Wetland Mapping and Classification Methodology

Overall Framework

A Method to Provide Baseline Mapping and Classification for Wetlands in Queensland

VERSION 1.2

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Contributors

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1. Introduction

Approximately four percent of Queensland's mainland is permanently or periodically inundated by water. These 'wetlands' occur across the range of climatic and landscape variation present throughout the State, from the large semi-permanent and permanent systems of the Gulf of Carpentaria and Cape York Peninsula, along the east coast, and inland to the semi-arid areas of the south-west (Environmental Protection Agency 1999).

In 1999, Queensland Cabinet endorsed the *Strategy for the Conservation and Management of Queensland Wetlands* (Wetland Strategy) (Environmental Protection Agency 1999), with the Queensland Environmental Protection Agency as the lead agency for implementation. The Wetland Strategy provides the primary policy document to guide wetlands conservation and management within the State. The implementation of the Wetlands Strategy involves a number of Government departments and other key stakeholders.

In addition to the Wetlands Strategy, specific actions are required for the conservation and management of wetlands under the Reef Water Quality Protection Plan (Department of the Premier and Cabinet 2003), National Heritage Trust 2 (NHT2) Wetlands Programme, State and Regional Coastal Management Plans and many other programmes.

The main driver behind the commitments of the State and Australian Governments to wetlands is the need to address the loss and degradation of wetland systems, which is resulting in declining water quality and a loss of biodiversity in Queensland, particularly the Great Barrier Reef. Additionally, wetlands are managed under many regimes and the greater emphasis on management and conservation of wetlands increases the need to consistently define wetland characteristics and locations.

Every attempt has been made to link the overall Mapping and Classification Methodology, including the Framework and Technical Specifications, to other initiatives of the State and Australian Governments. In particular a strong link has been made between the *Draft Queensland Water Quality Guidelines 2005* (Environmental Protection Agency 2005c) and the wetland classification process.

The Wetland Mapping and Classification Project (WMC project) has been progressed through joint State and Australian Government funding via the NHT2 Wetlands Programme.

2. The Need for a Baseline Wetland Map

A fundamental requirement of any wetland management programme is the inclusion of comprehensive information about the distribution of wetlands, mapped and classified at an appropriate scale, with sufficient detail to allow management actions to be implemented, or for further mapping and inventory work to be undertaken. Significant wetland mapping has already been conducted for a number of areas, using different methods and scales (such as Queensland Department of Primary Industries and Fisheries (QDPI&F) mapping of coastal wetlands vegetation communities at 1:100,000 scale for the Queensland coast and the Directory of Important Wetlands mapping). The WMC Project will build on and incorporate existing knowledge into a more consistent and comprehensive wetland mapping product.

Ideally, mapping and classification of wetlands would be based on data acquired on site and include geographic and hydrological survey, geomorphological characteristics, and an ecological inventory. Practically, this is very unlikely in all but a few instances. A technique that can be applied remotely, and modified as detailed information becomes available, is necessary to provide a baseline map of wetlands within the State.

2.1 Document Purpose

The purpose of this document is to:

- Present a wetland definition that can be applied for mapping and classification purposes and which can be interpreted at a practical level of detail;
- Provide details on a method for satellite image water body mapping, including limitations and accuracy assessment. These data will be used as a base layer for the overall wetland mapping; and
- Present a consistent mapping and classification framework that will be used to provide a baseline map of wetlands in Queensland, using information from multiple sources, at a scale which will be determined by the detail and accuracy of the base information.

The mapping and classification component of the NHT2 Wetlands Programme incorporates seven key modules and processes (Figure 1). This document (and attachments) presents the data requirements and methodological steps used to develop wetland classification and mapping products. The document does not provide the detail necessary to operationalise the method. This latter information and related specifications are retained in a Technical Specifications and Data Recording Standards document, by the Environmental Protection Agency for version control and intellectual property reasons. The information contained in the technical specification document includes the technical steps, computer programming tools, a data base, and internal reports.

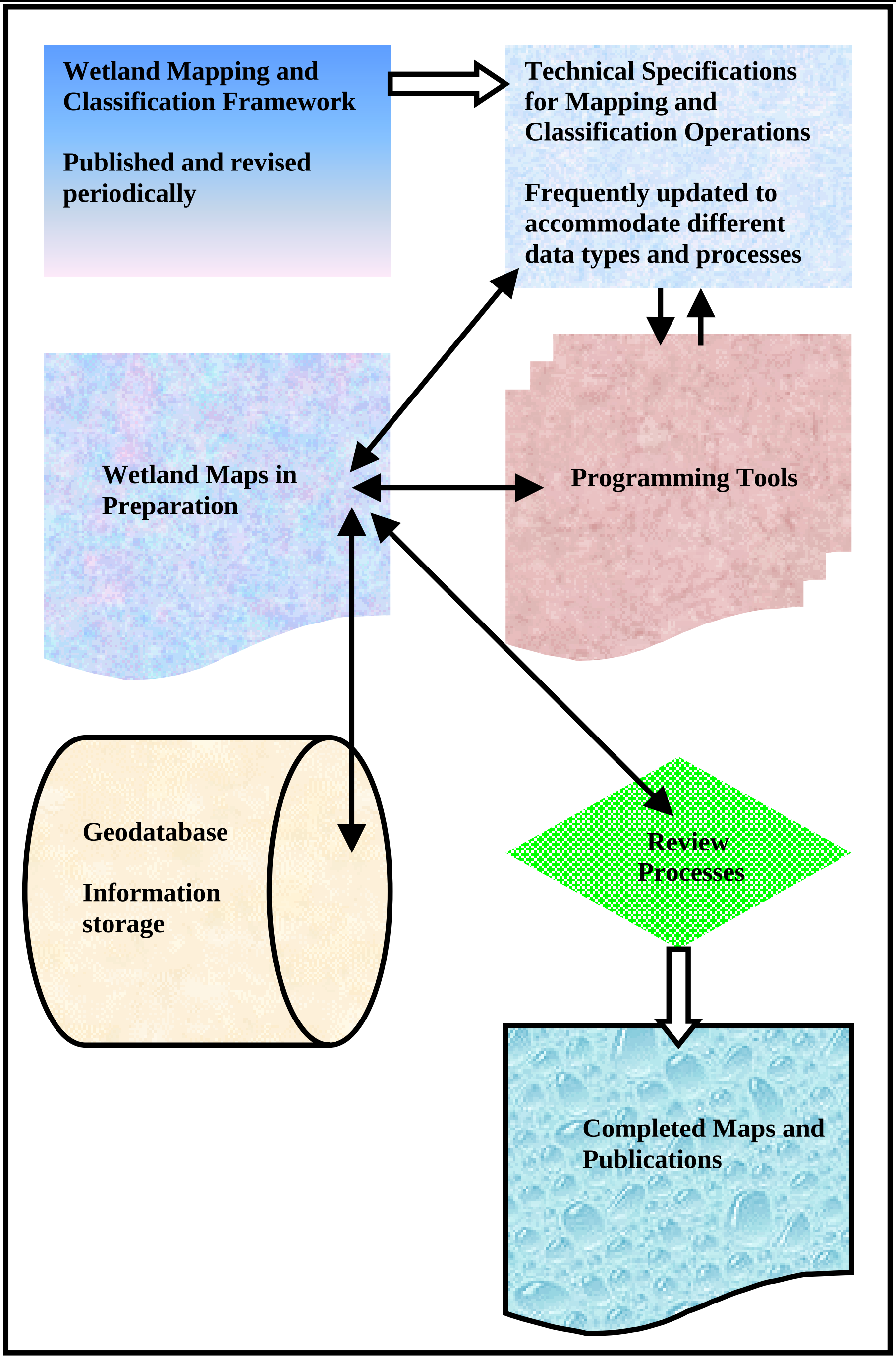

Figure 1. The modules and processes for wetland mapping and classification.

2.2 Mapping and Classification Outcomes

Accurate mapping, incorporating classified wetland features, supports the following outcomes:

- Acts as a primary tool to meet Government statutory and policy obligations;
- Increases the efficiency of existing mapping products;
- Enables protection of wetlands through the Regional Vegetation Management Planning process;
- Guides investment of natural resource management funding;
- Guides local government planning;

- Provides the basis for relevant planning triggers under the *Integrated Planning Act 1997*;
- Provides the basis for relevant property level management;
- Provides the basis for tenure dealing associated with leasehold land;
- Guides processes for the *Nature Conservation Act 1992*, including priority acquisitions and conservation agreements;
- Underpins many of the strategies in the Reef Water Quality Protection Plan;
- Provides a sound basis for coastal and near shore marine park planning; and
- Provides the basic mapping layer for environmental values and water quality objectives.

The significant advantages of the proposed WMC project approach as outlined in the method are that it:

- Builds on existing information and adds value to this information;
- Will result in a process that will be consistently used throughout the State and can be updated consistently as more information becomes available;
- Utilises the significant expertise which already exists within State and Australian Government agencies and other key stakeholders regarding wetland mapping;
- Will result in a wetland map for the State at a scale of 1:100,000, but finer detail in some parts of the State (mainly coastal) where appropriate mapping data exist;
- Will provide mapping information on wetlands which existed prior to recent alterations (modified wetlands);
- Will be consistent with the Water Quality Guidelines for main classes of wetland types such as freshwater, estuarine and marine; and
- Will be available as a base information layer for multiple stakeholders both within and outside Government (as outlined above).

3. What is a Wetland?

A "wetland" is defined, in the Wetland Strategy, as:

> "*Areas of permanent or periodic/intermittent inundation, whether natural or artificial, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 metres*."

The definition in the Wetland Strategy is based on the definition in the *Wetlands of International Importance* (Anon. 1971 (Ramsar, Iran)). Both definitions include elements such as shallow marine waters, estuaries, rivers, streams and creeks, lakes, pools, marshes, peatlands and springs.

The Ramsar definition for wetlands was amended in 2003 (Article 2.1) to include:

> "*may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands*."

If this definition were strictly applied it could be argued that many landscapes that shed water are wetlands, and it is clear that such an approach would not appropriately identify those wetland areas that have characteristics that require more significant management intervention.

3.1 Agreed Definition for the Purpose of Mapping and Classification

The following definition has been derived through a series of workshops and discussions involving State Government scientists and officers, based on internationally accepted definitions and Queensland conditions and information. The definition was finalised at the Wetland Mapping Workshop held 21 and 22 April 2004.

