long duration streamflow data which are either recorded or can be simulated from long periods of rainfall data. A modelling approach will invariably be required to define the management objectives and to demonstrate post-development compliance with these management objectives.

Deriving representative pre-development flow duration curves may require the development proponent to obtain either streamflow record of adjoining watercourses with its catchments largely undeveloped. In the majority of cases, the scale of a development will be different (generally smaller) than the catchment area of gauging stations. Two approaches are suggested in defining the representative flow duration curves for a development site that can be subsequently used to guide the formulation of post-development catchment management practices, ie.

1. A direct scaling of a flow duration curve derived from the observed streamflow record according to the ratios of development site to gauging station catchment areas and mean annual rainfalls. The scaling adaptation will involve multiplying the average flow values derived for the reference catchment with the ratio of the product of mean annual rainfall (R) and area (A) of the site to the reference catchment, ie.

$$\text{adjustment factor} = \frac{(R \times A)_{site}}{(R \times A)_{reference}}$$

2. Calibration of a rainfall-runoff model to the observed streamflow record and using the model to predict pre-development runoff from the development site.

(i) Scaling of Regional Flow Duration Curves

In determining the appropriateness of a reference catchment for defining representative flow duration curves, it is necessary to ensure that rainfall seasonal pattern of the reference catchment is similar to that of the site in question. The rainfall seasonal pattern is best defined by two plots, ie. (i) the mean monthly rainfall expressed as percentage of the mean annual rainfall, and (ii) the mean monthly raindays. Figures 3 and 4 show the mean monthly rainfall (expressed as percentage of the mean annual rainfall) and the mean monthly raindays observed in Wyong and maybe representative of the Jilliby Jilliby catchment. Sites outside the Jilliby Jilliby Creek catchment could use the adjusted flow duration curves derived from flow data recorded in Jilliby Jilliby Creek if their meteorological characteristics are similar to that shown in Figures 3 and 4. The adjustments to be made to the flow magnitude derived from the Jilliby Jilliby Creek data is simply to multiple these values with the adjustment factor as outlined above.

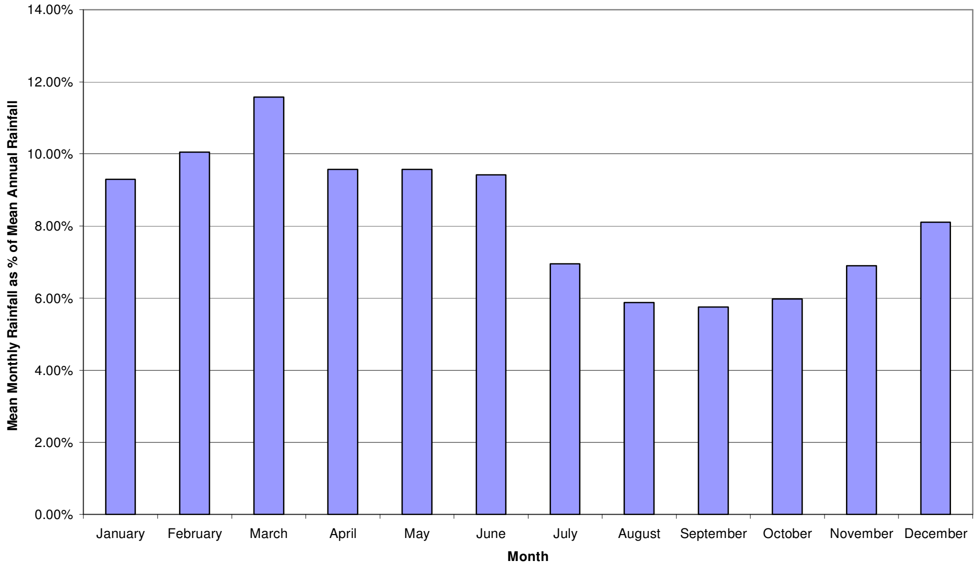

Figure 3 - Mean Monthly Rainfall as percentage of Mean Annual Rainfall - Wyong

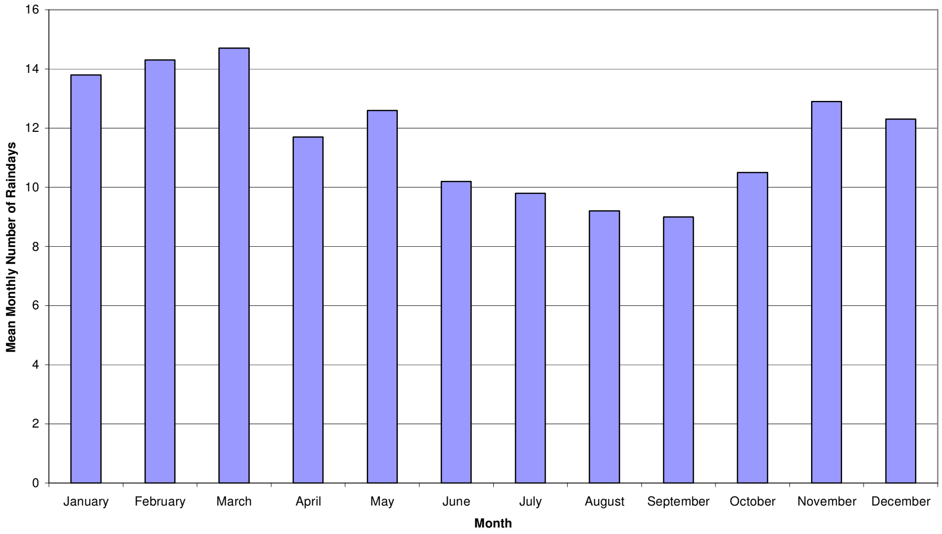

Figure 4 - Mean Monthly Raindays - Wyong

(ii) Calibration of Rainfall Runoff Models

There are a number of suitable rainfall runoff models which could be calibrated to the observed streamflow data of the reference catchment. These models include AWBM, RRL, MUSIC and SYMHYD, available from the CRC for Catchment Hydrology's *Catchment Modelling Toolkit* (see http://www.toolkit.net.au/cgi-bin/WebObjects/toolkit).

This method can only be applied if the streamflow data are accompanied by reliable rainfall data for the same period of record. It is recommended that simulation of catchment runoff be undertaken at daily time steps. Calibration to flow duration characteristics would normally be sufficient to enable the calibrated model to generate the baseline flow duration curves for the development site. This method is discussed in more detailed, with a worked example, in Sections 4.3 and 4.5.

2.2.2 Low Flow Duration Frequency Curves

Figure 5 shows the minimum flow duration curves derived from analysis of 30 years of streamflow data recorded at Jilliby Jillby Creek upstream of Wyong River for 1, 7, 14, 30 and 60 consecutive days. An example of how the curves may be interpreted is as follows:- "*64% of the years for which data is available have a minimum average 30-day flow of greater than 10 ML/d*".

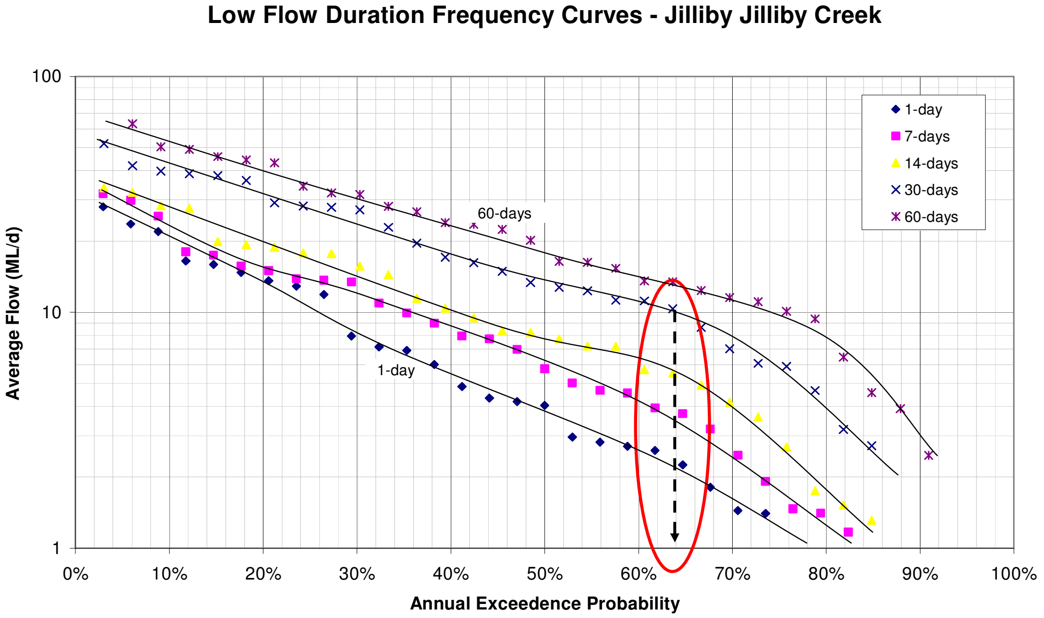

Figure 5 - Low Flow Duration Frequency Curves for Jilliby Jilliby Creek

The information contained in the low flow duration frequency curve can be used to define the flow management objective to protect natural wetlands from the hydrologic effect of catchment urbanisation related to the frequency of drying of the wetland in question, eg.

> *A hypothetical existing natural wetland in the Jilliby Jilliby Creek catchment has the vegetation characteristics that are supported by a frequency of drying, for a 30-day consecutive period, of at least 2 season in three (ie. probability of exceedence is 33%). If development in the catchment were to occur, flow management associated with the development should ensure that the 30-day low flow*

corresponding to a probability of exceedence of 33% is preserved. From Figure 2.3, the 30-day low flow corresponding to a probability of exceedence of 33% is approximately 23 ML/d.

The low flow duration frequency curves presented could be used to develop target low flow values corresponding to different frequency of drying. The corresponding flow values for Jilliby Jilliby Creek (from Figure 5) are summarised in Table 3.

Table 3 - Target low flow for wetland "drying" frequency

Frequency of Drying	Annual Exceedence Probability	Duration of Drying(days)		
		14-days	30-days	60-days
Four times every 5 years	20%	20 Ml/d	31 Ml/d	43 ML/d
Three times every 4 years	25%	18 ML/d	28 ML/d	33 ML/d
Twice every 3 years	33%	14 ML/d	23 ML/d	28 ML/d
Once every 2 years	50%	8 ML/d	13 ML/d	18 ML/d

2.2.3 High Flow Duration Frequency Curves

Figure 6 shows the high flow duration frequency curves derived from the same Jilliby Jilliby Creek flow data set and the curves may be interpreted as follows:- "*30% of the years for which data is available have a maximum average 30-day flow of greater than 1000 ML/d*".

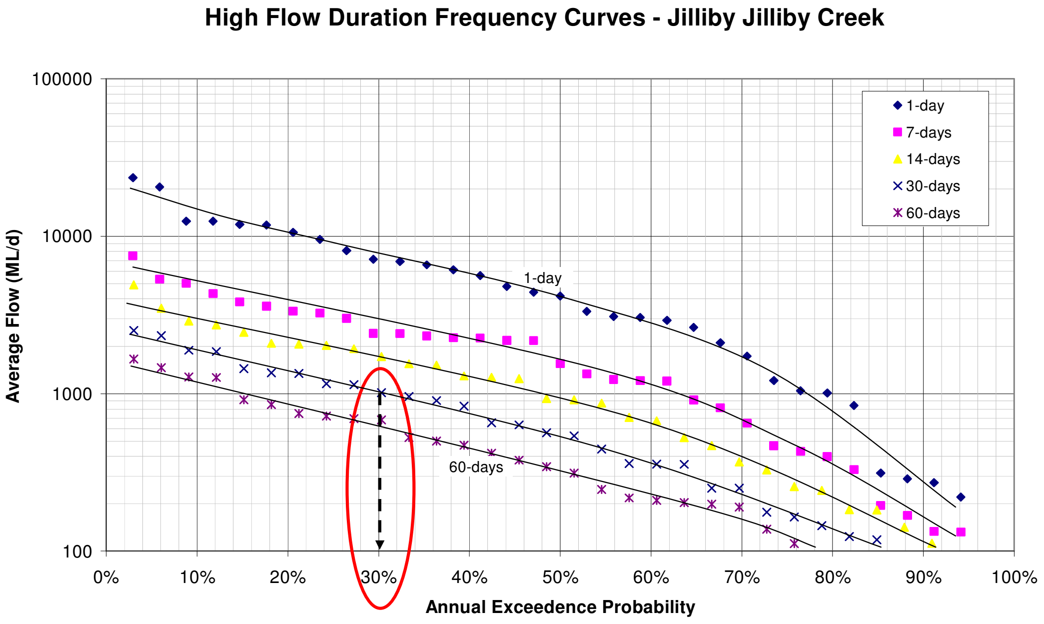

Figure 6 - High Flow Duration Frequency Curves for Jilliby Jilliby Creek

The information contained in the low flow duration frequency curve can be used to define the flow management objective to protect natural wetlands from the hydrologic effect of catchment urbanisation is related to the frequency of flooding of the wetland in question, eg.

> *A hypothetical existing natural wetland in the Jilliby Jilliby Creek catchment has the vegetation characteristics that are supported by a frequency of flooding, for a 30-day consecutive period, of at least 2 season in three (ie. probability of exceedence is 67%). If development in the catchment were to occur, flow management associated with the development should ensure that the 30-day high flow corresponding to a probability of exceedence of 67% is preserved. From Figure 2.7, the 30-day high flow corresponding to a probability of exceedence of 67% is approximately 250 ML/d.*

The high flow duration frequency curves presented could be used to develop target high flow values corresponding to different frequency of flooding. The corresponding flow values for Jilliby Jilliby Creek (from Figure 6) are summarised in Table 4.

Table 4 - Target average high flow for wetland flooding frequency

Frequency of flooding	Probability of Exceedence	Duration of Drying(days)		
		14-days	30-days	60-days
Twice every 3 years	67%	470 Ml/d	250 ML/d	200 ML/d
Once every 2 years	50%	910 ML/d	540 ML/d	310 ML/d
Once every 3 years	33%	1540 Ml/d	950 ML/d	540 ML/d
Once every 4 years	25%	2010 ML/d	1150 ML/d	710 ML/d

2.2.4 Selection of Reference Flow Duration

The selection of the appropriate reference flow duration in undertaking flow duration analysis is based on consideration of the typical duration of drying and frequency of inundation of the wetland in question. Freshwater inundation from catchment runoff of tidally affected wetland systems are, in the majority of cases, over short duration of between 1 day and 7 days.

Flooding duration

For wetlands which are affected pre-dominantly by catchment flooding, it is reasonable to expect the ratio of the mean annual runoff volume (MARV = mean annual rainfall x volumetric runoff coefficient x catchment area) to the wetland storage volume ($V_{wetland}$ = mean inundation depth x wetland area) to directly influence the flooding frequency and flooding duration. Field geomorphic survey of the wetland in question will be necessary to define the mean depth of inundation of the wetland. A low wetland inundation volume to catchment runoff volume ratio suggests that the wetland can be expected to be inundated frequently and short reference flow durations would be appropriate.

As a rough rule, the following recommended reference flow durations listed in Table 5 are suggested. These are based on examination of rainfall data for eastern and western NSW sites.

Table 5 - Suggested reference duration for wetland flooding frequency

MARV/ $V_{wetland}$	Reference Flow Duration
≥ 60	7 days
≥ 35 to <60	14 days
≥ 15 to < 35	30 days
< 15	60 days

$V_{wetland}$ – wetland inundation volume
MARV – mean annual runoff volume from catchment

Drying Duration

This ratio of catchment runoff volume to wetland storage volume is less relevant for determining the reference duration for defining the drying hydrologic characteristics of natural wetlands. Wetland drying durations are often long durations of at least 30 days except for tidally affected systems where tidal inundation may result in highly variable drying durations ranging from twice daily to several months. Catchment management objectives directed at preserving the drying hydrology of tidally affected wetlands are closely related to preserving its (freshwater) flooding hydrology and thus a similar critical duration could be used.

For wetlands where the flooding pathways are associated with overbank flows, field geomorphic survey and long-term hydrologic and hydraulic modelling of the watercourses within the wetland will be necessary to define the drying characteristics of natural wetlands.

Table 1 (p3) attempts to identify typical values of these characteristics. These values should be used, in the absence of any geomorphic survey of wetlands, to guide the determination of the appropriate reference duration for analysis.

The selection of a reference duration for flow duration analysis merely allows for a basis of hydrologic analysis and need not strictly be correlated with the typical duration of drying of natural wetland although there should be a consistent trend that wetlands with longer drying duration should have corresponding reference durations that are generally longer that those with shorter drying duration. Some degree of pragmatism should be exercised in selecting the reference duration for wetlands with long drying durations as the recommended critical period for flow analysis is only over a 4-month period (see Figure 2).

2.2.5 Low flow spell frequency

Low flow spell frequency curves describe the cumulative probability distribution of the annual maximum consecutive period (days) in which streamflow is less than a given threshold discharge. Figure 7 is an illustration of the low flow spell frequency curves derived from analysis of the Jilliby Jilliby Creek data for threshold flows of 1, 3, 5, 7and 9 ML/d. An example of how the curves may be interpreted is as follows:- "*67% of the years for which data is available contain at least 2 consecutive days in which the daily flows is less than 7 ML/d*".

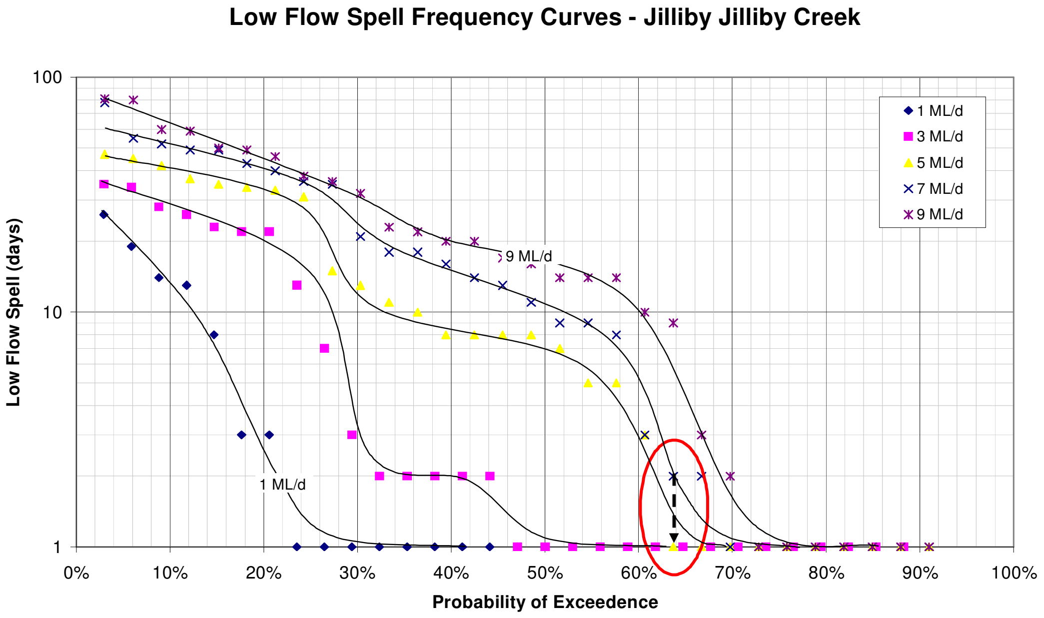

Figure 7 - Low Flow Spell Analysis - Jilliby Jilliby Creek

2.2.6 Selection of Threshold Discharge for Spell Analysis

A threshold discharge for spell analysis need to be defined for wetlands subjected to flooding either by overbank flow or overland flow.

The selection of the appropriate threshold discharge for (dry) spell analysis for wetlands that are inundated by overbank flow flooding pathways is dependent on the geomorphic characteristics of the watercourse(s) in the wetland. Most natural watercourses have bankfull discharges corresponding flood frequencies between 1.5 year and 5 year Average Recurrence Intervals (ARI). However, it is reasonable to expect bankfull discharge frequency in natural wetlands to be significantly higher than 1.5 year ARI but this can only be determined from geomorphic survey of wetland watercourses and hydraulic modelling.

It is recommended that a threshold discharge corresponding to the mean base flow (50% probability of exceedence) of the critical drying period be selected as the threshold discharge for computing low flow spell frequency curves for wetlands that are subjected to flooding by overland flow pathways.

In the absence of any field geomorphic survey of wetland watercourses, this same procedure can be adopted for defining the threshold discharge for wetlands subjected to overbank flow flooding.

3 URBAN WATER MANAGEMENT OBJECTIVES FOR CATCHMENTS UPSTREAM OF NATURAL WETLANDS

3.1 Wetland Hydrology

Having established the hydrologic indices for defining the flooding and drying hydrological characteristics supporting wetland ecology, it is possible to state the required performance objectives of hydrologic management measures that would be most suited to the protection of the seventeen types of wetlands identified. These recommendations are shown in the Table 6.

Hydrologic regime is a major factor responsible for the differences between wetlands. Table 1 is an attempt to quantify a series of hydrologic variables that can distinguish between wetlands. However, these variables contain no information on the dominant hydrologic pathway responsible for delivering water to wetlands.

Table 6 lists the recommended hydrologic performance objectives for urban developments upstream of natural wetlands. There are exceptions to the “rule” as wetland morphology will also influence the appropriate hydrologic management objective.

As discussed in Section 2.2.4, some degree of pragmatism should be exercised in selecting the reference duration for wetlands with long drying durations.

For general application of the hydrologic performance objectives, it is recommended that a maximum reference duration for hydrologic analysis be set at 60-days as analysis found WSUD solutions to match hydrologic conditions to longer reference durations to be very restrictive and that is will be necessary for hydraulic intervention measures in the form of flow diversions measures to be adopted over and above source-control hydrologic intervention measures.

In demonstrating compliance to the hydrologic management objectives with the adoption of WSUD in catchments upstream of natural wetlands it will be necessary to compare the post development hydrologic indices with pre-development hydrologic indices. It is often unrealistic to expect the post development flow duration frequency curves and spell frequency curves to match the corresponding pre-development curves in its entirety and mis-match will be most common at either ends of the probability distribution curve. An inability to match flow characteristics at these ends are not considered critical in the overall scheme of preserving the hydrologic characteristics of natural wetlands as it is often the more frequently recurring conditions that are critical. Furthermore, flow magnitudes corresponding to the two ends of the probability distribution are the least reliable and thus some level of pragmatism in assessing compliance is reasonable.

It is recommended that the critical region of the flow duration and spell frequency curves that need to be preserved should be limited to between 10% and 90% AEP to avoid the extremities of the pre-development hydrologic characteristics.

There are no known theoretical probability distributions for the flow duration curves and thus it is not possible to reliably define their confidence limits. Achieving compliance of the hydrologic management objectives should be demonstrated by the post-development flow duration curves and spell frequency curves attaining similar shapes and slopes. The examples shown in Section 4.7 provide some illustrations of what may be considered acceptable WSUD solutions.

Table 6 - Hydrologic Management Objectives for Natural Wetlands

Wetland Category	Flooding Hydrology	Drying Hydrology		Reference Duration
	High Flow Duration Frequency Curve	Low Flow Duration Frequency Curve	Low Flow Spell Frequency	
1. Coastal Flats	✓			7 days
2. Inland Flats	✓	Isolate wetland from upstream catchment		30 to 60 days
3. Bogs	✓	✓	✓	30 to 60 days
4. Deep Marsh		✓	✓	30 to 60 days
5. Fen	✓	✓	✓	30 to 60 days
6. Shallow Marsh		✓	✓	60 days
7. Salt Marsh	✓	✓	✓	7 days
8. Seagrass Beds	✓			7 days
9. Deep Salt Pans	✓	Isolate wetland from upstream catchment		30 to 60 days
10. Deep Open Water	No hydrologic management objectives required			
11. Shallow Open Water		✓	✓	60 days
12. Wet Heath		✓	✓	60 days
13. Mangrove	✓			7 days
14. Scrub Swamp	✓	✓*	✓*	60 days
15. Forest Swamp – Wet		✓	✓	60 days
16. Forest Swamp – Ephemeral		✓	✓	60 days
17. Forest Swamp – Dry	✓	✓*	✓*	60 days

* For development along the fringe of wetland with Overland Flow Flooding Pathways (see Section 2.1) only. Note that reference to “fringe of wetland” simply related to areas that do not have a well defined conveyance pathway for stormwater into the wetland and are not meant to have any scientific definition of what the margin or fringe of a wetland is.

An overview of how the recommendations set out in the table can be interpreted is as follows:-

- **Coastal flats** are subjected to frequent inundation, largely driven by tide. The hydrologic management of catchments upstream is primarily related to ensuring that excessive urban (freshwater) runoff resulting from urban development is not going to “disrupt” the freshwater/marine water mix of inundation water in these wetlands. The reference duration will be relative short and a 7-day duration should cover the range of tidal fluctuation expected. The management objective is to match the pre-development high flow duration characteristics.

- **Inland flats** are similar to coastal flats, with the main distinction being that these are generally semi-arid and arid freshwater or brackish systems, depending on the source of their supporting hydrology (ie. catchment runoff or groundwater). The reference duration for flow duration frequency analysis is 30 or 60 days to reflect the occasional flooding of these systems during extended wet periods. The management objective is to isolate the wetland from the effect of upstream development and preserve the flooding hydrology (through a combination of low flow diversion and managed overflow flooding).

