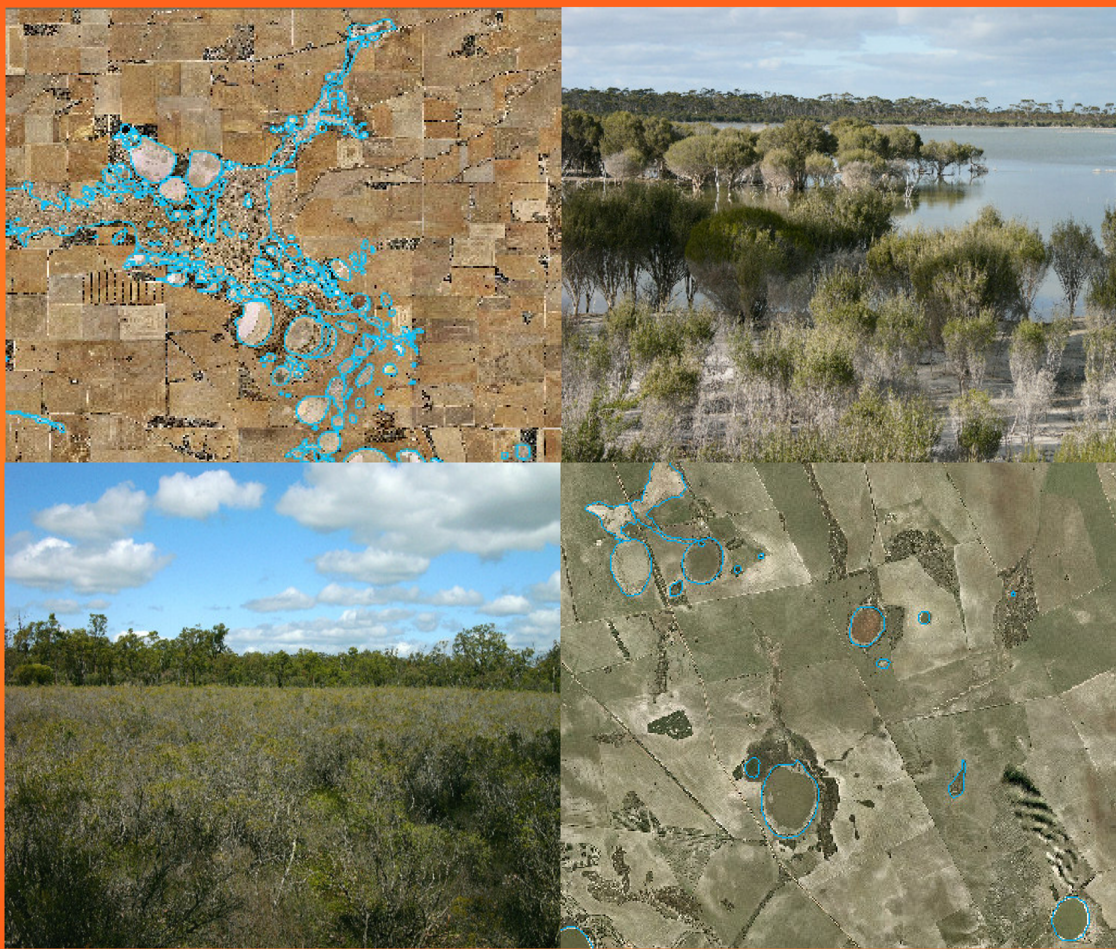
Evaluating the conservation significance of basin and granite outcrop wetlands within the Avon Natural Resource Management region:

Stage One Assessment Method



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October 2008

AVON CATCHMENT COUNCIL
Australian Government
Landgate
GOVERNMENT OF WESTERN AUSTRALIA
Department of Environment and Conservation

Evaluating the conservation significance of basin and granite outcrop wetlands in the Avon Natural Resource Management region:

Stage One Assessment Method

Prepared by

Science Division
Department of Environment and Conservation

Department of Environment and Conservation
October 2008

Executive summary: *Evaluating the conservation significance of basin and granite outcrop wetlands within the Avon Natural Resource Management region: Stage One Assessment Method.*

Introduction

This publication describes a wetland evaluation and classification methodology for use at a regional scale in the Avon Natural Resource Management region and the broader Wheatbelt of Western Australia. The results of the application of this methodology have also been presented in Section 5.

Table 1 - Form of wetland inventory

Form of wetland inventory	Methodology	Application
Identification		
Delineation		
Classification	√	√
Evaluation	√	√

Publication details

This methodology has been developed by the Science Division, Department of Environment and Conservation (DEC), Western Australia. The report was written by Susan Jones (DEC), Adrian Pinder (DEC), Lien Sim (DEC) and Stuart Halse (DEC).

The authors of this document would like to acknowledge the following people for their important contributions:

- Members of the Wetland Status Working Group and Wetlands Coordinating Committee
- John Lizamore, Danielle Halliday, Cara Francis, Anna Leung and David Cale from the Woodvale Wetlands Group within the DEC Science Division
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- Rebecca Palumbo from the Avon Catchment Council
- Mike Lyons and Jim Lane from the DEC Science Division

Copies of this document can be viewed or downloaded from the Department of Environment and Conservation's website at www.dec.wa.gov.au.

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Funding

This methodology was funded by the Avon Catchment Council's Avon Natural Diversity Alliance Program.

Study area

The area in which the methodology can be applied is the Avon NRM region and the wider Wheatbelt, as shown in Figure 1.

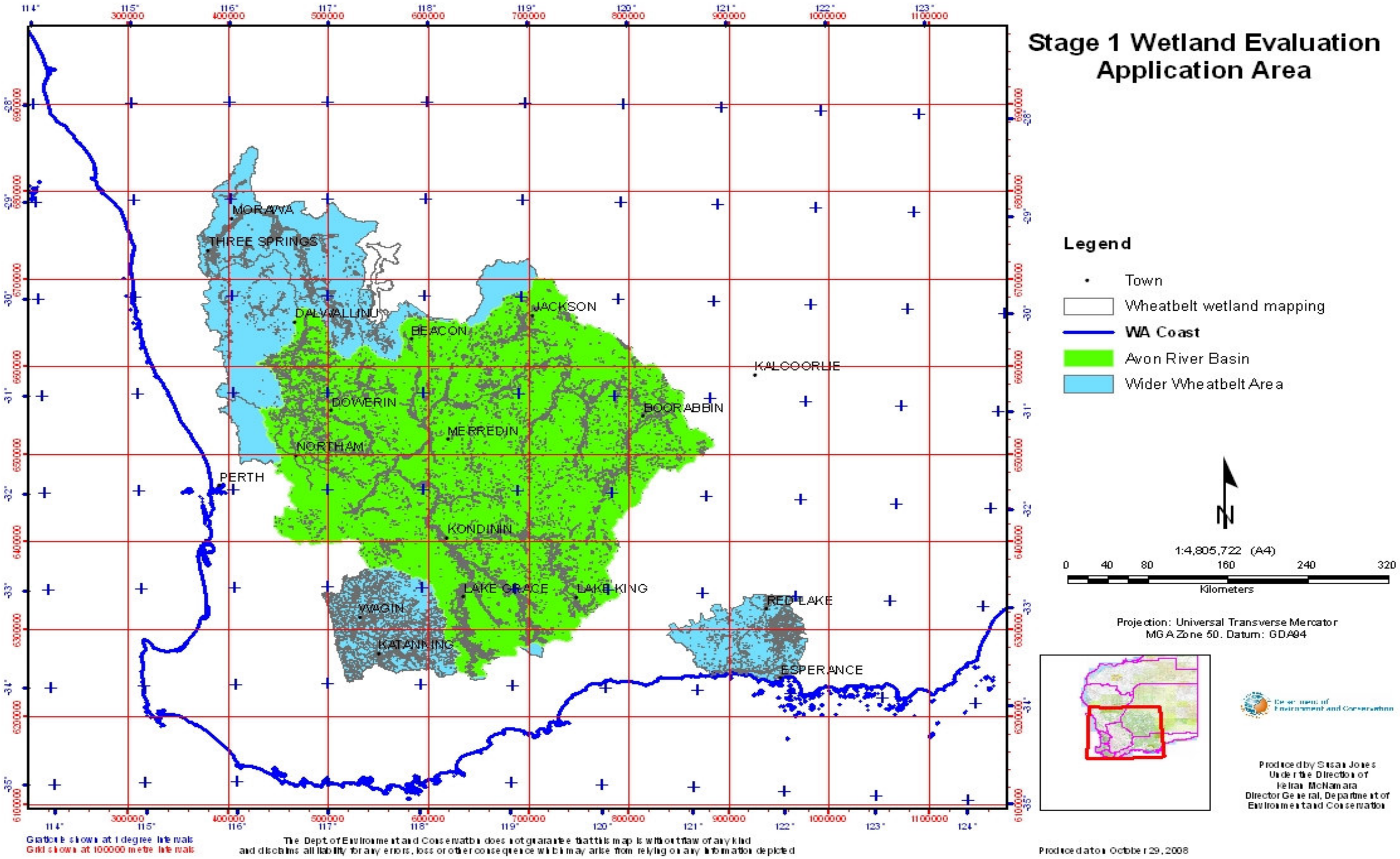

Figure 1 - Map showing the area to which the Avon Stage 1 methodology is applied to

Wetland mapping stage

The Western Australian Wetlands Coordinating Committee, with the advice of its Wetland Status Working Group, considers that the methodology fulfils the requirements of a Stage 1 evaluation methodology. While the methodology provides an advanced Stage 1 evaluation methodology, the Wetland Status Working Group has determined that it is not detailed enough to satisfy the requirements of a Stage 2 methodology. Table 2 outlines the key aspects of a Stage 1 mapping project.

Table 2- Primary stages of wetland mapping identified in Department of Environment and Conservation (2007).

Stage	Purpose/ objective	Scale	Approach	Mapping	Mapped classification	Evaluation	Outcome
1	*Broad wetland distribution*	*Regional*	*Reconnaissance Desktop 'Drive by'*	*Satellite imagery, aerial photographs, topography Map 'centroid' or approximate boundary 1:250,000 to 1: 100,000 scale*	*Wetland vs. dryland*	*Existing data only No further evaluations*	*Quantify wetland resource*
2	*Asset evaluation, priority setting*	*Group of wetlands*	*Field sampling of sub-set and extrapolation of information*	*Aerial photograph. Precise or approximate boundaries 1:50,000 to 1:10,000 scale*	*Geomorphic wetland type*	*Preliminary indication of conservation value*	*Preliminary evaluation and prioritisation for future detailed assessment*
3	*Protection, management, environmental impact assessment*	*Individual*	*Individual wetland assessment in field*	*Aerial photographs (stereoscopic analysis). Precise boundaries 1:25,000 to 1:5,000 scale*	*Geomorphic wetland type*	*Detailed assessment of conservation value*	*Identification of values of individual wetlands as basis for protection, management and/or nomination.*

Relevant wetland types

The evaluation methodology is applicable to the wetland types highlighted in Table 3:

Table 3 - The wetland types to which the methodology can be applied (shaded), from the geomorphic wetland types identified by Semeniuk and Semeniuk (1995). This includes those granite outcrops supporting small basin pools.

Hydroperiod	Landform				
	Basin	Channel	Flat	Slope	Highland
Permanent inundation	Lake	River	-	-	-
Seasonal inundation	Sumpland	Creek	Floodplain	-	-
Intermittent inundation	Playa	Wadi	Barlkarra	-	-
Seasonal waterlogging	Dampland	Trough	Palusplain	Paluslope	Palusmont

Basin wetland types are the focus of this methodology due to the pressing need to understand their values, in order to inform natural resource management decision making, and in particular, the assessment of deep drainage proposals.

Evaluation summary

The wetland attributes, functions and values subject to evaluation using the methodology are:

- Known ecological significance
- Inferred naturalness
- Human significance indicators
- Representativeness indicators

Associated datasets

DEC has applied the wetland evaluation and classification methodology to the study area and the resulting data has been incorporated into the “Wheatbelt basin and granite outcrop wetland evaluations dataset”. This dataset is linked to the “Wetlands of the Wheatbelt and other prioritized areas” dataset through a unique identifier given to each polygon. The combination of these datasets show the location, approximate boundary, and conservation significance of wetlands in the study area. DEC is the custodian of this dataset. These datasets will be available through Nature Map from January 2009. For information on the dataset, including metadata and the data modification processes, contact the Science Division, DEC on (08) 9405 5183.

Endorsement

Evaluating the conservation significance of basin and granite outcrop wetlands in the Avon Natural Resource Management region: Stage One Assessment Method has been endorsed by the:

Department of Environment and Conservation
Wetland Status Working Group
Wetlands Coordinating Committee

Recommended reference

The recommended reference for this publication is: Jones S.M., Pinder A.M., Sim L.L., Halse S.A. (2008). *Evaluating the conservation significance of basin and granite outcrop wetlands in the Avon Natural Resource Management region: Stage One Assessment Method*. Prepared for the Avon Catchment Council by the Department of Environment and Conservation.

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1. Introduction

This methodology, funded by the Avon Catchment Council (ACC) through Natural Heritage Trust (NHT) and National Action Plan for salinity (NAP) funding, provides a procedure for classifying and evaluating basin and granite outcrop wetlands in the Avon Natural Resource Management (NRM) region, at a regional-scale. The results of the application of this methodology to the region outlined in Figure 1 are presented in Section 5.

For the purposes of this methodology the conservation significance of a wetland reflects its scientific, educational, amenity, spiritual, philosophical, recreational, consumptive use and ecosystem service value. The information available on each of these values at the regional-scale is limited, therefore not every value is represented in this document (for example, there is limited data available on the ecosystem service value of wetlands, e.g. flood mitigation, nutrient stripping).

The classification and evaluation of wetlands provides an inventory of wetland assets in the region. This enables strategic catchment planning, so that wetlands of high conservation significance are maintained or improved, while those of low significance, with further assessment, may be considered for purposes other than conservation (e.g. incorporation into drainage schemes). This is vital for the management and protection of wetlands in the region as the Avon NRM region is under threat from dryland salinity.

Wetland evaluations can be undertaken at different scales, as outlined in the *Framework for mapping, classification and evaluation of wetlands in Western Australia* ('the framework') (Department of Environment and Conservation 2007). A <u>stage one</u> refers to "broadscale identification of the occurrence of wetlands within a study area and provides a basis for guiding further work". A <u>stage three</u> assessment "involves collection of information on wetland attributes and functions at all wetlands and incorporates detailed mapping of wetland boundaries and site specific evaluation". A draft stage three wetland evaluation methodology for inundated basin wetlands within the Avon NRM region has been produced by the Department of Environment and Conservation (DEC) (Jones*, et al.* 2008), and will be trialled in 2008 before finalisation.

This methodology outlines a procedure for conducting a <u>stage one</u> assessment of all mapped basin and granite outcrop wetlands in the Avon NRM region. Although this methodology has been designed for the Avon NRM region, it is intended to be applied to the wider Wheatbelt as part of the Wheatbelt Wetlands Project (WWP, see section 1.4). This methodology outlines an enhanced stage one assessment (Department of Environment and Conservation 2007), and is intended to inform and prioritise further, more detailed assessments (stage three).

This document has been endorsed by the state Wetlands Coordinating Committee (WCC). This endorsement ensures it is compatible with the broad methods recommended for all Western Australian wetland classification and evaluation methodologies (Department of Environment and Conservation 2007), and that data collected by following this method can be incorporated into a state-wide database. This evaluation methodology has been tailored to the basin and granite outcrop wetlands present in the Wheatbelt, and the particular threats they face, thus it may differ to wetland evaluation methodologies produced for other parts of Western Australia.

1.1 Methodology objectives

There are two objectives of this document:

- To outline a method for classifying basin wetlands into groups based on their inundation frequency, size, vegetation cover and indicated salinity. This will produce an inventory of wetland groups present in the region, which ensures the best representative from each wetland group, within each catchment, is identified as of high significance.

- To outline a repeatable, transparent and accountable method of evaluating the conservation significance (high, intermediate or low), at a regional scale, of basin and granite outcrops wetlands within the Avon NRM region.

1.2 Definition of terms

For the purposes of this document, the following definitions apply:

1.2.1 'Wetland'

The Wetlands Conservation Policy for Western Australia (Government of Western Australia 1997), uses the Ramsar definition of wetlands:

'*Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, 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 six metres* (UNESCO 1971)*.'*

This methodology applies to wetlands that have a basin landform. This includes small basins (pools) located on granite outcrops.