> *"Wetlands are:*
>
> *Areas of permanent or periodic/intermittent inundation, with water that is static or flowing fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6m. To be a wetland the area must have one or more of the following attributes:*
>
> *i. at least periodically the land supports plants or animals that are adapted to and dependent on living in wet conditions for at least part of their life cycle, or*
>
> *ii. the substratum is predominantly undrained soils that are saturated, flooded or ponded long enough to develop anaerobic conditions in the upper layers, or*
>
> *iii. the substratum is not soil and is saturated with water, or covered by water at some time."*

Examples under this definition include:

- Those areas shown as a river, stream, creek, swamp, lake, marsh, waterhole, wetland, billabong, pool or spring on the latest Sunmap1:25,000, 1:50,000, 1:100,000 or 1:250,000 topographic map[1];
- Areas defined as wetlands on local or regional maps prepared with the aim of mapping wetlands;
- Wetlands Regional Ecosystems (REs) (Attachment 1) as defined by the Queensland Herbarium (Environmental Protection Agency 2005a);
- Areas containing recognised Hydrophytes as provided by the Queensland Herbarium (Attachment 2);
- Saturated parts of the riparian zone;
- Artificial wetlands such as farm dams; and
- Water bodies not connected to rivers or flowing water such as billabongs and rock pools.

Examples under this definition exclude:

- Areas that may be covered by water but are not wetlands according to the definition;
- Floodplains that are intermittently covered by flowing water but do not meet the hydrophytes and soil criteria; and
- Riparian zone above the saturation level.

Note: If it is determined through the mapping process, as outlined in this framework, that a particular wetland identified in any of the above does not actually exist or that a new wetland has been formed, the wetland mapping process prevails; i.e. the wetland will be removed from or added to the final mapping product.

[1] Although the abovementioned Geodata feature codes are generally typical of wetland systems, they are by no means exclusively typical of such systems or an exhaustive list of topographic features which may be wetlands.

4. Framework to Identify, Map and Classify Wetlands

4.1 Principles

The following four principles form the basis for the wetland mapping and classification as outlined in this method. The method must:

- Satisfy a need for rapid wetland classification and mapping that uses aquatic ecosystem characteristics/features together with contemporary regional ecosystem (RE) protocols and other wetland information but is not reliant on detailed field assessment;
- Use existing and primarily remotely sensed data (i.e. no need for any new data in the first instance);
- Provide a process that is functional and consistent in application at catchment or basin scale; and
- Make use of existing, proven techniques for aquatic ecosystem classification and assessment.

4.2 Overview of Method

The wetland mapping method follows a number of logical steps, which are listed in Table 1. Each step is outlined in the body of this document. The Technical Specifications and Data Recording Standards document (Environmental Protection Agency 2005b) (see Decision Rule 11, Appendix 1) provides the technical detail necessary to apply the method.

Table 1. Overview of the wetland mapping and classification method.

Step 1	Gather and process data.
Step 2	Undertake water body map development and classification: a) Combine water body data (satellite imagery, Geodata and the remnant RE water features) and apply the water regime modifier and preliminary system level classification; and b) Allocate salinity and local hydrology/disturbance modifiers and manual edit/check of water bodies.
Step 3	Allocate REs to water bodies.
Step 4	Reconcile and update mapping products (RE pre-clearing, RE remnant and water body maps) and generate final remnant regional ecosystems wetland coverage.
Step 5	Generate final wetland map – combines i) drainage, ii) water bodies, iii) remnant wetland REs and iv) springs, data layers.
Step 6	Refine wetlands map through internal quality control and expert panel.

The method has been refined by trialling earlier drafts of the process in areas that included:

(a) Different geographical and geomorphological characteristics;
(b) Different types of wetlands including degrees of modifications; and
(c) Different climatic conditions.

4.2.1 Map scale and data currency

The scale of the final wetland mapping product is based on the regional ecosystem mapping scale as outlined in Neldner et al. (2004) (Attachment 3).

The initial wetland mapping product will be based on 2001 data and will not include any data developed after 2001. The wetland map will be updated in the future. To determine the current wetland mapping product date please refer to the associated metadata.

To ensure that no manually adjusted data are lost during the updating process, a method for updating the data is included in the Technical Specifications and Recording Standards document. The update process includes all manual edits required to amend data fields, including the provision of more accurate information during each phase of data assessment.

4.3 Decision Rules

Decision Rules are referred to throughout the Framework where specific directions are provided on particular steps, or on the use of specific information. These will provide consistency in the application of the method across different areas and operators. A list of the Decision Rules is provided in Appendix 1.

4.4 Method Framework – Detailed Steps

The goal of the framework is to provide the tools, linkages and the knowledge base required for mapping and classifying the wetlands of Queensland. To achieve this, the methods derive wetland units from various baseline data sources that include information on the wetland's location and ecological characteristics and processes (i.e. indicators for environmental status, including the initial hydrological classification (refer to the Definitions (Appendix 2) modified from Cowardin et al. 1979)). This information, when combined, defines wetland units, within wetland "complexes" which are unique combinations of water regime, system, modification, salinity and vegetation. These are the basic units of wetland classification derived from the mapping and classification project and will provide the basis for higher level analysis and labelling (e.g. aggregations/complexes and "typing") of wetland features in the future.

4.4.1 Step 1: Gather and process data

4.4.1.1 Data sources

A number of primary data layers are basic components of the wetland mapping process. The layers are stored separately but combined in a Geographic Information System (GIS) for use and analysis. Quality control checks are used to ensure the data are accurate and current. The data are sourced through the point of truth (data manager) with metadata (if a source of data does not have metadata it will not be used).

The current key data layers and sources to be used for mapping and classification are (Decision Rule 1):

- Water body mapping derived from Satellite Imagery (Environmental Protection Agency);
- Drainage mapping (Geoscience Australia, Department of Defence, Department of Natural Resources and Mines);
- Regional ecosystem mapping (Environmental Protection Agency);
- Queensland 3NM Limit (AMBIS) (Geoscience Australia 2001); and
- Springs database (Fensham and Fairfax 2002).

Other data sources and layers may be sourced and used as the information becomes available.

However, finer scale mapping data from other projects will not be included as base data layers in the Wetland Mapping Product as they should have been included in the RE layer (refer to Decision Rule 2).

The primary information to be used in the wetland mapping and classification must be accessed through the EPA Database Manager:

The Database Manager
Environmental Information Systems Unit
Environmental Sciences Division
Environmental Protection Agency
160 Ann Street, Brisbane, Queensland
PO Box 15155, Brisbane City East, QLD 4002

For any data developed or modified throughout this method, associated metadata must be developed and recorded in accordance with Australia and New Zealand Land Information Council (ANZLIC) guidelines (Decision Rule 3). Standards for the provision of this information may be found in the Technical Specifications and Recording Standards (Environmental Protection Agency 2005b).

4.4.1.2 Water body mapping using satellite image processing techniques

Two water body mapping techniques based on the processing of satellite imagery have been developed by the Environmental Protection Agency and are used in the method, one based on Density Slicing (DS) (Attachment 4) and the other technique based on the Normalised Difference Water Index (NDWI) (Attachment 5).

The DS and NDWI water body mapping techniques were applied to two data sets:

(i) Multi-temporal Landsat 5 and 7 Thematic Mapper (TM) imagery captured in 1991, 1995, 1997, 1999 and 2001. Additional images are available for 2000; however, these are only used if the 1999 or 2001 imagery is not available or of poorer quality due to cloud or other factors that adversely influence reflectance values. The imagery was spectrally and spatially corrected by the Department of Natural Resources and Mines (DNR&M) Statewide Landcover and Trees Study; and
(ii) A single Landsat 5 or 7 TM image selected to correspond with a maximum period of inundation (i.e. a "wet scene") in each area of Queensland. These scenes were selected on an ad hoc basis to ensure that favourable inundation conditions were captured (refer to Section 5 for further discussion of the limitations involved in the selection of wet scenes).

The rainfall and hydrological conditions that occurred at the time of satellite image capture are recorded and included in metadata where possible.

The accuracy of the outputs of the two water body mapping techniques were assessed for four trial areas located throughout Queensland. The methods and results of this assessment are presented in Attachment 6 – Accuracy Assessment Methodology and Results.

4.4.1.3 Update of regional ecosystem mapping

Updates to the regional ecosystem mapping are undertaken where necessary in accordance with the guidelines provided in Neldner et al. (2004). This includes the incorporation of information from other sources of wetland mapping data (e.g. specific wetland mapping by local governments, QDPI&F coastal wetland mapping) that are not considered primary data layers for the wetland mapping process. Where applicable, updates to the regional ecosystem mapping will include amendment of the coastline, delineation of river mouth cut-offs (Attachment 7e), bay cut-offs (Attachment 7c) and a surrogate for highest astronomical tide (HAT) (Attachment 7a).

4.4.1.4 Pre-processing of Geodata

Geodata (digital topographic data) water body polygon features (including double lined streams) and single line stream networks are extracted and stored in a GIS as separate layers. The single line stream network is buffered (Attachment 7g) for later use in the classification of water bodies.

4.4.2 Water body classification

4.4.2.1 Background

Any water body map (i.e. a map that principally depicts visible bodies of surface water) will have its own inherent diversity of aquatic ecosystems and hydrological processes. It is critical that this variability is objectively described to support wetland mapping and the subsequent wetland classification process. That is, water body data must be combined to enable the determination of water body types prior to further wetland mapping and classification process.

The hierarchical system, used for classification, is based on Cowardin et al. (1979) but has been modified to provide a rapid classification process. Although this is aimed at minimising the amount of detailed fieldwork required to validate the mapping and classification, it does not preclude the inclusion of such data to inform the process. An overview of the water body classification step is outlined in Figure 2.