- **Bogs** are ombrotrophic so receive water that falls directly on them as rain or snow. Their substratum is constantly saturated and may have permanent surface water. These systems have small local catchments and often no defined dominant watercourse delivering water into the system. Their geomorphic form promotes shallow depth of inundation. Their reference duration for flow duration frequency analysis is 30 or 60 days to reflect the relative small catchment contributing to the wetland. The management objective is to preserve the pre-development drying and flooding hydrology.

- **Deep marshes** can be expected to be inundated frequently and for prolonged periods. The sustainability of the wetland is reliant on the drying period and thus the hydrologic water management objective is to preserve its drying hydrology associated with the pre-development minimum 30-day or 60-day average flow. The management objective is to preserve the pre-development drying hydrology

- **Fens** are predominantly dependent on groundwater, but may also receive runoff from local catchments. Water level fluctuation in fens is often directly correlated to seasonal groundwater table fluctuation. The recommended hydrologic management objectives for fen systems would normally involve preserving both the pre-development flooding and drying hydrology, especially for frequent events (ie. high Annual Exceedence Probability), directed at preserving the pre-development relative contributions of surface water and groundwater to the hydrologic and water quality regime of this type of wetlands.

- **Shallow marshes** are systems that are occasionally flooded with a wider temporal range of inundation depth compared with deep marshes eventhough their maximum depths may be similar. The key influence on water level fluctuation is evapotranspiration losses and basin geomorphology. Although the water can be deep (>0.5 m) on occasions, the duration of inundation in these systems is limited and water will recede within a few hours to days. Changes to the flooding hydrology resulting from urbanisation is expected to be less influential on sustaining the ecology of the shallow marsh compared with unmitigated changes to their drying hydrology. Preserving the pre-development drying hydrology of shallow marsh is considered to be the key hydrologic management objective.

- **Salt marshes** are either coastal or inland systems with varying levels of water salinity. Inflows of freshwater are an important element of the reproduction in many salt marsh species. Thus, preventing either excessive dilution from increased surface runoff from urbanized catchments or diversion of diffuse freshwater inflows resulting in higher and more permanent salinities is an important hydrologic management consideration and covers both the flooding and drying (low flow) hydrologic characteristics.

- **Seagrass beds** are marine systems which may be affected by increased freshwater inflow during flood conditions as a result of increased volume and frequency of stormwater runoff changing the seasonal patterns of salinity. Changes to low flow conditions resulting from catchment urbanisation are less significant. The recommended hydrologic management objective is to preserve their pre-development flooding hydrology.

- **Deep salt pans** are isolated saline systems where their salt may be derived from past marine intrusions, from saline groundwater inflows, or from the accumulation of salts from atmospheric deposition and weathering processes in endorheic drainage systems. Water is usually sourced from local catchments or groundwater and the recommended hydrologic management objectives are similar to that for fens, ie. preserving both the pre-development flooding and drying hydrology for frequent events (ie. high Annual Exceedence Probability), directed at preserving the pre-development relative contributions of surface water and groundwater to the hydrologic and water quality regime

- **Deep open water** wetlands have freshwater and are often located on the floodplain of large rivers. They are generally permanently inundated with relatively small water level fluctuations and only dry out occasionally. Generally changes in catchment hydrology attributed to catchment urbanisation have only a marginal impact on the hydrology of these systems. No hydrologic management of developments in upstream catchments is considered necessary.

- **Shallow open water** wetlands are simply shallower versions of deep open water system that are subject to more frequent drying (through evaporation). Increased flooding flows are not expected to alter the inundation depths significantly. Like shallow marsh wetlands, preserving the pre-development drying hydrology of these systems is considered to be the key hydrologic management objective.

- **Wet heaths** are areas with substratum that is regularly (but not constantly) saturated, although only occasionally flooded. These systems generally have small local catchments and, like bogs, their geomorphic form promotes shallow depth of inundation. The management objective is to preserve the pre-development drying hydrology.

- **Mangrove wetlands** are marine systems that experience varying levels of salinity, but are generally regularly inundated by tides. However, inflows of freshwater are an important element of the reproduction in many mangrove species. Thus, preventing the diversion or reduction of freshwater inflows is an important hydrologic management consideration. It is thus important that the frequency of flooding of mangroves wetlands not be reduced as a result of catchment urbanisation while the overall increase in stormwater flow volume is less important as these systems still regularly experience tidal inundation with saline marine waters. The recommended hydrologic management objective is to preserve their pre-development flooding hydrology for frequent events of up to 1 year ARI.

- **Scrub swamp wetlands** are freshwater systems that are flooded on an ephemeral or seasonal basis. They are extensive overflow (floodplain) areas formed by floodwaters from a catchment. Depending on the geographic region, climate, size of river, and the distance of a wetland from the river, scrub swamps can be flooded once every one to two years, or once every ten years. The recommended hydrologic management objective is to preserve the pre-development flooding hydrology. For development along the fringe of Scrub Swamp wetlands and where they drain directly into these system (ie. overland flow flooding pathway – See Section 2.1), it will also be necessary for the drying hydrology to be preserved.

- **Forest swamp (wet)** wetlands are flooded on a regular or seasonal basis, and typically occur on floodplains. They are generally considered as wetland systems that are pre-dominantly wet. Depending on the geographic region, climate, local topography, size of river, and the distance of a wetland from the river, wet forest swamps are typically flooded annually and dry out for 2-6 month per year, but may not dry out every year. Preserving the pre-development drying hydrology, especially for annual exceedence probabilities less than 50%, is considered to be the principal hydrologic management objective.

- **Forest swamp (ephemeral)** wetlands are generally located further away from main watercourses compared to Forest Swamp (wet) systems and are subject to a higher frequency of drying. The hydrologic management objective for these systems is similar to that for Forest Swamp (wet) and is directed at preserving the pre-development drying hydrology for all events.

- **Forest swamp (dry)** wetlands are pre-dominantly dry wetland systems that are flooded less frequently compared with the previous two classifications of forest swamp. Depending on the geographic region, climate, size of river, and the distance of a wetland from the river, dry forest swamps can be flooded once every one to two years, or once every ten years. The recommended hydrologic management objective is to preserve the pre-development flooding hydrology. For development along the fringe of forest swamp wetlands and where they drain directly into these system (ie. overland flow flooding pathway – See Section 2.1), it will also be necessary for the drying hydrology to be preserved.

3.2 Wetland Water Quality

Wetlands occur in a very wide range of environments (Jacobs & Brock 1993, Green 1997, Sainty & Jacobs 2003). As a result, the supporting water quality of wetlands varies considerably and is the primary reason that the ANZECC (2000) guidelines provide no guidelines for wetlands in South-Eastern Australia. There is insufficient data available on the range of wetland types in this region.

In general water quality supporting various wetland types is related to the position of particular wetland types in the terrain. Upland wetlands (eg. bogs) or wetlands with limited catchments (wet heaths) tend to be adapted to very good water quality (low nutrient) conditions. Lowland wetlands (deep marshes, wet swamps) typically have large catchments and tend to regulate the supply of water and materials (sediment, nutrients, etc.) to downstream environments. As a result these systems tend to be adapted to poorer water quality (high nutrient) conditions. Some wetland types are very good at processing and utilising nutrients. In fact, marsh type wetlands are the typical model for constructed wetlands for the treatment of both wastewaters and urban runoff. This indicates the potential variation in the water quality requirements of different wetland types to maintain a healthy and sustainable condition. .

Where wetland environments have been impacted by changes in their catchments such as urban development, the impact is nearly always multifactorial. Un-controlled urbanisation typically results in both changes to runoff quality and quantity. Wetlands can be very sensitive to changes in hydrology and it is not always clear any one factor is responsible for the impact resulting from urbanisation. For example urban runoff may have little impact on marshland environments but have a major impact on swamp forests. The impact on swamp forests is clearly a combination of hydrologic change resulting in waterlogging in the death of trees. Increased runoff can enhance the release of nutrients from the in-situ soils as a result of the flooding process. Thus for low nutrient status wetlands (typically dry swamp forest and wet heaths) increased nutrient imports and increased release of in-situ nutrients can result in impacts to nutrient sensitive vegetation. Such impacts are more like nutrient impacts experienced in nutrient sensitive terrestrial vegetation.

3.2.1 Australian Runoff Quality Approach to setting Catchment Stormwater Quality Objectives

A possible procedure for determining catchment water quality management targets is described in Appendix C of this study and is based on the methodology contained in Australian Runoff Quality (Lawrence and Phillips, 2003). The procedure involves the application of a receiving water model such as the CRC for Freshwater Ecology’s Pond and Wetland model, coupled with a catchment model such as MUSIC or AQUALM. These models simulate the following processes of nutrient generation, mixing, assimilation and recycling:-

- MUSIC or AQUALM are catchment stormwater flow and pollutant generation models, used to define the nutrient loads and concentrations time series discharged from an urban catchment;

- CRC Pond Model and Wetland Model are models that simulate the biological and chemical processes affecting the pathways of nutrient within receiving waterbodies. Nutrient concentrations resulting from mixing of inflow stormwater with the waterbody are determined and nutrient assimilation by algae (typically represented as phytoplankton) computed at daily time intervals. Cumulative probability plot of nutrient concentrations (in the receiving waterbody) are then derived and compared against target concentrations that reflect healthy wetland systems.

The modelling procedure outlined in Australian Runoff Quality involves the application of the above models in a systematic way to related target pollutant concentrations established for the receiving water (eg. ANZECC) with pollutant loads discharged from the catchment. The modelling procedure involves progressively reducing the assumed pollutant load applied in the catchment until the modeled resulting median nutrient concentrations in the receiving waterbody are less that their corresponding target concentrations. Once achieved, the assumed pollutant load generated from the catchment becomes the target pollutant load that stormwater quality improvement measures in the catchment will need to meet. This may be different from the generally adopted 80% and 45% reduction in the mean annual load of suspended solids and nutrients typically generated from an urban catchment.

For wetlands where interim water quality trigger values can be estimated, these values should be used in the protocol proposed in ARQ by Lawrence and Phillips (2003) for determining sustainable loads from a catchment.

The Australian Runoff Quality procedure was developed in recognition of the fact that different catchments may have different water quality objectives specified even if the receiving waterbody has the same target water quality concentrations[2]. For sensitive receiving waterbodies, the widely adopted approach of requiring 80% and 45% reduction in suspended solids and nutrients may not be adequate. However, defining the appropriate water quality management objectives in catchments upstream of these sensitive receiving water environments requires significant computational effort and data.

The ARQ procedure can only be applied when target concentrations are known. As stated earlier, there is insufficient data to define the supporting water quality for the range of wetlands in South Eastern Australia. This is confirmed by recent enquiries of the Department of Infrastructure Planning and Natural Resources of available water quality data for wetlands in NSW. Nevertheless, interim water quality guidelines for the majority of wetland types have been suggested, based on existing ANZECC trigger levels and depending on the wetland type in the terrain (see Appendix C). These interim guidelines may be used in a applying the

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[2] This is because the effects of catchment hydrology and waterbody hydrodynamics combine to define the water quality objectives for the catchment to satisfy the target concentrations in the waterbody. For example, a large receiving waterbody (relative to the catchment runoff volume) with good mixing characteristics can have a significant dilution effect on inflow pollutant concentrations such that high inflow pollutant concentrations can be readily diluted to meet the specified target concentrations.

modelling approach outlined above to define the appropriate catchment water quality management objectives for the wetland in question.

It is not possible to derive generic catchment management objectives for stormwater quality that are directly linked to the protection of natural wetlands without firstly undertaking a sufficient number of wetland/catchment modelling investigation using the approach outlined. The number of case studies will need to include the range of wetland types as well as a number of combinations of catchment to wetland scales and hydrologic conditions with wetland size and hydrodynamic conditions. It may be possible following the completion of these case studies to undertake a multi-case analysis to derive generic relationships for establishing catchment stormwater quality management objectives.

3.2.2 A Pragmatic Approach to setting Catchment Stormwater Quality Objectives

By achieving appropriate hydrologic control many of the hydrologic related water quality impacts that are likely to occur in wetlands, such as un-seasonal waterlogging and release of in-situ soil nutrients, will be addressed). Furthermore, urban stormwater pollutants will be removed through WSUD solutions adopted to preserve pre-development hydrologic characteristics. For example, in preserving the 30-day drying hydrology of the Porters Creek Wetland, a reduction in stormwater volume associated with measures directed at meeting hydrologic management objectives is of the order of 20% of the mean annual runoff volume.

Initiatives to treat that component of stormwater runoff that is discharged to the wetland to current best practice objectives would further reduce stormwater pollutant loads by 80% of TSS and 45% of nutrients, thus giving an overall mean annual TSS and nutrient load reductions of 84% and 56% respectively.

In the absence of a modelling approach (outlined in Appendix C) to define the catchment water quality objectives, the following approach to setting catchment urban stormwater quality objectives is recommended:

- All stormwater discharged (following hydrologic control to meet hydrologic management objectives recommended in Section 3.1) is treated to “best practice” standards – at present best practice can be expected to reduce the mean annual export of suspended solids and nutrients (TP and TN) by 80% and 45% respectively.

- For wetlands where interim water quality trigger values can not be estimated (Fen, Wet Heath, Scrub Swamp, Ephemeral Swamp Forest and Dry Swamp Forest) 50 %tiles for wet weather flows should not exceed:
    - 0.06 mg/L for Total Phosphorus

- 1.0 mg/L for Total Nitrogen

These are concentrations are background concentrations that can be achieved by an appropriately designed stormwater treatment wetland at present but may be further reduced as new and better stormwater best management practices become available. It should be noted that these nutrient concentrations are associated with storm events and are not the same as ambient nutrient concentrations within a wetland. The latter can be expected to be lower owing to a combination of mixing (dilution) and nutrient assimilation within a wetland environment.

4 WSUD SOLUTIONS FOR URBAN DEVELOPMENT UPSTREAM OF WETLANDS – PORTERS CREEK WETLAND

4.1 Introduction

Water Sensitive Urban Design (WSUD) of urban development upstream of natural wetlands has the added objective of meeting the hydrologic performance objectives necessary to support wetland ecology. This section of the report presents an example of the design process to demonstrate the application of the methodology for computing hydrologic indices that sets the baseline for the hydrologic performance objectives required to preserve the supporting wetland hydrology and to examine possible WSUD solutions to match post-development hydrologic indices to baseline indices. A hypothetical development scenario in the Porters Creek catchment is used as a case study with the Porters Creek Wetland being the natural wetland to be protected.

There are a range of suitable WSUD elements that can be adopted to preserve pre-development hydrology and the majority of them are based on functions of stormwater retention and/or harvesting at allotment, precinct and regional scales. These include:-

- stormwater infiltration
- rainwater and stormwater harvesting, storage and reuse for
  - in-house non-potable use
  - open space watering
  - plantation and sporting fields
  - industrial use
  - regional water supply
- flow diversion

4.2 Design Process

Defining the baseline hydrologic indices involves continuous hydrologic modelling or analysis of historical streamflow data (such as that discussed in Section 2). The key steps in the design process are as follows:-

1. Selection and calibration (if data is available) of catchment hydrological model or obtain relevant long-term streamflow data for statistical analysis. A data length (either simulated or observed) of 15 to 20 years is desirable.

2. Identify the most suitable classification for the wetland to be protected and select the appropriate hydrologic performance objective(s) – see Sections 3 and 4.

3. Define the baseline hydrologic indices from the data simulated or observed (Step 1), ie. undertake the required flow duration frequency analysis and, if appropriate, the dry flow spell analysis as discussed in Section 2.

4. Define, through hydrologic modelling, the changes in hydrological behaviour as the result of proposed urban development in the catchment and compare the post-development hydrologic indices against the baseline indices for either wetland flooding or drying conditions.

5. Identify WSUD measures that have the capabilities to manage the hydrologic conditions of the proposed development to meet the hydrologic performance objectives established in Step 3.

4.3 Step 1: Porters Creek Hydrologic Data – A Model Simulation Approach

The Model for Urban Stormwater Improvement Conceptualisation (***MUSIC***) developed by the Cooperative Research Centre for Catchment Hydrology, and now widely used in development WSUD strategies, was selected to undertake hydrologic simulation of the Porters Creek catchment. The model simulates streamflow responses by modelling the catchment runoff processes of overland flow, soil moisture storage and groundwater dynamics.

Ideally, streamflow and rainfall data from the Porters Creek catchment would be used to calibrate a hydrological model, however Porters Creek is an ungauged creek. The closest streamflow gauge is located in the adjacent catchment of Jilliby Jilliby Creek, other streamflow gauges are located at Yarramalong and at Gracemere on the Wyong River.

Information on the three gauging stations are listed in Table 7 and their locations shown in Figure 8.

Table 7 - Summary Information of Streamflow Gauging Stations in the vicinity of Porters Creek Wetland

Location	Station number	Catchment area	Years of record	Average annual rainfall
Jilliby Jilliby @ U/S of Wyong River	211010	92km^2	1972 – 2004	607mm
Wyong River @ Yarramalong	211009	236 km^2	1972 – 2004	1171mm
Wyong River @ Gracemere	211014	181km^2	1976 – 2004	884mm

4.3.1 Selection of Calibration Data

Calibration of the model is achieved by comparing observed and predicted streamflow indices whereby model parameters are adjusted until the predicted low flow duration curves matches observed data as closely as possible.

The streamflow data for Jilliby Jillby Creek, Yarramalong and Gracemere were analysed for their suitability for use to represent the hydrologic behaviour of the Porters Creek catchment. Streamflow data from each gauging station were normalised for catchment area and mean annual rainfall, and low flow duration curves determined to enable them to be compared. Analyses of streamflow data show low flow characteristics in Jilliby Jilliby Creek to be significantly different from that observed in the Wyong River at both Gracemere and Yarramalong in that the Wyong River appears to have a longer period of sustained baseflow.

Anecdotal evidence indicated that the Wyong River was subject to dam releases in the headwaters which affected streamflows in the catchment. It was resolved to use Jilliby Jilliby Creek streamflow data as a better representation of the low flow hydrologic behaviour experienced in Porters Creek.

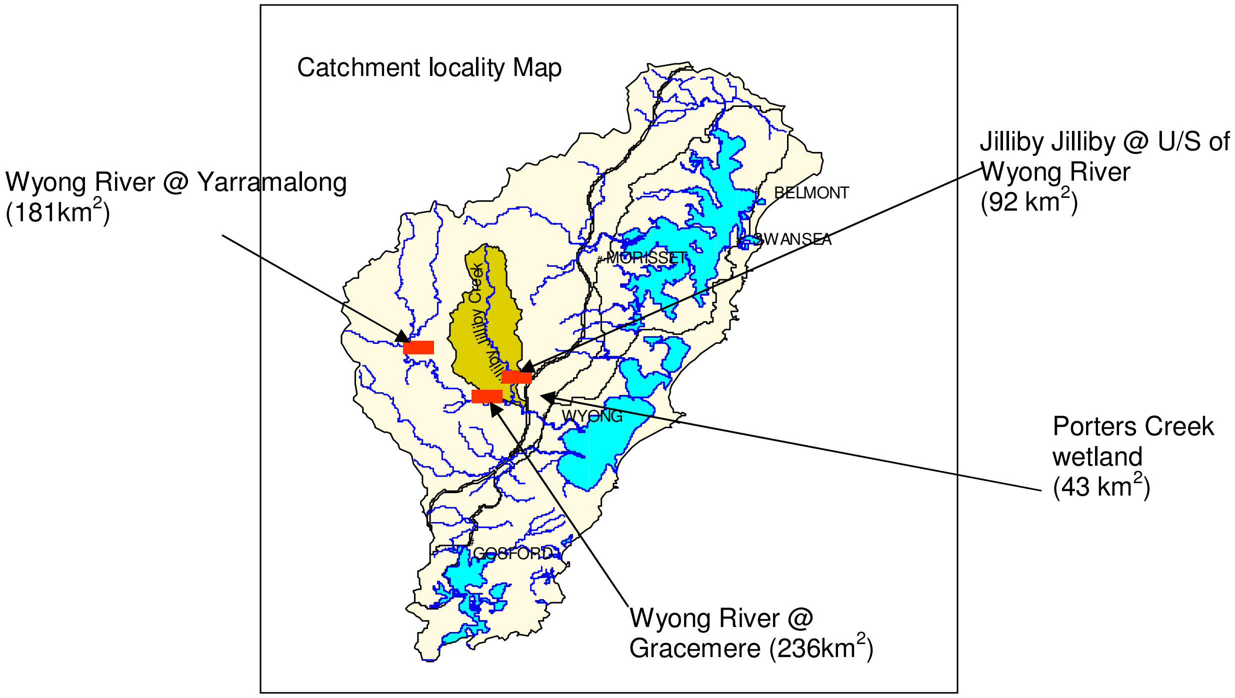


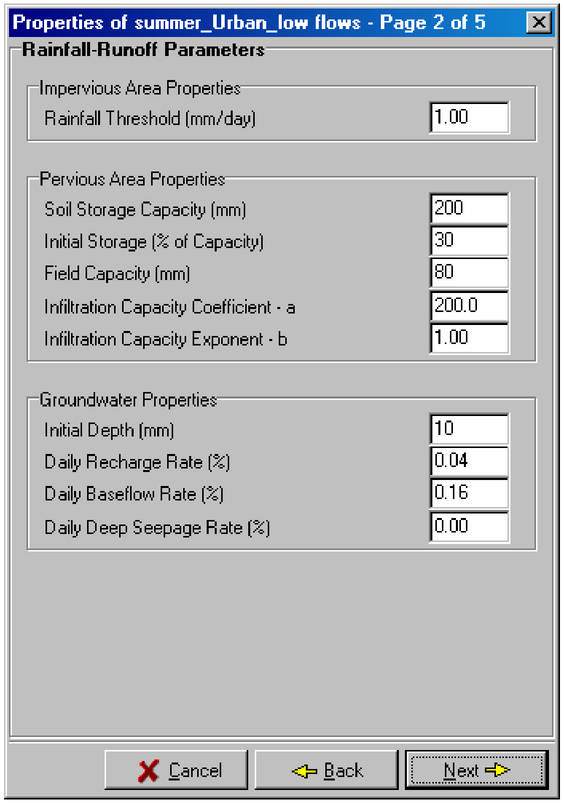
Figure 8 - Location of Streamflow Gauging Stations in the Vicinity of Porters Creek Wetland

4.3.2 Model Calibration

A ***MUSIC*** model was established for Porters Creek. Daily rainfall data recorded between 1/12/2000 and 9/3/2004 in close proximity to the Jilliby Jilliby Creek gauging station were available and these were imported to ***MUSIC*** to enable the model to simulate catchment runoff in response to the rainfall input. Calibration of the model is by adjustments to principal parameters such that simulated flow characteristics are similar to that represented by observed streamflows for the same period.

In the model established, Jilliby Jilliby Creek catchment was broken into three representative areas to represent the area of steep terrain (~87% of catchment), the flats along the valley (~13% of catchment) and a section of impervious area (~0.3% of catchment). The calibrated parameters for the rainfall-runoff models for the three areas are shown in Figure 9.