1.2.2 'Wetland classification'

'A procedure in which individual wetlands (as defined in section 1.2.1) are placed into groups based on quantitative or qualitative information on one or more characteristics inherent in wetlands (for example hydrological, biological, chemical and/or physical properties).'

1.2.3 'Conservation significance'

'The importance of a wetland retaining or improving its current state, based on a combination of its scientific, educational, amenity, spiritual, philosophical, recreational, consumptive use and ecosystem service value.'

1.2.4 'Wetland evaluation'

'The process of assessing and documenting a wetland's value by considering information about its attributes and functions obtained during the data collection phase (Department of Environment and Conservation 2007).'

1.3 Methodology limitations

The method outlined in this document is limited to:

- basin wetlands (including those on granite outcrops) that could be identified from aerial photography. Channel, flat, slope and highland wetland landforms were excluded from this methodology as they were not part of the original scope of the project, which was determined largely by the Avon Catchment Council. They are also, generally-speaking, continuous systems with poorly defined boundaries that usually cover vast areas. There is currently no method for evaluating these types of wetlands in the Avon NRM region, and it is highly recommended to be undertaken in the future.

- wetlands that are greater than one hectare in size. Leptoscale wetlands (< 1 hectare) were excluded from this methodology as they could not be accurately delineated at a scale of 1:10,000.

- data that is available at a regional scale. Innovative techniques using remote sensing have been incorporated, however, the results should be used with caution as they have only been validated with the data available at the time of development.

1.4 Wetland delineation

Mapping of the entire Wheatbelt has been undertaken by DEC as part of the Wheatbelt Wetlands Project (WWP), funded by the Department of Water. The resulting dataset, "Wetlands of the Wheatbelt and other prioritized areas" (Lizamore J.M. for the Department of Environment and Conservation 2008), is in accordance with the requirements of a stage one assessment as outlined in the *'Framework for mapping, classification and evaluation'* (Department of Environment and Conservation 2007).

The data contained within the "Wetlands of the Wheatbelt and other prioritized areas" dataset covers wetlands within most of the Wheatbelt region of south-west Western Australia, as well as in a small area of the Rangelands to the east, and the Darling Scarp to the west. This layer was captured at a scale of 1:10,000 and is accurate to be used at a scale of 1:100,000**.**

Digitising the wetland boundaries presented in the aforementioned dataset involved the use of remote sensing, orthophoto verification and cross referencing with other datsets. Remote sensing picked up areas of inundation in satellite imagery from 1990 and 2000, with 25m pixel resolution Behn (1990). This base wetland layer was then clipped to 1:100,000 topographic map grids and verified using orthophotos by several operators at a scale of 1:10,000. Orthophoto verification was undertaken to ensure the areas identified by remote sensing as subject to inundation were wetlands in reality. As a result, all wetlands within the study area were captured. The data was then checked against the 1:250,000 DEC corporate wetland layer (GEODATA Waterbodies Dataset) and cross-verified.

At this level only a preliminary indication of a wetland boundary can be determined. Wetland boundaries can be delineated using many factors (e.g vegetation), therefore, a hierarchy of decisions determined the final boundary delineated:

1. Presence of water inundation from remote sensing (Behn 1990).
2. Presence of wetland vegetation, or, a discernable vegetation change indicating vegetation zones around the wetland (e.g. wetland vegetation, Samphire communities, etc).
3. Analysis of contours, which indicate slopes, flow direction and potential areas of pooling.
4. Presence of any other data that indicates the area as a wetland, e.g. existing sampling sites, historic wetland boundaries or previously identified wetlands.

Granite outcrops were also delineated using aerial photography at a scale of 1:10,000. Due to the scale of the mapping, all granite outcrops were delineated regardless of whether basins were visible. The precautionary principle has been implemented and in this methodology it is assumed that each mapped granite outcrop has the capacity to hold water in the form of one to many pools (even if for only very brief periods), and therefore function as a basin wetland. This may not be the reality for many of these granite outcrops as they have diverse morphologies, some of which are not suitable for pool formation.

This methodology assumes that the wetland mapping used to undertake the evaluations "Wetlands of the Wheatbelt and other prioritized areas" (Lizamore J.M. for the Department of Environment and Conservation 2008) is accurate for the intended scale of use (1:100,000).

Important note: Any aerial photography displaying the wetland mapping in this document is being shown at a scale lower than what it is accurate for viewing (1:100,000). This is for communication purposes only and should not be viewed at a scale lower than 1:100,000 in the future.

2. Background to the Avon NRM Region

The Avon NRM region (Figure 2) is one of six NRM regions within Western Australia. It has an area almost twice the size of Tasmania [11.8 million hectares (Avon Catchment Council 2005)], extending east from the Perth Hills to include the Avon-Mortlock, Yilgarn and Lockhart river systems. Around 63% of the land in the Avon NRM region has been released for agricultural purpose (and mostly cleared), 8% has been set aside for conservation and 29% is either vacant crown land or pastoral lease with some mineral extraction (Avon Catchment Council 2005). Around 13,900 basin wetlands and 6,400 granite outcrops have been mapped in this area by DEC, and on-ground data is available for only a few hundred of these wetlands.

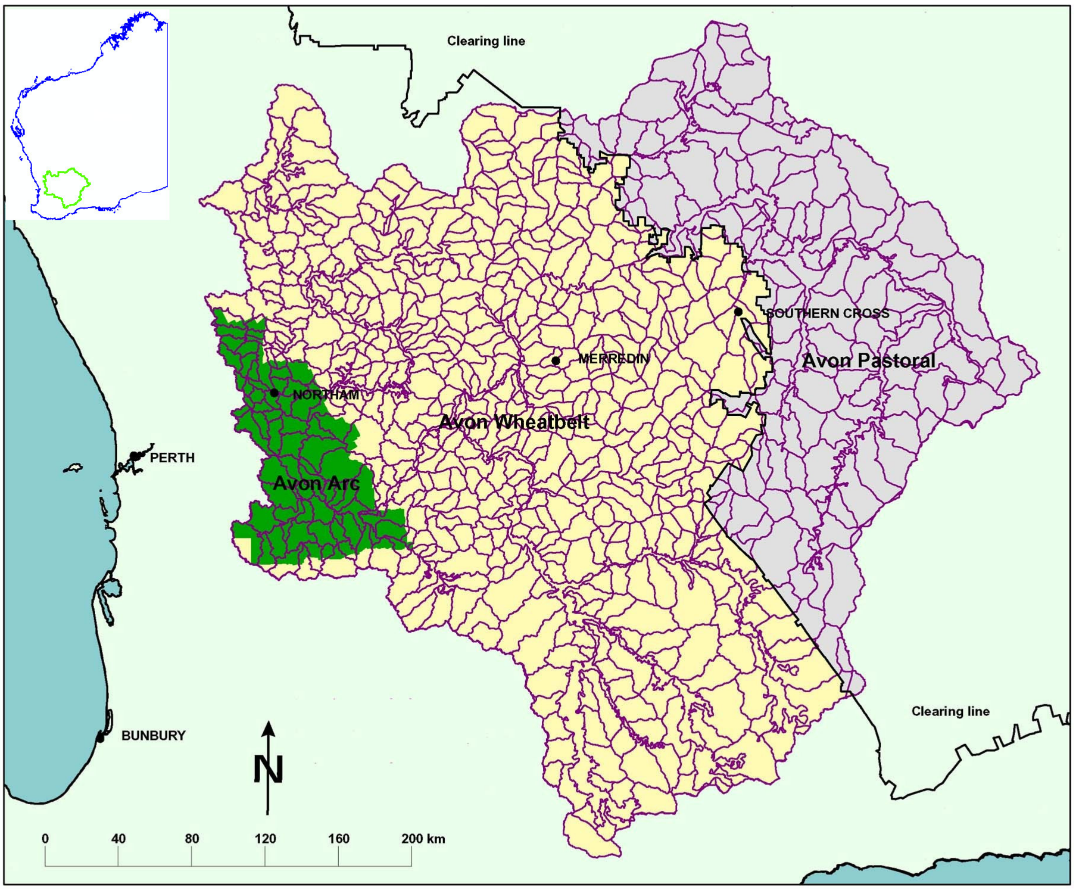


Figure 2 - Location and extent of the Avon NRM region

2.1 Climate

The climate of the Avon NRM region is characterised by hot, dry summers and cold winters. The average minimum temperature for the region is 6ºC in winter and 18 - 21ºC in summer. The average maximum temperature for the region is 15 - 21ºC in winter and 33 - 36ºC in summer.

The Avon NRM region mostly falls within a temperate to semi-arid area of Australia, as described by the Koppen system of climate classification. The average annual rainfall declines from 500 – 600mm along the western boundary, to 300mm east of the line drawn between Bonnie Rock, Trayning and Southern Cross. Thirty to 50% of this annual rainfall falls in the winter months, declining to 10 – 20% in the summer months.

2.2 Geomorphology and hydrology

The Avon NRM region is underlain by ancient landforms of low fertility derived from crystalline rocks such as granite and gneiss, which are estimated to be 2 - 3 billion years old. More than 2 million years ago (Cretaceous period) the western section of the region was uplifted to form the Darling Scarp, and an area referred to as the Zone of Rejuvenated Drainage. Waterways in this zone flow seasonally to the Avon River and thence to the Swan-Canning Estuary. To the east of this zone, separated by the Meckering Line, lies the Zone of Ancient Drainage. Waterways in this zone form a sparse, open drainage network that roughly approximates the paths of an ancient in-filled river system. This network has local internal drainages, except in years of extremely high rainfall when flow extends for greater distances, and occasionally feeds into the lower Avon (Mulcahy 1967).

The Avon NRM region has extensive areas of shallow, saline groundwater, which has been slowly rising since clearing. The rise in saline groundwater has been attributed to increased groundwater recharge and surface flow caused by the replacement of deep-rooted native vegetation with shallow-rooted annual agricultural crops (George*, et al.* 1997, Hobbs*, et al.* 1993, Teakle and Burville 1938). Mobilization of marine aerosol salts stored in the soil profile, due to groundwater rise, (Hingston and Gailitis 1976) has resulted in a salinised landscape. This process is known as dryland salinisation.

Dryland salinisation encompasses two threats:

- An increase in the salinity of groundwater, and therefore the salinity of water in groundwater-dependant wetlands. This has had a devastating effect on wetland vegetation and aquatic fauna (Clarke*, et al.* 2002, Williams 1999).
- A change in the inundation frequency of wetlands, such that previously seasonally waterlogged areas now have periods of prolonged inundation. It has been reported that this is a contributing factor to vegetation change in affected areas (McFarlane and Williamson 2002).

Estimates of the cost of dryland salinity to farmers has ranged from $60 million (State Salinity Strategy 1996) to $1 billion a year (George*, et al.* 1997, Select Committee Land Conservation 1991), and is predicted to worsen in the future (George and Coleman 2002, Short and McConnell 2001).

2.3 Previous wetland studies conducted in the region

Numerous surveys of various scales and intensities have been conducted at wetlands in the Avon NRM region. The Salinity Action Plan (SAP) Wheatbelt biological survey conducted by the former Department for Conservation and Land Management (now DEC) from 1997 to 2001 involved intensive studies at about 100 wetlands, and is the largest survey that has been conducted in the region (Halse*, et al.* 2004, Lyons*, et al.* 2004, Pinder*, et al.* 2004). The State Salinity Strategy also established a wetland monitoring program, which includes ten wetlands within the Avon NRM region. At these wetlands, biodiversity and water quality data is collected biennially (Cale*, et al.* 2004). A summary of the various projects and the data collected is shown in Appendix A**.**

Available on-ground data has been used to validate some of the indices described in this methodology (e.g. remotely sensed salinity indicator). Details of the accuracy of the relevant indices has been given where appropriate.

2.4 Types of basin wetlands found in the Avon NRM region

From previous biological studies conducted in the Wheatbelt, five broad wetland 'types' are known to support distinct water chemistry, flora and/or fauna attributes (Lyons*, et al.* 2004, Pinder*, et al.* 2004). These are:

- Naturally saline basins
- Freshwater basins
- Artificial reservoir basins
- Freshwater claypan basins
- Freshwater granite outcrop pools

Features such as water quality (in particular current and historical salinity), species of vegetation and basin morphology are used to separate these types. A detailed description of each of these types is presented in Appendix B**.**

3. Classification of study wetlands in the Avon NRM region

Classification of wetlands is a procedure in which individual wetlands are placed into groups based on quantitative or qualitative information on one or more characteristics inherent in them (for example hydrological, biological, chemical and/or physical properties). The aim of this process is to produce categories that are informative and ecologically meaningful.

This methodology employs the geomorphic classification system (Semeniuk and Semeniuk 1995) to describe wetlands based on landform and hydroperiod, along with other attributes such as wetland size, vegetation cover and salinity. The geomorphic classification system has been used extensively to inform other wetland evaluation methodologies, such as the one produced for the Swan Coastal Plain (Hill*, et al.* 1996).

The attributes used in this classification process will provide a description of a wetland's morphology and main ecological characteristics. Salinity, in particular, is the main environmental variable that defines the invertebrate, waterbird and vegetation communities of wetlands in the Wheatbelt (Halse*, et al.* 2004).

Granite outcrops will not be classified according to any of the attributes presented in the sections below. Due to their small size, most of the basins (pools) located on them cannot be detected through remote sensing. Thus, all of the attributes outlined in the following section will only be attributed to basin landforms not on granite outcrops, that are greater than one hectare in size.

The sections below describe the techniques involved in gathering the required data at a regional-scale. Aerial photography and satellite imagery are required to undertake the described techniques.

3.1 Landform

The landform of a wetland (i.e. whether a wetland is a basin, channel, flat, slope or highland) can be determined from aerial photography by observing the shape, and location of a wetland. Figure 3 shows sketches of the five different landforms outlined in Semeniuk and Semeniuk (1995). This Avon NRM methodology will only address wetlands with a basin landform greater than one hectare in size.

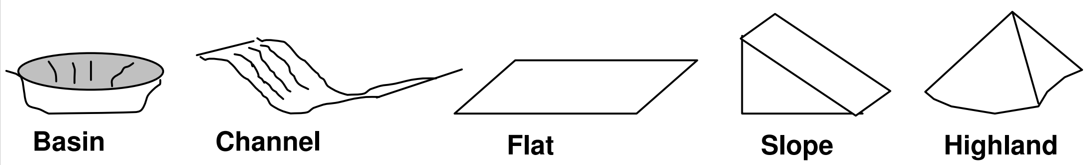


Figure 3 - Examples of different wetland landforms adapted from Semeniuk and Semeniuk (1995).

3.2 Hydroperiod

At a regional scale, the <u>recent</u> inundation frequency of a wetland can be inferred from a time series of processed summer Landsat Thematic Mapper (TM) imagery. Only summer imagery was available for the years 1990, 1992, 1994, 1996, 1998, 2000, 2002 – 2007 for use in this methodology, but can be readily purchased for any date after 1990 if project funds allow.

The spectral response of water and land in the short-wave, infrared part of the electromagnetic spectrum is different. There is an obvious difference between the terrestrial (land, vegetation) and aquatic (fresh and saline surface water) graphs, particularly in Band 5, as shown in Figure 4 below. This allows pixels of land and water to be separated to give a percentage of each within a defined boundary (the mapped wetland polygon). Damp exposed soils can also be detected using this method.