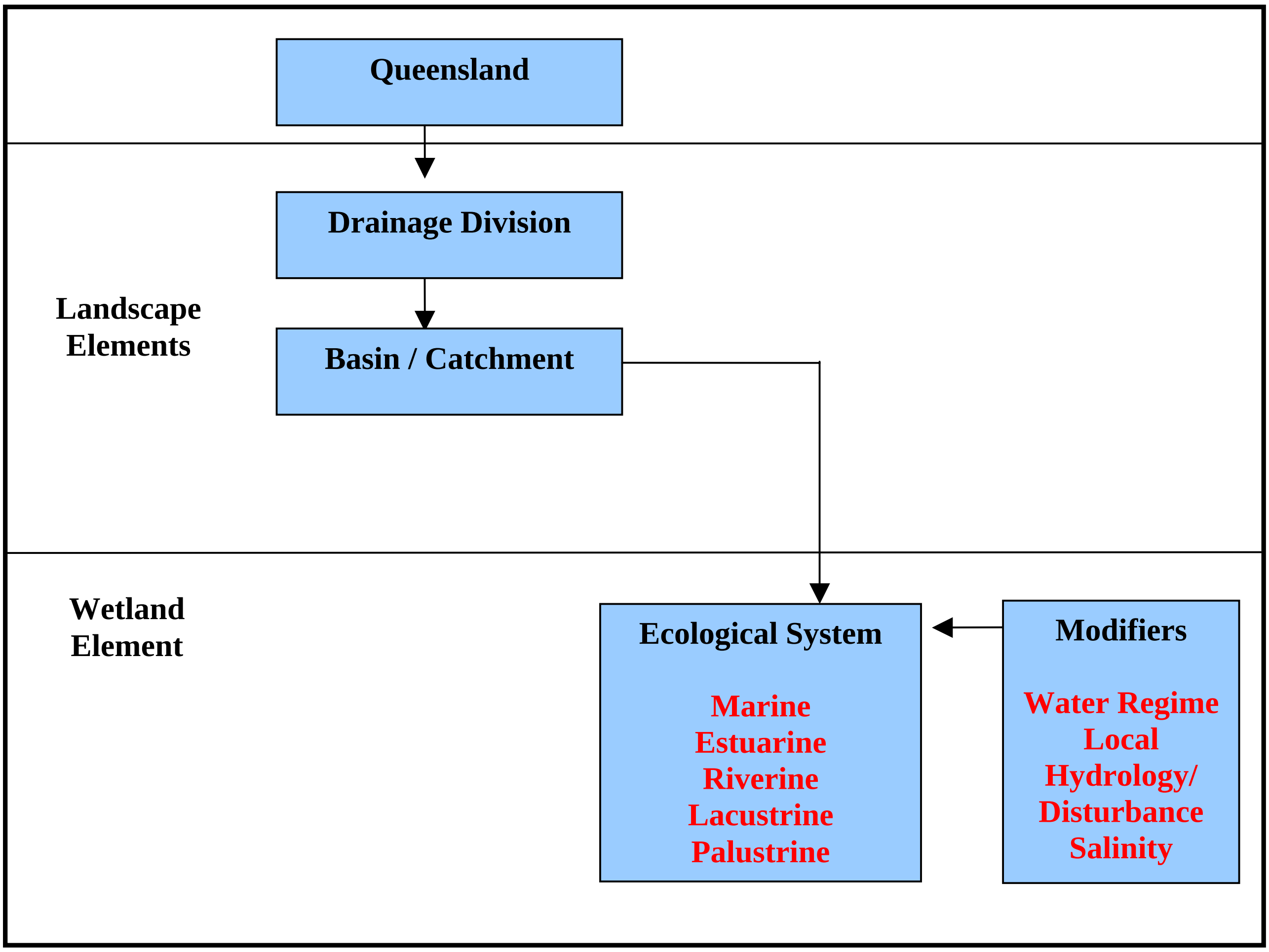

Figure 2. Overview of the water body classification framework.

Water bodies are initially placed in a drainage division and then a basin or catchment (Figure 3). They are then classified to an ecological system level, and water regime, salinity and local hydrology/disturbance modifiers are applied.

Five major "Ecological Systems" (systems) are recognised (after Cowardin et al. 1979 and Blackman et al. 1992).

- Marine (M) – Affected by tidal salinity
- Estuarine (E) – Affected by tidal salinity
- Riverine (R) – Not affected by tidal salinity
- Lacustrine (L) – Not affected by tidal salinity
- Palustrine (P) – Not affected by tidal salinity

The water body classification process involves a number of manual and automated steps and may produce some misclassifications; however, it is robust as a "first-pass" using desktop data. The combination of water body data with the regional ecosystem data completes the process, and changes to the water body classification may be required.

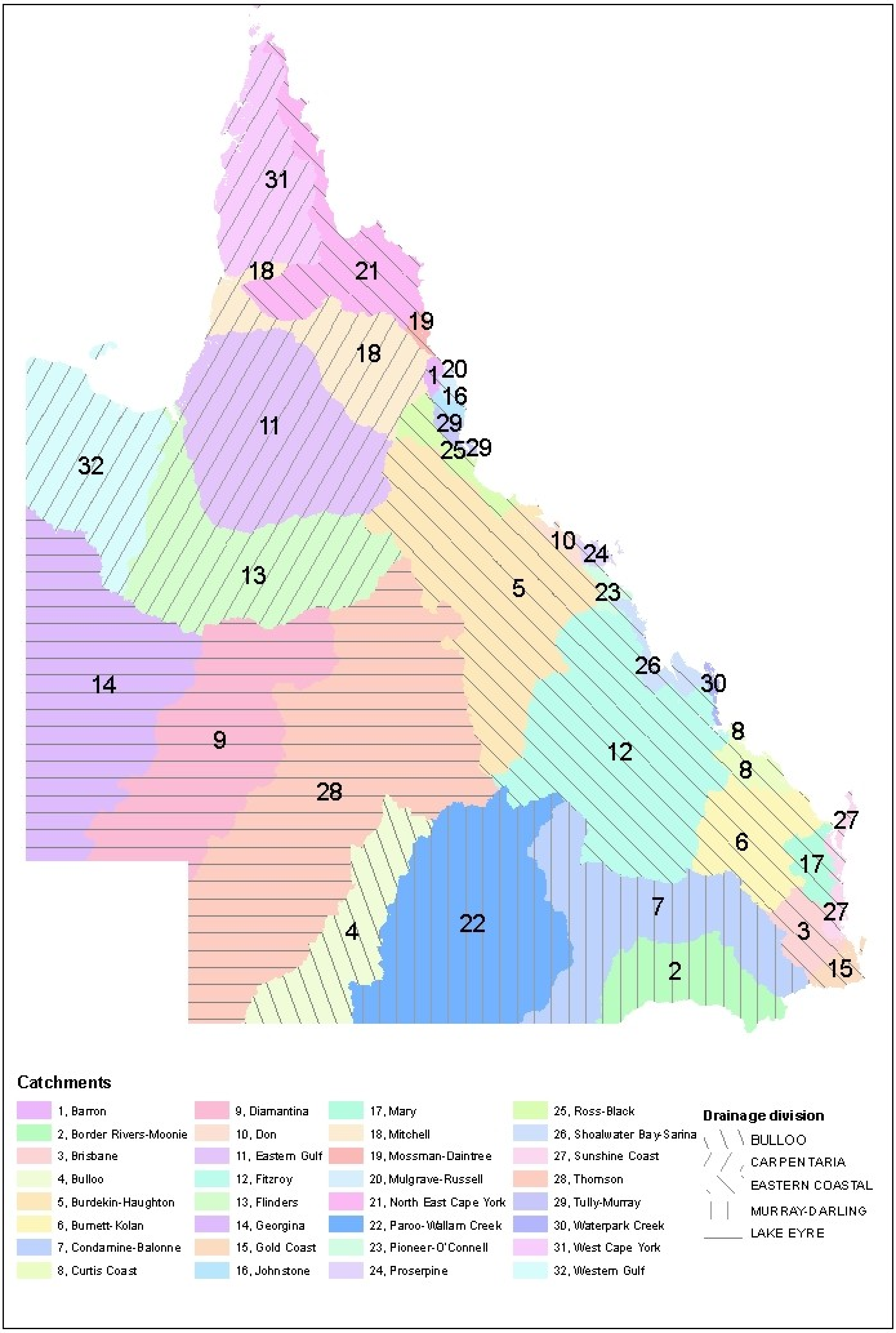

Figure 3. Queensland drainage divisions and basins.

4.4.2.2 Step 2a: Combine water body data (classified satellite imagery, Geodata and the remnant RE water features) and apply the water regime modifier and preliminary system level classification

To obtain a water body coverage, an automated process combines the classified satellite image multi-temporal data from the DS and NDWI water body mapping techniques with the extracted Geodata water body polygon features and remnant RE water body polygon feature. The maximum extent of water bodies in the water body coverage is determined by the outer boundary of the combined water body polygons.

Water regime modifiers (Table 2) that indicate the degree of water permanency in a water body polygon are then applied. This modifier is based on the analysis of inundation frequency in multi-temporal satellite image scenes (Decision Rule 4). For a water body polygon that has been created from more than one input feature, the water regime modifier is determined to be the value of the input feature that has the highest inundation frequency (Decision Rule 5). If a value cannot be obtained due to the water body polygon feature not coinciding with a feature derived from the classified imagery (i.e. from the Geodata or RE water features only), a value of WR0 is applied.

Table 2. Water Regime Modifiers.

Water Regime Modifier	Description	Inundation Frequency*
WR0	Uncertain	Not known
WR1	Rarely inundated	$\leq$ 20%
WR2	Intermediately inundated	20% $> x \leq$ 80%
WR3	Commonly inundated	> 80%

* Based on percentage of multi-temporal scenes on which water body was inundated

Finally, additional water body polygon features derived from the classified satellite image "wet scene" data from the DS and NDWI are combined and added to the water body coverage. These features may delineate additional areas that can be differentiated from the previously combined water bodies on the basis of their hydrological characteristics and frequency of inundation.

Note 1: Initial water regime modifiers are based on limited satellite data (five scenes) and care must be taken when using this modifier for decision-making purposes. As more satellite data are added to this process the precision of the modifier will improve.

Note 2: Water bodies polygons not evident from multi-temporal and "wet" scenes (i.e. not mapped with this method because no water could be detected through signature analysis), but mapped from topographic maps, probably (a) have not been detected due to certain limitations in the satellite imagery process (i.e. the capacity to penetrate vegetation); or (b) are very rarely flooded (primarily arid and semi-arid areas); or (c) are incorrectly mapped (temporal changes occur, e.g. some wetlands may have been filled).

A preliminary classification of the water bodies, based on the area of the maximum extent of the water body, is carried out through an automated process by following the dichotomous criteria provided in the key shown in Figure 4. This classification may lead to errors and will be assessed against the definitions for the five ecological systems (Appendix 2) and amended if necessary during later stages of the wetland map product development (Decision Rule 7).