Node 1: Area 3753.Ha, 0 % imperviousness,



Properties of summer_Urban_low flows - Page 2 of 5

Rainfall-Runoff Parameters

Impervious Area Properties

Rainfall Threshold (mm/day)	1.00

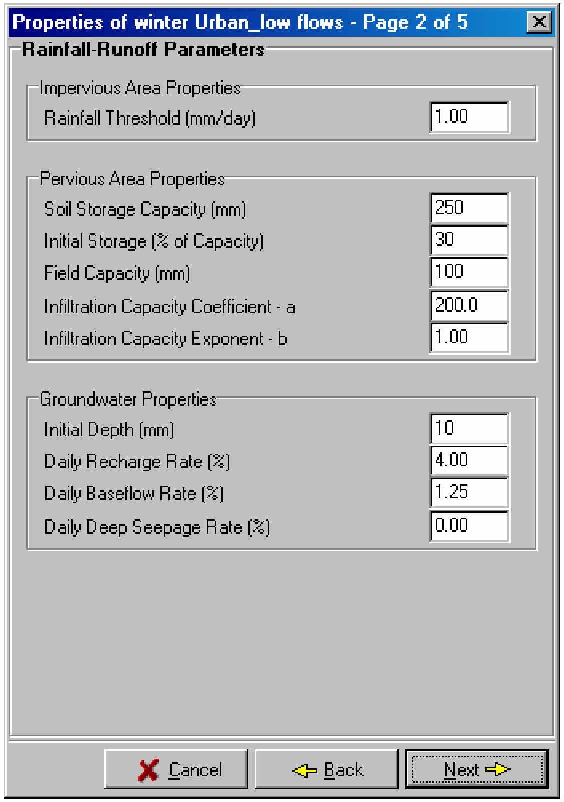
Pervious Area Properties

Soil Storage Capacity (mm)	200
Initial Storage (% of Capacity)	30
Field Capacity (mm)	80
Infiltration Capacity Coefficient - a	200.0
Infiltration Capacity Exponent - b	1.00

Groundwater Properties

Initial Depth (mm)	10
Daily Recharge Rate (%)	0.04
Daily Baseflow Rate (%)	0.16
Daily Deep Seepage Rate (%)	0.00

Node 2: Area 565 Ha, 0% imperviousness



Properties of winter Urban_low flows - Page 2 of 5

Rainfall-Runoff Parameters

Impervious Area Properties

Rainfall Threshold (mm/day)	1.00

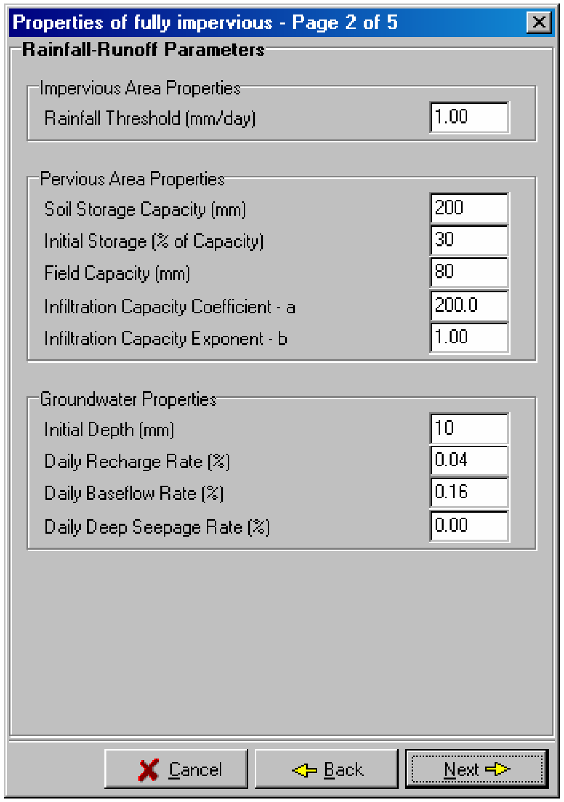
Pervious Area Properties

Soil Storage Capacity (mm)	250
Initial Storage (% of Capacity)	30
Field Capacity (mm)	100
Infiltration Capacity Coefficient - a	200.0
Infiltration Capacity Exponent - b	1.00

Groundwater Properties

Initial Depth (mm)	10
Daily Recharge Rate (%)	4.00
Daily Baseflow Rate (%)	1.25
Daily Deep Seepage Rate (%)	0.00

Node 3: Area 12 Ha, 100% impervious



Properties of fully impervious - Page 2 of 5

Rainfall-Runoff Parameters

Impervious Area Properties

Rainfall Threshold (mm/day)	1.00

Pervious Area Properties

Soil Storage Capacity (mm)	200
Initial Storage (% of Capacity)	30
Field Capacity (mm)	80
Infiltration Capacity Coefficient - a	200.0
Infiltration Capacity Exponent - b	1.00

Groundwater Properties

Initial Depth (mm)	10
Daily Recharge Rate (%)	0.04
Daily Baseflow Rate (%)	0.16
Daily Deep Seepage Rate (%)	0.00

Figure 9 - MUSIC Hydrologic Parameters Calibrated to Jilliby Jilliby Creek Flow Duration Frequency Curves Characteristics

Flow duration curves of average minimum flow for 7, 14, 30 and 60 days were derived and the model parameters adjusted to best reproduce the observed curves for the 3.5 years of concurrent rainfall and streamflow data available. The results of the calibration are shown in Figures 10 and 11. As shown in the plots, ***MUSIC*** has generally been able to simulate minimum dry season flows and minimum annual flows within the range observed from the data available for calibration. It should be noted that the results or the calibration are not entirely satisfactory in that the more extreme hydrologic behaviour for 7-day and 60-day were not well reproduced although reasonable calibration results were obtained for the 14-day and 30-day low flow duration characteristics.

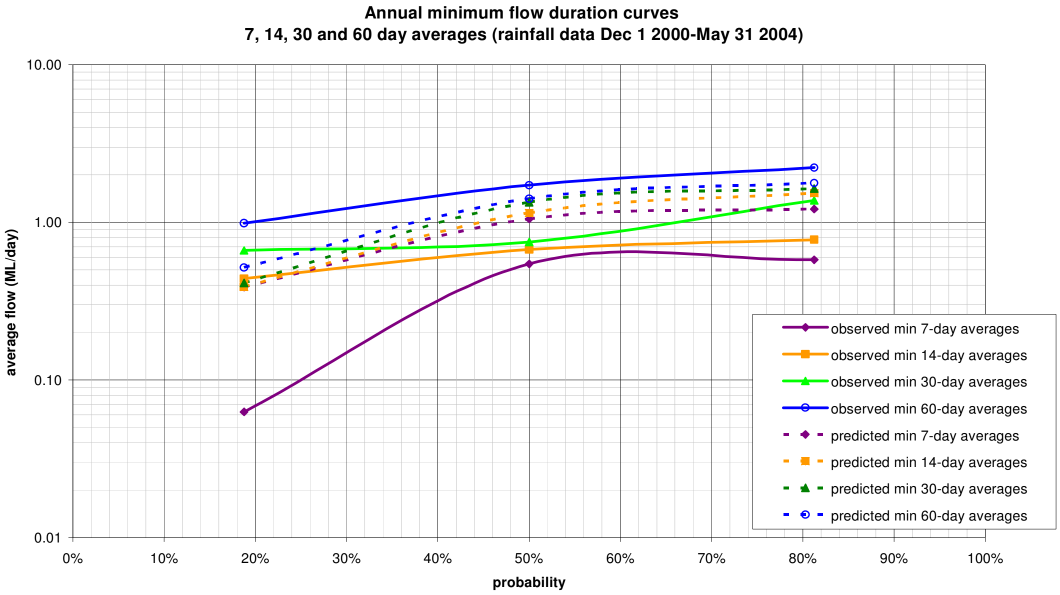


Figure 10 - Calibration Results - Annual Low Flow Duration Curves

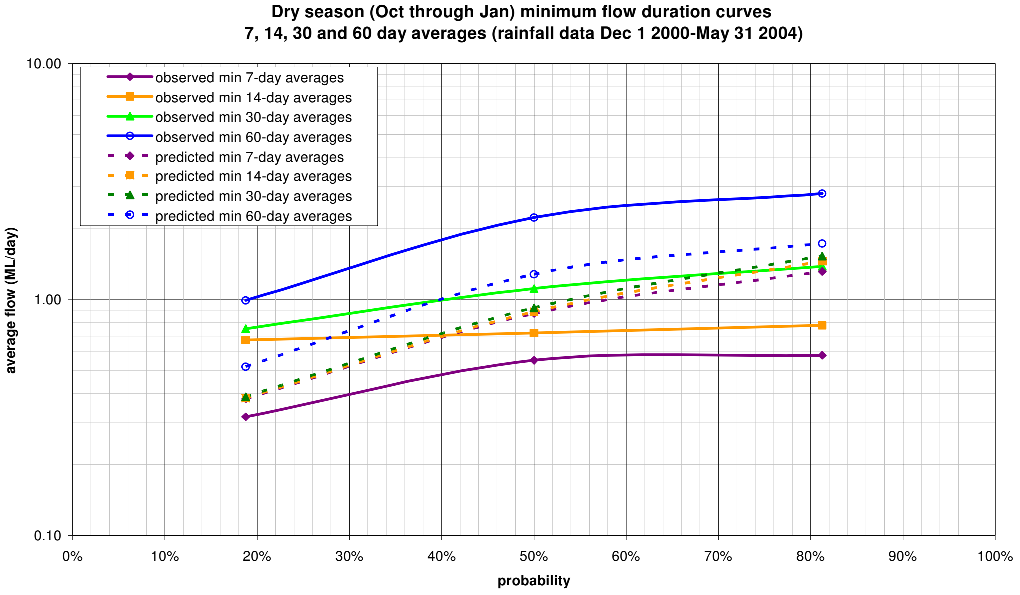


Figure 11 - Calibration Results - Drying Season Low Flow Duration Curves

4.4 Step 2: Identifying Wetland Type

Porters Creek wetland has been identified as a combination of Paperbark and Casuarina Wet Forest and Low Paperbark Swamp Forest with an isolated patch of Reed, Sedge & Herb Wetland. In general, the majority of the wetland can be considered as predominantly wet and the principal supporting hydrology is associated with a drying hydrology. The management objectives for upstream development are associated with preserving pre-development 30-day and/or 60-day low flow duration frequency curves (for the months of October to January) and corresponding dry spell.

4.5 Step 3: Defining Baseline Hydrologic Indices

The “calibrated” hydrologic parameters of the ***MUSIC*** model were used to simulate establish a model to representing the Porters Creek Wetland catchment. This model was then used to simulate the likely pre-development catchment flow discharging into Porters Creek using 20 years of rainfall data recorded in Sydney (the closest pluviographic rainfall station with long rainfall records). The simulated flows were then analysed to derive the low flow frequency curves and the low flow spell frequency curves. The derived curves are shown in Figures 12 and 13.

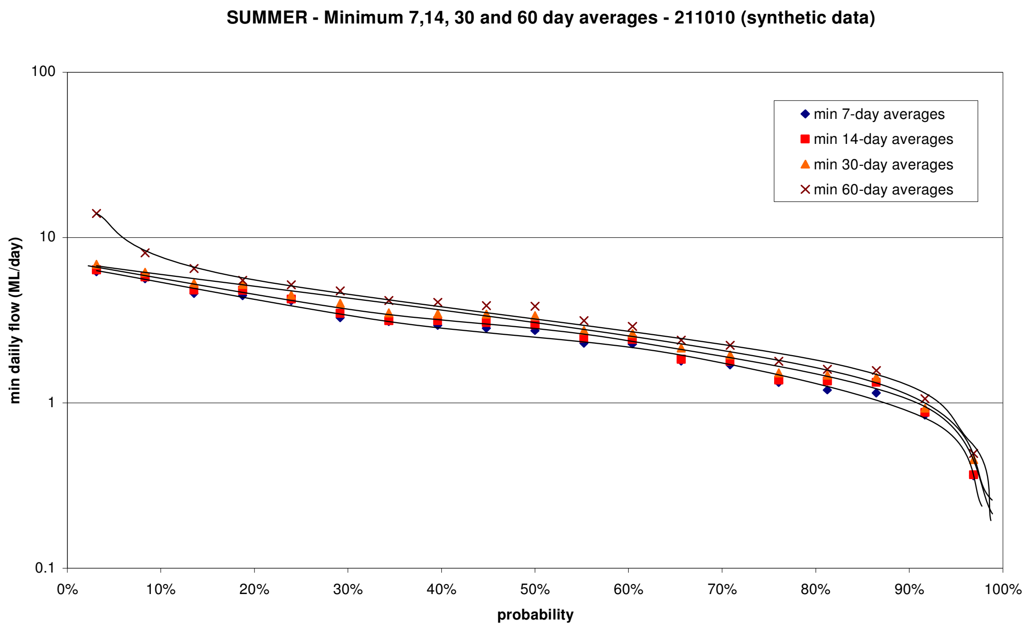


Figure 12 - Low Flow Duration Frequency Curves for Pre-development Conditions

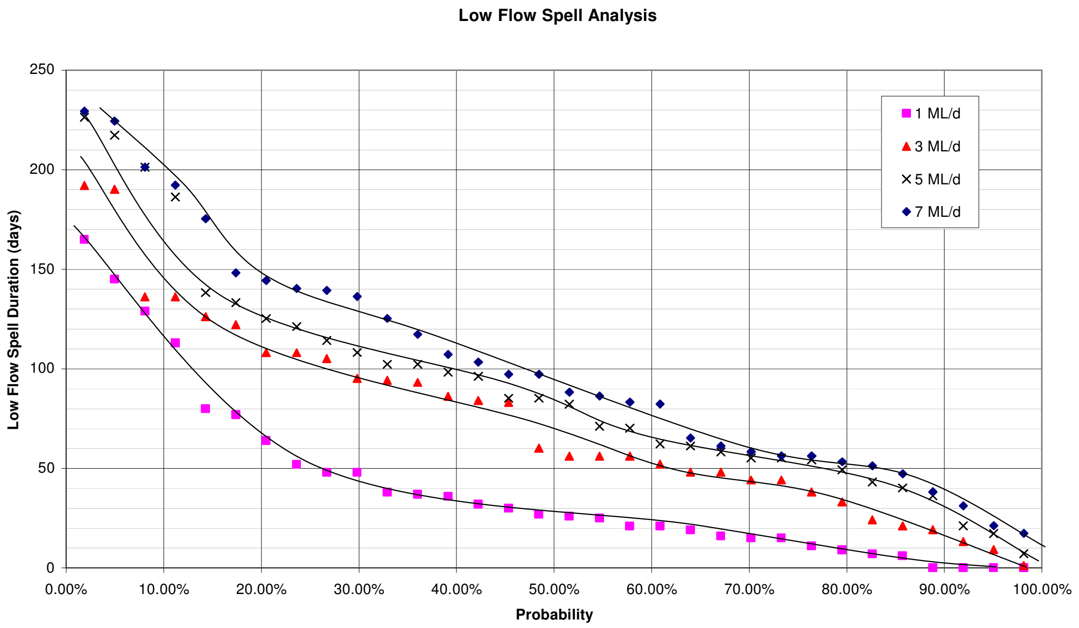


Figure 13 - Low Flow Spell Frequency Curves for Pre-development Conditions

4.6 Step 4: Defining the Post-development Hydrologic Indices

Following the simulation of pre-development hydrologic conditions, MUSIC was used to simulate post-development conditions by adjusting the relevant model parameters to represent a catchment with 40% fraction imperviousness. The results of these simulations, together with those derived in Step 5 are compared with the pre-development curves in figures contained in Section 4.7.

4.7 Step 5: Identifying Suitable WSUD Solutions

Runoff from urbanised catchments can alter the hydrologic regime of receiving environments with the general tendency for increased flows. Strategies that reduce the impact of urbanisation on receiving waters can include regional or onsite detention (to preserve pre-development flooding hydrology) or retention (to preserve pre-development drying hydrology). The main difference between detention and retention system is that the former is associated with peak flow reduction while that latter is associated with the removal of stormwater from the surface water conveyance system (eg. stormwater harvesting and reuse, infiltration etc.)

A number of hydrologic management options (referred herein as intervention options) are examined for the Porters Creek catchment case study for their capacity to offer WSUD solutions for managing the Swamp Forest (dry) wetlands within the Porters Creek wetland system. Each of the intervention option has been configured to mimic the pre-development drying hydrology for typical scenarios of catchment urbanisation.

1. **Intervention 1 “Open Space Irrigation”** – Catchment urbanisation of 15 dwellings/Ha with an overall catchment fraction imperviousness of 40%. Catchment runoff is stored in regional ponds and lakes and reused to irrigate Public Open Space (POS) or plantation. This option investigates reusing stored water for seasonal demands within the catchment however catchment planners could also investigate exporting water to industry or other water users outside the catchment.

2. **Intervention 2 “Rainwater Tanks”** – Catchment urbanisation of 15 dwellings/Ha with an overall catchment fraction imperviousness of 40% with each dwelling required to meet the target for potable water conservation established in BASIX (the Building Sustainability Index). BASIX requires 40% reduction in mains potable water demand through demand management measures (eg. water efficient fittings, xeriscaping of gardens etc.) and potable water substitution with an alternate water supply such as rainwater or stormwater. Analysis of required rainwater tank capacity to comply with the requirements of BASIX suggest the installation of 2.5KL rainwater tanks for each dwelling plumbed to toilets and garden irrigation. In addition to this, stormwater runoff from urban development was assumed to be subjected to stormwater quality treatment to meet current best practice stormwater quality objectives (ie. 80% reduction in mean annual TSS load and 45% reduction in mean annual nutrient (TP

and TN) loads from that typically generated from an urban area). In the analysis undertaken for this intervention option includes the installation of bioretention systems treat stormwater runoff. The bioretention systems cover an area the size of 4% of the upstream impervious area that is not connected to rainwater tanks.

3. **Intervention 3 "Open Space Irrigation & Rainwater Tanks "**– Combination of Intervention 1 and 2.

4. **Intervention 4 "Increased development density"** – Intervention 1 plus increasing development density and indoor water demand so as to increase the reuse of stormwater.

5. **Intervention 5 "Development Abutting Wetlands"** – Solutions for development in areas immediately abutting sensitive natural wetlands

4.7.1 Intervention 1 – Open Space Watering

Modelling using ***MUSIC*** was undertaken to determine the required storage capacity of a regional stormwater harvesting scheme and accompanying public open space irrigation area to enable the drying hydrology, as described by the low duration frequency curves, to be preserved. Table 8 list the solutions corresponding to the four reference durations. The resulting low flow duration curves are shown in Figures 14 to 17.

Table 8 - Hydrologic Management Elements for Intervention 1

Hydrologic Management Elements	Reference Duration			
	7-day	14-day	30-day	60-day
Stormwater Storage (% of mean annual runoff volume)	0.1%	0.2%	1.2%	4.1%
Stormwater Storage Volume/Ha (m^3)	7 m^3	12 m^3	84 m^3	280 m^3
Area of irrigated open space or plantation (% of catchment area)	4.2%	12%	35%	79%

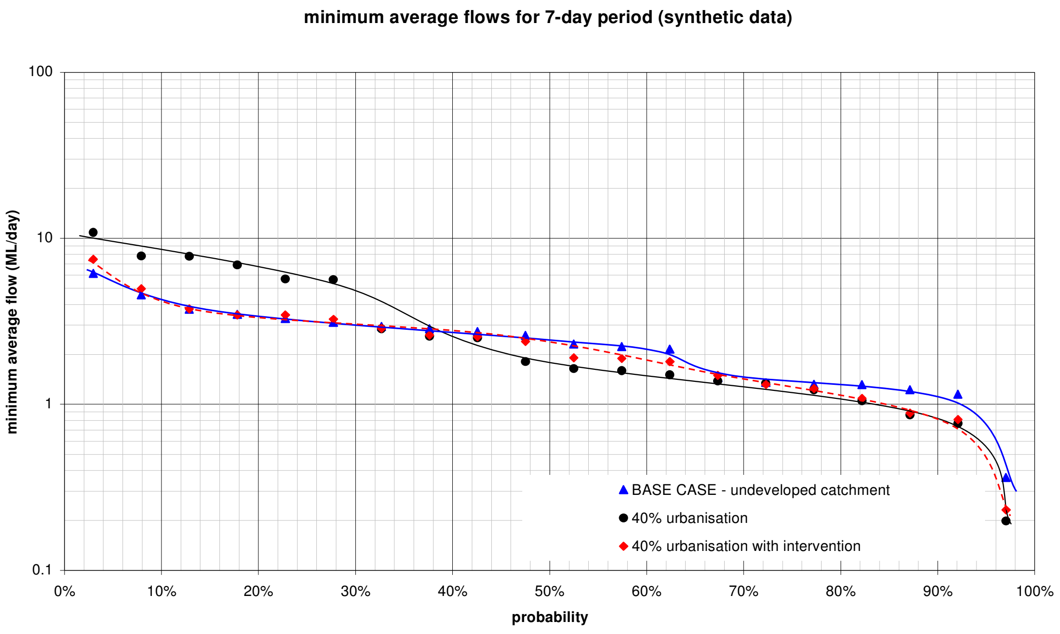


Figure 14 - 7-day Low Flow Duration Frequency Curve (i) pre-development; (ii) post-development with and without intervention (see Table 8)

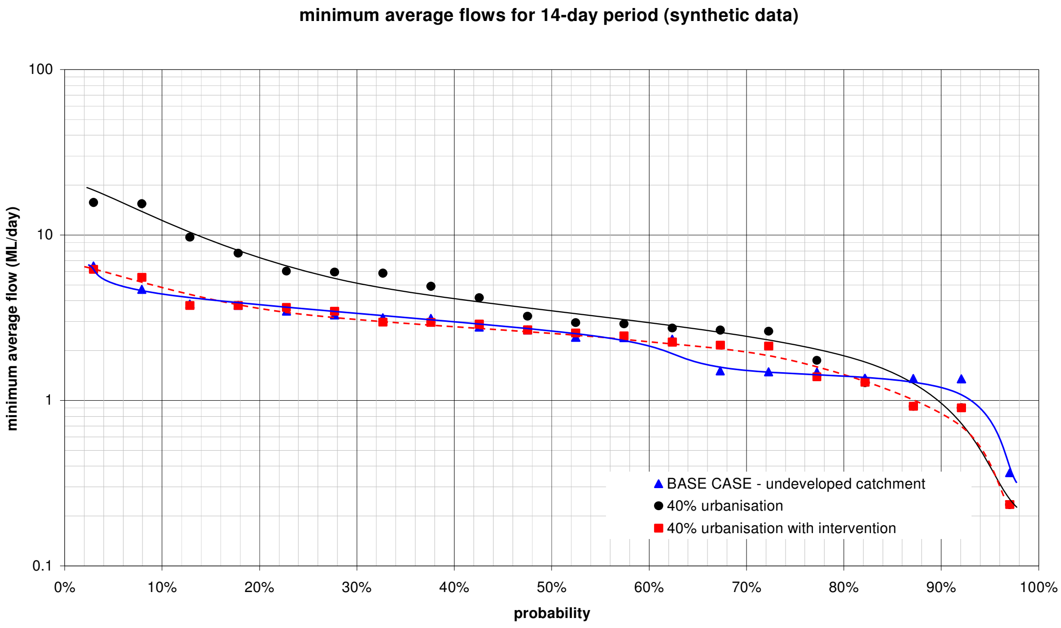


Figure 15 - 14-day Low Flow Duration Frequency Curve (i) pre-development; (ii) post-development with and without intervention (see Table 8)

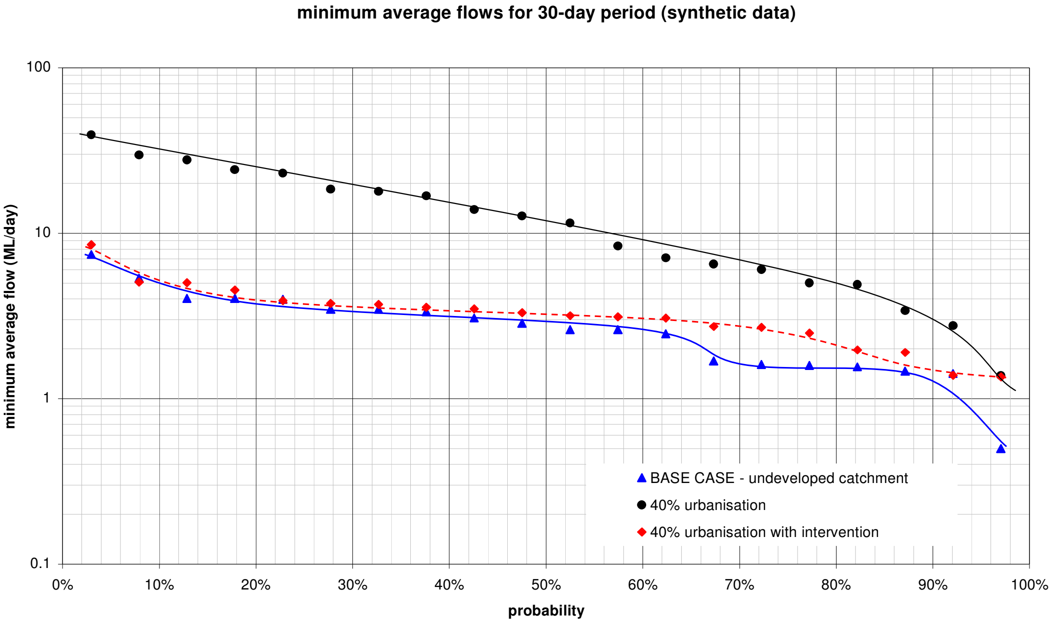


Figure 16 - 30-day Low Flow Duration Frequency Curve (i) pre-development; (ii) post-development with and without intervention (see Table 8)

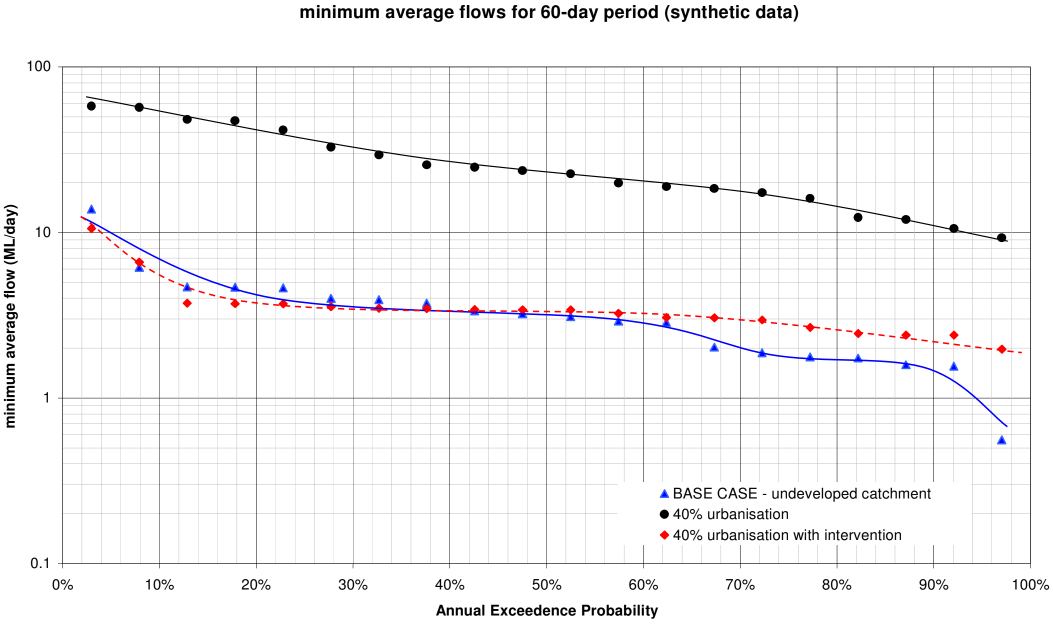


Figure 17 - 60-day Low Flow Duration Frequency Curve (i) pre-development; (ii) post-development with and without intervention (see Table 8)

The analysis undertaken showed the need for increasing storage and water reuse demand as the reference duration increases. The size of the Porters Creek wetland system is such that the 30-day or 60-day low flow duration curves are considered the most appropriate reference curves to represent its drying hydrology. In the case of a 30-day reference duration, the analysis shows that stormwater harvesting and reuse for public open space irrigation with storage volume of approximately 1.2% of the mean annual runoff volume (or 84 m^3/Ha of catchment area) and an irrigated total open space area equivalent to 35% of the catchment area will be necessary to preserve the drying hydrology. The corresponding figures for a reference duration of 60-day are storage volume of 4.1% of the mean annual runoff volume (280 m^3/Ha) and irrigated open space area equivalent to 79% of the catchment area respectively.