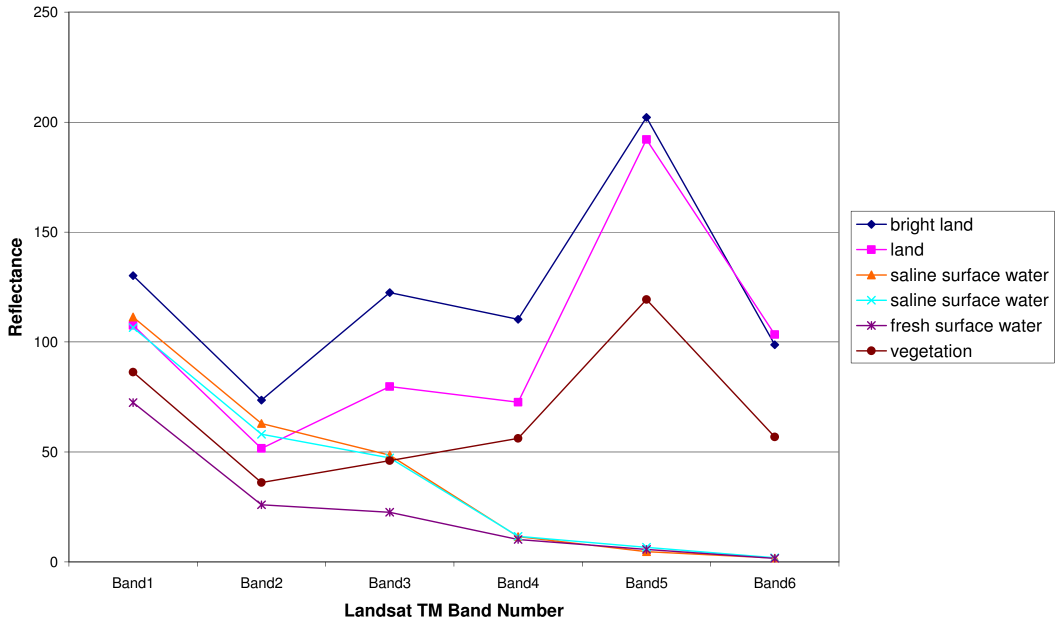


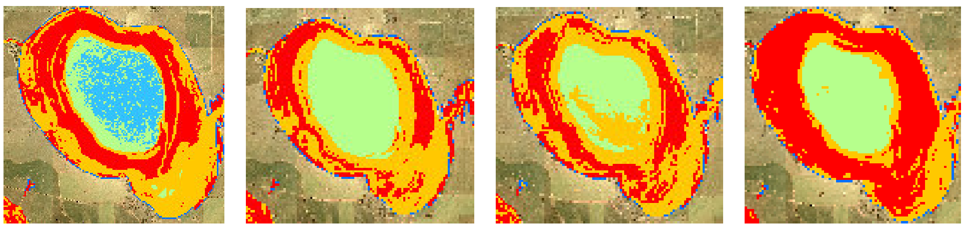
Figure 4 - Spectral signature in Landsat TM of different surfaces around wetlands (from Zdunic 2008).

The percentages of dry, damp and wet areas within a wetland boundary can be summarised to classify the wetland as being 'dry' or 'wet' at a certain point in time. A wetland is classified as being 'wet' when there is 10% or greater surface water present. A wetland is classified as being 'dry' when there is less than 10% surface water present. The thresholds identified above have been derived from expert opinion, and verified using on-ground data.

The criteria used to place wetlands into the three categories below are adapted from inundation classifications presented by Semeniuk and Semeniuk (1995) and Boulton and Brock (1999). Due to the scale of this methodology, it is not realistic to have more than three inundation frequency categories. The categories are calculated as percentages, as all years of imagery are not available for every wetland.

- Consistently inundated in summer - these wetlands are 'wet' during summer for 90% or more of years and are generally considered to be permanent wetlands (adapted from Boulton and Brock 1999).

  A time series of processed summer Landsat TM imagery is shown for Lake Hinds in Figure 5 below. The blue and green colouring indicates surface water, orange indicates damp soil and red indicates dry soil. Of the 12 years of available imagery, Lake Hinds is 'wet' for 11 years in summer, which indicates it is a permanently inundated wetland.

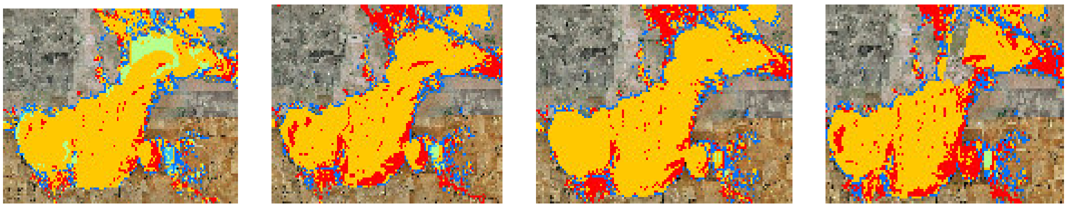


1990 - Above avg annual rainfall | **1994** - Above avg annual rainfall | **1998** – Avg – below avg annual rainfall | **2005** – Avg annual rainfall

Figure 5 - Example of processed Landsat TM imagery for Lake Hinds, showing surface water as green and blue, damp soil as orange and dry soil as red.

- Rarely inundated in summer – these wetlands are 'dry' during summer 80% or more of years. These wetlands are generally considered to be ephemeral or seasonal as they are predictably dry during the dry season. Eighty, rather than ninety percent, has been used as a benchmark for this inundation frequency as one year (summer 2000) recorded a much above average rainfall. This category will also include wetlands that rarely hold surface water throughout the year.

  A time series of processed summer Landsat TM imagery is shown for Cowcowing Lake in Figure 6 below. Of the 12 years of available imagery, Cowcowing Lake was 'wet' for 1 year and 'dry' or 'damp' for 11 years in summer, which indicates it is a seasonally or ephemerally inundated wetland.

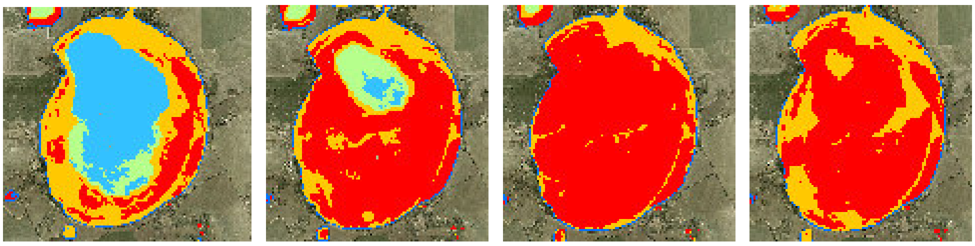


1990 - Above avg annual rainfall | **1994** - Above avg annual rainfall | **1998** – Avg – below avg annual rainfall | **2005** – Avg annual rainfall

Figure 6 - Example of processed Landsat TM imagery for Cowcowing Lakes, showing surface water as green and blue, damp soil as orange and dry soil as red.

- Often inundated in summer - these wetlands are between the two categories above as they are not consistently 'dry' or 'wet' during summer. This category includes wetlands that are 'wet' in summer between 11 and 79% of years.

  A time series of processed summer Landsat TM imagery is shown for Lake Walymouring in Figure 7 below. Of the 12 years of available imagery, Lake Walymouring was 'wet' for 5 years and 'dry' for 7 years in summer, which indicates it is an intermittently or episodically inundated wetland.



1990 - Above avg annual rainfall | **1994** – Below avg annual rainfall | **1998** – Avg – below avg annual rainfall | **2005** – Avg annual rainfall

Figure 7 - Example of processed Landsat TM imagery for Lake Walymouring, showing surface water as green and blue, damp soil as orange and dry soil as red.

Validation and Limitations

The presence of water indicated by this remote sensing technique has been validated using on-ground data for a subset of wetlands. The presence of water has been recorded at over 40 sites in the Mortlock area, some sites with multiple collection dates. The presence of water indicated by the on-ground data (i.e. if water chemistry data was recorded) was compared to processed spring satellite imagery for the years of data collection. Currently, no discrepencies have been found between surface water indicated and surface water actually observed. However, this has been checked only on the **presence** of water, not on the **area** of inundation, which may be interpreted from the processed satellite imagery.

This technique could have widespread implications for wetland monitoring in remote areas, and wetland modelling for climate change studies. By using this technique to relate the inundation frequency to climatic conditions, wetlands of particular interest can be modelled under different climatic scenarios. Further validation of this product is required for other areas of Western Australia.

3.3 Size

Following the classification produced by Semeniuk (1987), wetlands are categorised into five wetland sizes. Since this methodology addresses only wetlands greater than one hectare (10,000m^2), the leptoscale wetland size category has been automatically excluded.

- Megascale – Very large wetlands > 10km x 10km in scale (or >1000Ha)
- Macroscale – Large wetlands between 10km x 10km and 1km x 1km (or between 100 and 1000Ha)
- Mesoscale – Medium wetlands between 1km x 1km and 0.5km x 0.5km (or between 25 and 100Ha)
- Microscale – Small wetlands between 100m x 100m and 500m x 500m (or between 1 and 25Ha)

3.4 Vegetation cover

At a regional scale, the vegetation cover across the bed of a wetland can be detected from the analysis of aerial photography. Vegetation cover refers to the presence of trees and tall shrubs, it does not include small shrubs, herbs and grasses (e.g. Samphire). Vegetation cover can be split into three main groups: open, partially open and closed. These three categories give a good indication of whether the wetland is an open system or a closed vegetation ('swamp') system.

In the Avon NRM region, wetlands that have open and closed vegetation are likely to provide different habitats. The open systems are likely to be saline, and/or have deep water zones and higher submerged vegetation cover. The closed systems are likely to be freshwater and have more shelter for breeding waterbirds and other aquatic biota. The three categories of vegetation cover are displayed in Figure 8 below.

Drummond Lake
Closed Vegetation

Irving's Swamp
Partially Open Vegetation

Hagboom Lake
Open Vegetation

Figure 8 - Aerial photographs of three wetlands showing the three vegetation cover categories.

3.5 Indicated salinity

Water column salinity is the main environmental variable that defines the invertebrate, waterbird and aquatic vegetation communities of wetlands in the Wheatbelt (Halse*, et al.* 2004). There is also a difference, particularly in the invertebrate and vegetation populations, between saline wetlands that were originally freshwater, and those that are naturally saline. At a regional scale, there is no remote method of determining the history of salinity at each wetland. The techniques described below indicate the current salinity, which provides only half of the information needed to infer the flora and fauna communities that define the wetland.

At a regional scale, salinity of basin wetlands can be indicated using three different remote sensing techniques. The combination of these techniques provides only an indicator of salinity, so caution must be exercised when using the results. The remote sensing techniques are outlined in the first three dot points, and the last dot point outlines the decision rules for allocating a wetland to the 'fresh-subsaline' (TDS < 10ppt) or 'saline' (TDS > 10ppt) category. If on-ground data exists for a wetland it will be used instead of the indicated salinity, such that if the average spring salinity is <10ppt it is classified as 'fresh-subsaline', otherwise it is classified as 'saline'.

- Percent vegetation cover within the mapped wetland boundary in summer 2007. Land Monitor (Caccetta*, et al.* 2000) uses Landsat TM imagery to detect the presence of woody perennial vegetation for each 25m pixel. A pixel is classified as being 'vegetated' if there is greater than 20% woody perennial vegetation cover present. This is then converted into a rough measure of the area of perennial vegetation within the mapped wetland boundary for summer 2007.

  Following comparisons of on-ground water quality data with percent vegetation cover across the basin of these wetlands, a percentage cover of greater than 40% reliably indicates the wetland to be fresh-subsaline (<10 ppt). Thus, if a wetland has greater than 40% vegetation cover within the mapped wetland boundary in summer, 2007, it will be classified as fresh–subsaline.

  Validation and Limitations

  This index has been validated using data collected during the Salinity Action Plan Survey of Wheatbelt wetlands, State Salinity Strategy Wheatbelt Monitoring Program, Avon Baselining Project, Wheatbelt Wetlands Project and Monitoring of Depth-gauged Wetlands in Southwest Western Australia. Unfortunately, only 22 data points could be used to validate the accuracy of this index due to the low-number of heavily vegetated wetlands that have been sampled in the area. Further validation is required.

- Spectral response. This technique has been developed specifically for this methodology by DEC. It is an innovative approach that could be further refined with continuing comparisons with onground data collected in the future.

  Surface water can be separated from land due to the difference in the spectral response of each in the short-wave infrared part of the electromagnetic spectrum. As displayed in Figure 4 (from Zdunic 2008), separation of the spectral response of 'fresh' and 'saline' surface water in band one is possible. This works on the general principle that saline wetlands tend to be lighter in colour due to the lack of vegetation growth within the wetted area (including submerged and emergent). For more information on this remote sensing technique refer to Zdunic (2008).

  For each wetland, a percentage of 'saline' and 'fresh' surface water cells can be calculated, and converted into the salinity categories 'fresh-subsaline' and 'saline'. A 'fresh-subsaline' wetland is defined as having <10% 'saline' surface water cells for <10% of years and a 'saline' wetland has >10% saline surface water cells for ≥10% of years. These cutoffs have been specifically developed for basin wetlands in the Avon, and thus will require adjustment for different geographic areas. Refer to the section below for details on the validation and limitations of this technique.

Figure 9 shows processed Landsat TM imagery of Dambouring Lake, Lake Ninan, Walymouring Lake and Fraser Lake, which have been sampled multiple times. The green cells indicate 'saline' cells and the blue cells indicate 'freshwater' cells. The stratification shown in the processed imagery is not indicative of what occurs in reality, but is simply taken on the reflectance of that particular cell. The overall indicated salinity is calculated as a percentage of saline cells within the mapped boundary. Spring 2000 processed imagery has been used in the figure below as it was a high rainfall summer and is likely to best represent spring conditions.

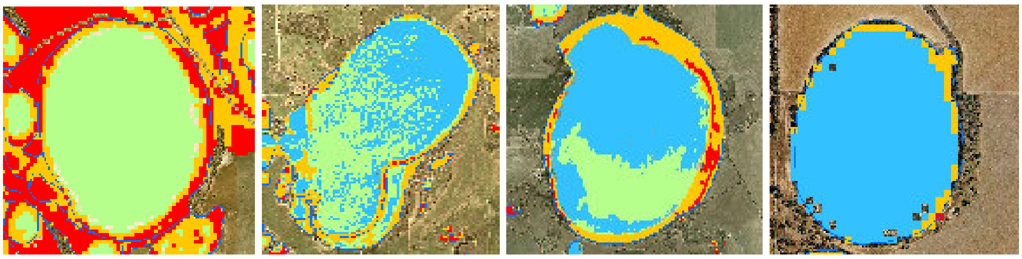


Figure 9 - Aerial photographs with inserted processed Landsat TM imagery. 'Fresh' surface water cells are blue and 'saline' surface water cells are green. The salinities are an average of multiple years of spring data collected.

Validation and Limitations

This index has been validated using data collected in the Wheatbelt during the following projects run by DEC: Salinity Action Plan Survey of Wheatbelt wetlands, State Salinity Strategy Wheatbelt Monitoring Program, Avon Baselining Project, Wheatbelt Wetlands Project and Monitoring of Depth-gauged Wetlands in Southwest Western Australia. This data, always collected during spring, ranged from one to five measurements at each wetland. Where multiple values were measured, an average was calculated and used for comparison purposes.

Of the 325 wetlands with available data, 34 were 'dry' for every year of available summer imagery (see section 3.2 for description of wetness categories), and therefore could not be included in the validation process. Of the 291 remaining wetlands, 245 wetlands were known to be saline (TDS >10ppt) and 46 wetlands were known to be fresh-subsaline (TDS <10ppt). Using the method described above, it was found that the predicted salinity from processed satellite imagery was on average 77% accurate. However, this technique is more accurate in correctly predicting saline wetlands (89% correct), rather than freshwater wetlands (44% correct). Generally, this method was found to overestimate the number of fresh-subsaline wetlands.

A major limitation of this method is that it cannot be calculated when the wetland does not have surface water. Many of the wetlands in the Wheatbelt are seasonal or ephemeral and are consequently dry every summer (when the imagery was available for this project), therefore many of the wetlands will be categorised based on the salinity risk and vegetation indicators.

Actual salinity data was collected in spring, and was compared against imagery that was captured during summer. As there are only two salinity categories ('fresh-subsaline' and 'saline'), this limitation would have a minor affect on the results. However, the technique could be further refined with the use of spring rather than summer imagery. This was not possible for this project due to the expense in purchasing imagery over such a large area.

- Slope hazard / Salinity risk mapping. Slope hazard mapping has been recently developed by GHD consultants for the Avon Catchment Council (GHD 2008). It follows on from the Land Monitor Project (Caccetta*, et al.* 2000), incorporating other resources such as Digital Elevation Models (DEM), geology and slope maps to determine the relative salinity risk, or degree of hazard to a specific area. This product assigns each wetland polygon to one of two categories – 'At Risk' and 'Not At Risk' of salinity.

  Slope hazard mapping is only available for the Avon NRM region. For areas outside of the Avon NRM region, it is possible to substitute this with salinity risk information from the LandMonitor Project. LandMonitor (Caccetta*, et al.* 2000) provides information on areas currently saline and areas at risk of salinity in the future. This information is calculated with the use of salinity maps and landform position in the landscape derived from high resolution Digital Elevation Models.

Validation and Limitations

The accuracy of slope hazard mapping relies on the skill of the analyst in interpreting datasets (GHD 2008).

