# A SUMMARY OF WETLAND MAPPING, MONITORING AND INVENTORY PROJECTS AND A DISCUSSION OF WETLAND CLASSIFICATION IN WESTERN AUSTRALIA

AN EXTENSION TO THE TRIAL OF NATIONAL WETLAND INDICATORS IN WESTERN AUSTRALIA

Part One: Regional assessment of data availability and wetland types

Part Two: Review of wetland classification systems and conceptual model development

*Discussion paper*

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# Executive summary

This report outlines two components of an extension to the Department of Environment and Conservation (DEC)'s trial of National Wetland Indicators (NWI) for Extent, Distribution and Condition in Western Australia. The aims of the first part were: to inventory the data available for implementation of the NWI and threats to wetlands in the remaining regions of Western Australia; and to undertake a gap analysis. The second component aimed to examine similarities and differences between the Geomorphic Wetland Classification system currently used within Western Australia (Semeniuk and Semeniuk 1995), and three other wetland classification systems that may be of relevance to Western Australian wetlands.

Note: The information in this discussion paper is intended to be updated as additional wetland mapping, monitoring and inventory projects are undertaken. It is also intended that the information currently contained here be reviewed by regional staff in 2009 to ensure its completeness and accuracy.

**Part One – Regional assessment of data availability**

The NWI for wetland extent and distribution are:

- Wetland extent – size of wetland in hectares; and
- Wetland distribution – location of wetland in landscape (latitude and longitude).

Mapping of wetlands is patchy across Western Australia, due to the size and inaccessibility of many areas of the state, and the resources required to undertake it. Of the wetland mapping projects that have been completed only some of the datasets have been digitised. Large areas of Western Australia still remain unmapped. The scope and attributes (including scale, accuracy and classification system) of each mapping project vary, and these have been documented for the NRM regions of Western Australia.

Seventeen NWI for wetland condition were proposed for trialling in different parts of Australia (Conrick *et al.* 2007), and eight of these were addressed as part of the Wheatbelt wetland indicators trial (Sim *et al.* 2008). In this report, we have presented a gap analysis, based on an analysis of the data required for use of the NWI indicator categories and the available wetland monitoring programs and inventory data, as well as the main threats to wetlands within each NRM region. Detail about the gap analysis, available data, threats, themes, indicators, possible measures for each indicator and proposed reference conditions is included in the main body of the report and the appendices.

Current or past wetland inventory and monitoring programs in the **South Coast Region** included:

- South Coast Wetland Monitoring Program
- South Coast Wetland Conservation Program
- Preventing Loss of Birds at Lake Warden
- South West Wetland Monitoring Program
- Salinity Action Plan Biological Survey and Monitoring
- Inland Aquatic Integrity Resource Condition Monitoring
- Annual waterbird surveys

Current or past wetland inventory and monitoring programs in the **South West Region** included:

- South West Wetland Mapping, Classification and Evaluation Program
- Peel-Yalgorup Ramsar Site Monitoring
- Vasse-Wonnerup Wetlands Ramsar Site Monitoring
- Swan Coastal Plain Waterbirds Monitoring
- South West Wetland Monitoring Program
- Salinity Action Plan Biological Survey and Monitoring
- Inland Aquatic Integrity Resource Condition Monitoring
- Annual waterbird surveys
- Frog monitoring (*Geocrinia sp.*) (Bunbury area)
- Bittern monitoring (Bunbury area)

Current or past wetland inventory and monitoring programs in the **Perth Region** included:

- 40 Wetlands Study
- Jandakot Mound Groundwater Scheme
- Gnangara Mound Environmental Monitoring
- Gnangara Mound Spring Survey
- Swan Coastal Plain Waterbirds Monitoring
- Wetland Watch

Current or past wetland inventory and monitoring programs in the **Northern Agricultural Region** included:

- Buntine-Marchagee Recovery Catchment Surveys
- Three Springs Tumulus Spring Survey
- Balancing Agricultural Production and Conservation in Wetlands of the Gingin Shire
- South West Wetland Monitoring Program
- Salinity Action Plan Biological Survey and Monitoring

- Inland Aquatic Integrity Resource Condition Monitoring
- Annual waterbird surveys

Current or past wetland inventory and monitoring programs in the **Rangelands Region** included:

- Inland Aquatic Integrity Resource Condition Monitoring
- Pilbara Surface Water Survey
- Pilbara Spring Study (Survey)
- Pilbara Marsh Study (Survey)
- Victoria-Bonaparte Mudflat Survey
- Lake Gregory Monitoring
- Kimberley Sites Monitoring
- Kimberley Mound Spring Biological Survey
- Priorities for Wetland Conservation & Management
- Lake Kununurra and Lily Creek Lagoon Monitoring
- Carnarvon Basin Biological Survey
- Hutt Catchment Biological Survey
- Desert / Goldfields Wetlands Biological Survey

**Part Two - Wetland classification systems and conceptual model development**

***Wetland classification***

Dividing wetlands into discrete and recognisable groupings facilitates reporting at regional, State and National Scales. The classification system(s) most appropriate for different types of reporting are likely to vary depending on the resolution of information required and the aims of the project, e.g. the facilitation of wetland mapping versus the development of conceptual models of wetland type.

Part Two of this discussion paper examines similarities and differences between four wetland classification systems with practical or potential relevance to wetlands in Western Australia. These are: the Geomorphic Wetland Classification system currently used within Western Australia (Semeniuk and Semeniuk 1995); the Cowardin *et al.* (1979) system developed for wetlands and deepwater habitats of the USA; the Queensland Wetland Habitat Typology (EPA Queensland Wetland Programme 2008a); and the NT arid wetland classification system (Duguid *et al.* 2007).

***Conceptual models***

The development of conceptual models for different wetland types is one of the next stages in the process of implementing the use of NWI in Western

Australia, and this requires an understanding of the ecology behind each 'type'. There is a tradeoff between using a formal wetland classification system that may not contain all the necessary ecological detail to make the models meaningful, and in using an ecological type system that may be less formally structured. Conceptual model development has not yet commenced in Western Australia, and some of these issues will need to be resolved as part of this process.

**The way forward for Western Australia**

In order to implement the NWI for extent, distribution and condition in Western Australia, the following tasks remain as a high priority:

- Check regional detail;
- Complete gap analysis;
- Decide on adoption or adaptation of Queensland Wetland Habitat Typology and/or other classification system;
    - Incorporate ecological detail into wetland classification;
- Use the ecological classification to develop conceptual models for each wetland type;
- Use typology, conceptual models, threat and stressor information and gap analysis, to refine our understanding of which indicators are relevant to particular regions and wetland types for Western Australia.

# Introduction

This report outlines an extension to the Department of Environment and Conservation (DEC)'s trial of National Wetland Indicators (NWI) for Extent, Distribution and Condition in Western Australia. The original project focused on a trial region, the Western Australian Wheatbelt, where the availability and suitability of existing data for testing NWI was assessed (Sim *et al.* 2008).

This extension has been undertaken to assess whether the necessary background information is compiled and available within Western Australia to facilitate future work on NWI including on-ground regional trials and the development of conceptual models of wetland types. This information has also been compiled to ensure that where possible DEC corporate data can be used for reporting changes in aquatic systems as measured by the NWI indicators for Extent, Distribution and Condition in Western Australia.

The project extension has two parts. The aims of the first part are: to inventory the data available for implementation of the NWI and threats to wetlands in the remaining regions of Western Australia; and to undertake a gap analysis. The consultation list for this process is presented in Appendix One. This process will facilitate further development of the NWI for use in Western Australia by highlighting areas where additional data may need to be collected, and clarifying which indicators may have importance in the different regions.