1. Areas influenced by tidal salinity (Attachment 7a)……………………..………………..2
1. Areas not influenced by tidal salinity (Attachment 7a)……………………………..……...8

2. Area outside Queensland's 3NM limit (Attachment 7b)…………………..NOT INCLUDED
2. Area within Queensland's 3NM limit (Attachment 7b)……………..………………………3

3. If Embayment (Attachment 7c)……………………………………..………………………4
3. If no Embayment (Attachment 7c)………………………………….……..…………….5

4. If salinity is ≥ 34ppt (Attachment 7d)..……………………………………… MARINE (M)
4. If salinity is ≥ 0.5ppt and < 34ppt (Attachment 7d)………………………ESTUARINE (E)

5. If River Mouth (Attachment 7e)...…………………………...……….……………………6
5. If No River Mouth (Attachment 7e)……………...……………...……………...…………7

6. If salinity is ≥ 34ppt (Attachment 7e)..……………………………………. ……………7
6. If salinity is ≥ 0.5ppt and < 34ppt (Attachment 7e)………………………ESTUARINE (E)

7. Area is < 6m below LAT (Attachment 7f)………………………………… MARINE (M)
7. Area is > 6m below LAT (Attachment 7f)……………………………… NOT INCLUDED

8. Not situated in a channel (usually basin or depression) (Attachment 7g)….………..…….9
8. Situated in a channel (Attachment 7g)………………………………..………...……..10

9. Area < 8ha (20acres) (Attachment 7h)………………………………… PALUSTRINE (P)
9. Area ≥ 8ha (20acres) (Attachment 7h)……...……… LACUSTRINE / PALUSTRINE (LP)*

10. < 20% of the water body occurs in the buffered channel (Attachment 7i)…….………...11
10. ≥20% of the water body is within the buffered channel (Attachment 7i) RIVERINE (R)

11. Perimeter^2: area ratio < 65 (Attachment 7j)…………………………………..…12
11. Perimeter^2: area ratio ≥ 65 (Attachment 7j)……….…………….…...……RIVERINE (R)

12. Area < 8ha (20acres) (Attachment 7k)…………….……………..……PALUSTRINE (P)
12. Area ≥ 8ha (20acres) (Attachment 7k)……….….… LACUSTRINE / PALUSTRINE (LP)*

Figure 4. Key to system level of classification.

***** It is not possible to determine the palustrine from the lacustrine systems at this stage and this will be determined through the RE allocation stage (Step 4).

See Appendices 3 and 4 for a flow chart version of Figure 4.

4.4.2.3 Step 2b: Allocate salinity and local hydrology/disturbance modifiers and manual edit/check of water bodies

The water body layer is manually assessed for spatial consistency and accuracy, data currency, errors and exclusions and is edited where necessary. Salinity and local hydrology/disturbance modifiers are attributed to each water body polygon (larger than 1ha) via a manual process (Decision Rule 8). Polygons between 0.25ha and 1ha will be mapped but will not be attributed with local hydrology disturbance or salinity modifiers. A variety of data sources exist and are used to assist with the water body editing and interpretation of modifiers. These include hard copy and digital remotely sensed imagery (including aerial photography), regional ecosystem and other vegetation-based mapping, land survey data, topographic information, site-based information and local mapping sources.

Salinity modifier

Salinity modifiers (Table 3) are attributed to all lacustrine, palustrine and riverine water body polygons that are greater than or equal to 1ha in size. These cannot be assessed remotely but may be applied manually on the basis of published literature or information of a known credible source. If no information is available, a default value of S1 is applied.

Table 3. Salinity modifiers*.

Code	Description	Salinity (parts per thousand)
S1 #	Fresh	< 0.5
S2	Brackish	0.5 to 30 (some salinity)
S3	Salt	> 30 (true salt lakes etc.)

* Only applies to lacustrine, palustrine and riverine systems
# Default Value

Local hydrology/disturbance modifier

The local hydrology/disturbance modifiers are attributed based on the categories outlined in Table 4, using the data sources outlined in Decision Rule 6 as a backdrop. These are applied manually using expert interpretation. Further modifications to the local hydrology/disturbance modifiers may be applied during the later stages of the wetland map product development. Further details and explanation relating to the application and interpretation of local hydrology/disturbance modifiers are provided in the notes accompanying Table 4. Examples are provided in Attachment 8.

Table 4. Local Hydrology/Disturbance Modifiers.

Modifier		Sub-modifier			
Code	**Label**	**Code**	**Label**	**Explanation/examples**	**Criteria and Data Sources**
H1	No local hydrology/ disturbance modification.			A water body classified under this heading has not undergone gross local hydrological disturbance that may be distinguished from satellite imagery / aerial photography (e.g. geomorphology, crops, built structures) (Please see Local Hydrology and/or other Disturbance Examples (Attachment 8) for examples. Local Hydrology/ Disturbance does not refer to the degree to which the wetland may have been cleared, have exotic species present or otherwise be in poor condition.	No evidence that H2 or H3 modifier is applicable (default value). See Notes below, Decision Rule 6 and Local Hydrology and/or other Disturbance Examples (Attachment 8).
H2	Modified local hydrology/ disturbance modification.	M1	Riverine or ex-riverine (lacustrine) water bodies associated with dams and weirs located in a channel. All wetlands of this type and with these conditions will be defined as lacustrine (or occasionally palustrine) systems.	Many artificial water bodies formed by dams and weirs fall into this category and are readily identifiable. Some cases may require use of additional data sources to identify the location and extent of the hydrological modification.	1. Drainage line in Geo or NRM data and; 2. Indicated as a. Dam, reservoir on Geodata or b. Evidence of construction from appropriate imagery, or has been identified through expert knowledge, ground truthing or other available data source. See Notes below, Decision Rule 6 and

				Where a weir or dam wall exists, the water body above the barrier is attributed as H2M1 (modifier code H2 + sub-modifier code M1) and the water body below is generally attributed as H1.	Local Hydrology and/or other Disturbance Examples (Attachment 8).
		M2	Palustrine/lacustrine water bodies where size and/or hydrology has changed due to levee bank (uncontrolled wall).	Typically single levee bank that raises/stabilises the water but water body will still retain many natural features. For example, a ring tank may be placed inside a natural wetland depression. Attributed as H2M2 outside of the retained/walled area (e.g. in the semi-natural wetland) but as H2M6 inside the ring tank.	1. Indicated as freshwater body on pre-clear RE map or on old aerial photography. 2. Evidence of levee construction across 1 or 2 sides on imagery on Geo or NRM data. 3. Has been identified through expert knowledge and/or ground truthing. See Notes below, Decision Rule 6 and Local Hydrology and/or other Disturbance Examples (Attachment 8).
		M3	Palustrine/lacustrine water bodies where size and/or hydrology has changed the water body classification from estuarine or marine systems to a fresh water system classification.	Similar to M2 but occurs in coastal areas where levees or bunding of salt-flats and mangroves is constructed to stop/stabilise encroachment of salt water. Attributed as H2M3 above the barrier but generally H1 below.	1. Indicated as estuarine or abuts estuarine water body on pre-clear RE map or on old aerial photography. 2. Evidence of levee construction across 1 or 2 sides on imagery or Geo or NRM data. 3. Has been identified through expert knowledge and/or ground truthing. See Notes below, Decision Rule 6 and Local Hydrology and/or other Disturbance Examples (Attachment 8).

		M3p	Palustrine/lacustrine water bodies where size and/or hydrology has changed the water body classification from estuarine or marine system to a fresh water system classification.	Ponded pastures.	Is a confirmed ponded pasture. See Notes below, Decision Rule 6 and Local Hydrology and/or other Disturbance Examples (Attachment 8).
		M4	Modified springs.	Natural springs that have been degraded by excavation, stock damage, or ponded pasture proliferation.	Can only be derived from on site inspection. See Notes below, Decision Rule 6 and Local Hydrology and/or other Disturbance Examples (Attachment 8).
		M4a	Modified springs.	Dormant springs.	Can only be derived from on site inspection. See Notes below, Decision Rule 6 and Local Hydrology and/or other Disturbance Examples (Attachment 8).
		M5	Palustrine/lacustrine water bodies where ecological character has changed due to gross mechanical disturbance e.g. cropping.	Areas of former wetland that are cropped (e.g. many sugar cane paddocks) that may become flooded. Does not include irrigated paddocks.	1. Evident as wetlands on the pre-clear RE mapping, historical aerial photos or Geodata. However, no (minimal) remnant vegetation remains around/in the current water body. 2. Not evident on remnant RE coverage or more recent aerial photos. 3. Has been identified through expert knowledge and/or ground truthing. See Notes below, Decision Rule 6 and Local Hydrology and/or other Disturbance Examples (Attachment 8).
		M6	Palustrine/lacustrine	Different from M2 and M3 in that	1. Indicated as freshwater body on pre-

			water bodies that have been converted, completely or mostly, to a ring tank or other controlled storage.	structure has completely divorced hydrology from original water body/wetland. Includes structures with four sides as well as ex-riverine controlled storage systems.	clear RE map or on old aerial photography or Geodata, 2. Evidence of wall construction around four sides on imagery or Geo or NRM data, or 3. Has been identified through expert knowledge and/or ground truthing. See Notes below, Decision Rule 6 and Local Hydrology and/or other Disturbance Examples (Attachment 8).
		M7	Riverine water bodies that have been converted mostly to canals or irrigation channels.	The water body has been significantly altered to a constructed waterway and has had construction to the bed and banks; however, the hydrology is not divorced from original water body / wetland.	1. Indicated as water body on pre-clear RE map or on old aerial photography or Geodata; and 2. Evidence of canals (straight line) construction on imagery or Geodata, local government or NRM data, or 3. Has been identified through expert knowledge and/or ground truthing. See Notes below, Decision Rule 6 and Local Hydrology and/or other Disturbance Examples (Attachment 8).
H3	Artificial (not on or in a natural water body).	C1	Artificial stand-alone water storages not within a natural water body or channel.	Typically ring tanks (enclosed by walls) on areas on or adjacent to floodplain.	Visible on imagery especially 1:25,000 Geodata or the Cadastre or derived products. See Notes below, Decision Rule 6 and Local Hydrology and/or other Disturbance Examples (Attachment 8).
		C2	Artificial Channel drain/canal – bore		Linear feature usually clearly visible on Geodata, imagery or cadastre.

			drains, swales, bores and irrigation channel overflows/ponding.		See Notes below, Decision Rule 6 and Local Hydrology and/or other Disturbance Examples (Attachment 8).

Notes Related to Table 4

Note 1: If the local hydrology/disturbance modifier cannot be determined the default value is H1 (a water body that has not been observed to have gross local hydrological disturbance).

Note 2: H1 and H2 Water bodies must be identified as a wetland on pre-clear RE map or on old aerial photography or as a drainage line in the Geodata (Topographic data). Otherwise they will be H3.

Note 3: If the water body is not depicted as a wetland on the pre-clear RE map, then old aerial photos will need to be checked to verify that the wetland is artificial, i.e. this could be missing from pre-clear RE map due to scale.

Note 4: H3 Water bodies must be indicated as "not a water body" on pre-clear RE map or on old aerial photography and not connected to a drainage line on Geodata.

Note 5: While the local hydrology/disturbance modifiers for springs have been included in Table 4, the data to which the modifiers are attributed are not derived from the combined water body layer (Step 2a above). The Springs database (Fensham and Fairfax 2002) is a stand-alone database that comprehensively provides all the information required to classify spring wetland modifiers. The Technical Specifications and Data Recording Standards (Environmental Protection Agency 2005b) do not contribute additional system modifiers to springs.