This index has been validated using the same data as described under "Spectral response'. Using the results from the slope hazard and salinity risk mapping, it was found that the predicted salinity was on average 75% accurate. However, this technique is again more accurate in correctly predicting saline wetlands (85% correct), rather than freshwater wetlands (36% correct). Even though this indicator was found not to be as accurate as the spectral response indicator, it has been incorporated where the spectral response information is not available.

- Assigning the wetland to a salinity category. The three remote sensing techniques are used to allocate a wetland to a salinity category. The following decision rules apply:

  1. Onground salinity data overrules any remotely gathered data. If the salinity is less than 10ppt, the basin is deemed 'fresh-subsaline', if greater than 10ppt the basin is put into the 'saline' category.
  2. Granite outcrops are automatically placed in the 'fresh-subsaline' category as the pools located on them are filled from rainfall.
  3. If a wetland has more than 40% vegetation within the wetland boundary in 2007 it is automatically allocated to the 'freshwater-subsaline' category. If this is not applicable, continue to decision rule #2.
  4. Where the spectral response indicates the wetland to be saline, and the wetland is 'At Risk' of salinity, then the wetland is deemed to be 'saline'.
  5. Where the spectral response indicates the wetland to be 'fresh-subsaline', and the wetland is 'Not At Risk' of salinity, then the wetland is deemed to be 'fresh-subsaline'.
  6. Where the results of the spectral response and slope hazard/salinity risk mapping are in conflict, the spectral salinity indicator determines the salinity category assigned to the wetland.
  7. Where there is no spectral response salinity indicator (e.g. if the wetland was always dry in summer), the slope hazard/salinity risk mapping determines the salinity category assigned to the wetland.

Validation

The salinity groups created from the above decision rules (without the inclusion of onground data) were compared to on-ground data collected at 325 wetlands from various projects. The on-ground data was a mix of single and multiple data points per wetland. It was found that the 'indicated salinity' categories were on average 84% correct. The accuracy of this technique in determining whether a wetland is 'saline' is higher (91%) than if determining if the wetland is 'fresh-subsaline' (58%). This method generally has a precautionary approach of over-estimating the number of wetlands in the 'fresh-subsaline' category.

3.6 Wetland groups produced from this classification

Using the descriptors outlined above, wetlands can be placed into one of fifty-two groups outlined in Table 4. Granite outcrops are assigned to their own wetland group as they are a unique category of wetland that has distinctive flora and fauna.

The inundation frequency categories have been shortened to permanent (consistently inundated in summer), seasonal (rarely inundated in summer) and intermittent (often inundated in summer) for ease of reading.

The data available indicates that there are no megascale wetlands that have complete vegetation, or are freshwater, so the corresponding groups have been excluded from the classification. Through expert knowledge it has been established that wetlands with closed vegetation are always freshwater, so the salinity category within the closed vegetation category has also been removed.

Table 4 - Wetland groups produced by the Avon Stage 1 classification

Size	Inundation frequency	Vegetation cover	Salinity	Wetland group
Megascale	Permanent	Peripheral	Saline	Megascale permanent open saline basin
		Partially open	Saline	Megascale permanent partially open saline basin
	Seasonal/ Ephemeral	Peripheral	Saline	Megascale seasonal open saline basin
		Partially open	Saline	Megascale seasonal partially open saline basin
	Intermittent/ Episodic	Peripheral	Saline	Megascale intermittent open saline basin
		Partially open	Saline	Megascale intermittent partially open saline basin
Macroscale	Permanent	Peripheral	Saline	Macroscale permanent open saline basin
			Fresh-subsaline	Macroscale permanent open fresh-subsaline basin
		Partially open	Saline	Macroscale permanent partially open saline basin
			Fresh-subsaline	Macroscale permanent partially open fresh-subsaline basin
		Closed	Fresh-subsaline	Macroscale permanent closed fresh-subsaline basin
	Seasonal/ Ephemeral	Peripheral	Saline	Macroscale seasonal open saline basin
			Fresh-subsaline	Macroscale seasonal open fresh-subsaline basin
		Partially open	Saline	Macroscale seasonal partially open saline basin
			Fresh-subsaline	Macroscale seasonal partially open fresh-subsaline basin
		Closed	Fresh-subsaline	Macroscale seasonal closed fresh-subsaline basin
	Intermittent/ Episodic	Peripheral	Saline	Macroscale intermittent open saline basin
			Fresh-subsaline	Macroscale intermittent open fresh-subsaline basin
		Partially open	Saline	Macroscale intermittent partially open saline basin
			Fresh-subsaline	Macroscale intermittent partially open fresh-subsaline basin
		Closed	Fresh-subsaline	Macroscale intermittent closed fresh-subsaline basin
Mesoscale	Permanent	Peripheral	Saline	Mesoscale permanent open saline basin
			Fresh-subsaline	Mesoscale permanent open fresh-subsaline basin
		Partially open	Saline	Mesoscale permanent partially open saline basin
			Fresh-subsaline	Mesoscale permanent partially open fresh-subsaline basin
		Closed	Fresh-subsaline	Mesoscale permanent closed fresh-subsaline basin
	Seasonal/ Ephemeral	Peripheral	Saline	Mesoscale seasonal open saline basin
			Fresh-subsaline	Mesoscale seasonal open freshwater basin
		Partially open	Saline	Mesoscale seasonal partially open saline basin
			Fresh-subsaline	Mesoscale seasonal partially open freshwater basin
		Closed	Fresh-subsaline	Mesoscale seasonal closed freshwater basin
	Intermittent/ Episodic	Peripheral	Saline	Mesoscale intermittent open saline basin
			Fresh-subsaline	Mesoscale intermittent open freshwater basin
		Partially open	Saline	Mesoscale intermittent partially open saline basin
			Fresh-subsaline	Mesoscale intermittent partially open freshwater basin
		Closed	Fresh-subsaline	Mesoscale intermittent closed freshwater basin
Microscale	Permanent	Peripheral	Saline	Microscale permanent open saline basin
			Freshwater	Microscale permanent open freshwater basin
		Partially open	Saline	Microscale permanent partially open saline basin
			Fresh-subsaline	Microscale permanent partially open fresh-subsaline basin
		Closed	Fresh-subsaline	Microscale permanent closed fresh-subsaline basin
	Seasonal/ Ephemeral	Peripheral	Saline	Microscale seasonal open saline basin
			Fresh-subsaline	Microscale seasonal open fresh-subsaline basin
		Partially open	Saline	Microscale seasonal partially open saline basin
			Fresh-subsaline	Microscale seasonal partially open fresh-subsaline basin
		Closed	Fresh-subsaline	Microscale seasonal closed fresh-subsaline basin
	Intermittent/ Episodic	Peripheral	Saline	Microscale intermittent open saline basin
			Fresh-subsaline	Microscale intermittent open fresh-subsaline basin
		Partially open	Saline	Microscale intermittent partially open saline basin
			Fresh-subsaline	Microscale intermittent partially open fresh-subsaline basin
		Closed	Fresh-subsaline	Microscale intermittent closed fresh-subsaline basin

4. Evaluation of Avon NRM region wetlands

The aim of this section is to describe a method for assigning basin and granite outcrop wetlands to one of three conservation significance categories: high, intermediate or low. This enables wetlands of high conservation significance to be identified and prioritised for future protection and/or restoration, and wetlands of low significance, with further assessment, to be considered for purposes other than conservation (e.g. receiving drainage water). Wetlands that have been deemed 'low significance' should not be perceived as having no conservation value. Proposals for structures or activities impacting the condition of wetlands of low conservation significance should be considered in the context of their remaining values and a thorough investigation undertaken.

As previously stated, this document does not provide a method for assessing the conservation significance of flat, channel or slope wetlands. These wetlands still have value but unfortunately are outside the scope of the current project. Flats in the Wheatbelt generally become inundated only after extreme rainfall events, and in these instances would share similar biota to nearby basins. This methodology should be reviewed and extended in the future to incorporate these wetland types in the assessment process.

Many existing wetland evaluation methodologies were reviewed prior to developing this document, none of which were found to be suitable without significant modification. In many cases, pre-existing methodologies required very detailed information, which is not currently available for the Avon NRM region. At a regional-scale, there are two types of information – that which is already available, and that which can be inferred from aerial imagery. The information that is already available comes from existing mechanisms that identify wetlands of importance. Wetlands can be identified as important for a range of values, which include: *scientific, educational, amenity, spiritual, philosophical, recreational, ecosystem service* and *consumptive use* (Wallace 2006). The information that we can infer from aerial imagery, such as the degree of anthropogenic impact, also reflects some of these values and is therefore incorporated into the scoring.

Granite outcrops are well represented in the literature, and are acknowledged as supporting unique and diverse flora and fauna, both terrestrial and aquatic. As well as their ecological value, granite outcrops also have tourism value and cultural significance to indigenous communities. The diverse values of granite outcrops are well documented in a collation of papers from the Granite Outcrops Symposium in 1996 (The Journal of the Royal Society of Western Australia 1997). In light of this knowledge, granite outcrops are automatically assigned to the high conservation significance category and will not be discussed further.

A detailed description of the process used to evaluate the conservation significance of basin wetlands is outlined in section 4.4. Wetlands are initially assessed for their known ecological significance, where they can be automatically assigned to the high conservation significance category depending on the criteria met. Wetlands are then assessed for their inferred naturalness using indicators such as land use, vegetation and structures. A score between one and three is calculated for the inferred naturalness criterion. A score of one indicates a low value (e.g. highly modified), and a score of three indicates a high value (e.g. close to natural). Once assessed for their known ecological significance and inferred naturalness, supplementary criteria, including representativeness and human significance indicators are incorporated into the scoring.

The interpretation of aerial photography, with regard to the buffer vegetation extent, connectivity and impacts of structures around wetlands can be very subjective. This subjectivity can be reduced by having well defined descriptions of each category, as specified in the mapping methodology developed by Lizamore*, et al.* (2008).

The measures used to evaluate each of the criteria are limited to the extent of data available for the entire region. Where on-ground survey data is available the wetland should be evaluated using a more detailed evaluation methodology. A stage three (as specified by Department of Environment and Conservation 2007) wetland evaluation methodology for inundated basin wetlands in the Avon NRM region is currently being trialled by DEC (Jones*, et al.* 2008).

4.1 Known Ecological Significance

The following policies and listings are already in place to identify wetlands that have ecological significance for their scientific or educational value. Existing mechanisms, such as Ramsar, incorporate criteria such as rarity, representativeness and diversity into their evaluation of potential wetlands. The incorporation of these indicators into the scoring is explained in Section 4.4.

- The Ramsar Convention on Wetlands (UNESCO 1971, Ward and Voelz 1994)

- State government endorsed candidate sites for the Ramsar Convention on Wetlands

- Directory of Important Wetlands (Environment Australia 2001)

- Environmental Protection (South West Agricultural Zone Wetlands) Policy, 1998

- Threatened and Priority fauna. The DEC 'Threatened and Priority Fauna Database' contains records of observations of any fauna listed as threatened under the Wildlife Conservation Act (1950), or listed on the DEC Priority Fauna List (current August 2007). By incorporating this GIS dataset into the wetland mapping layer, any records of rare and threatened fauna that fall within the mapped wetland boundary are identified. DEC databases of rare and threatened flora, fauna and communities include those identified under the Environmental Protection and Biodiversity Conservation Act, 1999.

- Threatened and Priority flora. The DEC 'Declared and Endangered Flora' dataset contains records of observations of flora populations listed as threatened (declared rare) or priority. By incorporating this GIS dataset into the wetland mapping layer, any records of threatened or priority flora that fall within 50m of the mapped wetland boundary are identified.

- Threatened and Priority Ecological Communities (TEC/PEC). The DEC 'Threatened Ecological Community Sites in WA' dataset identifies points at which the TEC's and PEC's have been recorded. By incorporating this GIS datasets into the wetland mapping layer, any TEC/PEC sites that fall within 50m of the mapped wetland boundary are identified. A list of TEC's assigned to the Avon-Wheatbelt are listed in Appendix E.

- Fresh-subsaline basins. Due to the ever-increasing problem with dryland salinisation in the Avon NRM region, freshwater has become a threatened water chemistry among basin wetlands. Freshwater wetlands are important to conserve because they:
  - are known to support around 80% of the invertebrate species found in the Wheatbelt
  - generally support a diverse array of wetland-associated flora and fauna
  - are an important resource for both human and stock drinking water

  A combination of landscape position, geology, vegetation cover and two other remote sensing products (as outlined in section 3.5) have been used to determine whether a wetland is likely to be fresh-subsaline or saline. Although it is recognised that this indicator overestimates the number of fresh-subsaline basins, the precautionary principle has been used and it has been incorporated into the scoring.

4.2 Inferred Naturalness

Naturalness for the purposes of this methodology is defined as *the degree to which the wetland has deviated from its pre-european state.*

Wetlands that are close to being in a natural state have a high scientific, educational and ecosystem service value as they are representative of pre-european conditions. They also provide an amenity value, as humans tend to be attracted to aesthetically pleasing sites for relaxation and leisure activities (e.g. bird-watching).

Onground information is not available for each of the thousands of basin wetlands in the Avon NRM region. As a lesser substitute to detailed data, the naturalness of a wetland can be estimated from the interpretation of aerial photography and analysis of remote sensing products. The methodology presented in this document uses information on land use, structures and vegetation within and around the wetland to conduct this estimation.

Inferred naturalness is initially scored according to degrading landuse, and the amount, likely condition, and connectivity of surrounding vegetation. This score is then adjusted according to the presence of degrading structures, and the presence and recent change to vegetation within the wetland boundary.This score ranges from one (significantly changed from natural) to three (close to natural).

4.2.1 Percentage of degrading landuse within 1km of the mapped wetland boundary

The method of calculating this index assumes that less than 20% of the area within 1km of a near-natural wetland is used for purposes that are degrading to the integrity of that wetland.

The impact of degrading landuses such as agriculture, urban and industrial areas on wetland ecosystems is well documented in the literature (a good summary is given by Davis and Froend 1999). General consequences of degrading landuse on wetlands are: altered hydrological regimes, nutrient enrichment, salinization, pesticide and heavy metal pollution and the introduction of alien species. It has also been documented that greater than 90% of seasonal clay-based wetland communities have been lost due to clearing for agriculture in the south-west of Western Australia (Gibson*, et al.* 2005). Collier and Quinn (2003) also recorded that stream macroinvertebrate communities are less stable at sites surrounded by pasture, compared to those in a forested area.

The impact of landuse on wetland systems largely relies on the landscape position and climatic setting of the wetland (e.g. area of surrounding catchment, runoff, proximity of degrading landuse to the wetland). At a regional scale, it is difficult to gather this information for each wetland. Therefore, this methodology uses an arbitrary measure of 1km from the mapped wetland boundary to get an indication of the potential degradation caused by surrounding landuse practices.

Landuse data is available for the entire study area from the National Land and Water Resources Audit (Beeston*, et al.* 2002). In addition to this, the dataset, “Wetlands of the Wheatbelt and other prioritized areas”, was added to the landuse dataset, so that the different types of wetlands (basin, flat, channel, slope etc.) became categories of land use. The NLWRA landuse layer (Beeston*, et al.* 2002) was also displayed over aerial photography and the area scanned for large intact bush blocks (>1km square) that have been zoned as agricultural. The percentage of degrading landuse was re-assessed for wetlands located within 1km of these intact bush blocks so that the bush areas were not included as a degrading landuse.

The land uses with a negative impact on wetlands, such as agriculture, urban and industrial, are summed, and the indicator scored using the criteria outlined in Table 5. The impact of livestock grazing, which is only indicated on the NLWRA landuse dataset to occur beyond the clearing line, could not be determined at this scale. Therefore it is not included as a degrading landuse in this methodology.

Table 5 - Land use percentage categories for each indicator score

Sum degrading land use within 1km of wetland	Score
>80	1
20 – 80%	2
<20%	3

In Figure 10 below, the approximate land use percentages within 1km of the bold-outlined wetland would be 55% channel wetland, 25% cropping, 10% nature reserve and 10% basin wetland. Using the scoring system in Table 5, this wetland would receive a score of 2 as it has 25% degrading land uses within 1 km of the boundary.