The case study identifies open space irrigation as a means of "disposal" of excess stormwater runoff generated from development within the catchment. This can be a combination of private and public open space. Typical private open space include gardens (which may be supplied by local rainwater tanks – see Section 4.7.2) while public open space irrigated area could be golf courses or sports fields. It is evident that a regional strategy may need to be developed to support development within the Porters Creek catchment, The strategy would define development density, public open space layout and regional; storages in addition to other initiatives for harvesting urban stormwater runoff from development in the catchment.

Whilst this intervention measure specifically addresses the use of open space irrigation as a means of promoting the use of excess stormwater to preserve the drying hydrology of Porters Creek wetland, other uses of the excess water are equally appropriate. These may include diverting excess water into a pipeline along Link Road to the Wyong River to replace environmental flows discharge from upstream of Wyong Weir thus increasing available catchment yield for regional water supply.

The WSUD solutions that satisfy the low flow duration frequency criterion were evaluated to determine their corresponding low flow spell frequency characteristics. The selection of the threshold discharge was somewhat uncertain in the absence of any geomorphic survey of the watercourses conveying catchment flow into Porters Creek Wetland.

In evaluating the dry spell frequency characteristics, it is first necessary to determine the appropriate threshold discharge to define the occurrence of a "dry spell". It is recommended in Section 2.2.6 that the mean base flow (50% probability of exceedence) of the critical drying period be selected as the threshold discharge for computing low flow spell frequency curves for wetlands that are subjected to flooding by overland flow pathways. This mean base flow was determined by first analysing the pre-development flow conditions to determine the distribution of the mean value[3] of the average low flows corresponding to 7, 14, 30 and 60 days for the months of October to February (inclusive). The resulting frequency curves are shown in Figure 18 and the 50%tile mean flows for the majority of the curves were found to be approximately 4 ML/d. This was adopted as the threshold discharge.

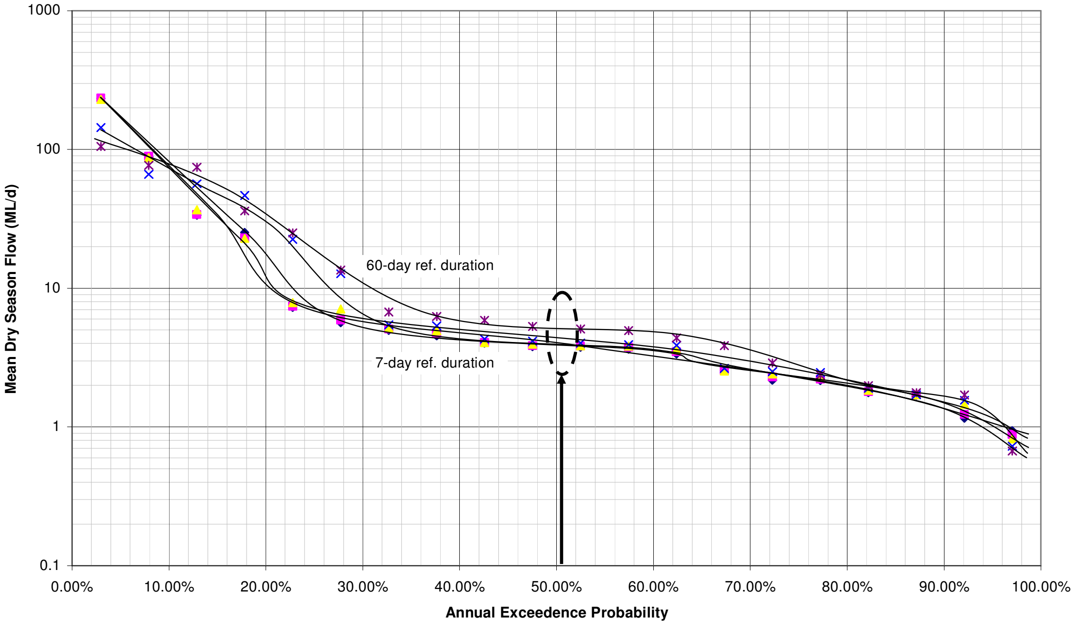


Figure 18 Mean Dry Season Flow under pre-development – threshold discharge for dry spell analysis corresponds to the 50% AEP value

Figure 19 shows the low flow spell frequency curve for the intervention measure corresponding to WSUD solutions that would meet the flow management criterion for the 7, 14, 30 and 60-day flow duration curves respectively. The results show that the different WSUD solutions resulted in different low flow spell frequency characteristics with the solution to preserve the 14-day low flow duration frequency curve best resembling the pre-development low flow spell frequency curve.

Comparison of performance against the two drying hydrology indices indicates that it is often not possible to satisfy precisely the two objectives of preserving the low flow duration frequency curve and the dry spell frequency curve. For wetlands with short reference durations (ie. 7-days and 14-days) solutions required to meet the dry spell frequency curve would require additional WSUD elements than that necessary to meet the low flow duration

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[3] The procedure is exactly the same as that used to determine the minimum average low flow duration frequency curve with the only difference being that mean of the average low flow rather than the minimum of the average low flow is used in defining the frequency curves.

frequency curve management objective. Conversely, solutions necessary to satisfy the preservation of low flow duration frequency characteristics for longer reference durations (ie. 30-days and 60-days) resulted in increased number of consecutive days of flows below the threshold flow.

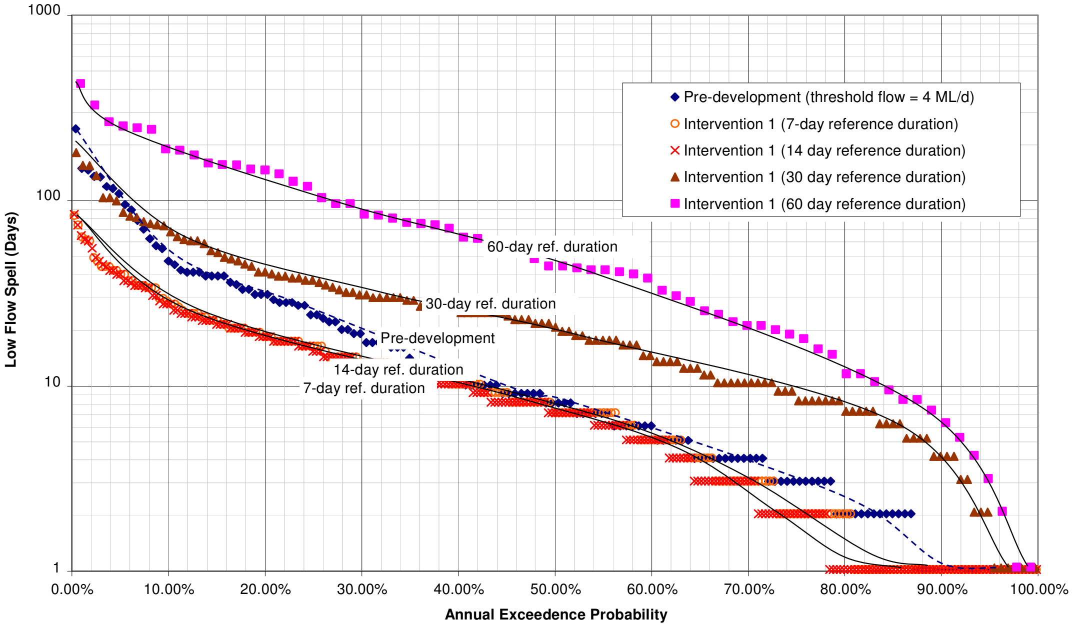

Figure 19 - Low Flow Spell Frequency Curve (i) pre-development; (ii) solutions for preserving the pre-development 7, 14, 30 and 60 days low flow duration frequency curves (see Table 8)

4.7.2 Intervention 2 – Rainwater Tanks

Intervention 2 considers the required stormwater harvesting to satisfy the requirements of BASIX in new residential development. Assuming a residential density of 15 dwellings/Ha, and the installation of a 2.5 kL rainwater tank for toilet flushing and garden watering assigned to each household, gives an equivalent catchment storage of 38 m^3/Ha of catchment area. This is more than the required storages for POS irrigation (ie. Intervention 1) for reference durations of 7-days and 14-days (see Table 8) and the resulting low flow duration frequency curves are shown in Figures 20 and 21. For reference durations longer than 14-days, the use of rainwater tanks of 2.5 kL alone will not be sufficient to entirely preserve the pre-development drying hydrology and departure from the pre-development curve is most significant for the longer flow duration. The resulting 30-day and 60-day low flow duration frequency curves are shown in Figures 22 and 23.

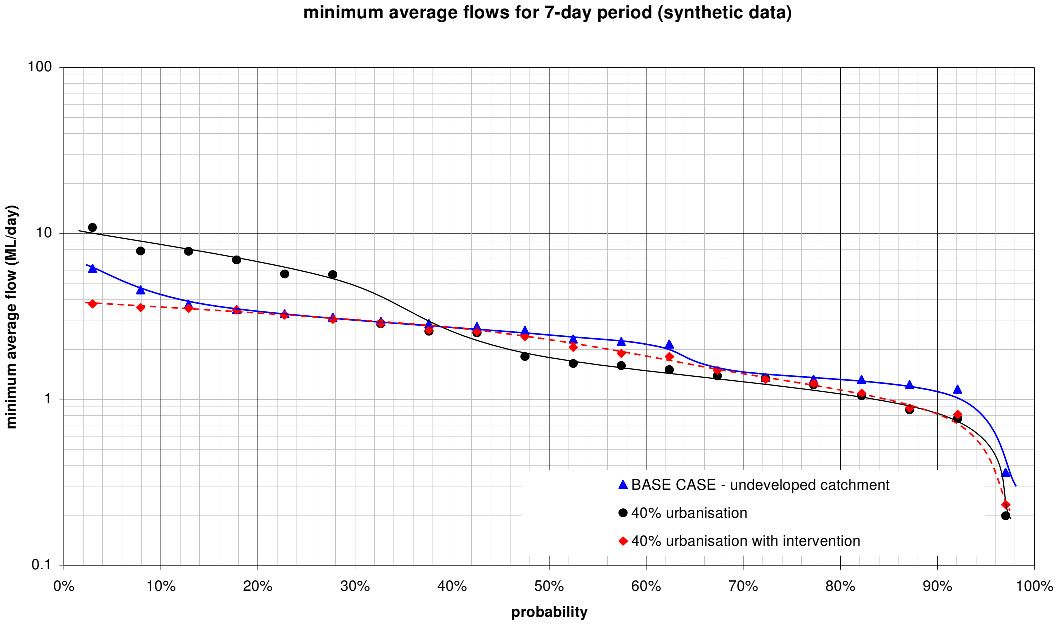

Figure 20 - 7-day Low Flow Duration Frequency Curve (i) pre-development; (ii) post-development with and without intervention (2.5kL Rainwater Tank)

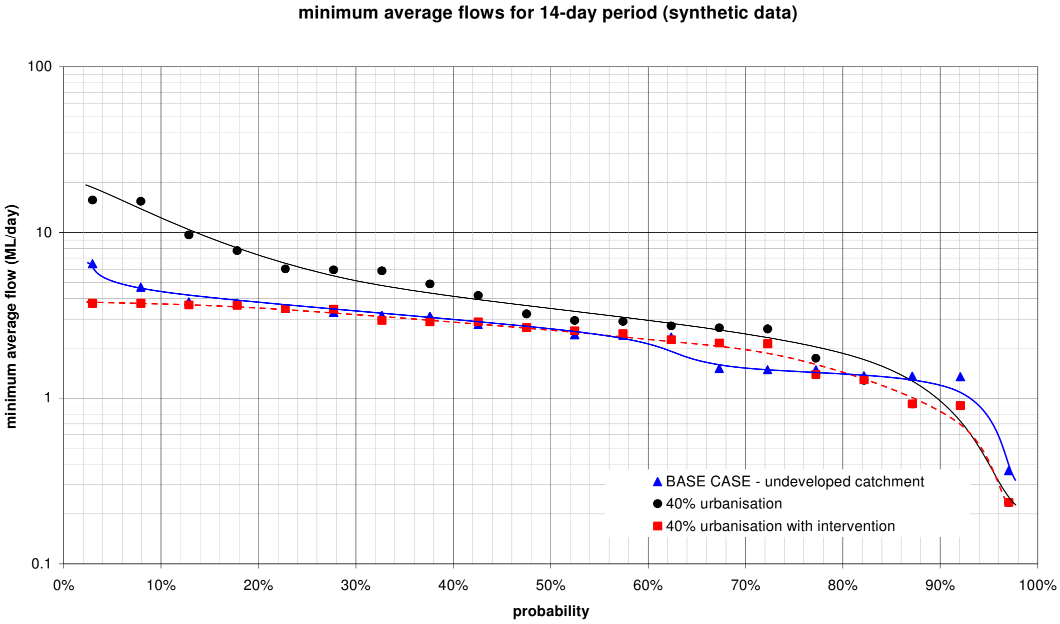

Figure 21 - 14-day Low Flow Duration Frequency Curve (i) pre-development; (ii) post-development with and without intervention (2.5KL Rainwater Tank)

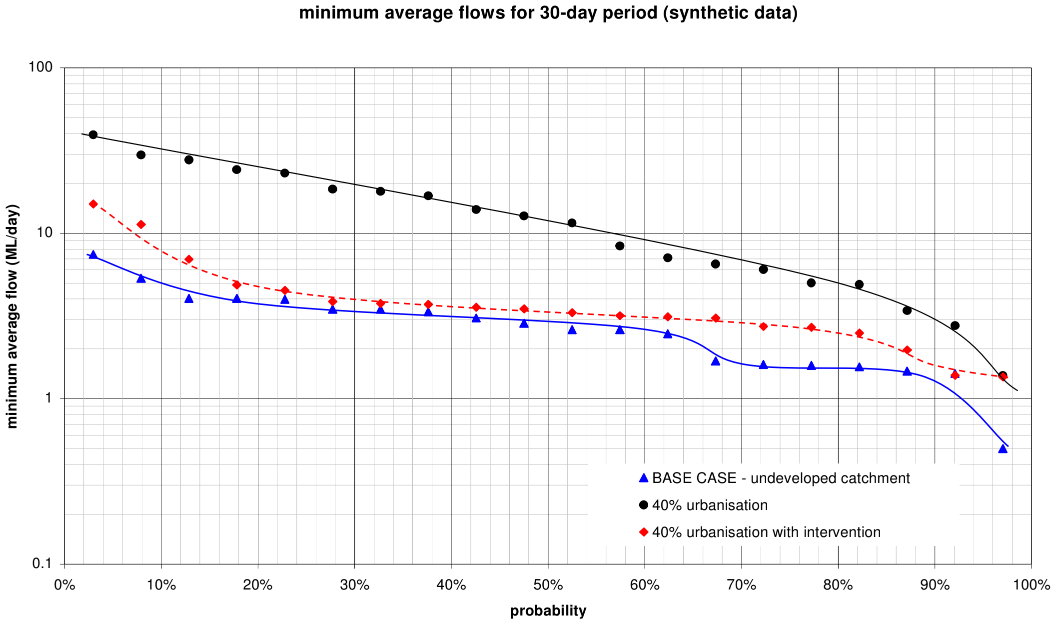

Figure 22 - 30-day Low Flow Duration Frequency Curve (i) pre-development; (ii) post-development with and without intervention (2.5kL Rainwater Tank)

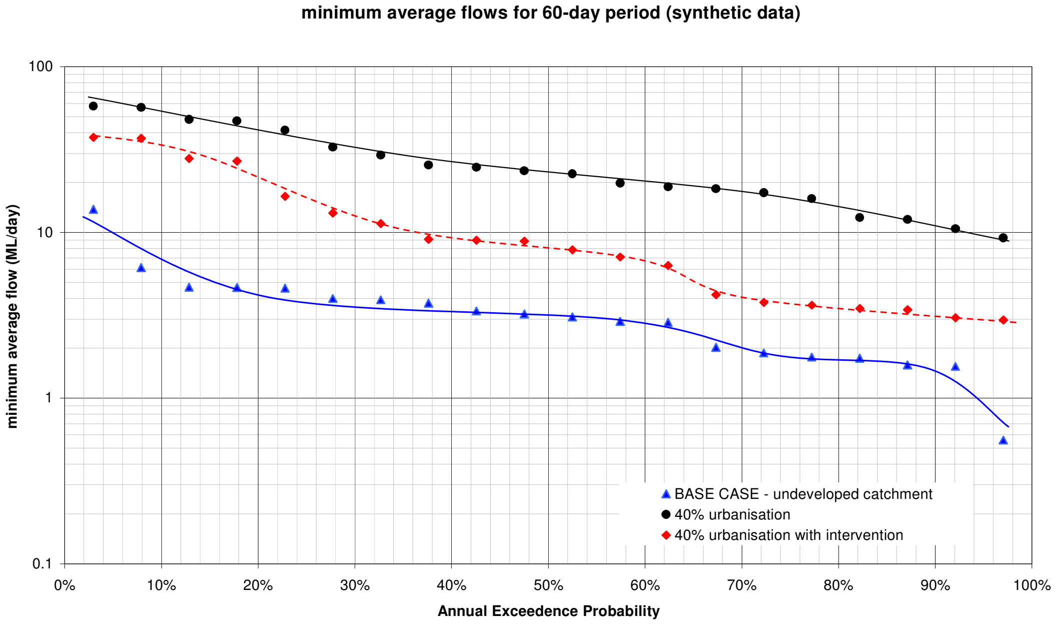

Figure 23 - 60-day Low Flow Duration Frequency Curve (i) pre-development; (ii) post-development with and without intervention (2.5KL Rainwater Tank)

There will be a need to introduce additional stormwater harvesting initiatives to address this inadequacy. Intervention 3 combines the use of rainwater tanks with some precinct or regional stormwater storages for public open space irrigation.

4.7.3 Intervention 3 – Rainwater Tanks and Public Open Space Irrigation

Combining the use of 2.5 kL rainwater tanks for harvesting of rainwater for toilet flushing and garden watering with regional storages for public open space watering is necessary for wetland drying hydrology defined by the 30-day and 60-day low flow duration frequency curves as discussed in Section 4.7.2.

In order to preserve the drying hydrology corresponding to these reference durations, modelling indicated required regional storage volumes of 23 m^3/Ha and 280 m^3/Ha of catchment area respectively with irrigated area of 12% and 32% of the catchment are respectively. The resulting low flow duration frequency curves are shown in Figures 24 and 25. Table 9 lists the solutions corresponding to the four reference durations.

Table 9 – Hydrologic Management Elements for Intervention 3

Hydrologic Management Elements	Reference Duration			
	7-day	14-day	30-day	60-day
Rainwater Tank connected to toilets and garden watering	2.5kL	2.5kL	2.5kL	2.5kL
Regional Stormwater Storage (% of mean annual runoff volume)	-	-	0.34%	4.1%
Regional Stormwater Storage Volume/Ha (m^3)	-	-	23 m^3	280 m^3
Area of irrigated open space or plantation (% of catchment area)	-	-	12%	32%

In preserving the 30-day drying hydrology of the Porters Creek Wetland, a reduction in stormwater volume associated with measures directed at meeting hydrologic management objectives is of the order of 20% of the mean annual runoff volume.

Stormwater quality initiatives associated with the provision of bioretention systems to treat that component of stormwater runoff that is discharged to the wetland to current best practice objectives would further reduce stormwater pollutant loads by 80% of TSS and 45% of nutrients. Modelling found the overall mean annual TSS and nutrient load reductions of 84% and 56% respectively, representing a further increase by 24% (from 45% TN removal to 56% TN removal) of reduction in nutrients discharged into natural wetlands from what would normally be stipulated in typical WSUD projects.

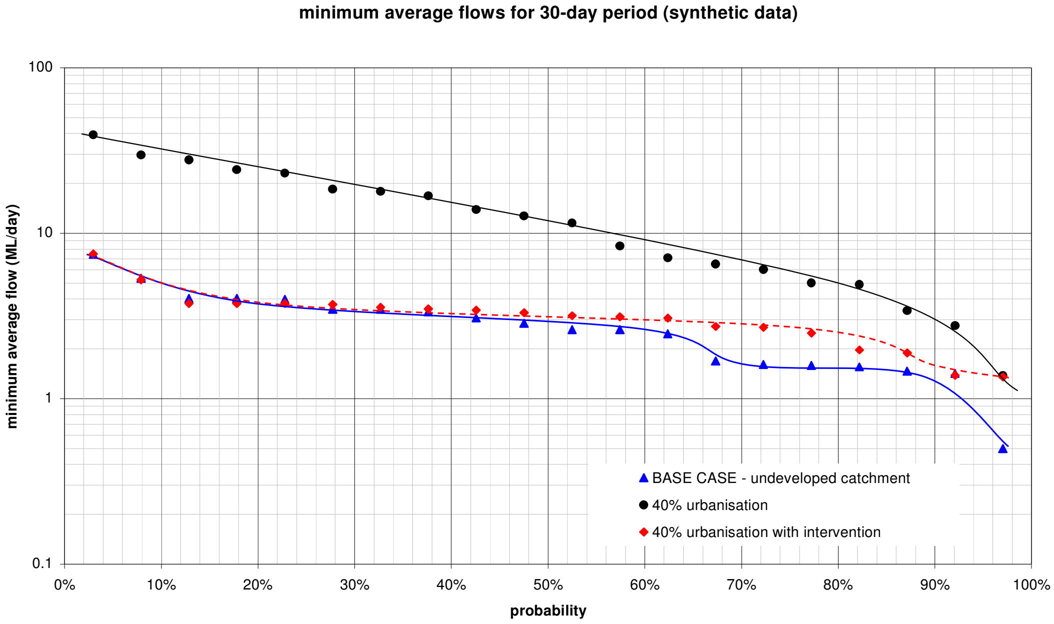

Figure 24 - 30-day Low Flow Duration Frequency Curve (i) pre-development; (ii) post-development with and without intervention (2.5KL Rainwater Tank & Stormwater Storage of 23 m^3/Ha and POS irrigated area of 12% of catchment area)

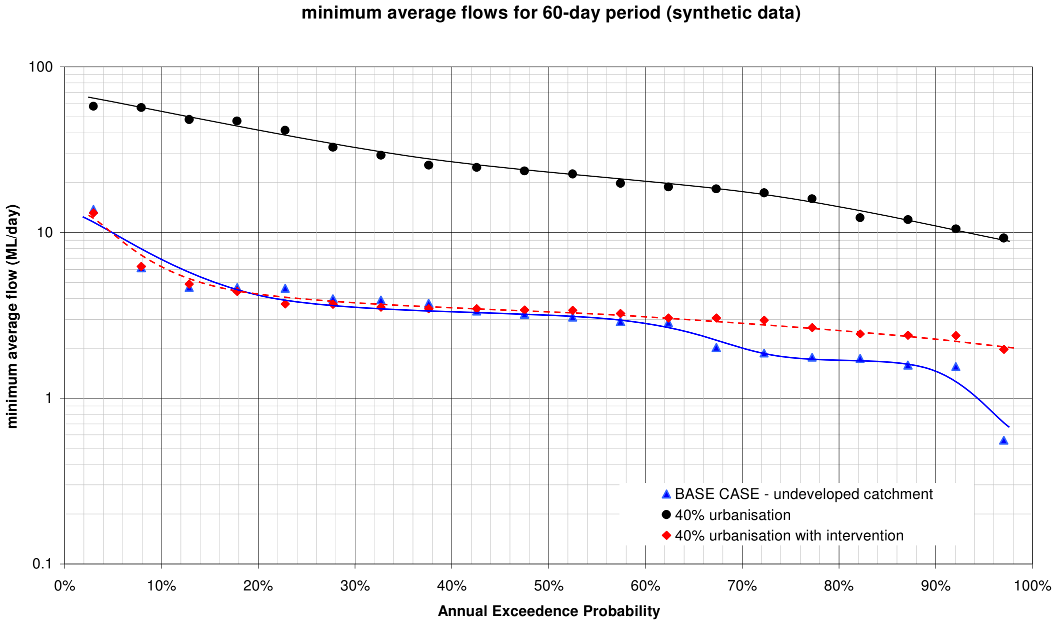

Figure 25 - 60-day Low Flow Duration Frequency Curve (i) pre-development; (ii) post-development with and without intervention (2.5KL Rainwater Tank & Stormwater Storage of 280 m^3/Ha and POS irrigated area of 32% of catchment area)

4.7.4 Intervention 4 –Increased Development Density

Increasing development density can be achieved by two basic means, ie. multi-unit development or higher single dwellings/Ha. The latter would result in increased catchment imperviousness and thus the mitigation measures defined in the above three intervention measures will apply, ie. combination of rainwater tank and POS irrigated area. However, if increased density is delivered in the form of multi-unit development, there is a corresponding increased ratio of total household water demand to roof area such that rainwater harvesting can effectively remove any stormwater runoff from roof areas for the majority of storm events. This has effectively removed the roof areas as being directly connected to the catchment drainage system (with the exception of large storm events) and would contribute to preserving the pre-development drying hydrology of downstream wetlands.