Manual edit of water body during local hydrology/disturbance modifier attribution step

During the attribution of local hydrology/disturbance modifiers, the following tasks may also be undertaken:

1. Removal of water bodies that no longer exist;
2. Removal of polygons that are **not** water bodies, including those derived from the "wet" scene evaluation (e.g. non-wetland elements of floodplains);
3. The addition of new or missed water bodies that have not been picked up through the existing data layers (and is a confirmed water body based on expert interpretation); and
4. Modifications to current water bodies (i.e. separation of a canal from river, more accurate delineation of floodplains, etc.).

When attributing or editing the map, care must be taken to ensure that the final date for the wetland map is taken into consideration. For example, if the final wetland map date is 2001 then no data collected after this date should be included in the updating process.

During the manual edit stage and the RE reconciliation (Step 3) some ground truthing may be required to confirm the status of the wetlands on the map.

4.4.3 Step 3: Allocate regional ecosystems (REs) to water bodies

The purpose of this step is to combine the water body information from the water body classification (Step 2), above, with regional ecosystem (RE) data. This allows further assessment of the range of wetland systems present within a given study area through the adoption of a multiple attribute mapping methodology.

4.4.3.1 Intersecting REs with water bodies

RE types are defined and described in the Regional Ecosystem Description Database (REDD) (Environmental Protection Agency 2005a [http://www.epa.qld.gov.au/nature_conservation/biodiversity/regional_ecosystems]). The REDD system provides a wetland field that classifies each RE into wetland systems (refer to Figure 4) and ecosystems affiliated with wetland systems. Floodplains are an important wetland affiliated ecosystem that is included through the regional ecosystem mapping. Marine systems are not recognised by the regional ecosystems framework.

The water bodies are allocated with a regional ecosystem by using a GIS intersection. However, water bodies generally intersect with more than one regional ecosystem polygon. In addition any single polygon on an RE map may be attributed with from one to five REs due to the occurrence of more than one RE in one area (i.e. mosaic polygons) (see Neldner et al. (2004) for explanation).

Water bodies are allocated one or more regional ecosystems using a GIS program that picks the most appropriate intersecting RE(s) by matching the water body system with the wetland type from the Wetlands Regional Ecosystems (Attachment 1) look-up table. The REs are allocated to the water body in decreasing proportion of area (Decision Rule 9). For example, in Figure 5 below, if the water body is assumed to be lacustrine or palustrine, it would be allocated the RE of 3.3.41 or 3.3.64 and the associated percentage would be included. If, however, the water body were assumed to be a riverine wetland it would then be allocated 3.3.10.

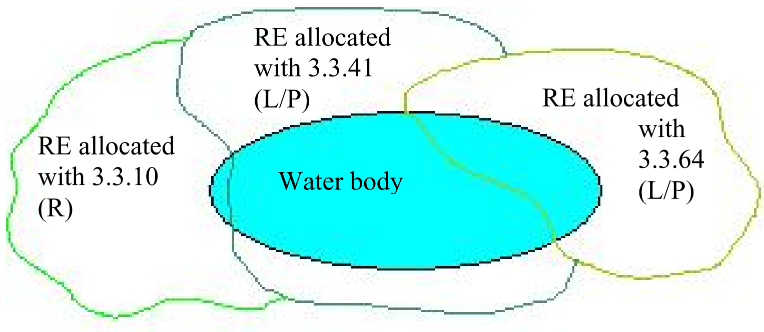

Figure 5. Example of RE allocation to water bodies.

4.4.3.2 Checking and reconciling of RE allocation

To aid in the reconciliation of water features and wetland regional ecosystems, an automated tool is run within the GIS to check the validity of the regional ecosystem codes and water body "types" (combinations of systems and local hydrology/disturbance modifiers). This process produces a series of mismatches between these two sets of data that must be accounted for before the production of a final wetland map. A manual check is carried out of mismatches between non-artificial water bodies and the regional ecosystems classification. This ensures that all currently or previously natural water bodies have wetland regional ecosystems allocated to them within the tolerances of the mapping scales being considered. For example non-artificial water bodies that do not match a wetland regional ecosystem or riverine water bodies that have been allocated a non-riverine regional ecosystem type would be manually checked on available imagery to determine if the RE or water body classification needs updating/changing.

After allocation of REs to water bodies and subsequent checking and reconciliation, a table of wetland regional ecosystems with water body types is produced for the area being mapped. Updates to REs determined through this process are made to the REDD master list of wetland REs (Attachment 1).

The water body map may undergo further updates through this process such as manual differentiation and attribution of lacustrine or palustrine systems and addition or removal of water bodies that had been missed during previous stages of the water body map development.

4.4.4 Step 4: Reconcile and update mapping products (RE pre-clearing, RE remnant and water body maps) and generate final remnant regional ecosystems wetland coverage

The remnant and pre-cleared RE mapping is updated by inspecting the imagery and adding the wetland to the RE coverage in accordance with the mapping principles outlined in Neldner et al. (2004) and as outlined below:

- If it is greater than 5 hectares in area or 75 metres wide (for linear features) for 1:100,000 scale or 1 hectare in area and 35 metres wide (for linear features) for 1:50,000 scale; or
- If the wetland size is less than these sizes but greater than 5 percent of the total area of the polygon then it is added as an RE subunit in a mosaic.

This step may be carried out concurrently with Step 3 or during the updating of RE maps on coastal areas.

A final remnant RE wetland layer is generated by utilising the wetland regional ecosystems table (Attachment 1) to extract all wetland REs from the remnant regional ecosystem map. The water body map is updated through this process by manually differentiating and attributing lacustrine or palustrine systems (Decision Rule 10), as well as providing a final edit for water bodies, including water body removal or addition.

4.4.5 Step 5: Generate final wetland map (combines drainage, water bodies, remnant REs and springs, data layers)

Wetland ecosystems are comprised of biotic and abiotic variables (water, vegetation, etc.). The mapping process outlined in this document involves the generation of a number of data layers, and combining the following layers produces the final wetland map:

- Final water bodies map from Step 4 above;
- RE wetland map from Step 4 above;
- Drainage lines from original Geodata drainage or single line stream network; and
- Springs point data.

4.4.6 Step 6: Refine wetlands map through internal quality control and expert panel

The draft wetland map will be checked by conducting some ground truthing, and after final manipulation the map will be examined by a panel of professionals with expertise in various wetlands related fields. The panel will review the draft wetlands map for accuracy and the final map will be reviewed based on their critique and feedback.

4.4.6.1 Index of reliability

An Index of Reliability related to scale and manual edits will be included in the metadata of the final map. This index will be developed through the Quality Control and Expert Panel (Step 6). For further information please refer to the Technical Specifications and Recording Standards document (see Decision Rule 11).

5. Limitations To Wetland Mapping and Classification

While the process outlined in this document results in a comprehensive baseline wetland map product with wetlands classified to a significant degree, as a natural consequence of the use of remotely sensed data and the limited use of field truthing, the method has accuracy limitations. As further information becomes available (e.g. through field truthing/assessment), or as remote assessment technologies improve, individual water body polygon attributes can be adjusted.

The following points outline the major limitations for each step of the method and these must be taken into consideration when the mapping and classification product is used for specific purposes.

Step 1 Gather and process data

Water body mapping derived from satellite imagery

Multi-temporal data used to generate this product are based on five scenes collected between 1991 and 2001, and the data collected to map vegetation were collected during dry seasonal conditions. The 1991–2001 period used to identify water bodies is considered a drought period and this will cause an underestimation of the number and extent of water bodies in the landscape.

The use of a coarse-scale Digital Elevation Model (DEM) (Attachment 4 and Attachment 5) to reduce topographic shadow and effects on water body identification causes a reduction in water body numbers and water body sizes in areas of greater relief.

Water bodies (particularly riverine) that have overhanging vegetation or are mainly vegetated by perennial vegetation may be poorly identified by remote sensing techniques.

Wet scenes were acquired from the Australian Centre for Remote Sensing and pre-processed by the DNR&M State Land and Tree Survey group to achieve consistent and highly corrected satellite data. Wet scenes were selected using rainfall data and image "quick-looks" to select scenes showing a comprehensive coverage of standing water bodies while minimising overbank flows. However, Landsat satellite scenes span approximately 180km swathes of land, with adjacent paths imaged at 16 day intervals. These spatial and temporal effects cause a substantial variation in the distribution and concentration of flows through time, causing discontinuities between adjacent imaged paths.

In many western areas, upland landforms are well drained and do not detain water, with water shedding into channels with potentially near-random flood patterns. Some western areas do not show a substantial number of water features due to the restricted distribution of rainfall and due to regional characteristics that determine run-off. Coastal wet scenes often contribute less to the water maps because of the obscuring effects of riparian and swamp-land vegetation. Conversely, western areas are more likely to show water over entire floodplains rather than just the wetlands within the floodplains.

Drainage mapping (Geoscience Australia)

Drainage and water body feature (topographic) information is highly variable throughout the State. Scales vary, as does the degree of development of the product (some areas have feature codes associated with water bodies and other areas only have basic drainage lines).

The data used to generate the drainage mapping information have been progressively developed over time, and some areas have not been updated for several decades and many of the features have been altered since the original map was produced.

Regional Ecosystem mapping (Queensland Herbarium)

This mapping is presently being updated and consequently the degree of rigor and comprehensiveness of the product varies between different regions and mapping areas at a given time and scale. This may result in misclassification of wetland REs.

Step 2 Undertake water body classification

Step 2a) Combine water body data (satellite imagery, Geodata and the remnant RE water features) and apply the water regime modifier and preliminary system level classification.

Drainage mapping (Geoscience Australia)

Combining the satellite imagery water body map with the drainage map may result in mismatches and these differences need to be accommodated in the procedure, which may result in errors.

Step 2b) Allocate salinity and local hydrology/disturbance modifiers and manual edit/check of water bodies.

Local hydrology/disturbance modifiers are mainly applied manually and therefore errors may occur through operator variability. These errors are reduced by the incorporation of detailed technical training for all staff working on the project, and through access to visual aids. Steps have been taken to incorporate automated error checking procedures into the analysis of key data layers to ensure error minimisation.

Classify water bodies to system level

The boundary between fresh, estuarine and marine systems remains difficult to determine. A number of techniques are promoted locally and nationally for remotely defining this boundary and to determine habitat inclusions and exclusions for each category. The decision matrix provided in the key to system level of classification (Figure 4) and the associated mapping surrogates have resulted from extensive consultation and technical input. However, improvements are expected with experience in application of this method and with refinements to remote sensing technology and improvements in available mapping information.