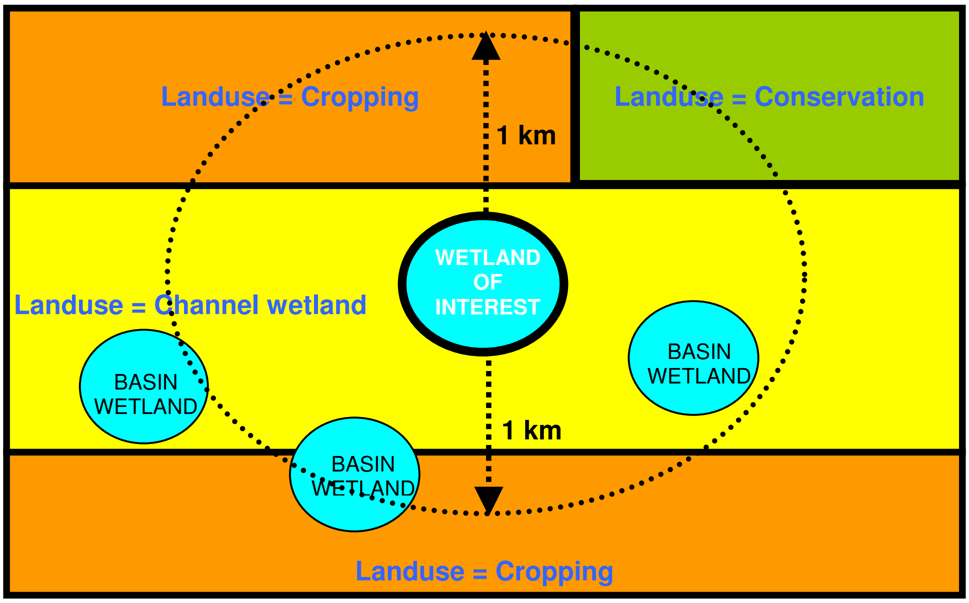


Figure 10 - Diagram representing the calculation of land use percentages

Some examples of aerial photography displaying the application of this categorisation is also shown in Figure 11 below.

0% degrading landuse (3) 51% degrading landuse (2) 91% degrading landuse (1)

Figure 11 - Aerial photography showing wetlands with different amounts of degrading landuse surrounding them. Resulting scores are shown in brackets.

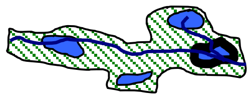
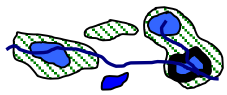
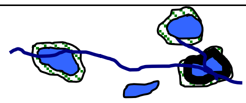
4.2.2 The degree of vegetation connectivity between hydrologically connected wetlands

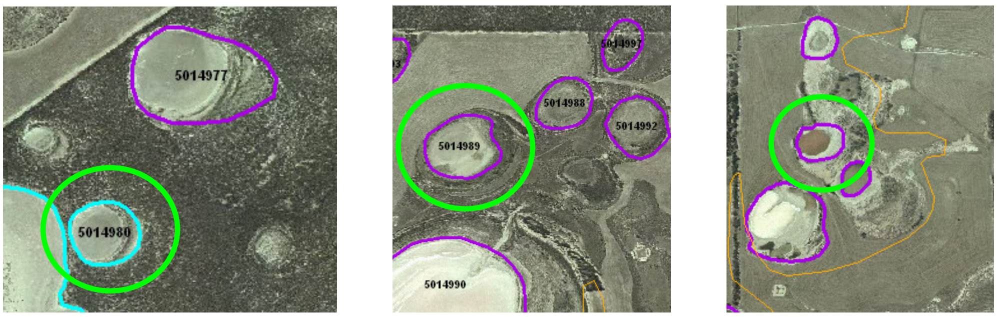
The method of calculating this index assumes that near-natural wetlands have extensive buffer vegetation connecting them to other hydrologically connected wetlands.

Wetlands that have good vegetation connections with other hydrologically linked wetlands are performing an ecosystem service. They provide habitat corridors for wetland-dependant species to move from one wetland to another as well as pathways for seed dispersal of wetland vegetation.

The degree of vegetation connectivity between hydrologically connected wetlands is determined by analysing aerial photography at a scale of 1:10,000. By looking for connecting vegetation patterns of wetlands that are hydrologically connected, it is possible to place the wetland into one of three categories. A written and graphical description of these categories is show in Table 6 and Figure 12 below. If the wetland is hydrologically isolated from other wetlands, no score is given for this index.

Table 6 - Description of vegetation connectivity categories and scoring adapted from Kotze*, et al.* 2005 (basin of interest has a bold outline)

Category (Score)	Description	Graphical description
High (3)	Vegetation surrounding the mapped wetland boundary is extensively connected with all other hydrologically connected wetlands	
Intermediate (2)	Vegetation surrounding the mapped wetland boundary is connected with some other hydrologically connected wetlands	
Low (1)	Vegetation surrounding the mapped wetland boundary is not connected with other hydrologically connected wetlands	



High connectivity (3) | Intermediate connectivity (2) | Low connectivity (1)

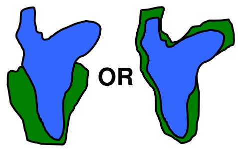
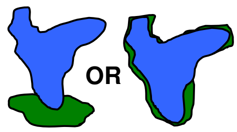
Figure 12 - Aerial photography showing the different levels of vegetation connectivity between hydrologically linked wetlands. Resulting scores for the basin circled in green are shown in brackets.

4.2.3 Amount of perennial vegetation within 50m of the mapped wetland boundary, incorporating change to woody perennial vegetation in this area from 1990 to 2007.

The method of calculating this index assumes that near-natural wetlands have greater than 75% perennial vegetation remaining within 50m of the mapped wetland boundary, which has not significantly declined from 1990 to 2007.

The amount of perennial vegetation remaining within 50m of the mapped wetland boundary is estimated from the analysis of aerial photography at a scale of 1:10,000. Table 7 gives written and graphical descriptions of the three categories, with the scores associated with each category in brackets (from Kotze*, et al.* 2005).

Table 7 - Description of surrounding vegetation categories adapted from Kotze*, et al.* 2005

Category (Score)	Description	Graphical description
High (3)	Greater than 75% of perennial vegetation remaining within 50m of the mapped wetland boundary	
Intermediate (2)	Between 25 & 75% of perennial vegetation remaining within 50m of the mapped wetland boundary	
Low (1)	Less than 25% of perennial vegetation remaining within 50m of the mapped wetland boundary	

The score for the amount of perennial vegetation within 50m of the mapped wetland boundary is downgraded according to the percent decrease in woody perennial vegetation cover in this area from 1990 - 2007. The change in woody perennial vegetation cover can be calculated from the vegetation monitoring product: “Vegetation change 1988-2007” (Caccetta*, et al.* 2000). This product was created from the Land Monitor II project as perennial vegetation cover can be calculated and classified for each year in a sequence of consistently processed imagery. By downgrading the score according to recent vegetation decline it is assumed that the recent decline indicates the current condition of the vegetation, which cannot always be determined from the interpretation of aerial photography.

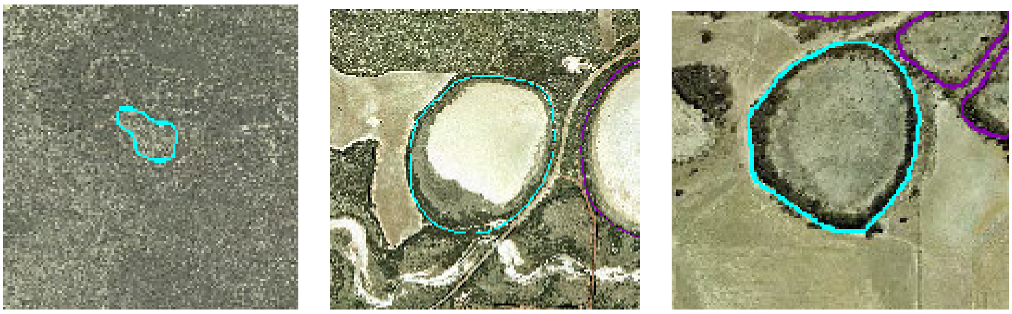
The scores are adjusted according to the following rules:

- >66% decline from 1990 to 2007 – subtract 0.67 from score
- 33 – 66% decline from 1990 to 2007 – subtract 0.33 from score
- 15 – 33% decline from 1990 to 2007 – subtract 0.17 from score
- <15% decline no adjustment made to score
- The score is also truncated so that it cannot go below one or above three

Wetlands that are located in bushland areas that are likely to have had a fire between 1990 and 2007 will not have their score downgraded for recent vegetation decline. This is because fire is a natural process that wetlands can, and usually do, recover from.

Fire events can be derived from fire scar maps, which are produced by Landgate every 9 days. However, after comparing the change in vegetation cover with aerial photography and fire scar maps, it appears that these maps do not cover all burnt areas. This is particularly the case for wetlands beyond the clearing line. Therefore wetlands beyond the clearing line are not downgraded for any vegetation loss. Wetlands inside the clearing line are analysed using fire scar maps and aerial photography, and those believed to have been burnt recently are also not downgraded for vegetation loss.

Three examples of the application of this scoring is shown in Figure 13 below.



High with no loss (3) | Intermediate with 7% recent loss (2.00) | Low with 22% recent loss (1.00)

Figure 13 - Aerial photography showing the different amounts of surrounding vegetation with varying degrees of recent (1990-2007) vegetation loss. Resulting scores are shown in brackets.

Limitations – LandMonitor has a limited ability to indicate the quality of woody perennial vegetation cover in each $25m^2$ pixel. A pixel is considered to be vegetated if there is greater than 20% woody perennial vegetation cover. Therefore even if the vegetation cover for that pixel declines from 70% to 25% cover, it will not be picked up as a decline using this method.

The reason for a decline in woody perennial vegetation cover from 1990 – 2007 at the included wetlands (i.e. those not burnt) is assumed to be due to degrading processes, such as clearing or dryland salinity. Some wetlands could be inaccurately scored for this due to other natural processes causing a decline in vegetation, such as flooding.

Low-lying vegetation (e.g. Samphire), which generally occurs around naturally saline wetlands, is not detected by LandMonitor and its decline is therefore also undetected. This means that wetlands that are surrounded by low-lying vegetation that is declining will not be downgraded accordingly.

Once the scores for landuse, vegetation connectivity and surrounding vegetation amount and change are calculated, they are averaged to produce a score between one and three. These scores are then adjusted according to the presence of structures or vegetation within the boundary where applicable.

4.2.4 Adjustment for the degrading impact of structures within or around the mapped wetland boundary

The presence of structures such as dams, roads and drains is assumed to be degrading to the wetland through a change in hydrology and water quality (in the case of drains).

The presence of degrading structures can be detected from the analysis of aerial photography at a scale of 1:10,000. The likely impacts of degrading structures, such as dams, drains, roads and buildings, can be estimated using the descriptions in Table 8 (from Lizamore*, et al.* 2008).

A negative adjustment is made to the score calculated thus far to account for the presence of moderate or major impacts. The amount subtracted from the score is shown in brackets.

Table 8 – Categories and descriptions of the impact of structures (with corresponding score adjustments) from Lizamore*, et al.* 2008

Impact category (Score Adjustment)	Description of impact
None (0)	No impact detected.
Minor (0)	An isolated impact. The structure does not appear to have altered the hydrology or the structure of the wetland.
Moderate (-0.17)	The impact is more pronounced. The hydrology of the wetland is most likely altered or disturbance of the wetland is more than 10% of the surface area.
Major (-0.33)	The impact is severe. The hydrology of the wetland is very likely to be altered, and/or more than 30% of the surface of the wetland area is disturbed

Some examples of the application of this impact categorization of structures is shown in Figure 14 below.

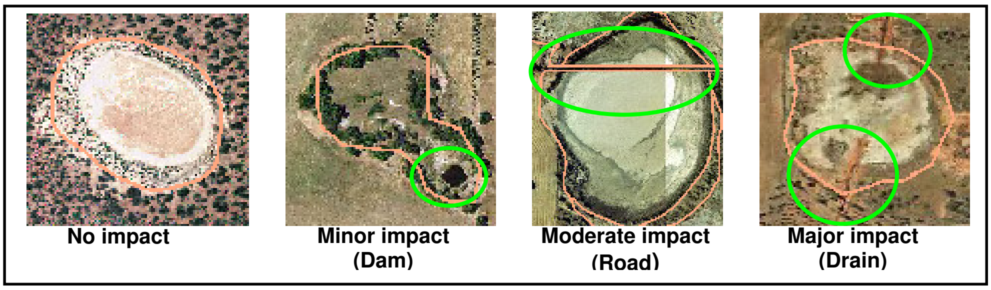


Figure 14 - Aerial shots of four wetlands showing the different impact levels. The impact is circled in green and the mapped wetland boundary is delineated in pink.

4.2.5 Adjustment for the presence of significant vegetation within the boundary, taking into account any decline from 1990 to 2007.

The presence of a significant amount of vegetation across the basin of a wetland is assumed to be an indication of additional habitat availability. Therefore the average score calculated thus far is upgraded according to the amount and likely condition of this vegetation.

The percentage of vegetation across the basin is derived using the remote sensing product "Vegetation change 1988-2007" (Caccetta, *et al.* 2000), as previously described in section 4.2.3. The percentage of vegetation within the wetland boundary is calculated in 1990 and then again in 2007.

From comparisons of aerial photography with the percentage of vegetation cover across the basin, forty percent vegetation cover within the mapped wetland boundary appears to reliably indicate the presence of vegetation across the wetland basin rather than around the periphery. Therefore, wetlands that have greater than 40% of perennial vegetation across the wetland basin in 2007 will have their score upgraded.

The amount that the score is upgraded depends on the percentage of vegetation loss since 1990. The following decision rules apply:

- Wetlands with greater than 40% vegetation within the boundary in 2007 and have had less than 10% decline since 1990 have 0.67 added to the score
- Wetlands with greater than 40% vegetation within the boundary in 2007 and have had between 10 and 40% decline since 1990 have 0.50 added to the score
- Wetlands with greater than 40% vegetation within the boundary in 2007 and have had 40% - 60% decline since 1990 have 0.33 added to the score

Wetlands located in bushland areas that are likely to have had a fire between 1990 and 2007 retain the percentage of vegetation that was within the mapped boundary in 1990. The exception to this rule is reservoirs built between 1990 and 2007 that are located in areas likely to have been burnt. Three examples of the application of this scoring is shown in Figure 15 below.

58% cover within boundary and no recent loss (+0.67)	42% cover within boundary and 15% recent loss (+0.50)	56% cover within boundary and 42% recent loss (+0.33)

Figure 15 - Aerial photography showing percent vegetation within the boundary and percent decline from 1990 to 2007. Resulting scores are shown in brackets.

Limitations – The same limitations apply to this indicator as for section 4.2.3. An additional limitation is wetlands with less than 40% vegetation cover within the mapped wetland boundary may, in reality, have vegetation present across the basin. Therefore there may be some basins with vegetation cover across the basin that will not have an adjustment made to the score.

The final scoring of the inferred naturalness criterion is outlined in Figure 16 below. A score of three indicates a wetland is likely to be close to natural, and a score of one indicates a wetland is likely to be severely degraded. Scores cannot be higher than three, or lower than one. Some worked examples of the whole scoring process are shown in Appendix C.