The second component of this project extension aims to examine similarities and differences between the Geomorphic Wetland Classification system currently used within Western Australia (Semeniuk and Semeniuk 1995), and three other wetland classification systems that may be of relevance to Western Australian wetlands: the Cowardin *et al.* (1979) system developed for wetlands and deepwater habitats of the USA, terminology from which has been adopted for national use within Australia; the Queensland Wetland Habitat Typology (EPA Queensland Wetland Programme 2008a) proposed for use nationally; and the NT arid wetland classification system (Duguid *et al.* 2007). This section of the paper also documents the range of ecological wetland types occurring within each region, and provides some of the background information required to support the development of conceptual ecosystem models for wetland types in the different regions of WA. Finally, comment is made on the way forward for Western Australia in relation to the implementation of the NWI.

For the purposes of this report, regionalisation of Western Australia follows existing Natural Resource Management (NRM) regions. However, as the Rangelands Region covers 90% of the state and includes a range of

biogeographical areas, this region has been further subdivided into the Kimberley, Pilbara, Midwest and Goldfields (which includes part of DEC South Coast Region). The regional divisions used in this report, and their relationships with DEC and NRM regions are presented in Figure 1.

**Please note that the information in this discussion paper is intended to be updated as additional wetland mapping, monitoring and inventory projects are undertaken. It is also intended that the information currently contained here be reviewed by regional staff in 2009 to ensure its completeness and accuracy.**

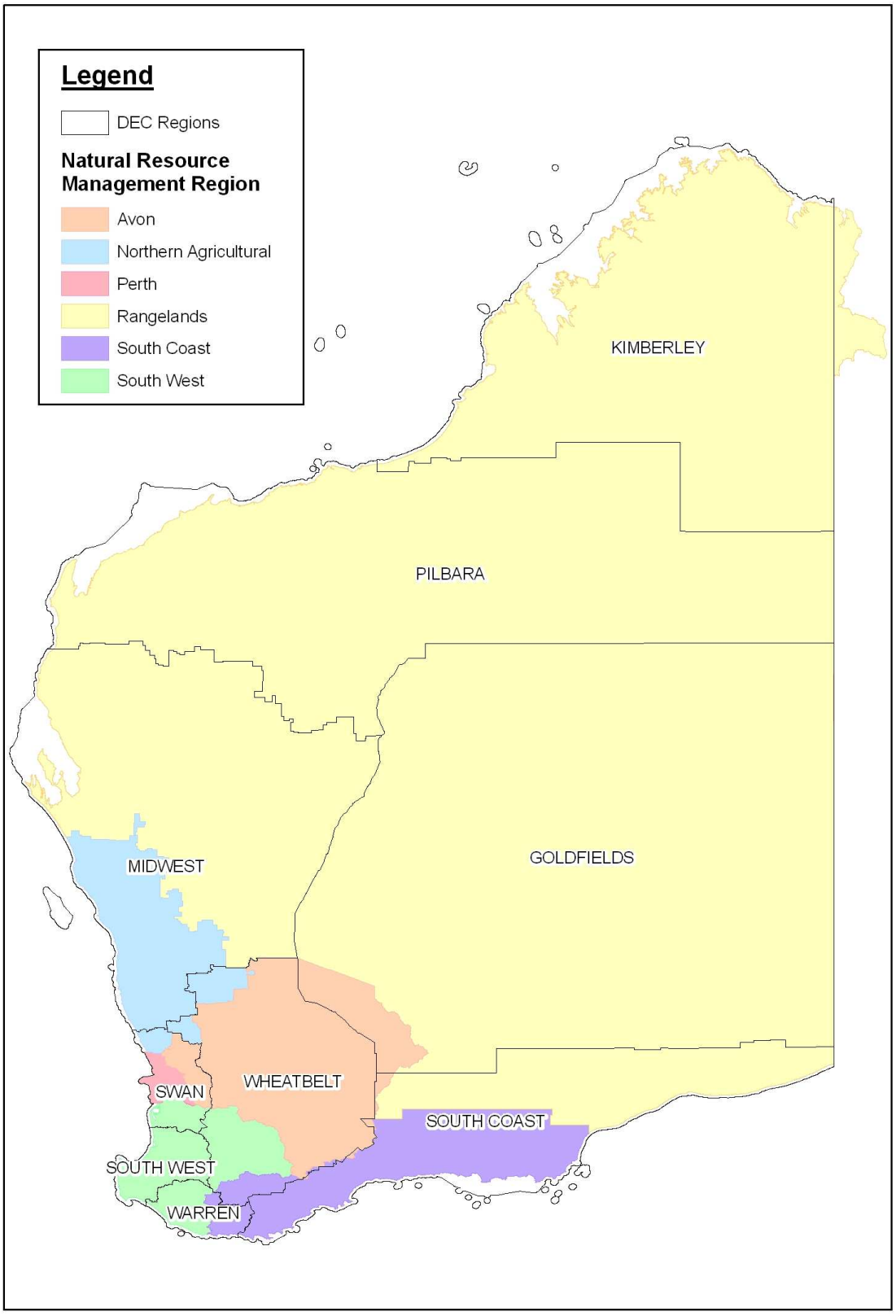


**Figure 1: Division of Western Australia into Natural Resource Management Regions (coloured) and Department of Environment and Conservation Regions (outlined and labelled)**

# Part One – Regional assessment of data availability

## *Indicators for Wetland Extent and Distribution*

The NWI for wetland extent and distribution are:

- Wetland extent – size of wetland in hectares; and
- Wetland distribution – location of wetland in landscape (latitude and longitude).

Data for both of these indicators are able to be extracted from wetland mapping datasets, however wetland extent data are most useful when captured at sufficient resolution to give an accurate boundary delineation. This type of detailed on-ground mapping of wetland boundaries is designated a 'Stage Three' delineation in the 'Framework for mapping, classification and evaluation of wetlands in Western Australia' (Department of Environment and Conservation 2007).

### Availability of wetland mapping data across Western Australia

Mapping of wetlands is patchy across Western Australia, due to the size and inaccessibility of many areas of the state, and the resources required to undertake it. Of the wetland mapping projects that have been completed (Figure 2) only some of the datasets have been digitised. New mapping projects are all available digitally, and it is often the older datasets that have not yet been converted. Applications for funding to support the process of digitisation are ongoing. It can be seen from Figure 2 that large areas of Western Australia still remain unmapped.

The scope and attributes (including scale, accuracy and classification system) of each wetland mapping project vary, and these have been documented for the NRM regions of Western Australia in Table 1.

DEC is moving towards a more standardised process for wetland delineation (mapping) by commissioning a detailed methodology for mapping at three different scales of resolution. This methodology will guide future wetland mapping projects within Western Australia. The overarching approach to these three scales of mapping is presented in the 'Framework for mapping, classification and evaluation of wetlands in Western Australia' (Department of Environment and Conservation 2007).

Completed wetland delineation methodologies and datasets are reviewed by the Wetland Status Working Group (WSWG), a subcommittee of the Western Australian Wetlands Coordinating Committee, for endorsement.