Figures 26 and 27 show the resulting 30-day and 60-day low flow duration frequency curve for a residential density of 35 dwellings/Ha (2 to 3 storey units) with a 2.5 KL rainwater tank/dwelling and demonstrate that the pre-development 30-day low flow duration frequency curve can be preserved with a higher density multi-unit development scenario.

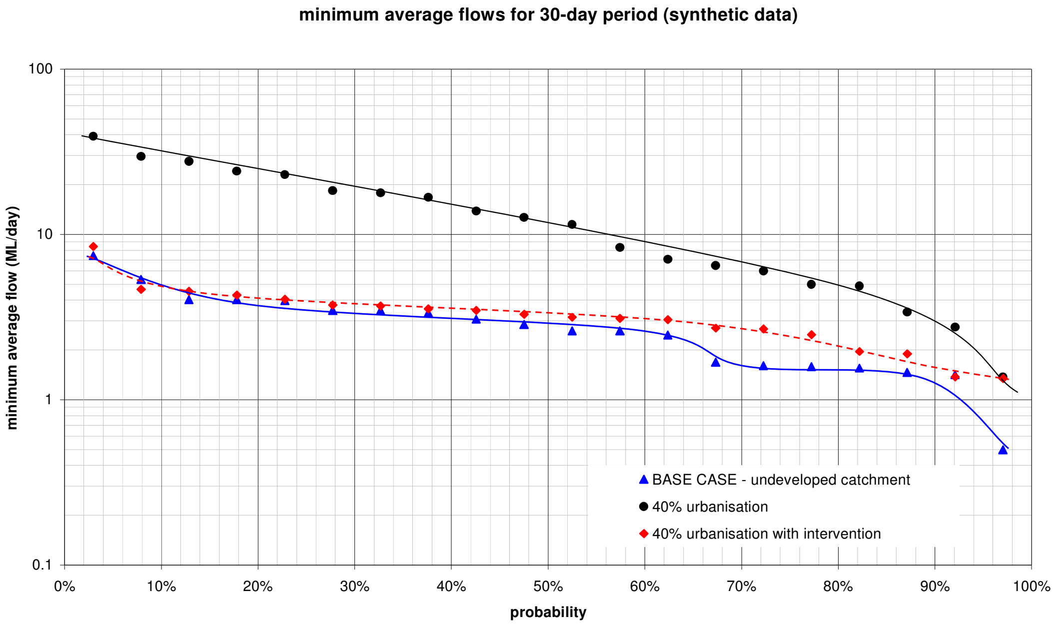

Figure 26 - 30-day Low Flow Duration Frequency Curve (i) pre-development; (ii) post-development with and without intervention (Multi-unit development at 35 dwellings/Ha; 2.5KL Rainwater Tank)

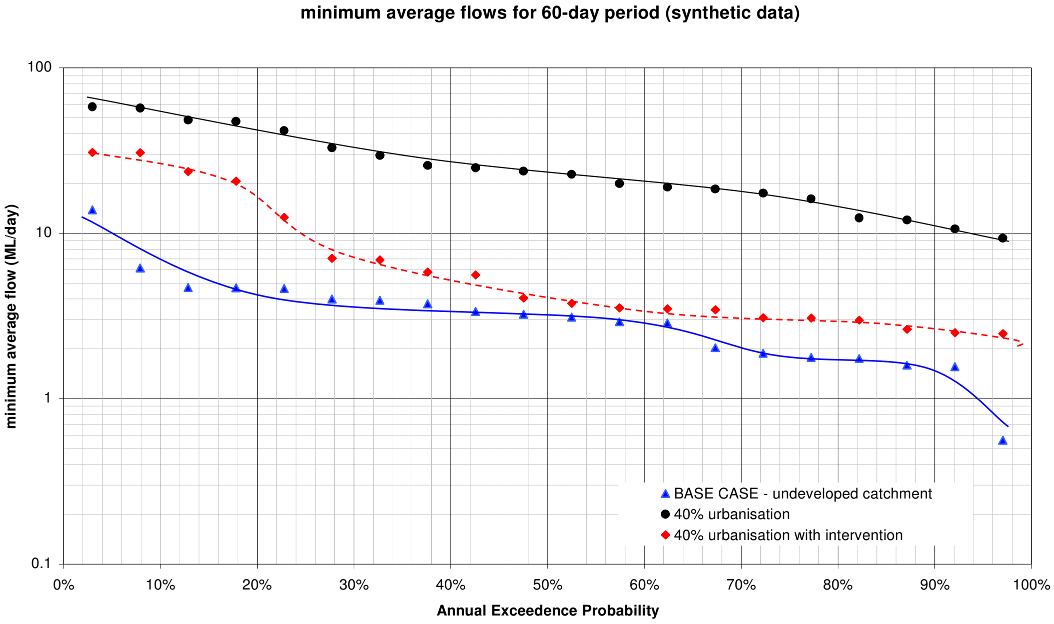

Figure 27 - 60-day Low Flow Duration Frequency Curve (i) pre-development; (ii) post-development with and without intervention (Multi-unit development at 35 dwellings/Ha; 2.5KL Rainwater Tank)

Comparing this result with that for Intervention 3 (Section 4.7.3) demonstrates that the increased dwelling density (and associated water demand) has effectively replaced the POS irrigation requirements of 12% of the catchment area and storage requirements of 23 m^3/Ha of catchment area. Note that the additional 20 dwellings/Ha has effectively increased the rainwater tank storage by 50 m^3/Ha. A multi-unit development density of 35 dwellings/Ha is not able to preserve the 60-day low flow duration frequency curve as shown in Figure 28. It will be necessary to increase the dwelling density to 120 dwellings/Ha to achieve this objective.

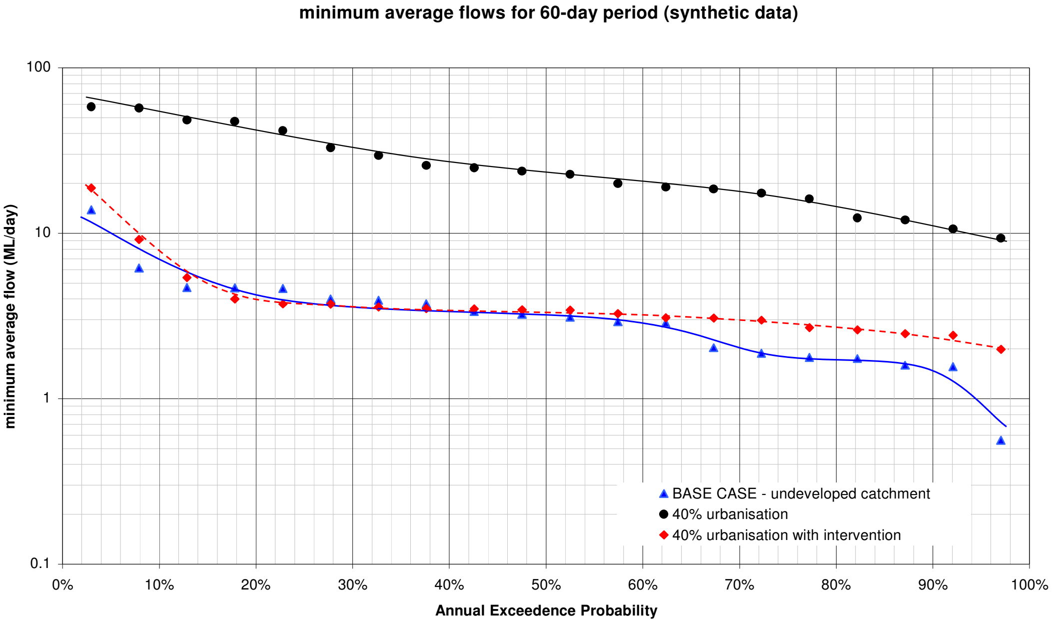

Figure 28 - 60-day Low Flow Duration Frequency Curve (i) pre-development; (ii) post-development with and without intervention (Multi-unit development at 120 dwellings/Ha; 2.5KL Rainwater Tank)

Combining the option of a 35 dwellings/Ha development density with public open space irrigation can be expected to preserve the pre-development 60-day low flow duration frequency curve. Computer simulations for a scenario of a 35 dwellings/Ha multi-unit density found that a 60-day low flow duration frequency curve can be preserved by any combination of storage and irrigated area. Two such solution sets are as follows:-

1. 150 m^3/Ha precinct/regional stormwater storage; POS irrigated area of 32% of catchment area (Figure 29)
2. 280 m^3/Ha precinct/regional stormwater storage; POS irrigated area of 11% of catchment area (Figure 30)

Table 10 summarised the parameters of this solution set.

Table 10 – Hydrologic Management Elements for Intervention 3

Hydrologic Management Elements	Reference Duration				
	≤14	30-day	60-day	60-day	60-day
Dwelling density with 2.5 kL rainwater tank connected to toilets and garden watering (for each dwelling)	15/Ha	35/Ha	120/Ha	35/Ha	35/Ha
Regional Stormwater Storage (% of mean annual runoff volume)	–	–	–	4.1%	7.7%
Regional Stormwater Storage Volume/Ha (m^3)	–	–	23 m^3	150 m^3	280 m^3
Area of irrigated open space or plantation (% of catchment area)	–	–	–	32%	11%

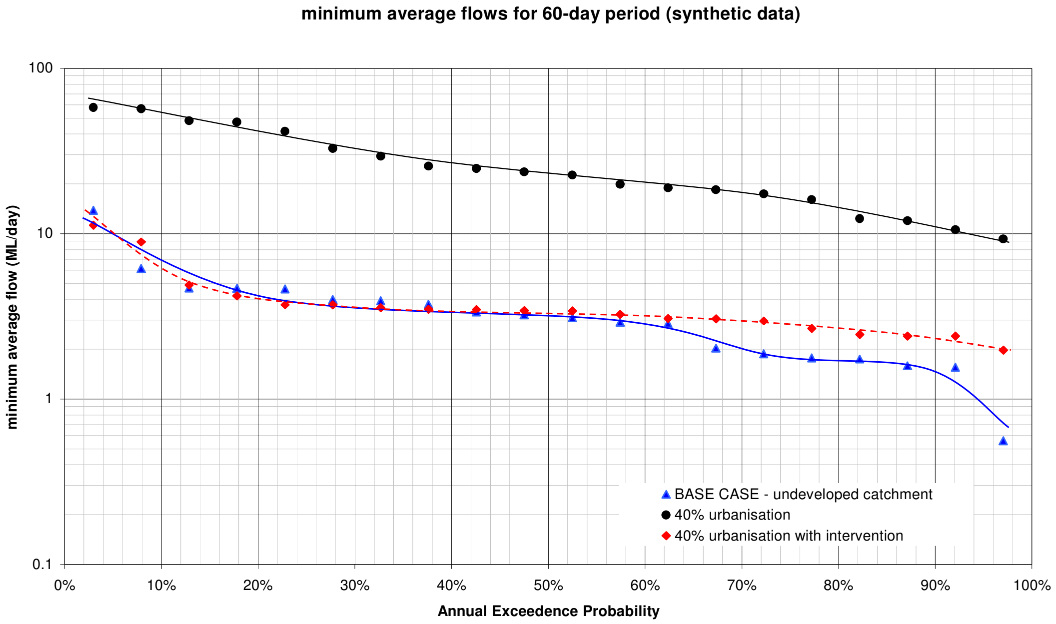

Figure 29 - 60-day Low Flow Duration Frequency Curve (i) pre-development; (ii) post-development with and without intervention (Multi-unit development at 35 dwellings/Ha; 2.5KL Rainwater Tank; Precinct Stormwater Storage = 150 m^3/Ha; Public Open Space irrigation area = 32% of catchment area)

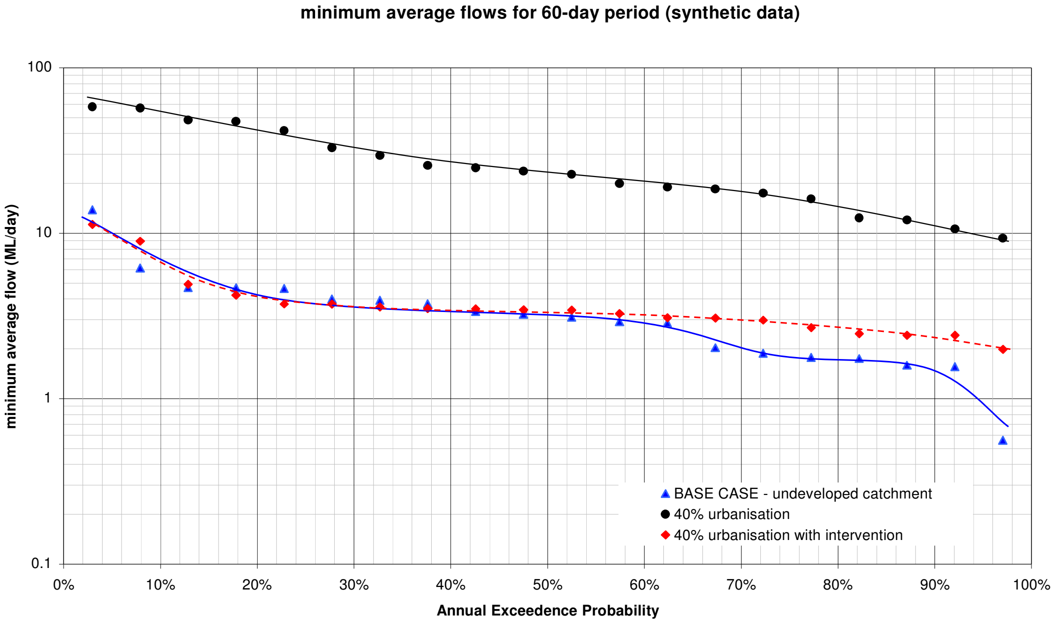

Figure 30 - 60-day Low Flow Duration Frequency Curve (i) pre-development; (ii) post-development with and without intervention (Multi-unit development at 35 dwellings/Ha; 2.5KL Rainwater Tank; Precinct Stormwater Storage = 280 m^3/Ha; Public Open Space irrigation area = 11% of catchment area)

4.7.5 Intervention 5 – Developments abutting wetlands

Developments abutting wetlands can often alter the dominant wetland flooding pathways from that of overbank flow to overland flow (see Section 2.1; Table 2). This often leads to increased flooding of wetland systems that are normally "pre-dominantly dry" and located at the fringe of a larger wetland system. Protecting these systems require both the flooding and drying hydrology of the development area to be preserved. These types of development scenario may require low flows to be diverted away from the adjoining wetland into watercourses that convey flows into the heart of the wetland system.

An example of such a development scenario is the Warnevale Industrial Land. This area is located in the Buttonderry Creek catchment, on very flat terrain. Runoff from the site occurs rarely and is dispersed across the fringe areas of the Porters Creek wetland, typical characteristics of the overland flow flooding pathways described in Table 2. Figure 31 illustrates the site location. It's proximity to sensitive wetland environment places a significant constraint on any opportunities for "disposal" of excess water via open space watering. Two solutions are nevertheless available, ie.

1. 5KL rainwater tanks installed for each allotment as well as a precinct stormwater storage facility occupying 3% of the site to collect stormwater runoff from ground impervious surfaces. Stormwater will be pumped to top-up the rainwater tanks. [*site-based solution*]

2. regional infrastructure to collect treated stormwater runoff from the site (treatment via a number of possible WSUD elements) and convey to the Wyong River as substitute environment flows and/or additional water to be pumped to Mardi Dam for treatment to potable standard. [*regional-based solution*]

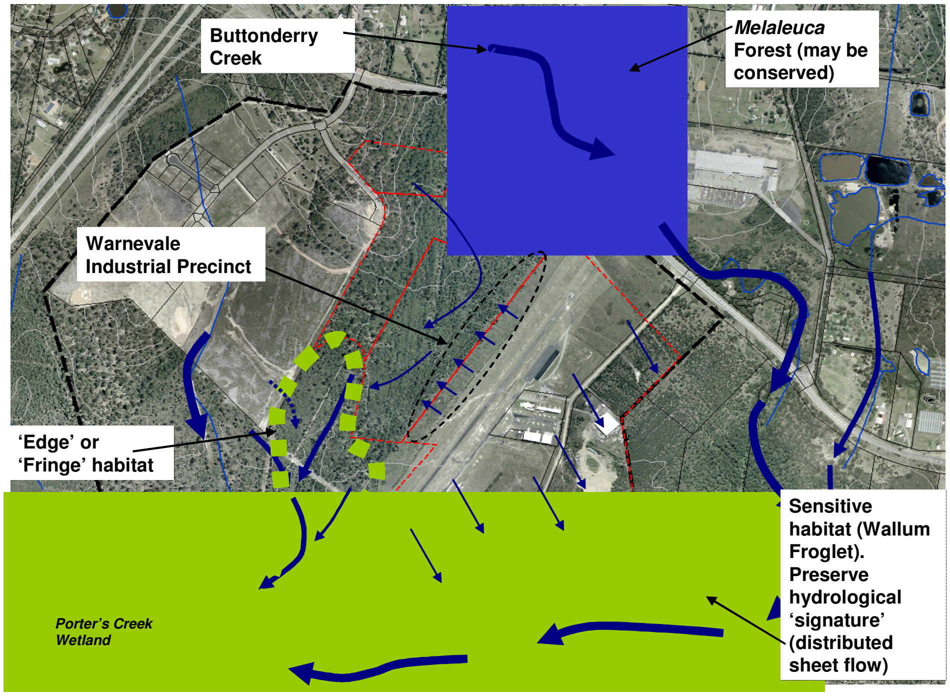

Figure 31 - Warnevale Industrial Area

Figure 32 compares the 30-day high flow duration frequency curve for the development site for pre-development, post-development without intervention and post-development with WSUD solutions for the first option. It is evident that the WSUD solution formulated was not able to preserve the entire shape of the pre-development high flow duration curve with the tendency to increase flooding in the wetland for events in the 15% to the 45% Annual Exceedence Probability range, ie. for the 1 in 2 year ARI to the 1 in 7 year ARI.

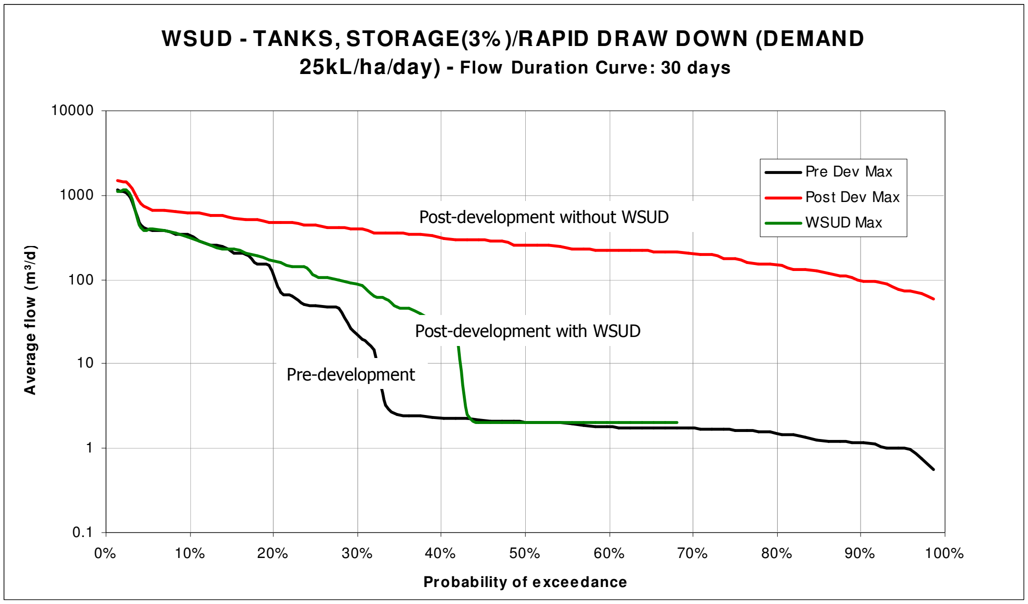

Figure 32 - 30-day High Flow Duration Frequency Curve (i) pre-development; (ii) post-development with and without intervention for Warnevale Industrial Precinct

5 KNOWLEDGE GAPS AND UNCERTAINTIES

The main objective of this investigation is to develop stormwater management objectives to guide urban development in catchments upstream of natural wetlands. These management objectives, envisaged to be defined at a higher level of detail, are necessary to accommodate the requirements for location-specific and finer resolution hydrological dynamics that are important to protecting wetlands. The guidelines developed through this project will include a method for specifying total catchment hydrological and water quality improvement performance and selecting from the available suite of WSUD techniques to achieve this performance.

There will be uncertainties introduced into the methodology when attempting to generalize to cover all of NSW. The recommendations made in defining the hydrologic management of urban catchments upstream of natural wetlands assume the principal flood pathway for the majority of the wetland types to be as a result of overbank flows from a distant channelised catchment, ie, an inside-out flood pattern, although they are equally relevant for wetlands that are inundated from overland flow pathways.

Key uncertainties stemming from knowledge gaps in current understanding in the critical element(s) of the supporting hydrology and water quality of natural wetlands hydrologic investigation undertaken and reported in this discussion paper may be summarised as follows:-

- selection of reference duration for flow duration frequency analysis
- relative impacts of changes in hydrology and water quality on ecology of natural wetlands
- selection of the threshold discharge for the low flow spell analysis
- water quality guidelines for natural wetlands in NSW

The main knowledge gap pertaining to the establishment of urban water management objectives is associated with water quality in natural wetlands. Unlike catchment hydrology where it was possible to define indices that can be normalised and applied across all catchments with the use of a modelling approach, a generic set of management objectives for water quality cannot be achieved at present for a number of reasons. Access to reliable water quality data is amongst one of the reasons and this is addressed in the following sections.

5.1 Water Quality of Wetlands

There appears to be a relative large data base of water quality monitoring undertaken but access to that data is extremely difficult. Much of the water quality monitoring that has occurred within wetland areas has been part of individual studies and contributed to a final discrete report for each individual study site. The results of such studies are reported to a variety of bodies across many regions. Further, as much of the catalogued data (for TN, TP and turbidity in or upstream of wetlands) are part of short term studies (e.g. less than 1 yr) they are unlikely to represent the natural variations between years (e.g. differences in loadings between 'wet' years and 'dry' years).

Discrete water quality monitoring sites (see http://waterinfo.dlwc.nsw.gov.au/wq/index.html) in streams upstream of wetland areas have been identified as a potential source of data in order to establish wetland water quality values. However accessing these data has proved fruitless, despite many conversations with DIPNR officers. The data from the monitoring sites are not readily downloadable and are supposedly stored at the regional offices associated with the sites.

It should be noted that if data is acquired (for sites within or upstream of wetlands), enough information to allow classification of the wetland type is also required (e.g. for small, relatively unknown wetland, a site visit or more specific site description would be required including some information on the vegetation types etc).

5.2 Field Monitoring of Natural Wetlands

In the absence of reliable data for natural wetlands in NSW, a comprehensive program of field monitoring of ambient water quality in pristine and slightly to moderately modified wetlands over a three to five year period is recommended. Monitoring frequency could range from weekly to monthly, with the final data set having sufficient samples to enable reliable definition of concentrations at the 80%tile level.

5.3 Water Quality Guidelines for Ephemeral Wetlands

As outlined in Appendix C, many questions on appropriate water quality guidelines for ephemeral wetlands including the relevance of ambient water quality concentrations in determining its ecosystem health. This issue requires further fundamental research.

5.4 Catchment Water Quality Objectives

The availability of reference conditions from which trigger levels of key water quality constituents can be determined for the 17 categories of wetlands provides the basis for determining generic catchment stormwater quality management objectives. To do this, it will be necessary to first undertake a sufficient number of coupled wetland and catchment modelling investigations using the approach outlined in Appendix C. The number of case studies will need to include the range of wetland type as well as a number of combinations of catchment to wetland scales and hydrologic conditions with wetland size and hydrodynamic conditions. It may be possible following the completion of these case studies to undertake a multi-case analysis to derive generic relationships for establishing catchment stormwater quality management objectives.

6 CONCLUSIONS

Catchment urbanisation leads to changes in the catchment hydrology that can affect the environmental value (and ecosystem health) of natural wetlands in urban environments. Hydrologic management objectives have been established to mitigate the impact of catchment urbanisation on the ecology of natural wetlands and these are based on preserving critical characteristics of the supporting hydrology of these wetland systems.

A simplified wetland classification procedure is developed to enable practitioners to undertake field assessment on the types of wetlands being managed and this was outlined in an earlier report. There are altogether 17 different wetland types in the classification method proposed and a broad characterisation of the supporting hydrology of these wetland types was established (Table 3.1). These hydrologic regimes are quantified using statistical measures to define the wetland flooding hydrology and drying hydrology. Water Sensitive Urban Design strategies associated with land development in catchment upstream of natural wetlands will need to include methods for preserving the pre-development drying hydrology and/or flooding hydrology characteristics in order to protect the ecology of these wetlands.

Wetland Hydrology

Following review and consideration of a number of possible hydrologic indices for drying and flooding hydrology in wetland systems, three are recommended, ie.