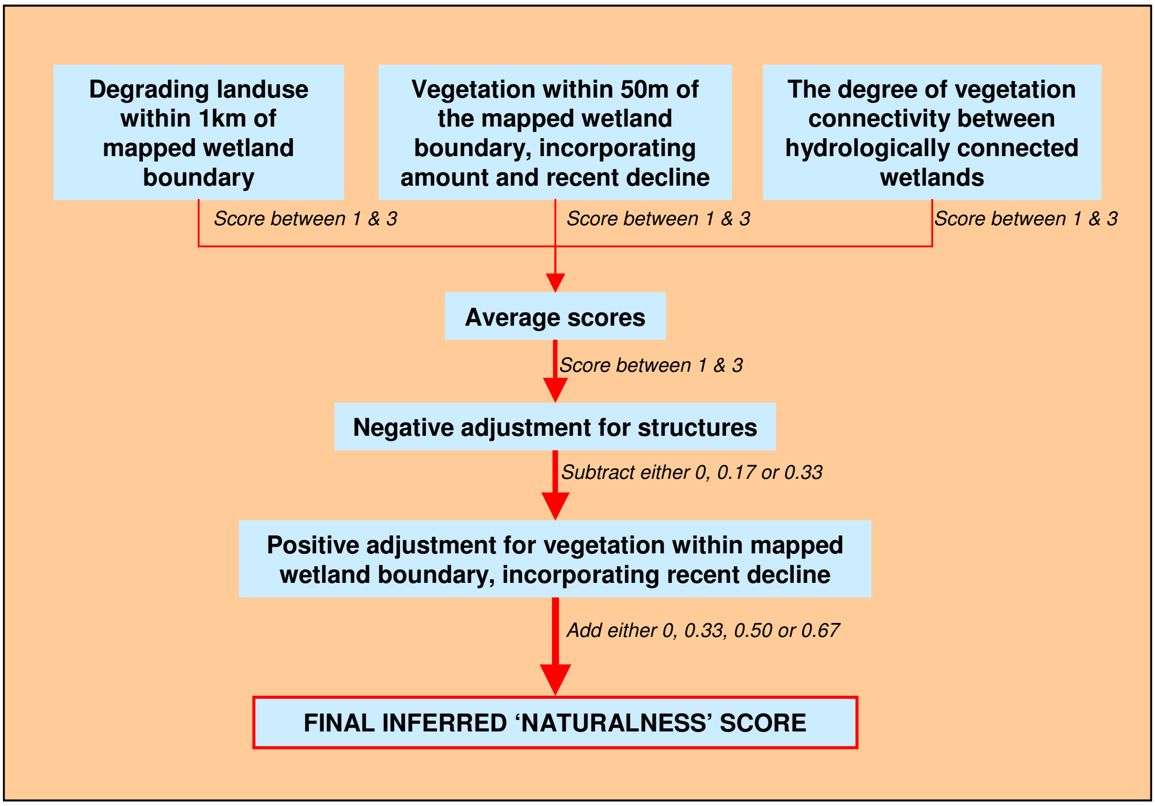


Figure 16 - Diagram summarising the scoring of the inferred 'naturalness' criterion

4.2.6 Derivation of scoring

In order to ensure the scores resulting from the above calculations (Figure 16) were logical, visual assessments of the basins were conducted using aerial photography. The scoring system was adjusted so that the final "naturalness" scores more closely matched 'naturalness' as determined by expert opinion (visual scoring of 2000 wetlands from aerial photographs by multiple wetland ecologists). This was a way of making sure the calculated scores were not overly biased towards low or high scores as a result of mathematical manipulation of the data.

4.3 Known Human Significance

The following documents and registers are in place to identify wetlands that are important to the community for their consumptive use, recreational, spiritual or philosophical values. The incorporation of these indicators into the scoring of conservation significance is discussed in section 4.4.

4.3.1 Consumptive use value

Wetlands that are identified as Public Drinking Water Supply Areas (PDWSA; Department of Water 2007) and Protection Zones covered under the Country Areas Water Supply Act, 1947 should be protected against degradation so that their consumptive use value is not compromised. The PDWSA's in the Avon NRM region are:

- Bolgart Water Reserve
- Brookton-Happy Valley Water Reserve
- Brookton Water Supply Catchment Area
- Bull Road Wellfield
- Yerecoin Water Reserve

4.3.2 Recreational value

Protecting wetlands that have recreational value to the local community is important to the mental health and well-being of community members.

Currently, the only wetlands that are recognised for their recreational value are those identified during the Salinity Investment Framework project. The Salinity Investment Framework (Department of Environment 2003) identified biodiversity, water resource, economic and social assets within the Avon NRM region. The purpose of the SIF was to determine NRM investment priorities to help manage salinity, so that assets of high public value at high threat from salinity are managed effectively. These are listed in the Avon Natural Resource Management Plan: Water Resource Supporting Document (Avon Catchment Council 2004, Appendix D).

4.3.3 Philosphical/spiritual value

Wetlands with a high philosophical or spiritual value are vital to a communities 'sense of place', and thus should be conserved. The following documents and registers, provide listings of the wetlands in the Avon NRM region, which are currently considered to have high biodiversity, water resource, philosophical or spiritual value. This is not an exhaustive list, as the philosophical or spiritual value of many wetlands has not been realised, however these were the only resources available for inclusion in this methodology.

- Avon Natural Resource Management Plan: Water Resource Supporting Document- mapped and identifiable regional water assets listed in Appendix D (Avon Catchment Council 2004). These consist of:
  - National Priority Water Resource Assets derived from the Australian Biodiversity Audit
  - State Priority Water Resource Assets derived from the Salinity Investment Framework
  - Local Water Resource Assets of Regional Priority derived from Local Government Authority-scale inventories
- Registered Aboriginal Site managed by the Department of Indigenous Affairs
- World heritage list (Wold Heritage Convention). There are currently no World Heritage sites that include wetlands in the Avon NRM region.

- Heritage listings controlled by the Commonwealth [Register of the National Estate (Australian Heritage Commission 1990), The National Heritage List, The Commonwealth Heritage List]. Currently, there are no basin or granite outcrop wetlands within the Avon NRM region that are listed on The National Heritage List or The Commonwealth Heritage List. There are many natural areas within the Avon NRM region, however, that are listed on the Register of the National Estate that have basin and granite outcrop wetlands within them.

4.4 Steps to assess the conservation significance of a wetland

Using the indicators outlined in sections 4.1 - 4.3, a wetland is assigned to one of three conservation significance categories using the steps outlined below. These are displayed graphically in Figure 17 and worked examples are provided in Appendix C:

1. Classify the wetland into a group as described in section 3.

2. Automatic High's – Wetlands that are granite outcrops or; Ramsar, Directory of Important Wetlands or Environmental Protection Policy listed, or support declared rare or threatened flora, fauna or communities (note that this does not include Priority species and communities) are automatically assigned to the high conservation significance category. See section 4.1 for further details of these listings.

3. If the wetland is not automatically of high conservation significance, then it is assessed for inferred 'naturalness' following the guidelines provided in section 4.2. If a wetland is in the high category, it is automatically of high conservation significance. If the wetland is in the low category, continue to step 4, if the wetland is in the intermediate category, continue to step 5 of this scoring procedure.

4. If the wetland has a known occurrence of species or community listed as 'priority' in the DEC corporate database, or the wetland is indicated to be fresh - subsaline (section 4.1), its significance is increased to intermediate. Wetlands with a known human significance (see section 4.3 e.g. recreational area) are also considered to be at least of intermediate conservation significance. For example, if the wetland has a low inferred 'naturalness' score, but has a known occurrence of a priority species, it is assigned to the intermediate conservation significance category. Continue the assessment.

5. After each wetland in a catchment has been assessed using steps 1 to 4 above, ensure that within each major catchment, each wetland group from the classification has a representative of high conservation significance. From the dataset "Hydrographic Catchments – Catchments", developed by the Department of Water, there are seven catchments within the Avon NRM region boundary: Swan-Avon Mortlock, Swan-Avon Main Avon, Swan–Avon Salt River, Swan-Avon Yilgarn, Swan-Avon Lockhart, Culham Inlet Phillips West Steere and Magenta Internal. If there is not, assess whether the wetland of interest is the best representative (i.e. has the highest inferred 'naturalness' score) of that group, within that catchment. If the wetland of interest is the best representative of the wetland group, it is assigned to the high conservation significance category. Catchments in which mapping and classification do not cover greater than 75% of the catchment area are excluded (e.g. Culham Inlet Phillips West Steere). Reservoirs are also excluded as they are artificial basins. If this rule is not applicable, continue the assessment.

6. If steps four and five do not affect the conservation significance category, the significance of the wetland remains as in step 3.

7. When updated or on-ground data becomes available, re-evaluate the wetland using the method appropriate for the level of assessment (i.e. Stage 2 or 3).

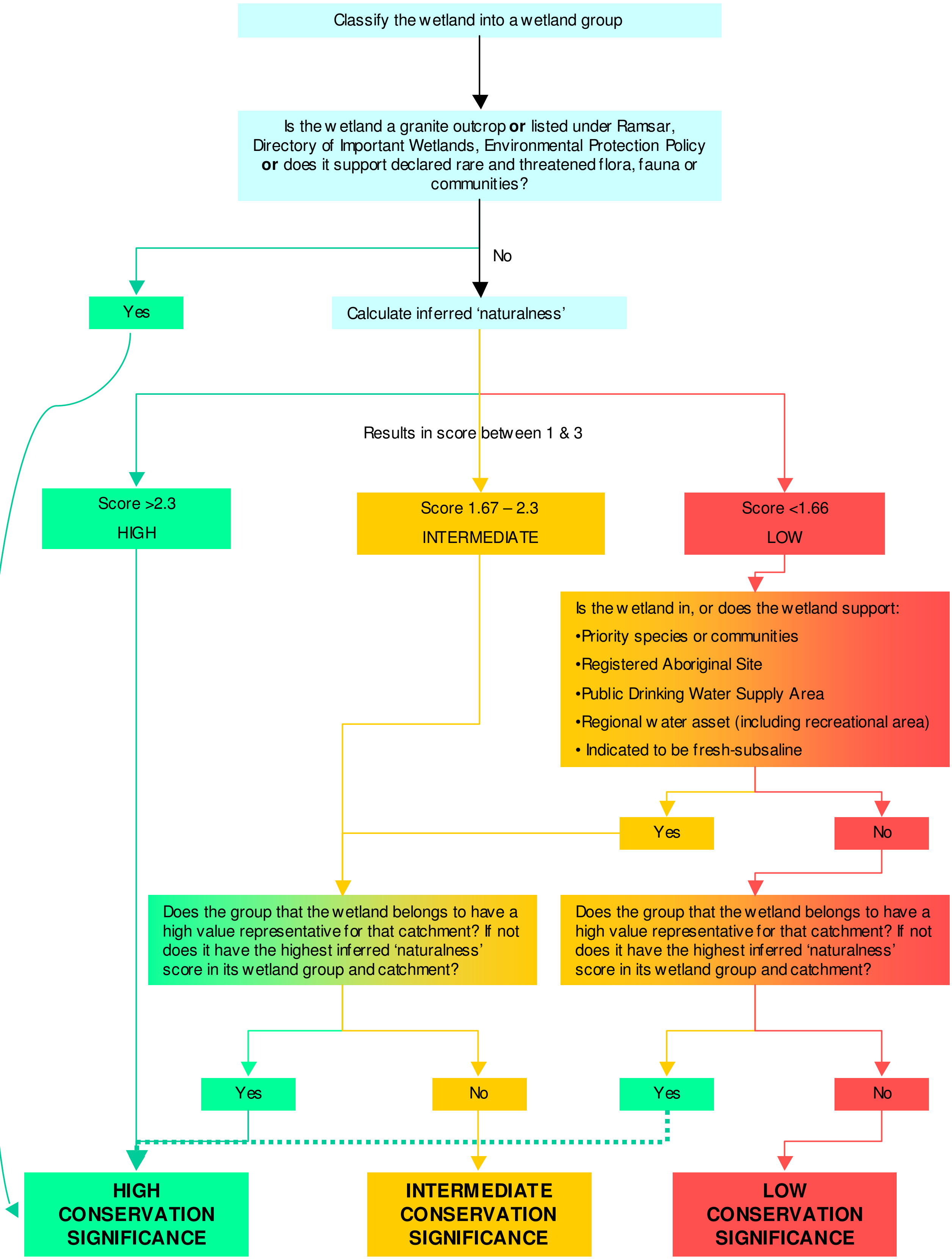


Figure 17 - Flow diagram outlining the steps in evaluating a mapped basin wetland at a regional scale

5. Application of Avon Stage 1 Methodology

The methodology presented in this document was followed to produce evaluations for every basin and granite outcrop wetland greater than one hectare, digitised in the dataset “Wetlands of the Wheatbelt and other prioritized areas” (region outlined in Figure 1). An overview of these evaluations is presented in Figure 18 below.

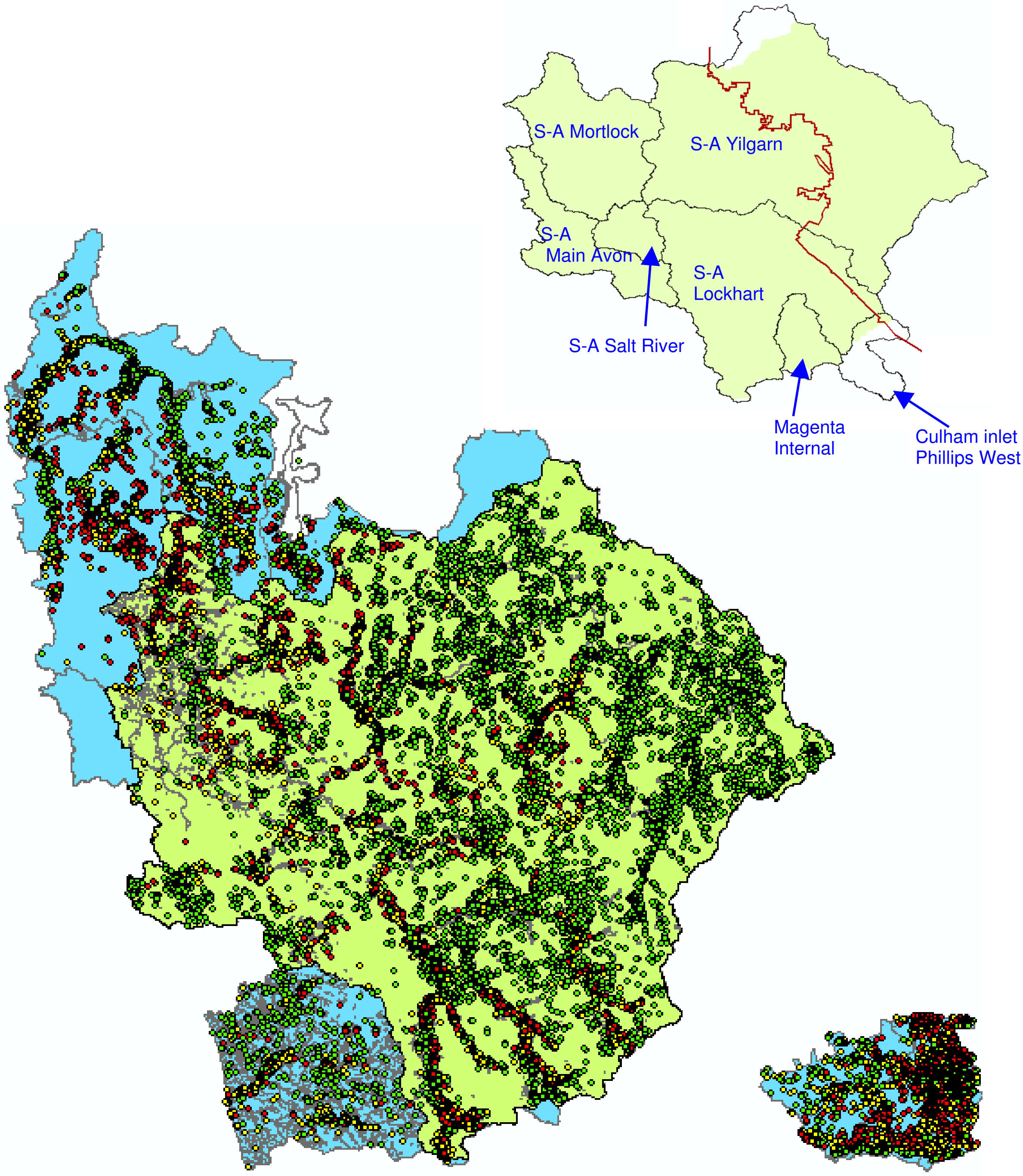


Figure 18 - Wetland evaluations for the area of application as shown in Figure 1. Green, yellow and red points represent wetlands of high, intermediate and low conservation significance respectively. Note, granite outcrops are included in this figure. Insert shows the catchment boundaries within the Avon NRM region and the clearing line (in red).

5.1 Summary statistics for the Avon NRM region

Summary statistics of the number of basins calculated to have high, intermediate and low conservation significance and their total area in each catchment of the Avon NRM region (note granite outcrops are not included) are presented in Table 9 below. Figure 18 also shows the catchments in the Avon.

In the Avon NRM region, the catchment with the largest area of basin wetlands was the Yilgarn, which also had the highest percentage of high conservation significance basins, both in area and number. This is caused by the large number of basins beyond the clearing line, which are predominantly of high conservation significance. The catchment with the second highest percentage of high conservation significance basins was Magenta Internal, however this catchment has a small area of basin wetlands relative to other catchments.

In the Avon NRM region, the Swan-Avon Mortlock catchment had the largest percentage of basin wetlands of low conservation significance in terms of number and the second largest in terms of area.

Table 9 - Summary statistics for each conservation significance category and catchment. Note that numbers in brackets are percentages of the sum column and granite outcrops are not included in figures.