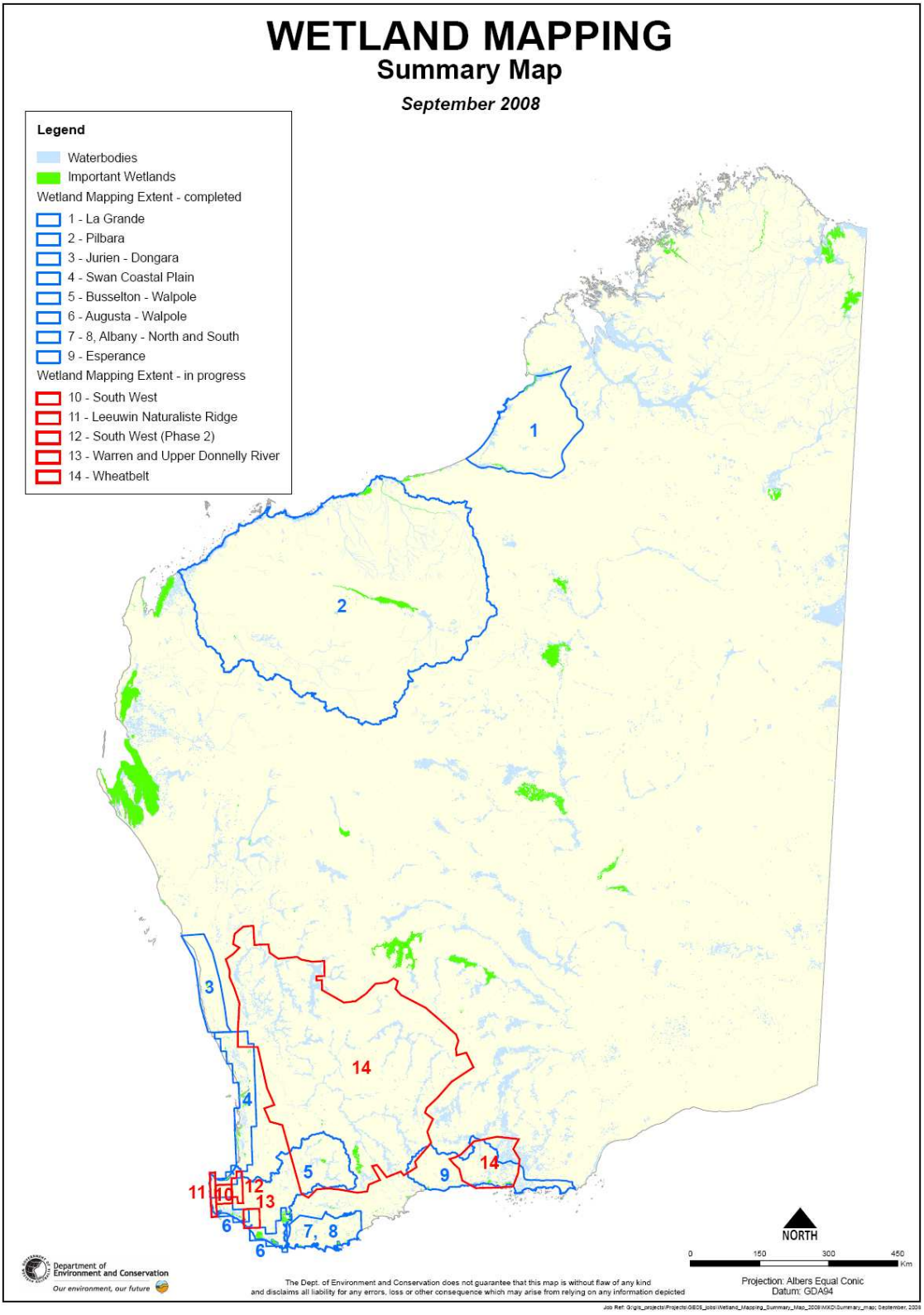


**Figure 2: Completed wetland mapping projects throughout Western Australia**

**Table 1: Status of wetland mapping projects in the different NRM regions of Western Australia**

| Region | Sub-region | Wetland mapping undertaken? | Available digitally? | Year of completion | Area mapped | Scale of mapping | Accuracy of mapping | Attributes captured | Classification system | Data custodian | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| South Coast | Albany, | YES | YES | 2007 | Albany area | 1:5 000 | | Metadata details to be supplied by DoW South Coast | (Semeniuk and Semeniuk 1995) | Department of Water | (Department of Water 2007b) |
| South Coast | Esperance (Hopetoun and Bremer Bay in progress) | YES | YES | 2009 | Esperance area | 1:5 000 | | Metadata details to be supplied by DoW South Coast | (Semeniuk and Semeniuk 1995) | Department of Water | (Department of Water 2007a) |
| South Coast | (significant wetlands) | YES | YES | 2001 | | | The metadata states: '*Due to the nature of the source data available the there is still a level of uncertainty in the derived dataset to date which will only be removed through thorough verification in the field. Positional Accuracy: At the very best equivalent to 25K depending on source data*' | • Area of wetland polygons<br>• Coordinates of polygons<br>• Details of when data was authorised and digitised<br>• Wetland names<br>• Ramsar wetland<br>• Directory of important wetlands<br>• Register of the National Estate<br>• Conservation class<br>• Consanguineous suites | | Department of Environment | Available on DEC's Geographic Data atlas (GDA). This means it is both available to view on a GIS program and to download for free. For the GDA, go to http://maps.dec.wa.gov.au/idelve/doedataext/ |
| South West | Augusta to Walpole | YES | YES | Mapping report 1997 | Augusta to Walpole; 3 study areas:<br>• Augusta – Donnelly River<br>• Meerup –Walpole<br>• Muir–Unicup area | 1:25 000 | ? | • Area of wetland polygons<br>• Coordinates of polygons<br>• Details of when data was authorised and digitised<br>• Wetland type (geomorphic classification system) | Geomorphic classification system | Water and Rivers Commission - now Department of Environment and Conservation, Wetlands Section (38 maps; digital and hard copy) | (V & C Semeniuk Research Group 1997 )<br><br>Available on DEC's Geographic Data atlas (GDA). http://maps.dec.wa.gov.au/idelve/doedataext/<br><br>Will also be available on the WA Atlas - SLIP portal website (https://www2.landgate.wa.gov.au/slip/portal/home/home.html) |
| South West | | YES South Eastern Coastal Plain mapped in 2006 (contracted by the former DoE) but it has not been endorsed yet, and has therefore not been released | YES (not endorsed) | Draft Mapping report 2005 | Southern Blackwood Plateau and Eastern Scott Coastal Plain | 1:25 000 | The metadata states: *Lakes and sumplands have been mapped to an accuracy of ±10 m. Damplands, palusplains, paluslopes and most floodplains are by nature more difficult to delineate and have been mapped to an* | • Area of wetland polygons<br>• Coordinates of polygons<br>• Consanguineous suites<br>• Wetland type (geomorphic classification system)<br>• Wetland evaluation, and assignation of management categories<br>(There is other attribute information within the dataset, | Geomorphic classification system | Department of Environment and Conservation | V & C Semeniuk Research Group (June 2005) *Wetland mapping, classification and evaluation, southern Blackwood Plateau and eastern Scott Coastal Plain* |