Lacustrine water bodies may occur that are smaller than 8ha (e.g. crater lakes). The water body classification key currently classifies these features as palustrine because, without depth information or *in situ* detail about substratum and shoreline, the distinction cannot be made in an automated fashion. Information about water body depth is not currently available remotely and therefore corrections in these instances rely on field truthing, expert knowledge and interpretation of the definitions (Cowardin et al. 1979) with reference to appropriately scaled remotely sensed data.

In arid landscapes many small, low order channels evident on stream network coverage may not actually exist or are very infrequently flooded. This may result in an underestimation of the extent of riverine systems and their frequency of inundation.

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Appendix 1. Decision Rules

DECISION RULE 1

The key data layers and sources to be used for mapping and classification are:

- ***Water body mapping derived from satellite imagery (Environmental Protection Agency);***
- ***Drainage mapping (Geoscience Australia, Department of Defence, Department of Natural Resources and Mines);***
- ***Regional ecosystem mapping (Environmental Protection Agency);***
- ***Queensland 3NM Limit (AMBIS) (Geoscience Australia 2001);***
- ***Springs database (Fensham and Fairfax 2002); and***
- ***Other – to be added to as more wetland mapping and classification become available.***

This information must be accessed through:

The Database Manager
Environmental Information Systems Unit
Environmental Sciences Division
Environmental Protection Agency
160 Ann Street, Brisbane, Queensland
PO Box 15155, Brisbane City East, QLD 4002

DECISION RULE 2

In order to deliver the final wetland mapping product to the appropriate scale, some areas of the RE mapping will have to be updated (pre-processing). This pre-processing involves the incorporation of available finer scale wetland mapping data (such as specific wetland mapping by local governments, QDPI&F coastal wetland mapping and research bodies, etc.) in accordance with Neldner et al. (2004). Consequently, finer scale mapping data from other projects will not be included as base data layers in the Wetland Mapping Product development as it should have already been included in the RE layer.

DECISION RULE 3

For any data developed or modified throughout this method, associated metadata must be developed and recorded in accordance with ANZLIC guidelines (Decision Rule 3). Standards for the provision of this information may be found in the Technical Specifications and Recording Standards (Environmental Protection Agency 2005b).

DECISION RULE 4

Degrees of water permanency are determined through multi-temporal scene analysis using the appropriate percent of scenes with water as follows:

- ***≤20% – rarely inundated (i.e. the number of scenes a water body has water divided by the number of scenes);***
- ***>20% to ≤80% – intermediately inundated; and***
- ***≥80% – commonly inundated.***

Note that these percentages only refer to the multi-temporal scenes and are applied to the total extent of the combined multi-temporal, Geodata and RE water derived water body.

DECISION RULE 5

Water bodies may be represented by one or more water permanency polygons (i.e. degrees of flooding) within a single, larger outline/boundary polygon (i.e. the largest known extent from analysed scenes, including "wet" scenes). Applying the precautionary principle, the water regime category to describe the combined multi-temporal, Geodata and RE water bodies is determined firstly by the wettest internal polygon based on the multi-temporal satellite imagery. Then if still not allocated a regime it will be given a water regime of "unknown" (WR0) based on the topographic/Geodata or "wet" scene analysis. This hierarchical process is both an automated and manual process that is described in more detail in the Technical Specifications and Recording Standards (Environmental Protection Agency 2005b).

DECISION RULE 6

The local hydrology/disturbance modifiers (Table 4) are attributed to water bodies by using several of the following data sources as backdrops. The same data sources are used to update the water body map through a manual editing process where water bodies are removed, added or edited for the date specified for the map release (refer to Technical Specifications and Data Recording Standards (Environmental Protection Agency 2005b):

Data Source	*Usage*
Imagery • Multi-temporal satellite imagery • "Wet" scene satellite imagery • Aerial photography • Other where available (e.g. SPOT, IKONOS)	➢ Technical limitations of the LANDSAT data (e.g. 25m pixel size). ➢ Extent alterations based on operator interpretation. ➢ Essential tool in the attribution of local hydrology/disturbance and salinity modifiers.
Regional Ecosystem Data • Remnant pre-clearing	➢ Reference should be made to both pre-clearing and remnant RE data. Assist in ascertaining modifier attributes (e.g. "changing" vegetation).
Land Survey Data • Land systems data • Valuer General's records • Land survey records • Water plans	➢ Numerous sources. Both spatial products (e.g. maps) and/or reports. Historical records may be especially useful.
Topographic Information • Mr SIDS • Drainage network • "Fine scale" data	➢ N.B. Feature codes from topographical maps relate directly to local hydrology/disturbance modifier, although generally must be manually interpreted in combination with drainage coverage to assign modifier. For example, if the feature code is a dam or reservoir, the water body is artificial (H3); if no drainage line exists or the drainline is modified the code for a lacustrine or palustrine system is N2M1. ➢ Often has information on ring tanks etc. ➢ Providing key information pertinent to the attribution of modifiers. ➢ Assisting in the checking of data quality.
Site Information and Local Knowledge • CORVEG and Q-sites • Soil survey sites • Water quality monitoring • Local mapping (e.g. Murray-Darling Basin)	➢ Information on the floristics, local hydrology/disturbance and water chemistry. Variable availability and quality. Will require significant operator input. For example, notes on the vegetation within non-remnant areas may give indications as to the way modifiers should be applied.
Queensland Land Use Mapping Programme	➢ Information on land use. Variable in usefulness (scale); however, is useful in some areas to determine land uses such as cropping.
UBD™ street directories	➢ Useful for more urban areas such as Gold Coast but quality may be patchy depending on area.

DECISION RULE 7

The application of the desktop classification key (Figure 4) is designed to be an automated process using a GIS tool. Consequently, the values assigned are default values. This classification may lead to errors and will be assessed against the definitions for the five ecological systems (Appendix 2) and amended if necessary during later stages of the wetland map product development.

DECISION RULE 8

Maximum surface water body area is used to identify the ecological system for the classification key in Figure 4, and for the local hydrology/disturbance modifiers in Table 4.

DECISION RULE 9

Where a water body intersects with more than one wetland RE, the REs are allocated to the water body in decreasing proportion of area.

DECISION RULE 10

All combined Lacustrine/Palustrine water bodies should be designated as either Lacustrine or Palustrine through the RE allocation process.

DECISION RULE 11

Due to the size and technical nature of the Technical Specifications and Data Recording Standards (Environmental Protection Agency 2005b), the document is not directly linked to this method but may be obtained from the Database Manager as outlined below. Please note that as improved processes are developed, the Technical Specifications and Data Recording Standards will be updated to reflect the changes.

This information must be accessed through the Database Manager:

The Database Manager
Environmental Information Systems Unit
Environmental Sciences Division
Environmental Protection Agency
160 Ann Street, Brisbane, Queensland
PO Box 15155, Brisbane City East, QLD 4002

Appendix 2. Definitions and Abbreviations

ANZLIC

Australia and New Zealand Land Information Council (http://www.anzlic.org.au/policies.html).

Bay

An area of water bordering land on three sides. A bay has "a clear concavity of which the penetration is proportional in such a way with the width of its mouth that it contains closed waters, which is more than just a coastal curve, but a concavity, not constituting a gulf/bay, except if the extent thereof is as wide as or is more extensive than the extent of a half-circle, of which the diameter is drawn, crossing the relative concavity mouth" (UN, Division for Ocean Affairs).

For the purposes of this document, a bay is a well-marked indentation whose penetration is in such proportion to the width of its mouth as to contain land locked waters and constitute more than a mere curvature of the coast. An indentation shall not, however, be regarded as a bay unless the area is as large as or larger than that of a semi-circle whose diameter is a line drawn across the mouth of that indentation.

Channel

A natural stream that conveys water; a ditch or channel excavated for the flow of water (US Environmental Protection Agency).

DNR&M

Department of Natural Resources and Mines.

DPI

Department of Primary Industries.

DPI&F

Department of Primary Industries and Fisheries.

Embayment

A notch in the shoreline, not restricted to any single form. It may be a lobe of water extending inland as deeply as a firth or fiord, or it may be as shallow as a quarter moon shape. For the purposes of this study this includes a cove, bay, gulf, passage or strait (UN, Division for Ocean Affairs).

EPA

Environmental Protection Agency.

Estuarine System

Includes wetlands with oceanic water that is at least occasionally diluted with freshwater run-off from the land.

There are two scenarios where the cut-off between estuarine system and freshwater wetlands need to be determined. The two scenarios are:

(1) where the cut-off is across a channel (Longitudinal cut-off); and
(2) where the cut-off is outside a channel (Latitudinal cut-off).

For those within a channel and which consequently often contain water (longitudinal cut-off), the Queensland Water Quality Guideline (2005) definition for estuaries has been adopted with some minor modifications. An estuary is:

(a) the mouth of a river where the tidal effects are evident and where freshwater and seawater mix; and/or
(b) the part of a tidal river that widens out as it approaches the coastline; and/or

(c) a body of water semi-enclosed by land with sporadic access to water from the open ocean, and where the ocean water is at least occasionally diluted by freshwater run-off from the land; and/or
(d) a body of water where salinity is periodically increased by evaporation to a level above that of the open ocean (such a water body is termed a reverse estuary).

This definition is open to some degree of interpretation and therefore some more precise delineation of the upper and lower boundaries are provided below.

As tidal salinity gradually decreases upstream, a decision must be made on where the salt concentration is deemed to be low enough for the water to be considered fresh. For the longitudinal boundary this line has been determined to be MHWS. This means that an area of tidal influence (the freshwater area that is moved back and forward by the tide but not saline) is included in the freshwater or "riverine" part of the system.

Upstream boundary of estuarine system within a channel (longitudinal cut-off): For the purposes of this document, the upstream boundary is taken as the upstream limit of tidal influence at mean high water springs (MHWS). This is the primary definition. The MHWS is the theoretical upstream limit for the mixing of salt water (see (a) above). However, in some large estuaries, slow rates of mixing and the constant inflow of freshwater means there is a permanent body of freshwater in the upper tidal reaches. This creates an anomaly if estuaries are taken to be where salt and freshwater mix. However, for water quality purposes, the tidal upper reaches are much more akin to an estuarine environment than a riverine environment.

If the MHWS mark is not defined for an estuary, the following surrogates can be used:

- The declared downstream limit (DDL) or Coastal Management District (CMD) lines (if based on officially determined estuary/freshwater cut-offs);
- A barrier or barrage that prevents the movement of any saline waters upstream;
- The upstream extent of the saline vegetation distribution along a stream;
- The limit of saltwater influence as determined by water quality (salinity or conductivity) measurements; and
- Local hydrological studies to estimate the MHWS mark.