		Final Score			
Catchment		**High**	**Intermediate**	**Low**	**Sum (%)**
Culham Inlet Phillips West Steere	# (%)	22 (44)	17 (34)	11 (22)	**50 (<1)**
	Hectares (%)	1060 (83)	91 (7)	121 (10)	**1272 (<1)**
Magenta Internal	# (%)	323 (50)	188 (29)	139 (21)	**650 (6)**
	Hectares (%)	17773 (73)	5040 (21)	1596 (7)	**24409 (8)**
Swan-Avon Lockhart	# (%)	1099 (35)	1178 (38)	825 (27)	**3102 (27)**
	Hectares (%)	52216 (59)	28049 (32)	7728 (9)	**87993 (27)**
Swan-Avon Main Avon	# (%)	26 (17)	85 (55)	44 (28)	**155 (1)**
	Hectares (%)	1045 (48)	700 (32)	411 (19)	**2156 (<1)**
Swan-Avon Mortlock	# (%)	537 (22)	924 (38)	990 (40)	**2451 (21)**
	Hectares (%)	20872 (45)	17927 (39)	7397 (16)	**46196 (14)**
Swan-Avon Salt River	# (%)	74 (45)	53 (33)	36 (22)	**163 (1)**
	Hectares (%)	1713 (57)	898 (30)	369 (12)	**2980 (1)**
Swan-Avon Yilgarn	# (%)	3581 (73)	789 (16)	562 (11)	**4932 (43)**
	Hectares (%)	141957 (90)	11870 (8)	4311 (3)	**158138 (49)**
Total number in each evaluation category (%)		**5662 (49)**	**3234 (28)**	**2607 (23)**	**11503**
Total number of hectares in each evaluation category (%)		**236634 (73)**	**64576 (20)**	**21932 (7)**	**323143**

The summary statistics for both the number and cumulative area of granite outcrops in the Avon NRM region is shown in Table 10 below. Note that granite outcrops are automatically of high conservation significance.

Table 10 - Granite outcrop statistics for catchments located in the Avon NRM region

Catchment	**Number of granite outcrops**	**Sum of hectares**
Culham Inlet Phillips West Steere	29	520
Magenta Internal	69	2017
Swan-Avon Lockhart	1608	32857
Swan-Avon Main Avon	430	1807
Swan-Avon Mortlock	427	2315
Swan-Avon Salt River	156	1506
Swan-Avon Yilgarn	3083	69034

5.2 Validation

Each evaluation produced by this methodology was double checked through visual assessment of aerial photography. This validation identified errors in the data contributing to the evaluation, in addition to detecting circumstances in which the evaluations may not be accurate.

It was found that around 8% of the basins had an error in the data contributing to the evaluations (e.g. wetland buffer and connectivity). These errors mainly occurred during the initial mapping and attribution of basins. The errors identified through the validation process have now been corrected and it is estimated that data errors are now below 5%.

It was observed that there may be two circumstances where the evaluations may not be accurate. These are:

- Isolated basin wetlands with an intermediate amount of buffer vegetation, surrounded by >80% degrading landuse. These basins are currently scored as of low conservation significance. Depending on the condition of the vegetation remaining, this evaluation may underestimate the conservation significance of the wetland, however this can only be confirmed with ground-truthing.

- Isolated basin wetlands with a low amount of buffer vegetation, surrounded by >80% of degrading landuse that are indicated to be fresh-subsaline. These basins are currently scored as of intermediate conservation significance. Depending on the actual salinity of the wetland, this evaluation may overestimate the conservation significance of the wetland, however this can only be confirmed with ground-truthing.

5.2.1 Availability of recent orthophotos

Unfortunately, due to the large area of application and budgetary restraints, up to date orthophotos could not be purchased for the attribution of vegetation and structures information to the mapped basins in the study area. The orthophotos used were those available within DEC and the date of capture of these ranges from 1998 to 2005. Consequently, some of this information, particularly the structures information, will require updating when additional imagery becomes available.

Ideally, the most accurate way to validate these evaluations is to conduct on-ground assessments using a Stage Three methodology. Such a methodology for the Avon NRM region is currently being trialled by Jones*, et al.* (2008), and will provide a more objective validation tool once finalised.

6. Final comments and recommendations

- This methodology outlines a method for assigning wetlands within the Avon NRM region to one of three conservation significance categories, but is also applicable to wetlands in the wider Wheatbelt area.

- This is a desktop-based, regional-scale mapping and assessment process to guide decision making in a strategic way. Due to the constraints caused by the lack of available data for the entire region, it is vital that the data feeding into the evaluations are ground-truthed where any significant management decisions are to be made.

- Many of the techniques presented in this document are innovative and have not previously been used for evaluating the conservation significance of wetlands. Techniques such as remote sensing provide a valuable resource in terms of remote monitoring and information gathering. There is a real need to continue validating the information produced from techniques such as surface water detection and salinity so that they might be further refined and applied to different areas of the state. This is particularly applicable considering the current threat of climate change and hence the need for large-scale trend analysis.

- This methodology should be reviewed in the future to incorporate recent advances in remote sensing techniques.

- The results of this methodology, presented in section 5, should be revised on an annual basis to incorporate updated onground information with regard to salinity and records of declared rare, threatened and priority flora, fauna and communities.

- The results of this methodology should also be revised when updated orthophotos become available. This would involve checking the following attributes: amount of vegetation within 50m of the mapped wetland boundary, amount of vegetation connectivity with other hydrologically connected wetlands and the impact of structures on the hydrology of the basin.

- The results of this methodology should also be revised when updated datasets become available. For example, the NLWRA landuse dataset.

- The results of this methodology should also be revised when updated satellite imagery becomes available. This would involve the recalculation of: vegatation change within 50m of the mapped boundary and within the mapped boundary, as well as the indicated salinity and hydroperiod used in the classification.

- This methodology should be extended in future investments to include the assessment of the conservation significance of wetlands with flat, channel and slope landforms.

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Appendix A- Previous studies conducted on wetlands in the Avon NRM region

Study / Paper name	Organisation / Authors	# Wetlands in Avon NRM	Data collected				
			Inverte-brate	Water Quality	Water-bird	Depth	Flora
Wheatbelt biological survey, 1997 - 2001	DEC.	~100	✓	✓	✓	✓	✓
Wheatbelt monitoring program, 1997 - current	DEC	10	✓	✓	✓	✓	✓
Assessment of conservation status of wetlands in the Trayning area in relation to disposal of deep drainage water	Bennelongia Pty Ltd 2007	7	✓	✓	✓		✓
Oral histories documenting changes in Wheatbelt wetlands	Sanders 1991	Many					
Lake McDermott BioBlitz	Davis 2005	1			✓		✓
Kununoppin BioBlitz	Davis 2005	1			✓		✓
Moningarin BioBlitz	Davis 2005	1			✓		✓
Waterbirds in nature reserves of south-western Australia 1981-1985	Jaensch, *et al.* 1988	71		✓	✓	✓	✓
Annual waterfowl counts in South-Western Australia: 1988 – 1992	Halse, *et al.* 1990, Halse, *et al.* 1995, Halse, *et al.* 1992, Halse, *et al.* 1994	107			✓		
Vegetation of depth-gauged wetlands in nature reserves of the south-west Western Australia	Halse, *et al.* 1993	~22				✓	✓
Wheatbelt Geochemical Risk Assessment and Management Project	Dept of Water	53		✓			
A biological survey of the agricultural zone: vegetation and vascular flora of Drummond Nature Reserve	Keighery, *et al.* 2002	2					✓
Wetland characteristics and waterbird use of wetlands in south-western Australia	Halse, *et al.* 1993	~22		✓	✓	✓	✓
The aquatic macrophyte flora of saline wetlands in Western Australia in relation to salinity and permanence	Brock and Lane 1983	~18		✓		✓	✓
Depths and salinities of wetlands in south-western Australia: 1977-2000	Lane, *et al.* 2004	~36		✓		✓	

Appendix B- Detailed description of each wetland type found in the Avon NRM region

1. Naturally saline basins

Naturally saline basins (Figure 19) are mostly moderately to highly saline playas, but do include some mildly saline wetlands. These wetlands, especially the playas, support distinctive communities of endemic aquatic invertebrates and plants (generally restricted to the supra-littoral fringes, especially the lunettes). These wetlands can become degraded through the process of dryland salinisation (bottom photo in Figure 19) and those that are affected by this are referred to as ‘degraded naturally saline basins’.

Features of naturally saline basins are:

- Salinity greater than 10ppt (can be greater than 300ppt when the wetland is drying out)
- Generally alkaline water, though some are naturally acidic
- Generally clear water, although can become turbid in windy conditions
- Intermittent to seasonal inundation (i.e. playas and sumplands)
- Lunettes and associated crescentic embayments present on the downwind side of the basin
- Diverse and highly endemic vegetation communities on wetland fringes
- Vegetation patterning on the margins of these systems is complex and driven by edaphic factors such as soil texture, salinity, pH and gypsum content - coupled with elevation. Chenopod communities dominate lower elevations (typically *Tecticonia* spp. - formerley *Halosarcia*) and give way to *Melaleuca* and *Acacia* dominated shrublands upslope. These communities also include a rich herbaceous flora *(Pers comm. M. Lyons, DEC, April 2008)*. Alternatively, there is no vegetation present.
- During the wet phase, naturally saline basins may contain the widespread salt tolerant aquatic species: *Ruppia polycarpa, Ruppia megacarpa,* and *Lepilaena preissii (Pers comm. M. Lyons, DEC, April 2008)*.

Features of degraded naturally saline wetlands are:

- Evidence of death of the surrounding terrestrial vegetation due to an increase in water level
- More acidic (e.g pH 2 - 4) than most naturally saline wetlands. However, it is possible to have a naturally acidic saline basin.
- Unnaturally long inundation period compared to naturally saline basins – may be permanently inundated

a)  b) 

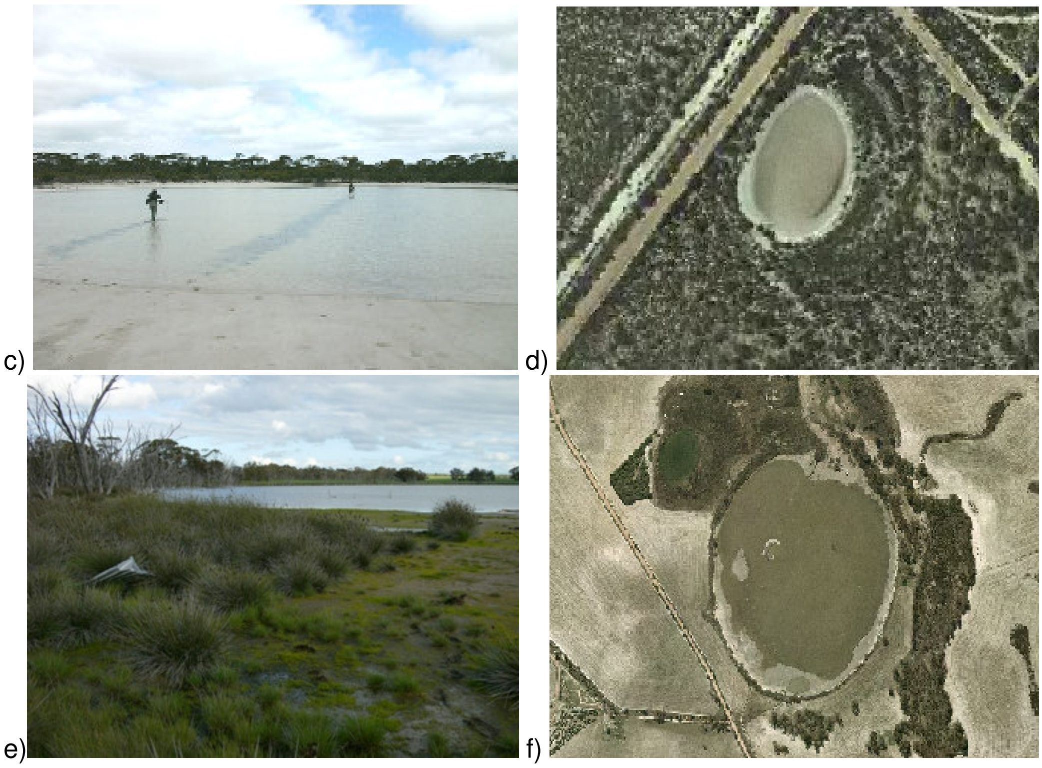


Figure 19 – a, b (Lake in Lake Magenta Nature Reserve) and c, d (Playa in Lake Cairlocup Nature Reserve) - naturally saline basins in good condition pictured from the ground (left) and aerial photography (right). e, f (lake east of Bejoording) – a degraded naturally saline basin, pictured from the ground (left) and from aerial photography (right)

2. Freshwater basins

Freshwater basins (Figure 20) support a diverse range of flora and fauna, particularly providing critical habitat during the breeding cycle of many waterbird species. Analysis of the SAP biological survey data for Wheatbelt wetlands indicates that freshwater wetlands support around 80% of the total invertebrate species richness found in all wetlands surveyed in the Wheatbelt (Pinder*, et al.* 2004).

Dryland salinisation has affected the hydrology, water chemistry (especially salinity and pH) and the associated aquatic and terrestrial flora (e.g. Cramer and Hobbs 2005, George*, et al.* 1995, Lyons*, et al.* 2007) and fauna (Clarke*, et al.* 2002, Halse*, et al.* 2003, Williams 1999) of many freshwater wetlands in the Wheatbelt. These wetlands are referred to as being 'secondarily salinised' (pictured on the bottom in Figure 20).

Features of freshwater basins are:

- Salinity naturally less than 3 ppt when wetland near capacity
- Varied depths
- Generally seasonal (sumplands), but sometimes episodic inundation (playas)
- In shallow freshwater wetlands, emergent vegetation such as Yate (*Eucalyptus occidentalis*), *Melaleuca strobophylla* and *Casuarina obesa* may occur in various combinations across the bed. In the northern Wheatbelt, *Eucalyptus occidentalis* is replaced by *Eucalyptus camaldulensis var. obtusa*. The periphehy of these wetlands contain a suite of annuals including *Agrostis avenacea, Elatine gratioloides,* and *Centipeda* spp. These latter species may occur accross the bed as the wetland dries *(Pers comm. M. Lyons, DEC, April 2008)*

- In higher rainfall areas, deeper freshwater basins are increasingly dominated by sedges including *Baumea articulata,* and *Baumea arthrophylla (Pers comm. M. Lyons, DEC, April 2008)*

Features of secondarily saline wetlands are:

- Salinity greater than 3ppt when wetland near capacity
- Evidence of death of the emergent and surrounding vegetation (see bottom picture in Figure 20)
- More acidic (pH 2 – 4) than most natural wetlands (e.g pH 6 - 8)
- Unnaturally long inundation period compared to natural freshwater basins – may be permanently inundated

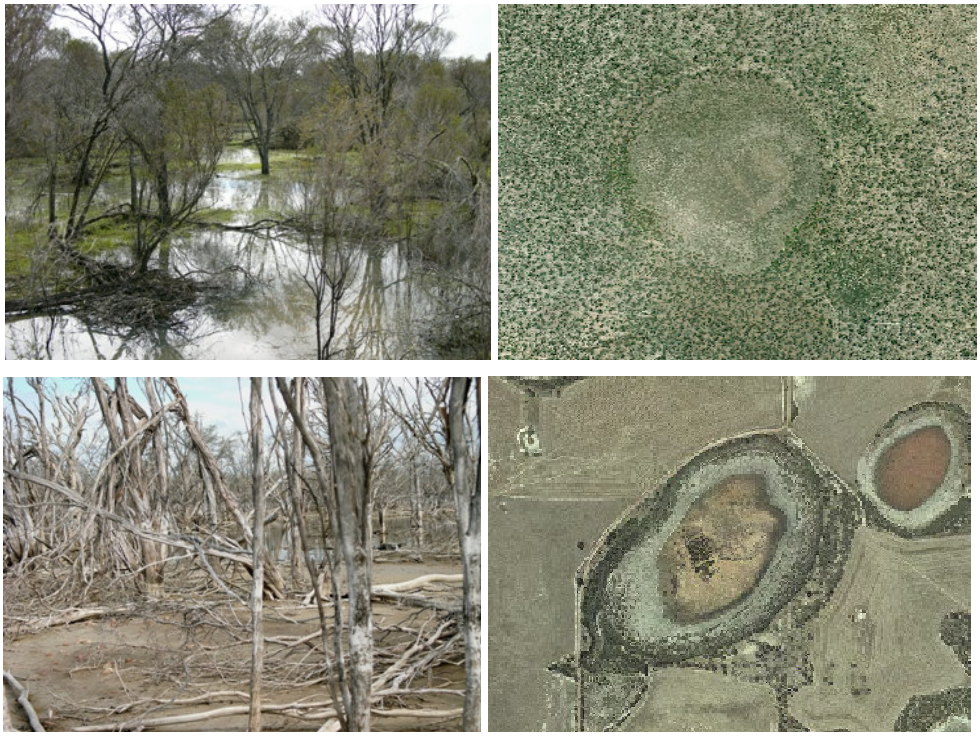


Figure 20 - Top (Dobaderry Swamp) - a freshwater basin in good condition, pictured on the ground (left) and from aerial photography (right). Bottom (Lake at Ongerup) – a secondarily salinised basin, pictured from the ground (left) and from aerial photography (right)

3. Artificial reservoir basins

As the name suggests, reservoirs (Figure 21) are man-made structures used for storing water supplies for stock or human consumption. In the assessment process, these wetlands are evaluated as freshwater basins, and can have a high conservation value as they often provide a refuge for freshwater species in the heavily salinised landscape of the Avon NRM region. Artificial waterbodies located on granite outcrops are considered to be reservoirs.