| Region | Sub-region | Wetland mapping undertaken? | Available digitally? | Year of completion | Area mapped | Scale of mapping | Accuracy of mapping | Attributes captured | Classification system | Data custodian | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | *accuracy of ±50 m. Note that wetland boundaries can appear variable because of the effect of climatic cycles on water levels, sediments and wetland vegetation, and because development can encroach on the area of some wetlands.* | however, DEC must be contacted for the metadata to explain the codes) | | | |
| South West | East of Margaret River | YES | YES (not endorsed) To be made available following endorsement by the state Wetlands Coordinating Committee | Mapping report 2006 | Mapsheets 1930-III NE, SE, 1930-II NW, SW, NE, SE, 1929-IV NE, and 1929-I NW, NE | 1:25 000 | Metadata states: *Sumplands have been mapped to an accuracy of +/- 10m. Damplands, palusplains, paluslopes, palusvales and most floodplains are by nature more difficult to define and have been mapped to an accuracy of +/- 50m. Note that wetlands boundaries can appear variable and that the speed of development may have encroached on the currency of some wetlands* | • Area of wetland polygons<br>• Consanguineous suites<br>• Wetland type (geomorphic classification system)<br>• Wetland evaluation, and assignation of management categories<br>There is other attribute information within the dataset | Geomorphic classification system | Department of Environment and Conservation, Wetlands Section | V & C Semeniuk Research Group (December 2006) *Wetlands mapping, classification and evaluation – south west region* |
| South West | Leeuwin Naturaliste Ridge | YES | In progress | Mapping report – draft 2008 | Mapsheets 1930-IV NW, 1930-IV SW, 1930-III NW, 1930-III SW, 1929-IV NW, 1929-IV SW, and 1929-III NW | 1:25,000 | As in previous projects | • Area of wetland polygons<br>• Consanguineous suites<br>• Wetland type (geomorphic classification system)<br>• Wetland evaluation, and assignation of management categories<br>• There is other attribute information within the dataset | Geomorphic classification system | Department of Environment and Conservation | V & C Semeniuk Research Group (Draft 2008) *Wetlands mapping, classification and evaluation – south west region* |
| South West | Donnybrook -Nannup area | YES | In progress | Mapping report – draft 2008 | Mapsheets 2030-IV NE, 2030-IV SW, 2030-IV SE, 2030-III NW, 2030-III NE, 2030-III SW, 2030-III SE, and 2029-IV NE | 1:25,00 | As in previous projects | • Area of wetland polygons<br>• Consanguineous suites<br>• Wetland type (geomorphic classification system)<br>• Wetland evaluation, and assignation of management categories | Geomorphic classification system | Department of Environment and Conservation | V & C Semeniuk Research Group (Draft 2008) *Wetlands mapping, classification and evaluation – south west region* |

| Region | Sub-region | Wetland mapping undertaken? | Available digitally? | Year of completion | Area mapped | Scale of mapping | Accuracy of mapping | Attributes captured | Classification system | Data custodian | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | • There is other attribute information within the dataset | | | |
| South West | Manjimup-Northcliffe | IN PROGRESS | | | Warren and Upper Donnelly River; Mapsheets 2029-II NW, 2029-II SW, 2028-I NW, 2029-II NE, 2029-II SE, 2028-I NE, 2129 III NW, 2129-III SW, and 2128-IV NW. | 1:25,000 | | • Area of wetland polygons<br>• Wetland type (geomorphic classification system) | Geomorphic classification system | | |
| Perth | IBRA Swan Coastal Plain Sub-region | YES | YES. *Geomorphic Wetlands Swan Coastal Plain* dataset (DEC) | Originally released in 1996 but subject to ongoing modification | Wedge Island - Dunsborough | 1:25 000 | Lakes and sumplands have been mapped to an accuracy of +/- 10 m. Damplands, palusplains, paluslopes, and most floodplains are by nature more difficult to define and have been mapped to an accuracy of +/- 50 m | • Area of wetland polygons<br>• Coordinates of polygons<br>• Details of when data was authorised and digitised<br>• Wetland names<br>• Wetland type (geomorphic classification system)<br>• Consanguineous suites<br>• Wetland management categories Conservation, Resource Enhancement & Multiple Use | Geomorphic classification system | Department of Environment and Conservation, Wetlands Section | (Hill *et al.* 1996b, a)<br><br>Available on the WA Atlas - SLIP portal website (https://www2.landgate.wa.gov.au/slip/portal/home/home.html) |
| Perth | Perth urban area | IN PROGRESS Highly detailed mapping of the Perth urban area (called Urban Monitor) is being conducted by CSIRO by Peter Cacetta using digital aerial photographs of high resolution. The project uses different bandwidths, which may be useful for stressor comparison purposes provided the mapping is done at the same time of year and under the same conditions | YES | IN PROGRESS | Perth urban area | ? | 10 cm resolution | ? | ? | CSIRO | http://www.csiro.au/science/UrbanMonitor.html |
| Avon | | YES | YES | 2008 | Most of the Western Australian Wheatbelt, including much of the Avon NRM Region | 1:100 000 (most), 1:250 000 in some areas | 1:100 000 (digitised from aerial photos at 1:10 000) | • Area of wetland polygons<br>• Coordinates of the wetland polygons<br>• Details of the data capturer<br>• 1:100 000 topographic map grid<br>• Wetland classification: 1:250 000 topographic map | Broad Geomorphic Wetland Classes (landform only), Ecological wetland type | Department of Environment and Conservation | (Jones *et al.* 2008b; Lizamore *et al.* 2008)<br>– will be available on DEC "WetlandBase" at http://www.dec.wa.gov.au/management-and-protection/wetlands/wetland-base/view-wetlandbase- |

| Region | Sub-region | Wetland mapping undertaken? | Available digitally? | Year of completion | Area mapped | Scale of mapping | Accuracy of mapping | Attributes captured | Classification system | Data custodian | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | classification<br>• Wetland classification: Semeniuk broad classes<br>• Wetland classification: additional information<br>• Wetland names<br>• Extent of vegetation cover<br>• Dominant vegetation cover type<br>• Wetland chains and suites<br>• Flow direction<br>• Hydrologic placement in the catchment<br>• Wetland connectivity in the landscape<br>• Natural buffer extent around the wetland<br>• Impacts on wetlands<br>• Severity of impacts on wetlands<br>• Spatial accuracy of remote sensing layer<br>• Catchment<br>• Sub-Catchment<br>• Confidence rating of the accuracy of the data layer<br>• Is any survey information available for the wetland<br>• Linking other survey information to the wetland layer<br>• Important wetland status<br>• Ramsar wetland status<br>• Gazetted name for wetlands<br>• Field verification<br>• Hydro-geomorphic Classification | | | online.html |
| Northern Agricultural | | IN PROGRESS. To be made available following finalisation and endorsement by the Wetlands Coordinating Committee. Indicative mapping of the Lancelin to Dongara area of the Northern Agricultural Region has been done (System 5 mapping), however, this is very | NO | 2006 | Jurien – Leeman (east to Badgingarra) | 1:25 000 | | | Geomorphic classification system | Department of Environment and Conservation | |

| Region | Sub-region | Wetland mapping undertaken? | Available digitally? | Year of completion | Area mapped | Scale of mapping | Accuracy of mapping | Attributes captured | Classification system | Data custodian | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | broad-scale and not particularly useful for anything other than preliminary identification of wetlands. The 2006 Mapping, Classification and Evaluation Report needs to be digitised, and the data and methodology need to undergo review and quality assurance process before they can be submitted to the Wetland Status Working Group (WSWG) for endorsement | | | | | | | | | |
| Rangelands | Kimberley | Some broad-scale wetland mapping in the Kimberley has been done as part of refugia mapping by DEC. This information needs to be collated, and a gap analysis of missing information conducted | | | | | | | | | |

## Use of remote-sensing data in wetland mapping

Additional detail is included here about two approaches that utilise remote-sensing (satellite imagery and aerial photography), which were trialled in 2006-2008 for wetland mapping in the Western Australian Wheatbelt. In this section, we aim to broadly assess the feasibility of these approaches for wetland mapping in other parts of Western Australia in the future. It is acknowledged that these approaches may not be appropriate for all future wetland mapping projects, but their broad-scale nature, and utilisation of remote-sensing data may make them cost effective for large, remote parts of the state.