Upper boundary of estuarine system outside a channel (latitudinal cut-off): The upper limit of an estuarine system that is outside a channel (i.e. within an embayment, at a river mouth) is defined as the landward limit of tidal inundation or highest astronomical tide (HAT).

Downstream boundary of estuarine system: The lower limit of the estuary is its boundary with fully saline marine waters at the coast. The boundary divides estuarine systems at or out from the mouth of an estuarine channel (where there is typically some residual mixing between fresh and marine waters) from marine systems where there is typically no residual freshwater influence except under extreme conditions such as major flood events.

For estuaries that flow directly into open oceanic waters or for passages, the lower limit is defined as the mouth of the estuary or passage, enclosed by adapting the semicircle rule (Beazley 1978).

Generally, the entrance is defined by the downstream limits of the drainage catchment of the passage or estuary (the heads). Where the heads are undefined, the catchment limits will need to be estimated using other landscape elements.

Geodata

Also known as geographic or topographic data, are the locations and descriptions of geographic features. The data set is a composite of spatial data and descriptive data. For the purposes of this method, this includes all topographic data and all themes (i.e. drainage relief etc.) from the 1:25,000, 1:50,000, 1:100,000 and 1:250,000 scales (ESRI Glossary Internet 2004).

HAT and LAT

Highest Astronomical Tide and Lowest Astronomical Tide. These are the highest and lowest levels that can be predicted to occur under average meteorological conditions and any combination of astronomical conditions. These levels will not be reached every year. HAT and LAT are not the extreme levels that can be reached, as storm surges may cause considerably higher and lower levels to occur (Department of Transport, 2005).

Headland

An area of land adjacent to water on three sides. A bay is the reverse, i.e. an area of water bordering land on three sides. Headlands and bays are usually, but not always, found together on the same stretch of coastline. Headlands and bays form on concordant coastlines, where bands of rock of alternating resistance run perpendicular to the coast. Bays form where weak (less resistant) rocks (such as sands and clays are eroded, leaving bands of stronger (more resistant) rocks (such as chalk, limestone, granite) forming a headland or peninsula (UN, Division for Ocean Affairs).

Particularly large headlands may also be called *peninsulas*. A peninsula can also be a cape, promontory or spit. Where they dramatically affect the ocean currents, they are called capes.

A *cape* is a coastal landform extending beyond the adjacent coast into the sea or a lake. A cape is usually more than just a headland and peninsula, having considerable effects on the directions of ocean currents around them (Division for Ocean Affairs (UN)).

Inlet

A narrow body of water that usually drains from a larger body of water, such as from an ocean (UN, Division for Ocean Affairs).

Lacustrine System

From Cowardin et al. 1979.

“The Lacustrine System (Figure A1) includes wetlands and deepwater habitats with all of the following characteristics: (1) situated in a topographic depression or a dammed river channel; (2) lacking trees, shrubs, persistent emergents, emergent mosses or lichens with greater than 30 percent areal coverage; and (3) total area exceeds 8ha (20 acres). Similar wetland and deepwater habitats totalling less than 8ha are also included in the Lacustrine System if an active wave-formed or bedrock shoreline feature makes up all or part of the boundary, or if the water depth in the deepest part of the basin exceeds 2m (6.6 feet) at low water.”

For the WMC project, lacustrine water may be tidal or non-tidal but ocean derived salinity is always less than 0.5ppt (Cowardin et al. 1979).

“**Limits**. The Lacustrine System is bounded by upland or by wetland dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens. Lacustrine Systems formed by damming a river channel are bounded by a contour approximating the normal spillway elevation or normal pool elevation, except where Palustrine wetlands extend lakeward of that boundary. Where a river enters a lake, the extension of the Lacustrine shoreline forms the Riverine-Lacustrine boundary.

Description. The Lacustrine System includes permanently flooded lakes and reservoirs (e.g., Lake Superior), intermittent lakes (e.g., playa lakes), and tidal lakes with ocean-derived salinities below 0.5 percent (e.g., Grand Lake, Louisiana). Typically, there are extensive areas of deep water and there is considerable wave action. Islands of Palustrine wetland may lie within the boundaries of the Lacustrine System.”

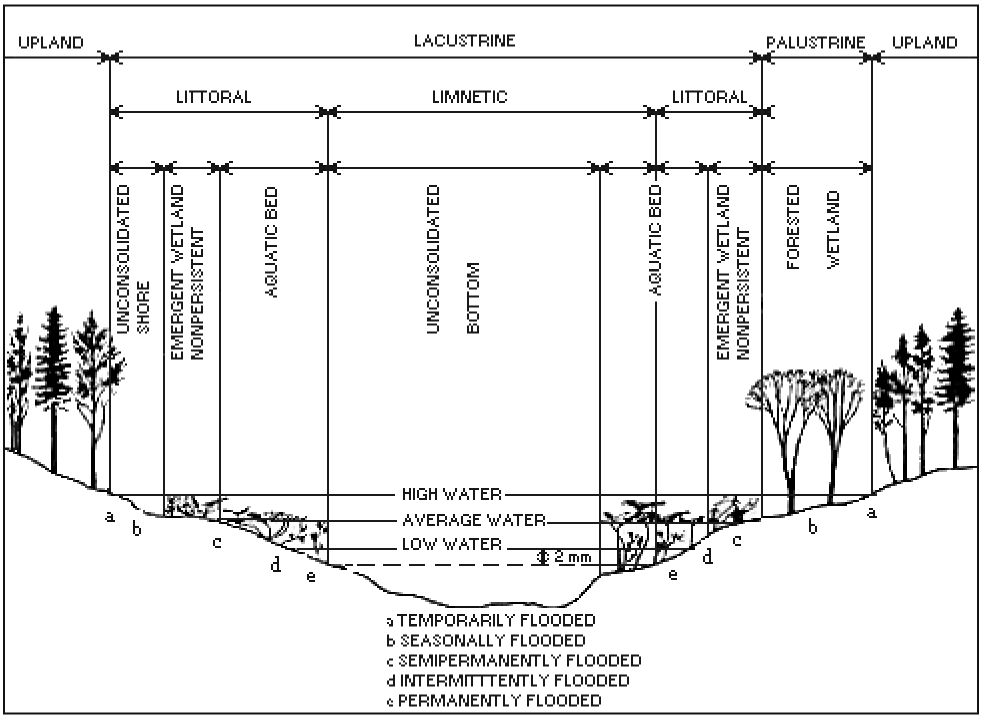


Figure A1. Distinguishing features and examples of habitats in the lacustrine system (from Cowardin et al. 1979).

Marine System

The following is taken from Cowardin et al. (1979) and Blackman et al. (1992) with slight modifications.

The marine system consists of open ocean overlying the continental shelf and its associated high energy coastline down to a depth of 6m below lowest astronomical tide (LAT). Shallow coastal indentations or bays (or parts thereof) without appreciable freshwater inflows, and coasts with exposed rocky islands that provide the mainland with little or no shelter from wind or waves, are also considered part of the marine system.

Marine habitats are exposed to the waves and currents of the open ocean, and the water regimes are determined primarily by the ebb and flow of oceanic tides. Salinities exceed 33ppt with little or no dilution outside the mouths of estuaries.

Boundaries of marine system:

- The landward boundary of the marine system is the landward limit of tidal inundation or highest astronomical tide (HAT);
- The boundary with the estuarine system; and
- The seaward limit to 6m below lowest astronomical tide (LAT).

MHWS (mean high water springs)

Long term average of the heights of two successive high waters during those periods of 24 hours (approximately once a fortnight) when the range of tide is greatest, at full and new moon (Department of Transport, 2005).

mS/cm

Millisiemens per centimetre. A measure of dissolved salts (conductivity) in water.

Palustrine System

The following is taken from Cowardin et al. (1979) and Blackman et al. (1992) and slightly modified to fit the Australian environment.

The palustrine system includes all non-tidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 percent. It also includes wetlands lacking such vegetation which have the following three characteristics: (a) where active waves are formed or bedrock features are lacking; (b) where the water depth in the deepest part of basin less than 2m at low water; and (c) the salinity due to ocean-derived salts is still less than 0.5 percent.

Boundaries. The palustrine system is bounded by upland or by any of the other four systems.

Description. The palustrine system was developed to group the vegetated wetlands traditionally called by such names as marsh, swamp, bog, fen, and prairie, which are found throughout the world. It also includes the small, shallow, permanent or intermittent water bodies often called ponds. Palustrine wetlands may be situated shoreward of lakes, river channels, or estuaries; on river floodplains; in isolated catchments; or on slopes. They may also occur as islands in lakes or rivers. The erosive forces of wind and water are of minor importance except during severe floods.

The emergent vegetation adjacent to rivers and lakes is often referred to as "the shore zone" or the "zone of emergent vegetation" (Reid and Wood 1976), and is generally considered separately from the river or lake. As an example, Hynes (1970:85) wrote in reference to riverine habitats: "We will not here consider the long list of emergent plants which may occur along the banks out of the current, as they do not belong, strictly speaking, to the running water habitat". There are often great similarities between wetlands lying adjacent to lakes or rivers and isolated wetlands of the same class in basins without open water.

PPT

Parts per thousand. A measure of the concentration of dissolved salts and solids in a solution.

Riparian

"Of or relating to or located on the banks of a river or stream; 'riparian land'" (Princeton University, 2003).

River

A large natural stream of water (larger than a creek).

Riverine System

From Cowardin et al. 1979.

"The Riverine System (Figure A2) includes all wetlands and deepwater habitats contained within a channel, with two exceptions: (1) wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and (2) habitats with water containing ocean-derived salts in excess of 0.5 percent. A channel is 'an open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of standing water' (Langbein and Iseri 1960:5).

Limits. The Riverine System is bounded on the landward side by upland, by the channel bank (including natural and man-made levees), or by wetland dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens. In braided streams, the system is bounded by the banks forming the outer limits of the depression within which the braiding occurs.

The Riverine System terminates at the downstream end where the concentration of ocean-derived salts in the water exceeds 0.5 percent during the period of annual average low flow, or where the channel enters a lake. It terminates at the upstream end where tributary streams originate, or where the channel leaves a lake. Springs discharging into a channel are considered part of the Riverine System.