Features of artificial reservoir basins are:

- Man-made structures
- Salinity of the water mostly less than 3ppt when full, unless the reservoir has become secondarily salinised
- Dams used for stock watering or fire-fighting are often turbid and those used for drinking water are usually clear
- Varied depths
- Reduced diversity of flora and fauna compared to natural wetlands

- The vegetation at the periphery of these wetlands is variable depending on the area, but often includes *Typha* and *Juncus* species, and a suite of introduced taxa, including *Polypogon monspeliensis, Symphyotrichum subulatum* and *Rumex crispus (Pers comm. M. Lyons, DEC, April 2008)*


Figure 21 - A freshwater artificial reservoir basin (Kondinin Golf Club Dam) pictured from the ground (left) and aerial photography (right)

4. Freshwater claypan basins

Freshwater claypans (Figure 22) support unique assemblages of aquatic invertebrates [e.g. clam shrimps and fairy shrimps (Pinder*, et al.* 2004)] and wetland vegetation (Gibson*, et al.* 2005, Lyons*, et al.* 2004). In the south-west, 36 taxa, occurring in 6 floristic communities of vegetation are identified as claypan specialists (Gibson*, et al.* 2005). Claypans have very low salinities as the clay sediments of the wetland isolate it from the water table so that the water is derived solely from surface runoff and direct filling from rainfall (i.e are perched). These wetlands are quite uncommon and they are difficult to identify from aerial photography as seen in Figure 22.

Features of freshwater claypan basins are:

- Salinity generally less than 1ppt
- Alkaline water
- Generally turbid, shallow water
- Intermittent to seasonal inundation (playas and sumplands)
- Clay sediments
- Isolated from saline surface flows
- Vegetation composition of freshwater claypans is variable depending on wetland depth, hydroperiod and turbidity. Vegetation species richness, and the occurrence of sedges and rushes, tends to increase with rainfall (Gibson*, et al.* 2005)
- The species of vegetation often includes *Tecticornia verrucosa* or *Muehlenbeckia florulenta* in lower rainfall areas. More typically these wetlands are herb dominated at their margin and across the bed, in the drying phase. Scattered trees such as *Casuarina obesa* and *Melaleuca* spp. may also be present. In the western areas of the Avon, taxa include *Chorizandra enodis, Amphibromus nervosus, and Eleocharis keigheryi (Pers comm. M. Lyons, DEC, April 2008)*

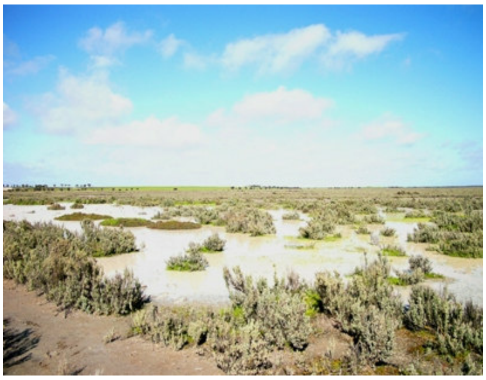



Figure 22 - Top - freshwater claypan south of Lake Grace, pictured from the ground (left) and from aerial photography (right). Bottom - (Koorda Claypan), pictured from the ground (left) and from aerial photography (right)

5. Freshwater granite outcrop pools

Freshwater granite outcrop pools (Figure 23) are known to support unique assemblages of aquatic invertebrates and flora that are adapted to ephemeral inundation (Bayly 1997, Bayly 2002, Main 1997, Pinder*, et al.* 2000, Withers and Edward 1997). A single granite outcrop may support one to many pools.

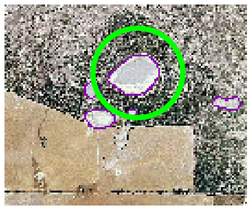
Features of freshwater granite outcrop pools are:

- Salinity less than 1ppt
- Generally clear, shallow water
- Ephemeral to seasonal inundation
- Minimal sediment
- Herbs such as Mudmat (*Glossostigma drummondii), Isoetes australis* and *Isoetes caroli* are often present in the shallow pools. The species rich margins of these wetlands (moss and herb swards) typically include annual Cypereaceae (eg *Centrolepis* and *Schoenus* spp.), and Asteraceae (eg *Quinetia urvillei,* and *Siloxerus multiflorus*) *(Pers comm. M. Lyons, DEC, April 2008)*

Figure 23 – Freshwater granite outcrop pool at Yorkrakine Rock. Pictured from the ground (left) and from aerial photography (right)

Appendix C- Worked example of a High, Intermediate and Low scoring wetland

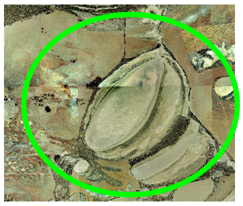
Example #1 of a high-scoring basin wetland

Indicator	Details	Score	Conservation Significance
Catchment	Swan-Avon Lockhart		
Wetland Classification	Microscale seasonal open saline basin		
Known Ecological Significance	None		
Percent degrading landuse within 1km of the wetland	24%	2.00	
Vegetation connectivity between hydrologically linked wetlands	High	3.00	
Amount of vegetation within 50m of the mapped wetland boundary incorporating recent change	High (3) with 11% decline	3.00	Inferred 'naturalness' =Average (2.00, 3.00, 3.00) = 2.67 = High
Negative adjustment for presence of degrading structures	N/A		
Positive adjustment for >40% vegetation within the wetland boundary, incorporating recent change	N/A		
Known Human Significance	None		
Final Conservation Significance			**HIGH**

Example #2 of a high-scoring basin wetland

Indicator	Details	Score	Conservation Significance
Catchment	Swan-Avon Lockhart		
Wetland Classification	Macroscale intermittent open saline basin		
Known Ecological Significance	Directory of Important Wetlands		Automatic high
Percent degrading landuse within 1km of the wetland	23%	2.00	
Vegetation connectivity between hydrologically linked wetlands	High	3.00	
Amount of vegetation within 50m of the mapped wetland boundary incorporating recent change	Intermediate (2) with 13% decline	2.00	This does not need scoring as it is an automatic high
Negative adjustment for presence of degrading structures	N/A		
Positive adjustment for >40% vegetation within the wetland boundary, incorporating recent change	N/A		
Known Human Significance	None		
Final Conservation Significance			**HIGH**

Example #1 of an intermediate-scoring basin wetland

Indicator	Details	Score	Conservation Significance
Catchment	Swan-Avon Lockhart		
Wetland Classification	Macroscale intermittent open saline basin		
Known Ecological Significance	No		
Percent degrading landuse within 1km of the wetland	46%	2.00	
Vegetation connectivity between hydrologically linked wetlands	Intermediate	2.00	
Amount of vegetation within 50m of the mapped wetland boundary incorporating recent change	Intermediate (2) with 5% decline	2.00	Inferred 'naturalness' =Average (2.00, 2.00, 2.00) = 2.00 <u>= Intermediate</u>
Negative adjustment for presence of degrading structures	N/A		
Positive adjustment for >40% vegetation within the wetland boundary, incorporating recent change	N/A		
Known Human Significance	Yes – cannot be low		
Final Conservation Significance			**INTERMEDIATE**

Example #2 of an intermediate-scoring basin wetland

Indicator	Details	Score	Conservation Significance
Catchment	Swan-Avon Lockhart		
Wetland Classification	Microscale intermittent open saline basin		
Known Ecological Significance	None		
Percent degrading landuse within 1km of the wetland	80%	2.00	
Vegetation connectivity between hydrologically linked wetlands	Intermediate	2.00	
Amount of vegetation within 50m of the mapped wetland boundary incorporating recent change	Intermediate (2) with 5.1% decline	2.00	
Negative adjustment for presence of degrading structures	N/A		Inferred 'naturalness' =Average (2.00, 2.00, 2.00) = 2.00 <u>= Intermediate</u>
Positive adjustment for >40% vegetation within the wetland boundary, incorporating recent change	N/A		
Known Human Significance	None		
Final Conservation Significance			**INTERMEDIATE**

Example #1 of a low-scoring basin wetland

Indicator	Details	Score	Conservation Significance
Catchment	Swan-Avon Mortlock		
Wetland Classification	Microscale intermittent open saline basin		
Known Ecological Significance	None		
Percent degrading landuse within 1km of the wetland	70%	2.00	
Vegetation connectivity between hydrologically linked wetlands	Isolated so no score is given	------	Inferred 'naturalness' =Average (2.00, 1.00) = 1.50 =Low
Amount of vegetation within 50m of the mapped wetland boundary incorporating recent change	Low (1) with 4% decline	1.00	
Negative adjustment for presence of degrading structures	N/A		
Positive adjustment for >40% vegetation within the wetland boundary, incorporating recent change	N/A		
Known Human Significance	None		
Final Conservation Significance			**LOW**

Example #2 of a low-scoring basin wetland

Indicator	Details	Score	Conservation Significance
Catchment	Swan-Avon Yilgarn		
Wetland Classification	Microscale seasonal open saline basin		
Known Ecological Significance	None		
Percent degrading landuse within 1km of the wetland	98%	1.00	
Vegetation connectivity between hydrologically linked wetlands	Low	1.00	Inferred 'naturalness' =Average (1.00, 1.00, 1.00) = 1.00 = Low
Amount of vegetation within 50m of the mapped wetland boundary incorporating recent change	Low (1) with no decline	1.00	
Negative adjustment for presence of degrading structures	-0.33 (but can't go below 1)		
Positive adjustment for >40% vegetation within the wetland boundary, incorporating recent change	N/A		
Known Human Significance	None		
Final Conservation Significance			**LOW**

Appendix D - List of mapped wetlands in the Avon NRM region that have been identified as national, state or local water assets

Source: Avon Catchment Council 2004, Department of Environment 2003

Asset Name	National	State	Regional	Local			
				Most valued	Most threatened	Iconic	Recreation
Abbots Lake		✓					
All granite outcrops	✓	✓	✓	✓	✓	✓	
Ardath Lake		✓					
Askew Lake		✓			✓		
Baandee Lake		✓	✓				✓
Beaton Lake					✓		
Bolgart Lakes		✓					
Carratti Lake					✓		
Chinocup Lake		✓	✓			✓	
Chook Run Water Reserve		✓					
Corrigin Water Reserve				✓			
Cowcowing Lakes	✓	✓		✓		✓	
Dragon Rocks Nature Reserve			✓				
Drummonds Wetlands		✓					
Fresh water Lake - Mills		✓					
Freshwater Lake- Watts		✓					
Freshwater lakes		✓					
FW Lakes 2 (3 Lakes)		✓					
Gidgeganup springs		✓					
Hagboom Lake		✓					
Hamilton Dam			✓				
Harvey Lake					✓		
Jilakin Lake system		✓					
Job Lake		✓			✓		
Kondinin/Kurrenkutten Lake System		✓				✓	
Koojedda Wetland		✓					
Lake Baandee		✓	✓				✓
Lake Borona					✓		
Lake Bryde Wetlands complex		✓	✓			✓	✓
Lake Camm						✓	
Lake Campion			✓				
Lake Cemetery			✓				✓
Lake Cronin	✓	✓					
Lake Grace System	✓		✓				
Lake Gulson						✓	
Lake King			✓				✓
Lake Magic		✓					
Lake McDermott System		✓			✓		
Lake Mears			✓				✓
Lake Mollerin System		✓			✓		
Lake Moore				✓			
Lake Ninan		✓					
Lake Royston						✓	
Lake Wallambin System		✓			✓		

Asset Name	National	State	Regional	Local			
				Most valued	Most threatened	Iconic	Recreation
Metcalf Lake		✓					
Mt. Cramphorn Water Reserve		✓					
Mt. Roe Dam Water Reserve		✓	✓	✓			
Myarin Rock				✓			
Narembeen Ski Lake					✓		✓
Paperbark Swamp					✓		
Perched Freshwater Wetlands around Dowerin		✓	✓	✓			
Pink Lake						✓	
Pinkwerring Soak and Well		✓					
Rail dam (Wongan)		✓					
Red Swamp Brook		✓					
Sachses Lakes		✓					
Salt lake chain - south of Bullfinch Road for 1 kilometre and after		✓					
Scotsman Lake		✓		✓			
Shakelton Lakes		✓					
Telephone Exchange Lake		✓					
Wadderin Water Reserve		✓	✓	✓		✓	
Walyormouring Lake		✓					
Water Corporation tanks/Water reserves in Mount Marshall				✓			
Waterbidden Water Reserve		✓					
Wattening Lakes		✓					
Yealering Lake System (Brown lake, White Water Lake, Nonalling Lake, Yealering Lake)	✓		✓	✓			
Yenyening Lake System		✓	✓			✓	✓

Appendix E - Threatened Ecological Communities listed in the Avon-Wheatbelt area

Source: Western Australia Threatened Species and Communities website

No	Threatened Ecological Community	Category of threat and criteria met under WA criteria
1	Perched wetlands of the Wheatbelt region with extensive stands of living Swamp Sheoak (*Casuarina obesa*) and Paperbark (*Melaleuca strobophylla*) across the lake floor.	CR A) i); CR A) 11); CR C)
2	Perched fresh-water wetlands of the northern Wheatbelt dominated by extensive stands of living *Eucalyptus camaldulensis* (River Red Gum) across the lake floor.	PD B)
3	Unwooded freshwater wetlands of the southern Wheatbelt of Western Australia, dominated by *Muehlenbeckia horrida subsp. abdita* and *Tecticornia verrucosa* across the lake floor	CR B) i), CR B) ii)
4	Herbaceous plant assemblages on Bentonite Lakes	EN B) iii)
5	Heath dominated by one or more of *Regelia megacephala, Kunzea praestans* and *Allocasuarina campestris* on ridges and slopes of the chert hills of the Coomberdale floristic region.	EN B) ii)
6	Plant assemblages of the Billeranga System (Beard 1976): *Melaleuca filifolia* – *Allocasuarina campestris* thicket on clay sands over laterite on slopes and ridges; open mallee over mixed scrub on yellow sand over gravel on western slopes; *Eucalyptus loxophleba* woodland over sandy clay loam or rocky clay on lower slopes and creeklines; and mixed scrub or scrub dominated by *Dodonaea inaequifolia* over red/brown loamy soils on the slopes and ridges	VN A), VN B)
7	Plant assemblages of the Koolanooka System (Beard 1976): *Allocasuarina campestris* scrub over red loam on hill slopes; Shrubs and emergent mallees on shallow loam red over massive ironstone on steep rocky slopes; *Eucalyptus ebbanoensis subsp. ebbanoensis* mallee and *Acacia sp.* scrub with scattered *Allocasuarina huegeliana* over red loam and ironstone on the upper slopes and summits; *Eucalyptus loxophleba* woodland over scrub on the footslopes; and mixed *Acacia sp*. scrub on granite	VN A), VN B)
8	Plant assemblages of the Moonagin System (Beard 1976): *Acacia* scrub on red soil on hills; *Acacia* scrub with scattered *Eucalyptus loxophleba* and *Eucalyptus oleosa* on red loam flats on the foothills.	VN A), VN B)
9	Clay flats assemblages of the Irwin River: Sedgelands and grasslands with patches of *Eucalyptus loxophleba* and scattered *E. camaldulensis* over *Acacia acuminata* and *A. rosellifera* shrubland on brown sand/loam over clay flats of the Irwin River.	PD A), PD B)
10	Plant assemblages of the Inering System (Beard 1976)	VN A)
11	Plant assemblages of the Broomehill System	PD A)
12	Assemblages of the organic mound springs of the Three Springs area	EN B) i), EN

CR – Critically Edangered; EN – Endangered; VN – Vulnerable; PD – Presumed Destroyed