It should be noted that the wetland delineation methodology currently being developed for DEC will provide further guidance on broad-scale mapping, and that the information presented here is intended to complement this methodology.

### *Use of Landsat imagery*

The Department of Environment and Conservation has access to remote-sensed (satellite) imagery of the whole State. The imagery discussed here is captured as part of the 'Landsat' program, a satellite program that has been run jointly by NASA and the U.S. Geological Survey since 1972 (National Aeronautics and Space Administration 2008). In this case, the imagery was purchased by LandMonitor (a consortium of State Government departments) and by the Federal Government Australian Greenhouse Office (G. Behn pers. comm.). Imagery for southwest Western Australia is updated annually and for the rest of the State there are 25 m pixel images for 12 years between 1988 and 2006. Imagery for 2007 is currently being prepared for use.

Landsat images of Western Australia are captured multiple times per year, but the images available for use in Western Australia are primarily purchased in summer for vegetation monitoring. Ideally, alternative dates of imagery from the wetter months would be better suited for wetland definition. When purchasing imagery, cloud-free conditions are selected (usually summer or autumn imagery) to allow as much of the state to be viewed as possible.

In 2006–2007, Graeme Behn, a remote-sensing scientist with DEC, used Landsat imagery to develop a broad-scale tool for the delineation of Wheatbelt wetlands. Graeme developed an algorithm using Canonical Variate Analysis (CVA): a statistical procedure for analysis of spectral class separation between selected representative sites of wet, damp and dry locations. This was used to extract water bodies from the satellite images using Landsat spectral data. This procedure was developed using the 2000 summer imagery

(a wet year) and the results applied to the archive of summer imagery, so as to extract maximum information using all dates. The final wetland result was then intersected with Digital Elevation data which located only those areas associated with water flows. The mapping was intended to be accurate at a scale of 1:250 000 in some areas and 1:100 000 in other areas.

This approach of delineating wetlands was able to produce datasets for large areas at little cost; however, there were numerous inaccuracies in the dataset caused by:

- Imagery of very wet years was used and wetness was patchy across the landscape, meaning that it was a 'wet year' in some areas, but not in others;
- The wet year imagery meant that ponded areas were picked up as wetlands, when in many cases they may have been flooded paddocks;
- Infrequently wetted wetlands were not captured;
- Areas with dense vegetation, where a water signal was not clear, were underestimated or not captured.

As a result, this approach was not used for the Wheatbelt wetland mapping project, since these problems could not easily be overcome. However, with refinement and additional ground-truthing, remote sensing approaches could be useful when looking at wetland extent across the rest of Western Australia. Graeme produced imagery for the Wheatbelt area in just two weeks but this is probably one fiftieth of the State, or certainly a small fraction of it. Further imagery analysis would need to be undertaken in 1:250 000 or 1:500 000 sections in order for it to be achievable and probably use the same algorithm that was developed for the Wheatbelt.

The method independently developed by Graeme Behn in Western Australia was very similar to that successfully used by the Queensland Wetland Programme to map wetlands in Queensland (Queensland EPA 2005). The major difference between the approaches is the existence of detailed vegetation mapping for Queensland but not Western Australia, making it more difficult in WA to augment and refine the remote-sensing outputs with other forms of information on wetlands. In addition, Queensland receives the majority of its rainfall during summer, making the use of summer imagery in the methodology more robust. The Queensland Wetland Programme used various other forms of on-ground data to assist the delineation process. The Queensland methodology has been used with great success to map several areas of Queensland, and the general approach deserves some further

investigation within Western Australia. The purchase of appropriate imagery for Western Australia (in terms of seasonal timing and resolution) would also improve the outcome of this type of wetland delineation.

One of the advantages of using satellite imagery to map wetlands is the fact that other qualities of wetlands such as presence of water in a particular year, inferred water regime and water salinity, as well as changes to wetting patterns with climate change, can also be extracted for wetland areas, making the process highly informative (Jones *et al.* 2008a, b).

### *Use of aerial photography*

In 2007–2008 Wheatbelt wetlands were mapped by digitising wetland boundaries from ortho-rectified aerial photography, which is updated annually as part of DEC's corporate dataset. This approach primarily utilised landform and vegetation as delineators of the wetland boundary. The remote-sensing layer produced by Graeme Behn was used as a starting-point to identify the presence of water, and wetland boundaries were then delineated using aerial photography. Other data such as known sampling sites, and the Auslig 1:250 000 wetland mapping layer were also used to indicate potential wetland areas. The final mapping methodology is detailed in Lizamore *et al.* (2008)[1].

This method allowed a much larger area to be covered than is possible with more detailed forms of mapping, and is more accurate than automated processes such as the satellite imagery analysis. However, due to the large size of the study region, the work was very time-consuming and took months for three full-time staff members to complete (J. Lizamore pers. comm.).

The existence of more detailed vegetation mapping for Western Australia would also assist in mapping by this method, as it would help to narrow down the areas needing to be assessed for the presence of wetlands.

[1] This document is currently being revised and split into two parts: a mapping methodology and a series of metadata statements. Please contact the Wetlands Section, Department of Environment and Conservation, Kensington for the most up-to-date version.

## *Indicators for Wetland Condition*

The NWI for wetland condition (Conrick *et al.* 2007) are listed in Table 2. Eight of the 17 indicators listed here were trialled for the Western Australian Wheatbelt (Sim *et al.* 2008). Insufficient data were available to trial the remaining nine.

**Table 2: National Wetland Indicators for wetland condition, grouped under themes (Conrick *et al.* 2007), with priorities for further development in the Wheatbelt trial region (Sim *et al.* 2008)**

| Theme and indicator | Trialled? | Priority for further development in Wheatbelt? |
|---|---|---|
| **Catchment disturbance** | | |
| Catchment disturbance | N | N |
| **Physical form and process** | | |
| Change in wetland area | Y | N |
| Change in wetland topography | N | N |
| Soil disturbance (physical) | N | N |
| **Hydrological disturbance** | | |
| Physical modification to hydrology | Y | Y |
| Changes to water regime | Y | Y |
| **Water and soil quality** | | |
| Turbidity (light climate) regime | Y | N |
| Salinity regime | Y | N |
| Change in pH | Y | Y |
| Change in soil properties (salinity, acidity) | N | Y |
| **Fringing zone** | | |
| Change in fringing zone | N | Y |
| **Biota** | | |
| Change in wetland vegetation | N | N |
| Change in invertebrate diversity and community composition | Y | Y |
| Change in waterbird presence, breeding and | Y | Y? |

| Theme and indicator | Trialled? | Priority for further development in Wheatbelt? |
|---|---|---|
| abundance | | |
| Change in other wetland-dependent vertebrates presence, breeding and abundance | N | N |
| Change in introduced species | N | Y |
| Change in algae | N | N |

## Applying the condition indicators across Western Australia

It is beyond the scope of the current project to undertake a trial of the national indicators for wetland condition across the whole of Western Australia. Instead, we present here a gap analysis, based on an analysis of the data required for use of the NWI indicator categories and the available wetland monitoring programs and inventory data, as well as the main threats to wetlands within each NRM region. **Note: the Avon Region has been covered by the Wheatbelt trial (see Sim *et al.* 2008) and is not documented further here.** Additional detail about themes, indicators, possible measures for each indicator and proposed reference conditions is included in Appendix Two.