Drying Hydrology	1. Dry season flow duration frequency curves computed over the months of October to January (inclusive) for each water year;
	2. Low flow spell frequency curves computed over the months of October to January (inclusive) for each water year.
Flooding Hydrology	1. Annual high flow duration frequency curves

The selection of the critical hydrologic regime (whether drying hydrology and/or flooding hydrology) to emulate post-development is dependent on the type of wetland and also it's flooding pathways.

The selection of the reference duration (whether 7-day, 14-day, 30-day or 60-day) is dependent on the size of the wetland and its typical duration of inundation or drying.

Recommended hydrologic management objectives for each of the 17 different wetland types are presented in Table 3.1.

It is recommended that a threshold discharge corresponding to the mean base flow (50% probability of exceedence) of the critical drying period be selected as the threshold discharge for computing low flow spell frequency curves. The selection of the appropriate threshold discharge for low flow spell frequency analysis in wetlands where the flooding pathways are associated with overbank flow is dependent on the geomorphic characteristics of the watercourse(s) in the wetland. Field survey and hydraulic modelling may be necessary to more reliably define this value.

In order to preserve a level of pragmatism, it is recommended that the critical region of the flow duration and spell frequency curves that need to be preserved should be limited to between 10% and 90% AEP to avoid the extremities of the pre-development hydrologic characteristics

Wetland Water Quality

The supporting water quality of wetlands varies considerably and is the primary reason that the ANZECC (2000) guidelines provide no guidelines for wetlands in South-Eastern Australia. Where wetland environments have been impacted by changes in their catchments such as urban development, the impact is nearly always multifactorial. Un-controlled urbanisation typically results in both changes to runoff quality and quantity. Wetlands can be very sensitive to changes in hydrology and it is not always clear any one factor is responsible for the impact resulting from urbanisation.

By achieving appropriate hydrologic control and adopting best practice stormwater quality treatment for stormwater that is discharged from the site, substantial urban stormwater pollutants will be removed. It is recommended that stormwater leaving the site be treated to best practice water quality objectives, current set at 80% reduction in suspended solids and 45% reduction in nutrients (TP and TN). Furthermore, it is recommended that for wetlands where interim water quality trigger values can not be estimated (Fen, Wet Heath, Scrub Swamp, Ephemeral Swamp Forest and Dry Swamp Forest), the 50%tiles wet weather flows nutrient concentrations should not exceed 0.09 mg/L for Total Phosphorus and 1.3 mg/L for Total Nitrogen

WSUD Solutions

The Porters Creek wetland catchment is used as a case study to define the implications of these recommendations in defining WSUD solution for catchment upstream of natural wetlands. The case study shows that pre-development hydrologic conditions can be preserved using WSUD solutions that are primarily based on stormwater harvesting. The analysis confirms the practical requirements of these additional management objectives (over and above those of water quality and flood mitigation) in developing WSUD strategies for development upstream of natural wetlands. Localised (on-site) initiatives found to be effective include provision of rainwater tanks for harvesting of rainwater for in-house and open space watering in addition to precinct or regional harvesting of stormwater runoff from surface other than roof surfaces.

As a general rule, the use of rainwater tanks to comply with BASIX requirements will normally be sufficient to preserve the pre-development 7-day and 14-day low flow duration frequency curves if rainwater tanks are a key part of the initiative to comply with BASIX. This indicates that all coastal wetlands influenced by tidal inundation will not require any further intervention in residential development beyond the introduction of rainwater tanks for harvesting rainwater compliant to the requirements of BASIX. There are other means in which BASIX requirements can be met, including the availability of recycled water either as a centralized reticulated system or at a local scheme. However, for developments in catchment upstream of sensitive natural wetlands, it may be necessary to prioritise the use of stormwater (either through rainwater tanks or a centralized stormwater harvesting scheme) as a supplier of substitute water ahead of recycled water owing to their added benefit of protecting natural wetlands in these catchments.

Longer reference flow durations for protection of wetlands will require the harvesting of stormwater for public open space watering with the required public open space area to be 12% and 32% of the catchment area in order to preserve the pre-development 30-day and 60-day low flow duration frequency curves respectively. Increasing dwelling density through multi-unit development is found to be another means of preserving the pre-development drying hydrology through a combination of increasing in-house water demand relative to the available roof area for harvesting rainwater and larger opportunities for open space watering (while maintaining an overall whole-of-catchment development density) through clustering of development around a network of irrigated public open space.

Examination of WSUD solutions necessary to achieve the hydrologic management objectives suggest that it may be impractical to strive for solutions that would satisfy objectives corresponding to reference durations longer than 30 days. A regional strategy involving stormwater harvesting and reuse, and development density is considered necessary to achieve such stringent criteria. In the absence of a regional strategy, it is recommended that the adopted reference duration be not longer than 30-days to ensure that the hydrologic management objectives are practical can be readily achieved with current best practice WSUD methods.

Managing the hydrologic impact on wetland of development on area immediately abutting the fringe area of natural wetlands is considered to be the most challenging owing to the likelihood of such development affecting the relative dominance of wetland flooding pathways, altering it from that of overbank flow to overland flow leading to increased flooding of wetland systems that are normally “pre-dominantly dry”. Protecting these systems require both the flooding and drying hydrology of the development area to be preserved and often some level of flow diversion away from the wetland will be necessary.

Regional initiatives for harvesting urban stormwater can effectively preserve the pre-development wetland flooding and drying hydrologic regimes. Such initiatives will involve the construction of precinct and regional storages and the diversion of harvested stormwater for reuse in initiatives including public open space watering, industrial water use, source of potable water (after treatment).

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Water Sensitive Urban Design Solutions for Catchments above Wetlands

Appendix C: A Procedure for determining Catchment Stormwater Quality Management Objectives

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Appendix A: Wetlands Classification Scheme
Appendix B: Catchment Hydrologic Indices and Urban Water Management Performance Objectives
Appendix C: A Procedure for Determining Catchment Stormwater Management Objectives
Appendix D: Planning Mechanisms

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1 INTRODUCTION

Natural wetland systems downstream of catchments undergoing urbanisation are subject to environmental stresses at a number of levels, most notably in significant changes to their hydrology and inflow water quality. The adoption of Water Sensitive Urban Design (WSUD) practices in urban development is gaining prominence as a means of facilitating a more sustainable approach to urban water cycle management in urban environments. These practices include the treatment of urban stormwater for reduction in urban contaminants to current best practice standards. WSUD strategies for urban development cover a range of spatial scales, from implementation at an individual allotment scale to regional scales. Their appropriate combinations reflect site opportunities and constraints and are developed from a "whole-of-catchment" perspective.

Different types of wetlands will have different supporting hydrology and also different capacities to naturally accommodate changes in inflow water quality. In order to develop a practical and widely applicable catchment hydrologic and urban stormwater quality management objectives for the protection of downstream natural wetlands, it was first necessary to develop a simple classification of natural wetlands in NSW such that hydrologic and stormwater quality management objectives for each categories of wetlands can be established. A method for classification of natural wetlands in NSW was formulated as part of this project and reported separately in Appendix A. There are altogether 17 different wetland types in the classification method proposed. Developments in catchments upstream of natural wetlands will need to meet urban water management objectives directed at preserving their supporting hydrology and maintaining sustainable pollutant loads discharged from the development.

In a separate report (Appendix B), urban water management objectives are established to mitigate the impacts of catchment urbanisation on the ecology of natural wetlands. Both catchment hydrologic and water quality management objectives are formulated in a form which can be readily specified as conditions of development approval. Hydrologic management objectives recommended for developments in catchments upstream of natural wetlands are based on preserving critical characteristics of the supporting hydrology of these wetland systems. The formulation of stormwater quality management objectives is informed by investigations linking the ambient water quality of the wetlands to catchment stormwater quality. This report outlines a procedure that could be adopted in relating water quality guidelines of receiving waterbodies (eg. wetlands) to catchment-scale contaminant loads

2 LINKING CATCHMENT WATER QUALITY MANAGEMENT OBJECTIVES AND WETLAND WATER QUALITY GUIDELINES

Water quality guidelines for the protection of receiving waters have been prepared by ANZECC/ARMCANZ to support a risk-based approach to setting receiving water and catchment management objectives. The guidelines use the term “trigger levels” of concentrations of key water quality constituents to define conditions where the receiving waterbody may be exposed to a high risk of environmental (biological) degradation of the aquatic ecosystem. These trigger levels are defined from water quality sampling of reference sites of pristine and slightly modified aquatic systems. These data provide a series of reference water quality probability distribution from which trigger levels and associated probability can be determined. In the case of pristine aquatic environments, the ANZECC/ARMCANZ Guidelines adopts a “no change from reference condition water quality distribution” while trigger levels are set at the 20%tile and 80%tile of the reference conditions for slightly to moderately modified ecosystems. The latter is considered relevant to natural wetlands downstream of urban environments.

While water quality trigger levels in receiving waterbodies provide a basis for assessment of performance of land and water management across the catchment, they do not provide criteria against which the selection and design of catchment management measures can be directly made. Different catchments may have different water quality objectives specified even if the receiving waterbody has the same target water quality concentrations. The effects of catchment hydrology, waterbody hydrodynamics and ecosystem processes combine to define the water quality objectives for the catchment to satisfy the target concentrations in the receiving waterbody. For example, a large receiving waterbody (relative to the catchment runoff volume) with good mixing characteristics can accept a certain level of inflow pollutants such that these pollutants can be readily processed within the natural range of ecosystem processes to meet the specified target concentrations. Different receiving waterbodies have different combinations of hydrodynamics and ecosystem process capacities.

There is thus a need to link the catchment loading of key water quality constituents with water quality and ecological outcomes in the receiving waterway, in order to determine the water quality management objectives for developments in catchments upstream of these waterbodies.

2.1 A Modelling Approach to determining Catchment Water Quality Objectives

Lawrence and Phillips (2003) outlined a procedure for determining “sustainable load” of key water quality constituents from urban environments from pre-specified ambient water quality targets in receiving waterbodies. The procedure involves the application of a receiving water model such as the CRC for Freshwater Ecology Pond and Wetland model, coupled with a catchment model such as MUSIC or AQUALM. These models simulate the following processes of nutrient generation, mixing, assimilation and recycling:-

- MUSIC or AQUALM are catchment stormwater flow and pollutant generation models, used to define the nutrient, BOD, COD, DO loads and concentrations time series discharged from an urban catchment;

- CRC Pond Model and Wetland Model are models that simulate the biological and chemical processes affecting the pathways of nutrient within receiving waterbodies. Nutrient concentrations resulting from mixing of inflow stormwater with the waterbody are determined and nutrient assimilation by algae (typically represented as phytoplankton) computed at daily time intervals. Cumulative probability plot of nutrient concentrations (in the receiving waterbody) are then derived and compared against target concentrations that reflect healthy wetland systems.

The modelling procedure involves the application of the above models in a systematic way to related target pollutant concentrations established for the receiving water with pollutant loads discharged from the catchment. The modelling procedure involves progressively reducing the assumed pollutant load applied in the catchment until the modeled median levels are below the trigger levels of the reference conditions. This is illustrated in Figure 1.

Referring to Figure 1, the catchment contaminant load would “comply” with the water quality target of the receiving water when the modeled median ambient water quality concentration is to the left of the reference condition trigger level. This thus sets the catchment water quality objectives for the range of key water quality constituents and Lawrence and Phillips refer to the “complying” catchment contaminant load as the ‘sustainable’ average annual export load (SAAEL). These targets may be different from what would have resulted by adopting the general objectives of 80% and 45% reduction in the mean annual load of suspended solids and nutrients typically generated from an urban catchment.

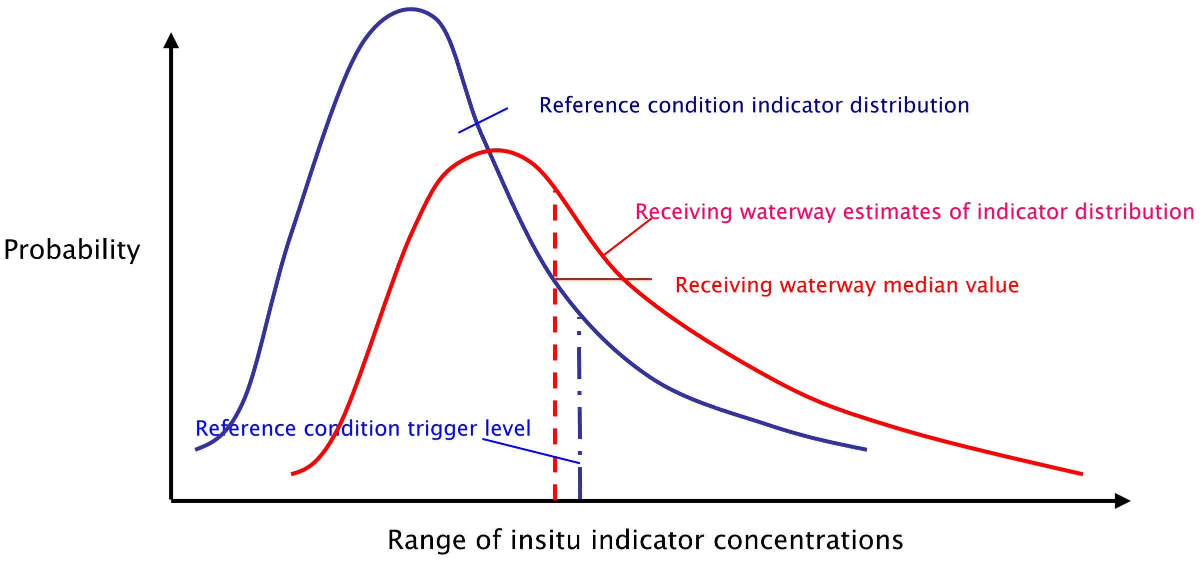

Figure 1 - Comparison of receiving waterbody ambient water quality indicator value estimates with reference condition distribution (source: Lawrence and Phillips, 2003)

This procedure can only be applied when target concentrations for the receiving waterbody are known. There are currently no reference water quality conditions applicable for natural wetlands in NSW. Much of the water quality monitoring that has occurred within wetland areas has been part of individual studies and contributed to a final report about the individual study site. The results of such studies are reported to a variety of bodies across many regions. As much of the catalogued data (for TN, TP and turbidity in or upstream of wetlands) are part of short term studies (e.g. less than 1 yr) they are unlikely to represent the natural variations between years (e.g. differences in loadings between 'wet' years and 'dry' years. Ecological Engineering have made many attempts to obtain water quality data for wetlands in NSW.

Discrete water quality monitoring sites (http://waterinfo.dlwc.nsw.gov.au/wq/index.html), in streams upstream of wetland areas, have been identified as a potential source of data in order to establish wetland water quality values. However accessing these data has proved to be almost impossible despite many conversations with DIPNR officers. The data are not readily downloadable and are supposedly stored at the regional offices.

It should be noted if data is acquired (for sites within or upstream of wetlands), enough information to allow classification of the wetland type is also required (e.g. for small, relatively unknown wetland, a site visit or more specific site description would be required including some information on the vegetation types etc).

Nevertheless, interim water quality guidelines for the majority of wetland types have been suggested in Section 3, based on consideration of existing ANZECC trigger levels and a consideration of the likely position of a wetland type in the terrain. These interim guidelines may be used in a applying the modelling approach outlined above to define the appropriate catchment water quality management objectives for the wetland in question.

3 WETLANDS AND WATER QUALITY

Wetlands occur in a very wide range of environments (Jacobs & Brock 1993, Green 1997, Sainty & Jacobs 2003). As a result the supporting water quality of wetlands can be expected to vary considerably. In general water quality supporting various wetland types is related to the position of particular wetland types in the terrain. Upland wetlands (eg. bogs) or wetlands with limited catchments (wet heaths) tend to be adapted to very good water quality (low nutrient) conditions as much of their water supply is derived directly from rainfall. Lowland wetlands (deep marshes, wet swamp forest) typically have large catchments and tend to regulate the supply of water and materials (sediment, nutrients, etc.) to downstream environments. As a result these systems tend to be adapted to poorer water quality (high nutrient) conditions as they receive, store and regulate water and contaminants from their catchments. Some wetland types are very good at processing and utilising nutrients. In fact marsh type wetlands are the typical model for constructed wetlands for the treatment of both wastewaters and urban runoff. This indicates the potential variation in the water quality requirements of different wetland types to maintain a healthy and sustainable condition.

As a result of the variability in wetland types and conditions, the ANZECC (2000) guidelines provide no guidelines for wetlands in South-eastern Australia. This is due to insufficient data available on the range of wetland types in this region (particularly in NSW). This study has re-confirmed the lack of water quality data suitable for deriving criteria or trigger values for the protection of wetlands. However to provide some guidance in this area we believe the existing ANZECC guidelines could be adapted to produce interim wetlands guidelines. We consider this is likely to be a conservative approach.

Wetlands derive their water supply from a range of source waters:

- Upland streams
- Lowland streams
- Lakes and reservoirs
- Marine coastal waters

Under some climate conditions, wetlands may also provide the source water for other aquatic systems (eg. upland streams). As result it is reasonable that the water quality of source waters or adjacent ecosystems could provide some indication of the water quality requirements of particular wetlands. Such an approach could only provide interim guidance and suggested values would need to be validated by a dedicated water quality sampling program aimed at compiling a wetland dataset adequate to derive ANZECC style guidelines based on statistical analysis.

Table 1 outlines the range of wetland classifications used in this study and attributes interim ambient water quality guidelines, based on existing ANZECC trigger levels, depending on the occurrence of the wetland type in the terrain. Water quality guidelines for a number of wetland types can not be even estimated from the existing ANZECC guidelines. Water quality in fens for example is normally determined by regional groundwater quality and will be highly site specific. The ANZECC guidelines provide no guidance on the water quality requirements of ephemeral systems (Wet Heath, Scrub Swamp, Ephemeral Swamp Forest and Dry Swamp Forest).

Water quality guidelines for ephemeral systems are a particularly difficult issue. Because of the temporal nature of the inundation, defining when in the inundation cycle is crucial in water quality terms is a fundamental question that needs to be address before monitored data can be appropriate interpreted, ie. the relative importance of water quality during the flooding, standing inundation or draining phases of ephemeral wetlands. This uncertainty has direct implications on when water quality should be determined in ephemeral wetlands since the inundation pattern of these wetlands can be relatively unpredictable.

Even if water quality criteria were determined for ephemeral wetlands, there is the further question of which part of the inundation phase should compliance be assessed and further poses the question of whether instantaneous water quality is even relevant in ephemeral wetlands and whether total loading is a more appropriate water quality management objective. The interim recommendation of this report for ephemeral systems is (with the exception of Dry Swamp Forest) that the identified hydrologic controls be applied and that any stormwater discharged to these systems meet the “best practice standards” identified below.

Where wetland environments have been impacted by changes in their catchments such as urban development, the impact is nearly always multifactorial. Un-controlled urbanisation typically results in both changes to runoff quality and quantity. Wetlands can be very sensitive to changes in hydrology and it is not always clear any one factor is responsible for the impact resulting from urbanisation. For example urban runoff may have little impact on marshland environments but have a major impact on swamp forests. The impact on swamp forests is clearly a combination of hydrologic change resulting in waterlogging in the death of trees. The runoff also contains increased nutrients and can enhance the release of nutrients from the in-situ soils as a result of the flooding process. Thus for low nutrient status wetlands (typically dry swamp forest and wet heaths) increased nutrient imports and increased release of in-situ nutrients can result in impacts to nutrient sensitive vegetation. Such impacts are more like nutrient impacts experienced in nutrient sensitive terrestrial vegetation.

Table 1 - Suggested interim ambient water quality trigger levels (80%tile) for wetlands

Wetland category	ANZECC guiding ecosystem type	Chl a µg/L	TSS mg/L	TP µg/L	FRP µg/L	TN µg/L	NO_x–N µg/L	NH_4^+–N µg/L
Coastal Flats	Estuaries SE	5	6	30	5	300	15	15
Inland Flats	Lowland river SC	–	50	100	40	1000	100	100
Bogs	Upland river SE	–	6	20	15	250	15	13
Deep Marsh	Lowland river SC	(10)[1]	(30)	100	40	1000	100	100
Fen	None	–	–	–	–	–	–	–
Shallow Marsh	Lowland river SC	(10)	(30)	100	40	1000	100	100
Salt Marsh	Estuaries/Lowland river SE	(10)	(20)	30	5	300	15	15
Seagrass Beds	Estuaries SE	5	6	30	5	300	15	15
Deep Salt Pans	Lakes & Reservoirs SE	(10)	(10)	10	5	350	10	10
Deep Open water	Lakes & Reservoirs SE	5	6	10	5	350	10	10
Shallow Open Water	Lakes & Reservoirs SE	5	6	10	5	350	10	10
Wet Heath	None	–	–	–	–	–	–	–
Mangrove	Estuaries SE	5	6	30	5	300	15	15
Scrub Swamp	None	–	–	–	–	–	–	–
Swamp Forest – Wet	None	(10)	(30)	100	40	1000	100	100
Swamp Forest – Ephemeral	None	–	–	–	–	–	–	–
Swamp Forest – Dry	None	–	–	–	–	–	–	–

1. Values in brackets are estimates or interpolations

Chl a	Chlorophyll a
FRP	Filterable reactive phosphorus
TN	Total Nitrogen
NH_4^+-N	Ammonium nitrogen
NO_x-N	Nitrogen oxides
TP	Total Phosphorus
TSS	Total Suspended Solids

4 CATCHMENT WATER QUALITY MANAGEMENT OBJECTIVES

With regard to the water quality protection of wetlands downstream from urban development the following approach is recommended:

- As a default all stormwater is treated to current “best practice” standards
    - Load reductions of 80%, 45% and 45% for Total suspended solids, Total Nitrogen and Total Phosphorus, respectively.
- For wetland where interim water quality trigger values can be estimated, these values be used in the protocol proposed in ARQ (2003) for determining sustainable loads from a catchment.

- For wetlands where interim water quality trigger values can not be estimated (Fen, Wet Heath, Scrub Swamp, Ephemeral Swamp Forest and Dry Swamp Forest) 50 %tiles for wet weather flows should not exceed:
    - 0.06 mg/L for Total Phosphorus
    - 1.0 mg/L for Total Nitrogen

  (These are concentrations are background concentrations that can be achieved by an appropriately designed stormwater treatment wetland at present but may be further reduced as new and better stormwater best management practices become available)

- Through the application of appropriate hydrologic controls on stormwater runoff to ephemeral wetlands, in general a high level of water quality control is also achieved, as such un-seasonal waterlogging and release of in-situ soil nutrients, will be addressed.

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Water Sensitive Urban Design Solutions for Catchments above Wetlands

Appendix D: Planning Mechanisms

May 2007

Hunter & Central Coast
Regional Environmental
Management Strategy

stormwater
TRUST
A NSW Government initiative

HCC REMS

Water Sensitive Urban Design Solutions for Catchments Above Wetlands

DOCUMENT SERIES:

- Overview Report
- Appendix A: Wetlands Classification Scheme
- Appendix B: Catchment Hydrologic Indices and Urban Water Management Performance Objectives
- Appendix C: A Procedure for Determining Catchment Stormwater Management Objectives
- **Appendix D: Planning Mechanisms**

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Abbreviations

DCP	development control plan
DEC	Department of Environment and Conservation
DEUS	Department of Energy Utilities and Sustainability
DIPNR	Department of Infrastructure, Planning and Natural Resources
EP&A Act	(NSW) *Environmental Planning and Assessment Act 1979*
EPBC Act	(Commonwealth) *Environment Protection and Biodiversity Conservation Act 1999*
HREP 1989	Hunter Regional Environmental Plan 1989
LEP	local environmental plan
LHCCREMS	Lower Hunter and Central Coast Regional Environmental Management Strategy
SEPP	State environmental planning policy

1 INTRODUCTION

Since the introduction of *State Environmental Planning Policy No. 14—Coastal Wetlands* in 1985, numerous planning instruments and development guidelines have specifically addressed the impacts of development within or immediately adjoining wetlands. This has reflected increased understanding of the importance of wetlands in providing ecosystem services, and of their sensitivity to ecological disturbances generated by human activities.

Whilst development controls applying directly to wetland areas are important, attention must also be given to development within the catchment areas flowing into wetlands. Urban and rural activities can bring about significant changes to catchment hydrology and water quality, which affect the function and ecosystem health of downstream wetlands. This project seeks to overcome this deficit by proposing appropriate catchment wide planning mechanisms to protect downstream wetlands.

Underlying this project is the recognition that water management solutions within catchments need to be tailored to the hydrological requirements of receiving water bodies such as wetlands. However, current 'water sensitive urban design' (WSUD) planning provisions (such as UPRCT, WSROC and SCC Group, 2003) tend to focus on best practice water quality objectives for all new developments. An important aim of this project is to identify suitable water quality and quantity objectives and planning approaches to guide land development specifically within wetland catchment areas.

Potential planning responses were explored at a workshop held on Wednesday 28th July 2004 at Boolaroo. The workshop was attended by planning, development assessment and stormwater management staff from councils throughout the Lower Hunter and Central Coast Region. The purpose of the workshop was to seek local government input on planning tools for promoting water management objectives within wetland catchment areas, to assess the strengths and weaknesses of various tools, and to identify good examples and potential improvements.

This report builds on this workshop to present a range of planning mechanisms to assist council in guiding development in catchments above wetlands.

2 USING THIS REPORT

This document identifies possible planning mechanisms that can be used to promote and guide the implementation of WSUD solutions within wetland catchment areas. It is aimed principally at council planning officers. Whilst many these mechanisms can be applied locally by local councils, others will require cooperative action between adjoining councils, or with State and regional agencies. Matters described include:

- State and regional mechanisms (section 3)
- local environmental plans (section 4)
- development control plans (section 5)
- planning processes for wetland catchment areas (section 6)
- setting and applying hydrological objectives (section 7)
- developing planning options for wetland catchment areas (section 8).