Description. Water is usually, but not always, flowing in the Riverine System. Upland islands or palustrine wetlands may occur in the channel, but they are not included in the Riverine System. Palustrine Moss-Lichen Wetlands, Emergent Wetlands, Scrub-Shrub Wetlands, and Forested Wetlands may occur adjacent to the Riverine System, often on a floodplain. Many biologists have suggested that all the wetlands occurring on the river floodplain should be a part of the Riverine System because they consider their presence to be the result of river flooding. However, we concur with Reid and Wood (1976:72,84) who stated, 'The floodplain is a flat expanse of land bordering an old river . . . Often the floodplain may take the form of a very level plain occupied by the present stream channel, and it may never, or only occasionally, be flooded . . . It is this subsurface water [the ground water] that controls to a great extent the level of lake surfaces, the flow of streams, and the extent of swamps and marshes.'

Subsystems. The Riverine System is divided into four Subsystems: the Tidal, the Lower Perennial, the Upper Perennial, and the Intermittent. Each is defined in terms of water permanence, gradient, water velocity, substrate, and the extent of floodplain development. The Subsystems have characteristic flora and fauna (see Illies and Botosaneau 1963; Hynes 1970; Reid and Wood 1976). All four Subsystems are not necessarily present in all rivers, and the order of occurrence may be other than that given below.

Tidal. The gradient is low and water velocity fluctuates under tidal influence. The streambed is mainly mud with occasional patches of sand. Oxygen deficits may sometimes occur and the fauna is similar to that in the Lower Perennial Subsystem. The floodplain is typically well developed.

Lower Perennial. The gradient is low and water velocity is slow. There is no tidal influence, and some water flows throughout the year. The substrate consists mainly of sand and mud. Oxygen deficits may sometimes occur, the fauna is composed mostly of species that reach their maximum abundance in still water, and true planktonic organisms are common. The gradient is lower than that of the Upper Perennial Subsystem and the floodplain is well developed.

Upper Perennial. The gradient is high and velocity of the water fast. There is no tidal influence and some water flows throughout the year. The substrate consists of rock, cobbles, or gravel with occasional patches of sand. The natural dissolved oxygen concentration is normally near saturation. The fauna is characteristic of running water, and there are few or no planktonic forms. The gradient is high compared with that of the Lower Perennial Subsystem, and there is very little floodplain development.

Intermittent. In this Subsystem, the channel contains flowing water for only part of the year. When the water is not flowing, it may remain in isolated pools or surface water may be absent.

Classes. Rock Bottom, Unconsolidated Bottom, Aquatic Bed, Streambed, Rocky Shore, Unconsolidated Shore, and Emergent Wetland (nonpersistent)."

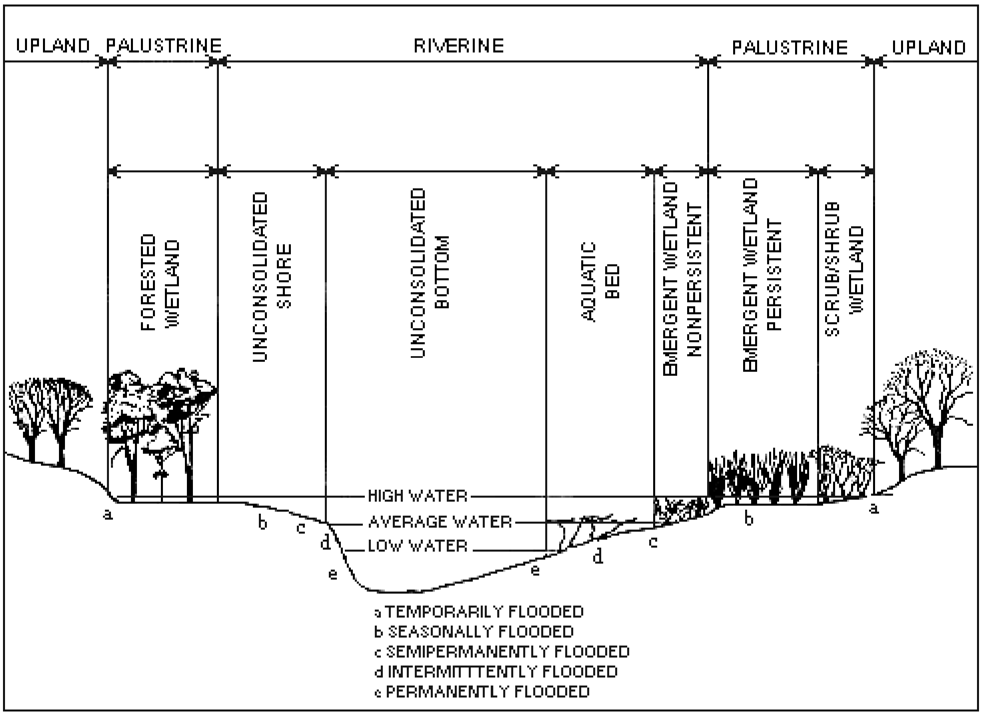


Figure A2. Distinguishing features and examples of habitats in the riverine system (from Cowardin et al. 1979).

General

Includes all wetlands and deepwater habitats within an open channel with two exceptions: wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens; and habitats with water containing ocean derived salts in excess of 0.5ppt (Cowardin et al. 1979). However, due to the issues presented by the relatively coarse mapping scale (with a minimum width of 35m for regional ecosystem mapping), for the purposes of this mapping methodology, the fringing palustrine vegetation around a riverine system will be called riverine.

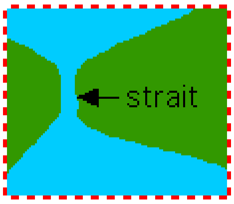
River Mouth

The point where a stream issues into a larger body of water. For the purposes of this method the larger body of water is the ocean (Webnox Corp., 2003).

Salinity

The total amount of solid material in grams contained in 1 kilogram of seawater when all the carbonate has been converted to oxide, the bromine and iodine replaced by chlorine, and all organic matter completely oxidised (Webnox Corp. 2003).

Strait



A narrow channel of water that connects two larger bodies of water, and thus lies between two land masses. A landmass is a large extent of land. Landmasses include continents, supercontinents and large islands. The terms *strait*, *channel* and *passage* can be synonymous and interchangeable, although channel also has other meanings. Many straits are economically important. Straits can lie on important shipping routes, and wars have been fought for control of these straits. Numerous artificial channels, called *canals* have been constructed to connect two bodies of water over land (UN, Division for Ocean Affairs).

Tidal

Of or pertaining to tides; caused by tides; having tides; periodically rising and falling, or following and ebbing; as, tidal waters (Webnox Corp. 2003).

Tidal Salinity

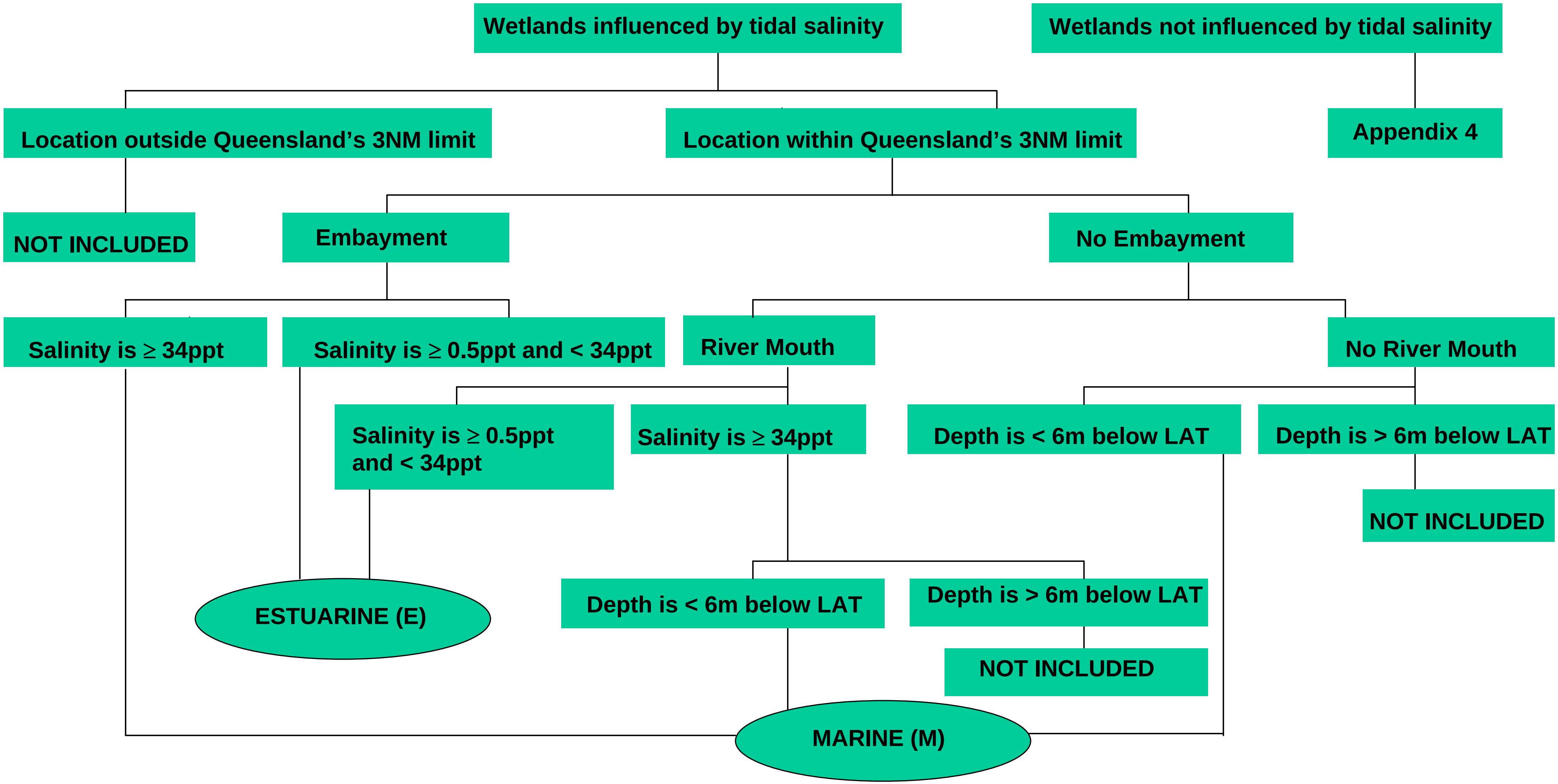
Marine and estuarine wetlands can be described in terms of their salinity structure. The salinity structure of the estuary is determined by its geometry as well as prevailing and antecedent climatic conditions that include (Webnox Corp. 2003):

- Fresh water inflow;
- Tides, and
- Wind.

WMC

Acronym for the Environmental Protection Agency Wetland Mapping and Classification project.

Appendix 3. Wetlands Influenced by Tidal Salinity



Appendix 4. Wetlands not Influenced by Tidal Salinity