## A note on the documentation of threats to wetlands

An assessment of key threats to wetlands in each region has been undertaken by reviewing the information detailed in 'A Biodiversity Audit of Western Australia's 53 Biogeographic Sub-regions in 2002' (Department of Conservation and Land Management 2003) and also from other reports on wetlands in the region (Wild *et al.* 2004; Hale and Butcher 2007; Vernes 2007; Wetland Research & Management 2007; Frodsham 2008a, b). This information needs to be reviewed and updated by practitioners in each region, as currently it does not fully capture the key threats to wetlands on the ground, and some of it may be out of date. An effort has been made to ensure that this information is as comprehensive as possible, but input from the regions will improve its accuracy.

In addition, climate change is likely to have a significant future impact on wetlands throughout Western Australia, and this has often not been documented in analyses of threats. In some cases other landscape-scale impacts (e.g. secondary salinisation) will swamp the effects of climate change, making its effects on wetlands more difficult to detect, however it still needs to be considered at a bioregional scale, particularly where it interacts with other threats such as exposure of acid sulphate soils, changed fire regimes and spread of invasive plant species, animal pests and diseases.

## South Coast Region

### *Survey and monitoring programs*

In 1998, the Water and Rivers Commission (WRC; now Department of Water, DoW) contracted V & C Semeniuk and Ecologia to survey, classify and evaluate the wetlands of the South Coast Region (at the level of consanguineous suites), as well as to identify significant wetlands and wetlands at risk. A final report of their findings was released in 1999 (V & C Semeniuk Research Group 1997). This initial regional assessment of wetlands gave rise to the ongoing Regional Wetland Program which consists of the South Coast Monitoring Program and the South Coast Wetland Conservation Program (Table 5).

The Wetlands Conservation Program is jointly managed by DEC and Green Skills[2]. Management plans are developed for priority wetlands, based on the reports prepared for the WRC (Table 3). Additionally, surveys are being conducted in several catchments throughout the South Coast Region (Table 4).

**Table 3: Green Skills wetland management plan projects since 1999**

| Wetland Suite | Location | Completed |
|---|---|---|
| Manypeaks/Pabelup Lake | Bremer Bay | 1999 |
| Lake Corimup | Manypeaks | 2000 |
| Mortijinup lakes | Esperance | 2000 |
| Mills Lake | Ongerup | 2001 |
| Coobidge Creek/Lake Gore | Esperance | 2001 |
| Coomalbidgup Swamp | Esperance | 2002 |
| Unicup Lake | Upper Kent River catchment | 2002 |
| Moates/Gardner lakes | Two Peoples Bay | 2003 |
| Roberts Swamp | Grass Patch, North Esperance | 2003 |
| Boyatup Swamp | Cape Le Grand, Esperance | 2004 |
| Balicup Lake | North Stirlings | 2005 |
| South of the Stirlings | South Stirling-Wellstead | 2005 |
| Cascades | Esperance | 2005 |
| Benje-Benjimup | Esperance | 2006 |
| Owingup Swamp | Denmark | 2006 |
| Jerdacuttup-Shaster Lakes | Ravensthorpe-Jerdacuttup | 2007 |
| Wilson Inlet Catchment | Denmark-Platnagenet | 2007 |
| Hopetoun Lakes | Hopetoun | 2008 |
| King River | Albany | 2008 |

[2] http://www.greenskills.green.net.au/pub.html

**Table 4: Green Skills wetland survey reports since 2002**

| Wetland (suite) | Completed |
|---|---|
| Owingup Waterways | 2002 |
| Cascade Wetlands | 2005 |
| Owingup Wetland | 2006 |
| Benje Benjenup Wetland | 2006 |
| Jerdacuttup-Ravensthorpe area | 2007 |
| Wilson Inlet Catchment | 2007 |
| King River wetland suites | 2008 |
| Hopetoun wetland suites | 2008 |

The South Coast Monitoring Program (commenced in 1998) initially included 30 wetlands and aimed to provide baseline information on wetland condition and seasonal variation (Table 5) (Department of Water 2006). Wetlands were selected based on representativeness, high ecological value, and implementation (wetlands where catchment works are known to have taken place that may have bearing on water quality and wetland condition). The program was later extended to include 69 wetlands. The South Coast Monitoring Program is expected to provide information on wetland condition and trend analysis, and to provide a known resource condition for priority wetlands and near pristine wetland assets. The project also aims to increase community knowledge of wetland condition and values, as well as to improve understanding of hydrological and aquatic threats and processes (T. Calvert pers. comm.).

The Lake Warden Wetland System (LWWS), a Ramsar listed site and part of a Natural Diversity Recovery Catchment, is threatened by salinity, flooding, eutrophication and sedimentation resulting from surrounding agricultural and urban land uses (CSIRO Land and Water 2000; Department of Environment and Conservation 2008b). Clearing of perennial vegetation has resulted in rising water tables and excessive inundation, which is in turn threatening the riparian vegetation and waterbirds of the LWWS. Engineering intervention has been deemed necessary to mitigate the impacts of these threats and for the catchment to recover. It is proposed to de-water Lake Wheatfield and Lake Warden, with disposal into the boat harbour and Bandy Creek respectively, in an attempt to restore the historical water regime. DEC's management objective is for the LWWS to "*recover the existing (2003) waterbird species richness and abundance and its living assemblages, to a near natural condition by the year 2030*" (Department of Environment and Conservation 2008b). To assess the effectiveness of management intervention, a monitoring program has been established (Table 5).

The South West Wetlands Monitoring Program (SWWMP) commenced in 1977, with twice-yearly (September and November) water level and salinity monitoring of eighty-two wetlands in the south west of Western Australia (Geraldton to Esperance) to feed into waterbird management for hunting (Lane *et al.* 2004). In 1981 the number of wetlands and scope of the project was increased for four years (119 wetlands monitored at two-month intervals). After waterbird hunting was banned (1992), the program was continued at a smaller number of sites (60), and funding for the program started to decline.

In 1996, with the release of the Salinity Action Plan, the South West Wetland Monitoring Program was identified as one of very few programs providing long-term routinely collected salinity data across the south west. As a result, the number of monitored wetlands was increased again to 100 (Cale *et al.* 2004; Lane *et al.* 2004) and the program was expanded to include monitoring of wetland biota at 25 of these sites. This project was designed to provide on-going monitoring of wetland salinity and biological resources in wetlands of the agricultural zone of south west Western Australia, to determine long-term trends in natural diversity and provide a sound basis for corrective action.

The Salinity Action Plan ultimately gave rise to two main wetland survey and inventory programs: the Salinity Action Plan 'Wheatbelt Wetland Monitoring Program' (the 25 wetlands mentioned above), and the Salinity Action Plan 'Wheatbelt Wetland Biological Survey'. The Monitoring Program has now been operating since 1997 and involves the collection of water quality, invertebrate and vegetation data for 25 wetlands throughout the Wheatbelt[3]. Water quality sampling and waterbird surveys have been occurring three times per year every second year, and aquatic invertebrates are sampled once every second year. The suitability of data collected as part of the Monitoring Program was discussed in detail in a previous report (Sim *et al.* 2008). However, as this monitoring program includes wetlands from several regions of WA some of this information is replicated in the current report. The Biological Survey collected the same suite of data from a total of 207 wetlands as part of a baseline inventory between 1997 and 2003. The specific objectives of the Biological Survey were to assess the distribution of aquatic faunal diversity in the agricultural region of WA and to determine the relationships between aquatic invertebrate species and assemblages, and environmental values (salinity in particular). This information provided a regional perspective on wetland biodiversity and conservation priorities in the Wheatbelt (Wallace 2001; Cale *et al.* 2004; Pinder *et al.* 2004; Pinder *et al.* 2005).