Throughout the document sample planning provisions have been provided that councils can use to incorporate in local environmental plans and development control plans.

This document should be used in conjunction with the other appendices listed in this report which together form the *WSUD Solutions for Catchments above Wetlands Project*. As can be seen in Figure 1 the overview report links processes to determine the wetland type as outlined in Appendix A; with the hydrological and water quality objectives appropriate for those wetlands (Appendicis B and C respectively). When this report suggests links to another appendix of this study please refer to that appendix.

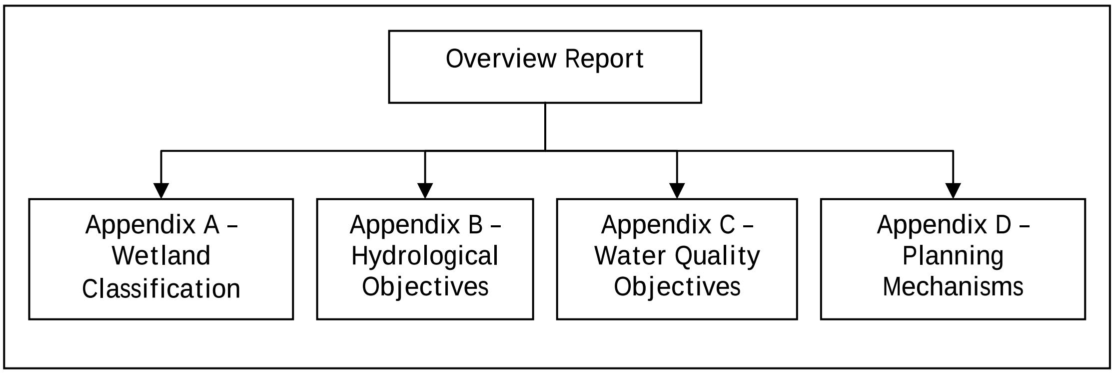

Figure 1 - Document Structure

3 STATE & REGIONAL MECHANISMS

3.1 Legislative changes

Whilst development consent conditions are an effective enforcement tool during the construction phase, they are generally inadequate or inappropriate for ensuring the long-term operation of decentralised site-level WSUD measures. The planning workshop expressed the need for legislative changes to support effective enforcement of WSUD measures.

Restrictive and positive covenants provide a possible mechanism for ensuring a long-term maintenance and operations (see Lees, 2003). This entails the creation of a series of legal instruments on individual land title documents, usually as a condition of development consent. Apart from the administrative difficulties involved, the lack of an income stream to finance regular inspections may challenge the effectiveness of such covenants.

The need to create covenants could be avoided by legislation enabling local councils or accredited certifiers to operate an inspection/certification/licensing regime similar to that for septic tanks. Possible approaches that could be considered include:

- amendment of Chapter 7 of the *Local Government Act 1993* or the *Local Government (Approvals) Regulation*, so as to require periodic approval to operate a stormwater treatment device;
- amendment of the *Protection of the Environment Operations Act 1997;* and,
- amendment of the *Conveyancing (Sale of Land) Regulation*, thereby linking inspections to the land conveyancing process.

3.2 SEPP 14—Coastal Wetlands

State Environmental Planning Policy No. 14—Coastal Wetlands (SEPP 14) has been a major break through in the protection of wetlands in NSW. The Policy, which aims to ensure that coastal wetlands are preserved and protected, applies to over 1300 defined areas of mapped coastal wetlands. Under the Policy, land clearing, levee construction, drainage work or filling within a mapped wetland area requires development consent. Such development is also declared to be 'designated development', thereby requiring development applications to be accompanied by an environmental impact statement.

There is a need to review, update and broaden SEPP 14, to address potential deficiencies of the Policy which include:

- The Policy relates only to ‘coastal wetlands’; consequently other types of wetlands are subject to various control regimes (for example, the *Hunter Regional Environmental Plan 1989*, specific LEPs and DCP provisions), or have no specific local planning provisions.

- The Policy’s control regime only relates to development *within* mapped wetland areas, hence the emphasis placed upon the delineation of wetland boundaries. Development within the broader catchment area of a wetland may have significant impacts upon its values or function, yet is generally not controlled or influenced by the Policy.

- The Policy provides no guidance on how councils should prepare compatible detailed local plan provisions (local environmental plans and development control plans) for mapped wetlands, wetland margins or wetland catchment areas, nor does it seek to influence decisions relating to the conversion of non-urban land within wetland catchments to urban zones.

Revision of SEPP 14 is beyond the scope of this project. However, the suggested regional framework for local plan provisions outlined in section 3.3 provides an indication of the type of improvements that may need to be considered. Guidance on local planning controls and processes is outlined in sections 4-6.

3.3 Regional plans

The Lower Hunter and Central Coast Region contains some of the State’s most important wetland sites. Several sites are declared Ramsar wetlands, or are regularly frequented by listed migratory species, reflecting the national and international significance of the region’s wetlands.

The *Hunter Regional Environmental Plan* (HREP) *1989* provides the broad regional framework for local planning within the Hunter Region, which includes the Lower Hunter council areas of Port Stephens, Maitland, Cessnock, Newcastle and Lake Macquarie. The HREP 1989 contains only limited references to wetlands. For example, clause 62 requires development consent for certain activities within a number of mapped wetland areas that are not subject to SEPP 14. In addition, it contains a policy that councils should protect wetlands within environmental protection zones.

The Central Coast council areas of Wyong and Gosford are located within the Sydney Region, for which there is no single regional planning instrument. Over 30 separate issue-specific or site-specific regional environmental plans have been made for the Sydney Region, none of which specifically relate to wetlands within the Central Coast.

As the HREP 1989 is currently under review, priority should be given to including revised provisions that reflect the significance of the region's wetlands. Specific guidance should be provided on the preparation and implementation of regionally-consistent local planning provisions relating to wetlands, wetland margins and wetland catchment areas. This will provide a solid foundation for local controls found in local environmental plans and development control plans, give support to their interpretation in planning appeals, and promote better integration with the management of other natural ecosystems across the region.

In keeping with government policy to simplify the planning system, regional environmental plans should not contain development control provisions, but rather provide a consistent regional framework for local plan making, development control and land management. In relation to wetlands, this framework could include the following components relating to regional studies, regional management and rehabilitation plans, urban investigation and local planning controls:

- *Regional studies*—the Hunter-Central Rivers Catchment Management Authority or other appropriate regional body should coordinate the preparation of studies to:
    - identify the region's wetlands, wetland margins and wetland catchment areas.
    - identify the values, characteristics, objectives, management principles and priorities for the region's wetlands, wetland margins and wetland catchment areas
    - identify any relevant matters protected under Part 3 of the (Commonwealth) *Environment Protection and Biodiversity Conservation Act 1999*, such as world heritage values, national heritage values, declared Ramsar wetlands, listed migratory species and nationally-listed threatened species and ecological communities. This will clarify the need for Commonwealth approval and assessment processes to observed, and the potential for joint Commonwealth-State management instruments.
- *Regional management and rehabilitation plans*—the Hunter-Central Rivers Catchment Management Authority, in cooperation with landowners and relevant agencies (such as DIPNR, DEC and local councils), should coordinate the preparation and implementation of comprehensive management and rehabilitation plans for the region's wetlands. Where appropriate, such plans should include joint Commonwealth-State management plans under Part 15 of the EPBC Act.

- *Local planning controls*—consistent with the above, councils should prepare local planning provisions that:
    - identify wetlands, wetland margins and wetland catchment areas, and specify management objectives for those areas
    - place wetlands and wetland margins within an Environmental Protection—Conservation Zone that restricts the type and scale of development to that compatible with protection of the values and ecological function of wetlands.
    - require development consent for clearing, draining, filling, construction of a levee or other development on land within or immediately adjoining wetland areas (including development comprising a public utility undertaking)
    - declare development that is likely to have a significant impact on the ecological function of a wetland, or a significant impact on any matter protected by Part 3 of the *Environment Protection and Biodiversity Conservation Act 1999*, to be designated development for the purposes of the *Environmental Planning and Assessment Act 1979*.
    - specify setbacks or other requirements for riparian land based on relevant environmental objectives, as outlined in the *Riparian Corridor Management Study* (DIPNR 2003)
    - require development within wetland catchment areas to satisfy specific performance measures relating to hydrologic regime, stormwater runoff quality, biodiversity conservation or other characteristics supporting the ecological function of wetland systems.

Local planning processes and controls that would be consistent with such a framework are described in sections 4-7 below.

4 LOCAL ENVIRONMENTAL PLANS

Local environmental plans (LEPs) provide the statutory planning framework at the local level. Whilst a variety of planning tools can be implemented by councils through LEPs, the tools most relevant to the protection of wetlands and their catchments include:

- plan objectives,
- consent requirements,
- zoning, and
- overlay controls.

The application of these tasks with appropriate provision is detailed in the next sections.

4.1 Plan objectives

The preliminary provisions of an LEP should include broad objectives relating to the protection, management and rehabilitation of wetlands, including broader development processes operating within wetland catchment areas. This will provide the rationale for detailed planning provisions, such as zoning and overlay controls, and support their interpretation in planning appeals. It will also support more detailed provisions contained in development control plans.

Sample LEP objectives are provided in Box 1. These seek to protect and rehabilitate the values and ecological function of wetlands, ensure that the effects of development within wetland catchments are considered, and importantly provide the justification for setting detailed performance measures for hydrological and water quality performance.

Box 1: Sample LEP objectives

These provisions are intended to be included in 'Part 1 Introduction' of the LEP. They allow specific objectives to be inserted relating to the protection of wetlands and their catchments

Aims and objectives

(1) The overall aim of this plan is to ………

(2) The specific objectives of this plan are as follows:

Protection of wetlands & their catchments

- (a) to protect and rehabilitate the values and ecological function of wetlands,
- (b) to ensure that the value of wetlands is considered, having regard to matters of national, state and regional significance,
- (c) to restrict the type and scale of development that may be carried out within wetlands and their margins,
- (d) to take into account the impacts of development within wetland catchment areas on the values and ecological function of wetlands, and
- (e) to require development within wetland catchment areas to be assessed against performance measures relating to hydrology, water quality and other matters affecting the values and ecological function of downstream wetlands.

4.2 Consent requirements

Activities with significant water management implications should be covered by general consent requirements. Examples include earthworks, filling, drainage, dredging and clearing of native vegetation. Sample LEP consent requirements are provided in Box 2.

Box 2: Sample consent requirements

These provisions are intended to be included in that part of the LEP concerned with regulatory framework, urban structure and zoning.

Explanatory note

This part enables general controls over the carrying out of development and establishes a pattern of broad zones that support the sustainable urban structure principles of the plan. In particular, it identifies:

- development activities that require development consent
- the types of development that may be carried out within each zone
- matters that must be taken into consideration when the consent authority determines development applications relating to land within each zone.

Development that requires consent

Except as otherwise provided by this plan, the following may be carried out only with development consent:

(a) a use of land,
(b) the subdivision of land,
(c) the erection of a building,
(d) the carrying out of a work, including:
    (i) the excavation, filling or dredging of land, and
    (ii) the disposal of waste,
(e) clearing, other than clearing of native vegetation on land that is subject to the operation of the *Native Vegetation Act 2003*,
(f) [*other matters relating to heritage items, heritage conservation areas, excavation of relics, advertising, relocation of buildings, etc*]

4.3 Environmental protection zones

Environmental protection zones are a useful tool for controlling development located within or immediately adjoining wetlands. Ideally, zoning should protect wetland habitat complexes, that is, both ‘core’ areas and adjoining wetland margins. This allows zone boundaries to reflect the fact that wetlands are dynamic communities that undergo wetting and drying cycles. Zoning provisions should permit only a restricted range of development that is compatible with long-term conservation or rehabilitation of these areas.

Sample LEP provisions for an Environmental Protection Zones are provided in Box 3. This zone seeks to protect areas of high environmental value such as cultural landscapes, remnant vegetation, fragile landforms, wetlands and escarpments.

This zone may also be appropriate for highly sensitive areas within wetland catchment areas that are unsuitable for urban development because of significant development constraints (for example, where stormwater management performance standards are higher than ‘best practice’ measures can achieve). However, it is emphasised that this zone should not be applied broadly across wetland catchment areas. It is only intended to be applied to actual wetland habitats and their immediate margins, as well as other areas of high environmental value.

Box 3: Sample zoning controls

These provisions are intended to be included in that part of the LEP concerned with regulatory framework, urban structure and zoning.

Zone (Environmental Protection—Conservation)
[Note: this zone is intended to be applied to actual wetland habitats and their margins, as well as other areas of high environmental value. It should not be applied broadly across wetland catchment areas.]

1 Objectives of zone

The general objectives of this zone are to provide for the protection and management of areas of high environmental value such as cultural landscapes, remnant vegetation, fragile landforms, wetlands and escarpments.

The specific objectives of this zone in relation to wetlands are:

(a) to protect and conserve wetland habitat complexes, including adjoining wetland margins that contribute to maintaining the ecological function of wetlands,
(b) to protect the inherent values of wetlands, including values relating to biodiversity, habitat, fisheries management, hydrological and water quality regulation, water supply, sediment and carbon accumulation, cultural heritage, scenic quality, tourism, recreation, scientific research and education,
(c) to protect the ecological function of wetlands from detrimental changes to their hydrological regime, water quality regime, substratum, organic matter cycling, biodiversity, fire regime or other characteristics,
(d) to ensure that recognition is given to matters of national, state and regional significance, and
(e) to restrict the type and scale of development to that compatible with:
  (i) the protection of wetland values and ecological function
  (ii) likely risks to life and property due to flooding
  (iii) likely risks to the environment due to disturbance of acid sulphate soils.

2 Without development consent

Bushfire hazard reduction work that is consistent with a bushfire risk management plan within the meaning of the *Rural Fires Act 1997*.

3 Only with development consent

Agriculture; clearing; dams; drainage; dwelling-houses; home occupations, earthworks, environmental facilities; environmental protection works, flood works; recreation areas; utility installations.

4 Prohibited

Any purpose other than a purpose included in item 2 or 3 of the matter relating to this zone.

5 Matters for consideration

The consent authority must consider:

(a) likely impacts of the development on the values of the land (for example, values relating to biodiversity conservation, hydrological and water quality regulation, fisheries management, water supply, sediment and carbon accumulation, cultural heritage, scenic quality, tourism, recreation, scientific research and education),
(b) likely impacts of the development on the function of natural ecological systems (for example, impacts as a consequence of changes to habitat, fire regime, hydrological regime, water quality regime, substratum, organic matter cycling or other characteristics),
(c) whether the development is consistent with any relevant regional or local management or rehabilitation plans,
(d) whether the proposed development incorporates best practice design techniques (for example, techniques relating to the management of biodiversity, hydrology, water quality, bushfire and visual impact), and
(e) whether mechanisms are proposed to promote appropriate long-term management and rehabilitation, such as conservation agreements.

4.4 Overlay controls

Environmental protection zones are generally not a useful tool for regulating development on land that is outside of a wetland but within a wetland catchment area. This is because many wetland catchment areas are already partly or substantially urbanised, and therefore fall within residential, business, industrial and other urban zones. Development controls relating to wetland catchment areas therefore need to apply special provisions that operate independently of zoning.

Control provisions should outline objectives and general qualitative requirements, but detailed numerical standards such as hydrological performance measures should be contained in development control plans. As a consequence, such measures will not be 'development standards' (as defined by the EP&A Act), thereby avoiding the application of *SEPP 1—Development Standards*.

Sample LEP provisions for wetland catchment areas are provided in Box 4 and include:

- Specifically identified wetland catchment areas identified on the LEP map.
- Proposals must be assessed against catchment-specific objectives that have been approved by the council (for example, through a development control plan). Objectives could relate to hydrology, water quality or other matters, and are outlined in section 5.
- Best practice WSUD techniques must be considered.
- The provisions apply to both consent authorities and determining authorities.
- A premium level of environmental assessment (environmental impact statement) is required where there is likely to be a 'significant' impact on the ecological function of a wetland.

The provisions illustrate how SEPP 14 could be replaced by local controls that are consistent across the State, and that integrate controls on development within both wetland areas and their upstream catchments. These controls also promote alignment with national processes under the EPBC Act, thereby facilitating Commonwealth-State accreditation processes.

Box 4: Overlay Controls

These provisions are intended to be included in that part of the LEP concerned with special provisions that overlay zoning.

Explanatory note
This Part identifies matters of environmental significance. It establishes special planning considerations and requirements that apply throughout the local area, or in relation to particular locations within the local area. The provisions give guidance about the issues relevant to these matters, and the factors that consent authorities and determining authorities must take into account when determining development proposals.
The matters of environmental significance are:

- Protection of wetlands
- [other matters not the subject of this report, such as heritage conservation, biodiversity conservation, etc].

Protection of wetlands
Land to which clause applies
(1) This clause applies to land within the following wetland catchment areas, as identified on the LEP Map:

- ABC Wetland Catchment Area
- XYZ Wetland Catchment Area

Objectives
(2) The objectives of this provision are:

(a) to draw attention to the extent of the hydrological catchment of particular wetlands, and

(b) to ensure that development undertaken within the hydrological catchment of a particular wetland is designed and constructed in a manner that:

- mitigates likely impacts on the values and ecological function of that wetland,
- has regard to catchment-specific performance measures for hydrology, water quality or other matters affecting the values and ecological function of downstream wetlands,
- incorporates best practice WSUD techniques, and
- takes into account matters of national, state and regional significance

When this clause applies

(3) This clause applies when:

(a) the consent authority determines a development application, or

(b) a determining authority carries out an activity or grants an approval in relation to an activity, in relation to land to which this clause applies.

Matters for consideration

(4) When this clause applies, the following matters must be taken into account:

(a) whether the proposed development would meet any applicable performance measures for hydrology, water quality or other matters affecting the values and ecological function of downstream wetlands, being performance measures that have been approved by the Council, and

(b) whether the proposed development incorporates best practice design techniques (for example, techniques relating to the management of biodiversity, hydrology, water quality, bushfire and visual impact), as described in technical manuals or other publications specified by a development control plan.

Designated development

(5) Pursuant to section 29 of the Act, development carried out within a wetland catchment area that is likely to have a significant impact on:

(a) the ecological function of a wetland, or

(b) any matter protected by a provision under Part 3 of the *Environment Protection and Biodiversity Conservation Act 1999* of the Commonwealth, is declared to be designated development for the purposes of the Act.

(6) For the purposes of subclause (5)(a), in deciding whether there is likely to be a significant effect on the ecological function of a wetland, consideration must be given to likely impacts on:

(a) wetland habitat (including its modification, removal or fragmentation), and

(b) fire regime, and

(c) hydrological regime, and

(d) water quality regime, and

(e) substratum, organic matter cycling or other characteristics.

(7) For the purposes of subclause (5)(b), in deciding whether there is likely to be a significant effect on any matter protected by a provision under Part 3 of the *Environment Protection and Biodiversity Conservation Act 1999* of the Commonwealth, consideration must be given to any relevant test of significance under that Act.

Note

Matters protected under Part 3 of the *Environment Protection and Biodiversity Conservation Act 1999* are commonly referred to as ‘matters of national environmental significance’. Examples of such matters include the world heritage values of a declared World Heritage property, the national heritage values of a National Heritage place, the ecological character of a declared Ramsar wetland, a listed threatened species (extinct in the wild, endangered or vulnerable categories), a listed threatened ecological community (in the endangered or critically endangered categories) and a listed migratory species.

The Commonwealth Department of Environment and Heritage has produced a set of administrative guidelines (‘Administrative Guidelines on Significance’) to assist in determining whether an action is likely to have a significant impact on matters of national environmental significance. The Guidelines set out ‘criteria for significance’ for each matter.

5 DEVELOPMENT CONTROL PLANS

A council's development control plan (DCP) supplements its local environmental plan by providing detailed criteria and guidelines for assessing development applications. Whilst such criteria and guidelines are not legally enforceable standards, they must be taken into consideration by consent authorities.

DCP provisions can be used to formally specify hydrological and stormwater quality performance standards for a specific wetland catchment (or any other sensitive catchments). This provides a mechanism to ensure that the hydrological and stormwater quality impacts of development are considered during the development consent process.

DCPs are a suitable mechanism for securing hydrological and stormwater quality outcomes for small-scale development. Where achievement of those outcomes requires the provision of subregional- or precinct-level infrastructure, the broader framework for development needs to be specified by structure plans, integrated water cycle management plans and master plan (see section 6 below), and also contributions plans where council-provided infrastructure is required.

Hydrological and stormwater quality criteria for development within wetland catchment areas need to be integrated with general DCP provisions relating to WSUD. Catchment-specific criteria relating to wetland catchment areas can be readily inserted into the 'water balance' and 'stormwater pollution' design elements. This enables the DCP provisions to contain both general WSUD requirements, as well as requirements that are tailored for specific wetland catchment areas. Sample DCP provisions for hydrology and water quality objectives for catchments above wetlands are shown in the following sections and approaches to derive catchment-specific objectives are detailed in Section 7 and Appendix B of this study.

It is important to note that hydrological and stormwater quality performance standards specified by a DCP for a specific wetland catchment may in many cases be more onerous than those otherwise required to achieve a 'BASIX certificate' under *State Environmental Planning Policy (Building Sustainability Index: BASIX) 2004*.

5.1 Hydrological objectives

DCP provisions for specific hydrological objectives within a catchment need to correspond to the correct wetland type for a particular catchment. This is achieved by determining the wetland type, of the 17 types identified and as outlined in Appendix A of this study. For example, if a particular wetland was classified as a 'Salt Marsh', the hydrological objective for development within its catchment would be to maintain the both the 'drying hydrology' and the 'flooding hydrology' with a reference duration of 7 days, as identified in Table 1.

Box 5 shows how these hydrologic objectives can be expressed as planning provisions within councils DCP. Appropriate site-level hydrological performance standards consistent with this objective should also be expressed in the DCP. More information on determining wetland types is contain in Appendix A of this study, while information on determining the correct hydrological objectives are contained in Section 6.1 of this report and Appendix B of this study.

Table 1 - Hydrologic Management Objectives for Natural Wetlands

Wetland Category	**Flooding Hydrology**	**Drying Hydrology**		**Reference Duration**
	High Flow Duration Frequency Curve	**Low Flow Duration Frequency Curve**	**Low Flow Spell Frequency**	
1. Coastal Flats	✓			7 days
2. Inland Flats	✓	Isolate wetland from upstream catchment		30-60 days
3. Bogs	✓	✓	✓	30-60 days
4. Deep Marsh		✓	✓	30-60 days
5. Fen	✓	✓	✓	30-60 days
6. Shallow Marsh		✓	✓	60 days
7. Salt Marsh	✓	✓	✓	7 days
8. Seagrass Beds	✓			7 days
9. Deep Salt Pans	✓	Isolate wetland from upstream catchment		30-60 days
10. Deep Open Water	No hydrologic management objectives required			
11. Shallow Open Water		✓	✓	60 days
12. Wet Heath		✓	✓	60 days
13. Mangrove	✓			7 days
14. Scrub Swamp	✓	✓*	✓*	60 days
15. Forest Swamp - Wet		✓	✓	60 days
16. Forest Swamp - Ephemeral		✓	✓	60 days
17. Forest Swamp - Dry	✓	✓*	✓*	60 days

Box 5: Hydrological Objectives for DCP Provisions

These provisions are intended to be included in that part of a consolidated DCP dealing with WSUD. It provides an example of how performance standards can be specified for wetland catchment areas having specific hydrological and stormwater quality requirements.

Urbanisation also alters the relative balance between runoff, infiltration and evapotranspiration. Increased coverage by impermeable surfaces may act to reduce infiltration and increase the volume of surface runoff. This can have a variety of detrimental effects, including:

- reduced base flow in streams, thereby affecting water quality and the health of aquatic ecosystems

during dry periods
- adverse effects on ephemeral watercourses, wetlands and poorly flushed coastal lagoons
- dieback and weed growth in bushland communities that are sensitive to increased wetting, particularly by stormwater containing elevated levels of nutrients.

However, increased coverage by impermeable surfaces may also cause a significant loss of vegetation, particularly of deep-rooted perennial native species. This may result in lower evapotranspiration and increased groundwater recharge, which may contribute to rising water tables and soil salinity problems. Maintenance of natural water balance can be promoted by measures that capture stormwater during regular rainfall events, either for on-site infiltration or use. Infiltration devices allow captured stormwater to infiltrate to the soil over a period of up to two days, whilst rainwater tanks allow the water to be utilised for a variety of indoor and outdoor purposes.

The suitability of management measures will depend largely on site conditions. For example, infiltration devices may not be suitable in areas that have heavy clay soils, are affected by potential urban salinity or have native bushland on lower slopes.

1 Objectives

- To promote the maintenance of natural water balance.
- To minimise changes to pre-development stormwater volumes.
- To prevent adverse impacts to environments that are sensitive to increased stormwater volumes or infiltration (such as bushland, wetlands, coastal lagoons and areas subject to potential urban salinity).

2 Application

- Applies to residential, commercial, industrial, community service and recreational development (minor additions or alterations to existing buildings excepted)
- Applies to subdivision that requires the carrying out of road, stormwater or other works.
- Applies to the above development only if located within a wetland catchment area [or other specified sensitive areas].

3 Performance standards

Expected post-development stormwater volume must satisfy the following catchment-specific objectives and performance standards.