[3] The Wheatbelt region extends beyond the DEC jurisdictional boundary and incorporates most of the cleared area lying between the 300 and 600 mm rainfall isohyets.

Annual waterbird surveys undertaken in the south west began in 1988 as a four year program (running to 1992), in which waterfowl were counted biannually (November and March) at around 1250 wetlands (Halse *et al.* 1995). The aims of this work were to estimate numbers of key waterbird groups and to look at relative distributions of waterbirds in relation to environmental conditions and breeding.

The Inland Aquatic Integrity Resource Condition Monitoring project aimed to develop standardised methods for assessing and reporting on the condition of significant wetlands in Western Australia (Nowicki *et al.* 2008). The methodology was field tested via a survey of a total of 47 wetlands spanning each of the state's non-metropolitan regions. Permanent monitoring sites were established at each of the test sites, to allow ongoing study of the effects of threatening processes, particularly climate change. The data collected by the project will be synthesised into resource condition reports for each wetland. These reports, the methodology for the project, as well as the data collected during the survey, will be uploaded to a publicly accessible database (WetlandBase). Training and documentation will be provided to DEC regional staff, NRM practitioners and other stakeholders to assist them in establishing monitoring or continuing surveillance of wetlands under their jurisdiction.

The Salinity Action Plan projects and the Inland Aquatic Integrity Resource Condition Monitoring projects span a large geographical area including several NRM regions. As such, the parameters measured for these projects will be included in each of the tables summarising wetland monitoring and inventory projects for the relevant regions.

**Table 5: Wetland monitoring and inventory projects for the South Coast Region**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Name of project** | South Coast Wetland Monitoring Program | South Coast Wetland Conservation Program | Preventing Loss of Birds at Lake Warden | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfow in south WA |
| | **Monitoring or inventory?** | Monitoring | Inventory | Monitoring | Monitoring | Inventory / Monitoring | Inventory | Inventor |
| | **Duration of project** | 1998 - 2008 | 1999 - ongoing | 2006 - ongoing | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-199 |
| | **Organisation(s) responsible** | DoW | Green Skills Inc. | DEC | DEC | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | |
| **Catchment disturbance** | *Disturbance in the catchment* | DC: Land use change (e.g. clearing) | DC: Current land use | DC: Broadscale clearing in the catchment for agriculture | ND | ND | ND | ND |
| **Physical form and processes** | *Change in wetland area* | ND | ND | ND | DC (limited): Detailed bathymetry for some sites | ND | ND | ND |
| | *Change in wetland topography* | ND | ND | ND | DC (limited): Detailed bathymetry for some sites | ND | ND | ND |
| | *Soil disturbance* | ND | ND | ND | ND | ND | DC: Observations | ND |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Name of project** | South Coast Wetland Monitoring Program | South Coast Wetland Conservation Program | Preventing Loss of Birds at Lake Warden | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfow in south WA |
| | **Monitoring or inventory?** | Monitoring | Inventory | Monitoring | Monitoring | Inventory / Monitoring | Inventory | Inventor |
| | **Duration of project** | 1998 - 2008 | 1999 - ongoing | 2006 - ongoing | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-199 |
| | **Organisation(s) responsible** | DoW | Green Skills Inc. | DEC | DEC | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | |
| **Hydrological disturbance** | *Physical modification to hydrology* | DC: Hydrological processes; dam construction and drain excavation | DC: Information on drainage | DC: Proposed pump and gravity pipeline to dewater Lakes Warden and Wheatfield with disposal into Bandy Creek and the boat harbour | ND | DC: 'Impacts on wetlands' including drains, dams, etc., identified using orthophotographs | DC: Observations recorded | ND |
| | *Changes to water regime* | DC: Water level (survey from predetermined relative point to waters edge; twice yearly – autumn, spring) | DC (limited): Groundwater | DC: Duration and volumes of inundation (fortnightly for 8 years)<br>DC: Groundwater (monthly for 8 years) | DC: wetland depths (depth-gauge), rainfall. September and November | DC: Surface and groundwater depths<br>DC: 'Wetness' index derived from satellite imagery analysis has been developed for most of the Wheatbelt | DC (limited): Maximum depth sampled | DC: wetl depths, r |
| **Water and soil quality** | *Turbidity regime* | DC: NTU (twice yearly – autumn, spring) | DC | DC: Suspended soils | ND | DC (lab) | DC | ND |
| | *Salinity regime* | DC: EC (twice yearly – autumn, spring) | DC: EC | DC: EC (fortnightly) | DC: EC, salinity (lab). September and November | DC: EC, salinity | DC | ND |

| | | Name of project | South Coast Wetland Monitoring Program | South Coast Wetland Conservation Program | Preventing Loss of Birds at Lake Warden | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfow in south WA |
|---|---|---|---|---|---|---|---|---|---|
| | | **Monitoring or inventory?** | Monitoring | Inventory | Monitoring | Monitoring | Inventory / Monitoring | Inventory | Inventor |
| | | **Duration of project** | 1998 - 2008 | 1999 - ongoing | 2006 - ongoing | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-199 |
| | | **Organisation(s) responsible** | DoW | Green Skills Inc. | DEC | DEC | DEC | DEC | DEC |
| **Theme** | | **Indicator** | | | | | | | |
| **Water and soil quality** | | *pH* | DC (twice yearly – autumn, spring) | DC | DC: Fortnightly | ND | DC | DC | ND |
| | | *Soil properties* | ND | DC: Potential ASS | DC: ASS (field and lab) | ND | ND | DC: Sediment samples for composition | ND |
| | | *Change in fringing zone* | DC: Size of vegetation buffer zone<br>DC: Fringing vegetation types and condition; weediness and disturbance | DC: Map of change in vegetation for Hopetoun wetlands 1980-2007 | ND | ND | ND | ND | ND |
| | | *Change in wetland vegetation* | DC: Vegetation descriptions<br>DC: Weediness and disturbance<br>DC: Habitat photo points | DC: Nature and condition of littoral vegetation (emphasis on degradation) | DC: Riparian Vegetation Condition monitoring (multi spectral imaging, ground surveys and GIS analysis - surveys in April 1999, 2001, then every 3 years) | ND | ND suitable for use for indicator | DC: Vegetation presence/absence, condition and community composition | DC: dom vegetatio |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Name of project** | | South Coast Wetland Monitoring Program | South Coast Wetland Conservation Program | Preventing Loss of Birds at Lake Warden | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfow in south WA |
| **Monitoring or inventory?** | | Monitoring | Inventory | Monitoring | Monitoring | Inventory / Monitoring | Inventory | Inventor |
| **Duration of project** | | 1998 - 2008 | 1999 - ongoing | 2006 - ongoing | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-199 |
| **Organisation(s) responsible** | | DoW | Green Skills Inc. | DEC | DEC | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | |
| | *Change in invertebrates* | DC: MI (ID to family); feeding group composition (twice yearly – autumn, spring) | DC: MI | DC: MI (Lake Wheatfield surveys every 3 years from 1997; annual spring surveys across LWWS since 2006) | ND | DC: Invertebrate diversity and community composition | DC: ID to species | ND |
| | *Change in vertebrates* | ND | DC: WB use of littoral vegetation and wetland habitats<br>DC: Fish | DC: Waterbirds (1979-2006: ad hoc surveys; 2006 onwards: annual spring surveys) | ND | DC: Waterbirds | DC: Waterbirds<br>DC: Frog observations | DC: wat counts |
| | *Change in introduced species* | DC: Weeds (field observations; (twice yearly – autumn, spring) | DC: Weeds<br>DC: Dieback | ND | ND | ND | DC: Weeds<br>DC: Observations of exotic fauna: scats, tracks, habitat disturbance | ND |
| | *Change in algae* | DC: Chlorophyll-a,b,c; phaeophytin; macroalgae, surface scum (twice yearly – autumn, spring) | ND | ND | ND | DC: Chlorophyll-a,b,c; phaeophytin | DC: Chlorophyll-a,b,c | ND |