Wetland catchment area & category	**Catchment hydrological objective(s)***	**Performance standard***
Insert wetland catchment area name and category **Example:** *XYZ Wetland Catchment Area* *(Salt marsh)*	*Insert relevant catchment hydrological objective(s)* **Example:** 1. Maintain the pre-urban flooding hydrology, as expressed by the annual high-flow duration frequency curve, with a reference duration of 7 days (for all annual exceedence probabilities). 2. Maintain the pre-urban drying hydrology, as expressed by: • the annual dry season flow duration frequency curve, with a reference duration of 7 days (for all annual exceedence probabilities), and • the low flow spell frequency curve with a reference threshold discharge of … megalitres per day.	*Insert relevant site-level performance standards for stormwater detention and retention*

** Note: refer to [insert relevant technical document] regarding the derivation and interpretation of these hydrological objectives and performance standards. These performance requirements may exceed those for a 'BASIX certificate' under State Environmental Planning Policy (Building Sustainability Index: BASIX) 2004.*

4 Management measures

The objectives and performance standard can be achieved by applying the following measures.

S L	✓✓	Detention devices
L	✓✓	Roofwater tanks
S L	✓✓	Infiltration devices
S L	✓✓*	Stormwater tanks
S L	✓✓*	Aquifer storage and recovery systems

Key:

S	Can be applied at the street or subdivision level
L	Can be applied at the lot level
✓✓	Can provide a major performance contribution
✓	Can provide a subsidiary performance contribution
*	Generally applicable only to larger development projects

Guidance is provided for each of the above measures in [*insert relevant technical or design documents*]. Selection of measures will need to take into account site conditions, effectiveness, economics and other factors.

5 Assessment criteria

Development proposals should:

- satisfy applicable hydrological objectives and performance standards, and
- be consistent with relevant better practice guidelines contained in *[insert relevant technical or design documents*].

5.2 Stormwater quality objectives

Wetlands occur in a wide range of environments (Jacobs & Brock 1993, and Green 1997). As a result, the supporting water quality of wetlands varies considerably.

In general water quality supporting various wetland types is related to the position of a wetland in the terrain. Upland wetlands (eg. bogs) or wetlands with limited catchments (wet heaths) tend to be adapted to very good water quality (low nutrient) conditions. Lowland wetlands (deep marshes, wet swamps) typically have large catchments and tend to regulate the supply of water and materials (sediment, nutrients, etc.) to downstream environments. As a result these systems tend to be adapted to poorer water quality (high nutrient) conditions. Some wetland types are very good at processing and utilising nutrients. More information on determining wetland types is contained in Appendix A of this study. With regard to the water quality protection of wetlands downstream from urban development the following approach is recommended:

- As a default all stormwater is treated to current “best practice” standards – load reductions of 80% for total suspended solids, and 45% for nitrogen and phosphorus.
- For wetland where interim water quality trigger values can be estimated, these values be used in the protocol proposed in Australian Runoff Quality (Engineers Australia 2003) for determining sustainable loads from a catchment.
- For wetlands where interim water quality trigger values can not be estimated (Fen, Wet Heath, Scrub Swamp, Ephemeral Swamp Forest and Dry Swamp Forest) 50 %tiles for wet weather flows should not exceed:
    - 0.06 mg/L for Total Phosphorus
    - 1.0 mg/L for Total Nitrogen

  (These are concentrations are background concentrations that can be achieved by an appropriately designed stormwater treatment wetland at present but may be further reduced as new and better stormwater best management practices become available)
- Through the application of appropriate hydrologic controls on stormwater runoff to ephemeral wetlands, a high level of water quality control is also achieved, as such un-seasonal waterlogging and release of in-situ soil nutrients, will be addressed.

More information on determining the appropriate stormwater quality objectives are contained in Appendix C of this study. Box 6 shows how these performance standards can be incorporated in DCP provisions.

Box 6: Stormwater quality objectives for DCP Provisions

These provisions are intended to be included in that part of a consolidated DCP dealing with WSUD. It provides an example of how performance standards can be specified for wetland catchment areas having specific hydrological and stormwater quality requirements.

Urban development typically introduces greater quantities and a broader variety of pollutants to the land surface. The replacement of natural ground surfaces and vegetation by buildings, roads and other impermeable surfaces in turn significantly increases the potential for these pollutants to be transported to streams and waterways by stormwater runoff. The majority of pollutants reaching streams are washed from impermeable surfaces during regular rainfall events (those with an average recurrence interval of up to 6 months).

Stormwater generated by these rainfall events can be captured and treated by a variety of management measures. Runoff from both roofs and paved areas needs to be treated.

Significant water quality improvements can be achieved by configuring a sequence of treatment measures (a 'treatment train'). Some measures may provide a variety of subsidiary benefits, such as urban flood control and water conservation. The suitability of treatment measures will depend largely on site conditions. For example, Infiltration devices may not be suitable in areas with heavy clay soils or which are affected by potential urban salinity.

1 Objectives

- To capture and treat stormwater flows during regular rainfall events.
- To achieve stormwater quality treatment objectives contained in relevant stormwater management plans or other adopted plans or strategies.

2 Application

- Applies to residential, commercial, industrial, community service and recreational development (minor additions or alterations to existing buildings excepted).
- Applies to subdivision that requires the carrying out of road, stormwater or other works.

3 Performance standard

Expected average annual post-development pollutant loads in stormwater discharges from the site must not exceed the following values:

> [*insert relevant values for new development, as adopted by the council's Stormwater Management Plan. Different values may apply to different types of development or specific areas with sensitive requirements. The following is an example*.]

Pollutant	**Standard to be achieved** [1]		
	General	**XYZ Wetland Catchment Area**	**ABC Wetland Catchment Area**
Total suspended solids	20% of baseline annual pollutant load[2] ('80% reduction')[3]	20% of baseline annual pollutant load[2] ('80% reduction')[3]	
Total Phosphorous	55% of baseline annual pollutant load [2] ('45% reduction')[3]	55% of baseline annual pollutant load[2] ('45% reduction')[3]	50th percentile wet weather flow nutrient concentration should not exceed 0.06 mg/litre[4]
Total Nitrogen	55% of baseline annual pollutant load[2] ('45% reduction')[3]	55% of baseline annual pollutant load2 ('45% reduction')[3]	50th percentile wet weather flow nutrient concentration should not exceed 1.0 mg/litre[4]

[1] *These performance requirements may exceed those for a 'BASIX certificate' under State Environmental Planning Policy (Building Sustainability Index: BASIX) 2004.*

[2] *Baseline annual pollutant load is the expected post-development pollutant load that would be discharged from the site over the course of an average year, following compliance with the hydrological management objectives, but with no other measures applied for stormwater quality treatment.*

[3] *This corresponds to current 'best practice'.*

[4] *These requirements are based on current knowledge of background concentration in treatment wetlands would typically be applied to nutrient-sensitive wetlands such as dry swamp forest and wet heaths.*

4 Management measures

The objectives and performance standard can be achieved by applying the following measures.

L	✓✓	Roofwater tanks
S L	✓✓	Infiltration devices
S L	✓✓	Filtration and bioretention devices
L	✓✓	Porous paving
S L	✓✓	Grassed swales
S L	✓	Landscape practices
S L	✓✓*	Ponds and wetlands
S L	✓✓*	Stormwater tanks

Key:

S	Can be applied at the street or subdivision level
L	Can be applied at the lot level
✓✓	Can provide a major performance contribution
✓	Can provide a subsidiary performance contribution
*	Generally applicable only to larger development projects

Guidance is provided for each of the above measures in [*insert relevant technical or design documents*]. Selection of measures will need to take into account site conditions, effectiveness, economics and other factors.

5 Assessment criteria

Development proposals should:

- satisfy applicable stormwater quality objectives and performance standards, and
- be consistent with relevant better practice guidelines contained in *[insert relevant technical or design documents*].

5.3 Deemed-to-comply provisions & complying development

There is also a role for 'deemed to comply provisions' in DCPs for routine forms of development (such as dwelling-houses). These provisions would indicate design responses that are deemed to meet the performance measures without the need to undertake a detailed hydrological analysis. Any such requirements would also need to be incorporated in the council's complying development provisions. Depending on the particular council, these provisions may be located in its LEP, or a DCP that is specifically referenced by a LEP.

Councils will need to determine such 'deemed to comply' requirements after taking into account the applicable hydrological/ water quality objectives the particular wetland catchment area, soil conditions, the type of development and other local factors.

In particularly sensitive catchments it maybe appropriate to exclude complying development from wetland catchment areas, thereby requiring a development application to be submitted.

6 PLANNING FOR URBAN DEVELOPMENT IN CATCHMENTS ABOVE WETLANDS

Urban development results in changes to both runoff quality and quantity. Where such changes occur within a wetland catchment area, significant adverse impacts on the ecological function of wetlands may result. Accordingly, planning processes need to establish appropriate hydrological and water quality controls and infrastructure systems for wetland catchment areas. These processes must consider both existing development patterns, as well as any proposals to extend or intensify urban development or other activities within wetland catchment areas.

The initial step for a council in establishing catchment-specific planning controls for a wetland catchment area, is to determine the number and type of wetlands that are to be protected within a given LGA. Once a given wetland has been classified it is possible to apply appropriate water quality and hydrological objectives. It is then the responsibility of council to protect the wetland through LEP provisions and apply these objectives through DCP provisions, as outlined above.

A process for suitable investigation for wetland catchment areas to identify the characteristics of the catchment, suitable management objectives and compatible development options is outlined below. Such investigations will often be prompted by proposals for intensification of urban development within the catchment area (for example, an environmental study or other planning reports prepared to support a draft local environmental plan).

The intensification of development will allow the objectives as stipulated in LEPs and DCPs to be integrated into structure planning for a region and masterplanning for a given development. Importantly, the objectives should also be integrated into the local water authority's integrated water cycle management plan, or the development of WSUD strategies for larger developments feeding into masterplanning processes. The adoption of WSUD into these planning processes is outlined below.

6.1 Investigating wetland catchment areas

The following provides a guideline to the matters that need to be assessed by any planning study that seeks to provide a foundation for planning controls for a wetland catchment area.

- *Wetland values*. The values and characteristics of the wetland and its catchment should be identified. It is important to establish a general understanding of what needs to be protected. Wetland values may relate to matters such as biodiversity conservation, fisheries management, hydrological and water quality regulation, water supply, sediment and carbon accumulation, cultural heritage, scenic quality, tourism, recreation, scientific research and education.

- *EPBC Act matters*. It is particularly important to identify any relevant matters protected under Part 3 of the (Commonwealth) *Environment Protection and Biodiversity Conservation Act 1999*, such as world heritage values, national heritage values, declared Ramsar wetlands, listed migratory species and nationally-listed threatened species and ecological communities. This will clarify the need to observe Commonwealth approval and assessment processes, and the potential for a joint Commonwealth-State management regime.

- *Wetland classification*. Wetlands within the catchment should be classified using the methodology described in Appendix A of this study. This is a critical step in the process of establishing catchment-specific hydrological objectives. The following seventeen wetland types are recognised.

1. Coastal Flats
2. Inland Flats
3. Bogs
4. Deep Marsh
5. Fen
6. Shallow Marsh
7. Salt Marsh
8. Seagrass Beds
9. Deep Salt Pans
10. Deep Open Water
11. Shallow Open Water
12. Wet Heath
13. Mangrove
14. Scrub Swamp
15. Forest Swamp - Wet
16. Forest Swamp - Ephemeral
17. Forest Swamp - Dry

- *Hydrological objectives*. Hydrological management objectives for the relevant wetland type should be defined using the methodology described in Appendix B of this study. This design process has been developed to assist councils in setting and applying hydrological performance objectives for wetland catchment areas, and it outlines the methodology for computing baseline and post-development hydrological indices, and for assessing the level of performance required to preserve the supporting wetland hydrology. Defining baseline hydrologic indices involves continuous hydrologic modelling or analysis of historical streamflow data. The key steps in the process are as follows:

1. Select and calibrate (if data is available) catchment hydrological model or obtain relevant long-term streamflow data for statistical analysis. A data length (either simulated or observed) of 15-20 years is desirable.

2. Identify the most suitable classification for the wetland to be protected (see Appendix A of this study).

3. Define the baseline hydrologic indices from the data simulated or observed (Step 1), ie. undertake the required flow duration frequency analysis and, if appropriate, the dry flow spell analysis as discussed in Section 3 of Appendix B of this study.

4. Define, through hydrologic modelling, the changes in hydrological behaviour as the result of proposed urban development in the catchment and compare the post-development hydrologic indices against the baseline indices for either wetland flooding or drying conditions.

5. Identify WSUD measures that have the capabilities to manage the hydrologic conditions of the proposed development to meet the hydrologic performance objectives established in Step 3.

- *Other environmental objectives*. Other relevant environmental objectives should be defined, such as objectives relating to fire regime, water quality, habitat, and introduced species.

- *Development options*. Possible development options that could potentially satisfy relevant objectives (including a ‘no development option’) should be identified. Options should be considered at various spatial scales, including the subregional, precinct and site-level scales. The process for developing planning options is outlined in section 8 below.

- *Assessment of options*. Possible development options need to be assessed according to how well they satisfy relevant environmental objectives. Consideration also needs to be given to consistency with broad planning objectives such as settlement pattern, urban structure and infrastructure provision.

- *Selection of the preferred option* (or combination of options). It needs to be demonstrated that the preferred option will not compromise the values and management objectives for the wetland and its catchment.

- *Recommendations*. Recommendations need to be made regarding the preferred planning controls to be included in the Council’s local environmental plan and development control plan (see sections 4 and 5), and the design principles that should be incorporated in structures plans and master plans.

6.2 Structure planning

Structure planning is concerned with integrated planning concepts that guide the implementation of subregional-scale projects such as urban release corridors. Such projects are implemented incrementally over several decades, and thus need to be strategically planned and coordinated.

Typically, a ‘structure plan’ summarises the proposed settlement pattern and urban structure. It comprises a schematic generalisation of principal structural elements such as access systems, land use and infrastructure (and their rationale), and provides a foundation for detailed local planning and design. Structure plans serve to:

- outline the desired location, layout, form and staging of development
- provide a long-term planning framework
- express how development should respond to relevant planning objectives and strategies and regional constraints, opportunities and context
- assist councils when regulating the release of urban land through the rezoning process.
- help the public to understand future subregional directions and outcomes

Structure plans should therefore address any necessary subregional strategies for achieving hydrological objectives for wetland catchment areas (see section 6.1). These strategies need to be integrated with the full range of other planning issues. Relevant matters that need to be addressed include development density, open space networks, subregional water infrastructure systems, and broad WSUD principles.

6.3 Integrated water cycle management plans

Typically, any urban development in NSW will either be part of a local water utility (including Sydney) service area, or it is regulated under the rules of DIPNR, NSW Health, and the Water Management Act. An integrated water cycle management plan (see DEUS 2004) should be prepared by each local water utility in NSW, with the primary objective of providing sustainable urban water services. This plan should provide a detailed investigation and refinement of the preferred management option, as well as describing the proposed strategy for achieving applicable hydrological, water quality and other water-related objectives and performance standards. The strategy should encompass matters such as planning principles, infrastructure provision, and proposed design and management measures.

It is therefore necessary for local water authorities when preparing their integrated water cycle plans to determine how regional water supply, wastewater and stormwater systems and reuse schemes may assist achieving hydrological and water quality objectives

Therefore for a subdivision or allotment scale development the water supply and wastewater has already been determined by the water supply authority and therefore most of the investigation will be focused on stormwater management, and linkages into potable mains water and its substitution, and wastewater from the site.

6.4 Master planning

Master planning is concerned with integrated planning concepts that guide the implementation of major development projects at the neighbourhood or precinct-scale, such as redevelopment areas or new housing estates. Master plans serve to:

- outline the desired location, layout, form and staging of development
- provide a long-term planning framework, particularly where staged development and approvals are involved
- express how development should respond to relevant planning objectives and strategies and the site's constraints, opportunities and context
- help the public to understand the project's future outcomes
- assist councils when considering development applications.

Master plans should therefore address any necessary precinct-level strategies for achieving hydrological objectives for wetland catchment areas (see section 6.1). These strategies need to be integrated with the full range of other planning issues. Relevant matters that need to be addressed include development density, public open space provision and layout, and detailed WSUD principles.

6.5 Development of a WSUD strategy

A WSUD strategy aims to optimise and integrate stormwater, potable mains water supply and wastewater within a given urban development or release area. A WSUD strategy evaluates a number of factors including the development scenarios, transport systems, and site constraints to identify appropriate WSUD elements to meet relevant site water objectives. The WSUD strategy needs to be consistent with the local water authority's IWCMP.

As shown in Table 2 there is a synergistic overlap between the three urban water cycle streams, for example stormwater reuse will support potable water conservation and reduce stormwater volumes and pollutant loads. The opportunities for integrating WSUD into urban planning include:

- treating urban stormwater to meet stormwater quality objectives for reuse and/or discharge to surface waters

- using stormwater in the urban landscape to maximise the visual and recreational amenity of developments

- reducing potable mains water demand through water efficient appliances, rainwater, stormwater and greywater or wastewater reuse, and

- minimising wastewater generation, as well as treatment of wastewater to a standard suitable for effluent reuse opportunities and/ or release to receiving waters.

Table 2 - Interactions between the three elements of the urban water cycle (after Landcom 2003)

Potable Water Conservation	Wastewater Minimisation	Stormwater Management
Demand management	Demand Management	
Rain / stormwater harvesting		Rain / stormwater harvesting
Greywater reuse	Greywater reuse	
Reclaimed “blackwater” reuse	Reclaimed “blackwater” reuse	
		Stormwater quality improvement
	Reduced stormwater inflow to sewers	Stormwater detention & retention

6.6 Example of planning for Wetland Protection – Porters Creek

An example of the use of planning instruments to implement WSUD so as to meet hydrological objectives for catchments above wetlands is given by Porters Creek. This site was used as a case study for determining the hydrological objectives for this study (Appendix B).

The Warnervale/Wyong land release zone lies within the drainage catchment of the Porters Creek Wetland (one of the largest freshwater wetlands on the NSW coast) and other sensitive terrestrial and aquatic ecosystems (including sensitive Wallum Froglet habitat). The following is a summary of findings which indicates the importance of careful management of the water cycle in the wetland’s catchment:

- Porter’s Creek Wetland has been identified as a combination ‘Paperbark / Casuarina Wet Forest’ and ‘Low Paperbark Swamp Forest’ with an isolated patch of ‘Reed, Sedge & Herb Wetland’. The wetland is particularly sensitive to the ‘drying’ frequency during the summer months and the water management objective is to *preserve the ‘hydrologic signature’ of summer minimum 30-day average flow duration and the low flow spell* *frequency characteristics at 'pre-development' levels.* At present the wetland is under threat as a result of the significant urban development occurring in its catchment and the associated change in hydrologic behaviour.

- Conceptual water balance models established to test the possible WSUD options for delivering on the water management objective indicate that: significant water 'loss' must occur to deliver hydrologic objectives for Porter's Creek Wetland and additional 'loss' or reuse must occur over-and-above that to meet the requirements of BASIX. Examples of how this ***additional 'loss'*** can be achieved are:
    - development in Porters Creek Wetland catchment should include 20% of the urbanised area set aside for irrigated plantation; and
    - stormwater harvesting at a regional scale for reuse either within or external to the catchment.

Consideration must therefore be given to the regional collection, storage and reuse or 'loss' of harvested stormwater through the Warnervale/Wyong region to protect the Porters Creek Wetland and other valuable ecosystems.

These WSUD elements can only be holistically implemented through a broad combination of requirements of land use zoning under councils LEP provisions, adoption of hydrological objectives through councils DCP provisions, the development of regional integrated water cycle management plans which take into account the hydrological needs of Porters Creek and identifies potential reuse demands, and masterplans which adhere to the principles and targets required for their development in the catchment. Once these processes have been established, WSUD elements such as reuse, open space irrigation, and detention, such as those discussed in the next section, can be implemented.

7 DEVELOPING PLANNING OPTIONS FOR WETLAND CATCHMENT AREAS

There are a range of options for meeting hydrological objectives within wetland catchment areas. Options need to be considered at a variety of spatial scales (subregional, precinct and site-levels). The higher the spatial scale of an option, the earlier it needs to be considered in the urban investigation/ rezoning process.

Urbanisation results in significant alterations to the hydrologic regime of downstream catchments, with the general tendency for increased flows. Consequently, there are two broad strategies that may be employed:

- strategies to preserve pre-development flooding hydrology, such as the provision of detention storage to reduce peak flows, and
- strategies to preserve pre-development drying hydrology, such as retention measures to remove stormwater from the surface water conveyance system (e.g. stormwater harvesting/reuse and infiltration).

Preservation of pre-urban hydrological regimes therefore usually involves the 'disposal' of excess stormwater runoff generated from urban development. The quantity of stormwater required to be removed will depend on the hydrological objectives for the relevant catchment, and these will affect the suitability of various options. Important options and their potential at various spatial scales is summarised in Table 3.

Table 3 - Potential to apply hydrological management options at various spatial scales

Scale	Hydrological management options						
	Open space irrigation	Indoor use (toilets, etc)	Industrial use	Increased density	Infiltration	Detention	Flow diversion
Site	✓	✓			✓	✓	
Precinct	✓	✓	✓	✓	✓	✓	
Sub-regional	✓		✓	✓	✓	✓	✓

7.1 Open space irrigation

Open space includes both 'public open space' such as parks, sportsfields, golf courses, and footpaths, and 'private open space' such as gardens and lawns. Irrigation of public open space presents opportunities to reuse large quantities of stormwater, but requires a subregional- or precinct-level solution to ensure its broader implementation.

Requirements for the quantity and layout of irrigated public open space, and the storage and reticulation of stormwater, need to be specifically addressed by structure plans (in the case of subregional solutions) and master plans (in the case of precinct-level solutions) so as to ensure that individual development proposals are undertaken in accordance with the broader strategy. In contrast, irrigation of private open space from on-site rainwater tanks does not require public infrastructure provision, and can be implemented through requirements on individual development applications. However, the quantity of stormwater involved may be insufficient to achieve applicable hydrological objectives.

7.2 Indoor rainwater use

Indoor rainwater use for toilets, hot water, laundry, and other non-potable uses may be achieved through the collection of roofwater at the site or precinct-levels. Precinct-level solutions will need to be addressed by master plans, whereas site-level solutions can be addressed by simple requirements in development control plans or complying development provisions (eg minimum tank size, connection requirements).

Where indoor use is insufficient to achieve relevant hydrological objectives, supplementation by other options will be necessary (for example, irrigation of public open space).

7.3 Industrial use

Stormwater can be supplied to industrial premises for low-grade uses. This option will generally require a nearby industrial activity requiring bulk water, and a subregional-level storage and supply solution. These requirements will limit the suitability of this option.

7.4 Increased density

Multi-unit residential development increases the ratio of total household water demand to roof area, thereby increasing the ability of rainwater harvesting to remove rainwater from roof areas. Thus, increased dwelling density is a possible option where indoor rainwater use would otherwise be insufficient to meet relevant hydrological objectives.

This option potentially provides a powerful financial mechanism to drive the adoption of rainwater harvesting, which is generally constrained by the low price of water. In general, increased density can only be considered at the subregional or precinct levels because of implications to a range of other planning issues such as accessibility, urban structure, street layout and infrastructure provision. It must therefore be considered at the earliest stages of planning, and will usually need to be addressed by zoning within the council's local environmental plan.

7.5 Infiltration

Infiltration of stormwater runoff from roads and other paved surfaces may be an appropriate option where soil and hydro-geological conditions are suitable. This option may require significant investigation due to the potential for a variety of groundwater-related hazards. Aquifer storage and recovery systems are a further possibility. Implementation is mainly at the site and precinct levels, but needs to be integrated with the management of regional groundwater systems.

7.6 Detention

Stormwater detention may be necessary in the case of wetlands that require preservation of their flooding hydrology. The provision of regional detention storage needs to be coordinated with open space planning principles expressed in structure plans and master plans. It also needs to be addressed by contributions plans.

7.7 Flow diversion

Excess stormwater can be exported to other catchments via pipelines and discharged into rivers as 'environmental flows', subject to suitable treatment. This may enable increased extraction yields for water supply or agricultural uses. This option needs to be addressed by infrastructure programs outlined in structure plans and integrated water cycle management plans.

8. CONCLUSIONS

Wetlands have widely suffered as a result of urban development and encroachment, altering their ecological functioning. Councils themselves have been limited in their knowledge and ability to identify appropriate planning mechanisms to negate the impact of urban development on these wetlands.

This project has been developed so as to assist councils in determining the type of wetlands within their local government area and the associated hydrological and water quality objectives which need to be applied so as to sustain the ecological functioning of wetlands. The methodology outlined in Appendix B of this study enables councils to set hydrological objectives for individual wetland catchment areas based on a relatively simple wetland classification scheme.

Councils can utilise a variety of appropriate planning mechanisms to promote the adoption of these objectives and WSUD within wetland catchment areas, so as to protect the ecological values and functioning of these wetland systems. These include LEP provisions which provide the rationale for detailed planning provisions, such as zoning and overlay controls, and support their interpretation in planning appeals. It will also support more detailed provisions contained in development control plans.

Further urbanisation within these catchments above wetlands will allow the objectives as stipulated in LEPs and DCPs to be integrated into structure and masterplanning. The objectives can also be integrated into the local water authority's integrated water cycle management plan, or the development of WSUD strategies for larger developments feeding into masterplanning processes.

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