[1] ND – No data [2] DC – Data collected [3] EC – Electrical conductivity [4] ASS – Acid Sulphate Soils [5] MI – Macroinvertebrates [6] TSS - Total Suspended Sediments

### *Data storage*

For more information on monitoring/inventory projects in the South Coast Region refer to the reports or contact the persons listed in Table 6.

**Table 6: Storage of wetland monitoring and inventory datasets for the South Coast Region**

| Project | Data storage | Key personnel (current positions) | Relevant Report/s |
|---|---|---|---|
| South Coast Wetland Monitoring Program | DoW – Water Information Network (WIN) database, DEC WetlandBase | Tracy Calvert, Environmental Officer, Albany, DoW | (Department of Water 2006), monitoring reports for individual wetlands |
| South Coast Wetland Conservation Program | Green Skills Inc. | Wetlands Project Manager, Green Skills Inc. (Tim Frodsham) | Various management plans (refer to Table 3 and Table 4) http://www.greenskills.green.net.au/pub.html |
| Preventing loss of birds at Lake Warden | DEC | Recovery Catchment Officer, Lake Warden (Tilo Massenbauer) | (CSIRO Land and Water 2000; Department of Environment and Conservation 2008b) http://www.nrm.gov.au/projects/wa/scst/2006-01.html |
| South West Wetland Monitoring Program (depth-gauged wetlands) | DEC | Jim Lane, Principal Research Scientist, Landscape Conservation Branch, Science Division DEC, Alan Clarke, Senior Technical Officer, Landscape Conservation Branch, Science Division DEC, Yvonne Winchcombe, Senior Technical Officer, Landscape Conservation Branch, Science Division DEC | (Lane *et al.* 2004) |
| Salinity Action Plan | DEC | Dr Stuart Halse, Managing Director, Bennelongia Pty Ltd, Adrian Pinder, Senior Research Scientist, Science Division, DEC | (Halse *et al.* 2003; Cale *et al.* 2004; Halse *et al.* 2004; Pinder *et al.* 2004; Pinder *et al.* 2005; Lyons *et al.* 2007) |
| Inland Aquatic Integrity Resource Condition Monitoring | DEC | Glen Daniel, Environmental Officer (Wetlands), Species and Communities Branch, DEC | (Nowicki *et al.* 2008) |
| Annual waterfowl counts in south west Western Australia | | Dr Stuart Halse, Managing Director, Bennelongia Pty Ltd Roger Jaench, Wetlands International Oceania | (Halse et al. 1992; Halse et al. 1994; Halse et al. 1995) |

***Threats to wetlands by region/wetland type***

Table 7 shows a matrix of threats to wetlands in Western Australia against the NWI for condition, with ticks indicating that measuring a particular indicator could provide information about the corresponding threat. This allows an evaluation of which indicators might have importance in monitoring the impact of particular threats. The bold type in Table 7 indicates those threats that are known to affect wetlands in the South Coast Region. Shaded threats (red) are those mentioned most often in the literature for the region, and therefore inferred as the most significant threats to wetlands for each region[4]. Shaded indicators (yellow) are those which have three or more priority threats against them, and which therefore are likely to be particularly important for the region.

**Table 7: Threats to wetlands in the South Coast Region (in bold) against relevant NWI**

| Threat | Condition indicator: Catchment disturbance | Change in wetland area | Change in wetland topography | Soil disturbance (physical) | Physical modification to hydrology | Changes to water regime | Turbidity (light climate) regime | Salinity regime | Change in pH | Change in [sediment] properties (salinity, acidity) | Change in fringing zone | Change in wetland vegetation | Change in [aquatic] invertebrate diversity and community composition | Change in waterbird presence, breeding and abundance | Change in other wetland-dependent vertebrates presence, breeding and abundance | Change in introduced species | Change in algae | Other indicators required? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Broad-scale vegetation clearing** | ✓ | | | ✓ | | | | | | | ✓ | ✓ | | | ✓ | | | |
| **Increasing fragmentation, loss of remnants and lack of recruitment** | ✓ | | | | | | | | | | ✓ | ✓ | | | ✓ | | | |
| **Firewood collection** | | | | | | | | | | | ✓ | ✓ | | | | | | Not directly measured |
| **Grazing pressure** | ✓ | | | ✓ | | | ✓ | | | | ✓ | ✓ | | | | | | |
| **Feral animals** | | | | | | | | | | | | | | ✓ | ✓ | ✓ | | |
| **Exotic weeds** | | | | | | | | | | | ✓ | ✓ | | | | ✓ | | |
| **Altered fire regimes** | ✓ | | | | | | | | | | ✓ | ✓ | | | ✓ | | | Not directly measured |
| **Pathogens (including phytopthora)** | | | | | | | | | | | ✓ | ✓ | | ✓ | ✓ | | | Wide range possible? |
| **Secondary salinisation** | ✓ | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| **Altered hydrology (surface and ground water)** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| **Pollution (including eutrophication)** | | | | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | ✓ | |
| **Mining** | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | | | | |
| **Recreational vehicles** | | | ✓ | ✓ | ✓ | | | | | | | | | ✓ | ✓ | | | |
| **Direct human disturbance of ecosystem** | | | ✓ | ✓ | ✓ | | | | | | ✓ | ✓ | | ✓ | ✓ | | | |
| **Impacts of roads** | | ✓ | ✓ | ✓ | ✓ | | | | | | ✓ | ✓ | | ✓ | ✓ | ✓ | | |
| **Vegetation harvesting** | | | | ✓ | | | | | | | ✓ | ✓ | | | | | | |
| **Agriculture (including farm dams and infrastructure)** | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | | |

[4] Feedback on priority threats for each region is welcomed. Please contact the Wetlands Section, Department of Environment & Conservation, Kensington.

| | Condition indicator | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Catchment disturbance | Change in wetland area | Change in wetland topography | Soil disturbance (physical) | Physical modification to hydrology | Changes to water regime | Turbidity (light climate) regime | Salinity regime | Change in pH | Change in [sediment] properties (salinity, acidity) | Change in fringing zone | Change in wetland vegetation | Change in [aquatic] invertebrate diversity and community composition | Change in waterbird presence, breeding and abundance | Change in other wetland-dependent vertebrates presence, breeding and abundance | Change in introduced species | Change in algae | Other indicators required? |
| **Acid Sulphate Soils** | | | | | | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | |
| **Urban and pre-urban development** | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | ✓ | ✓ | | | | ✓ | | |
| Commercial and recreational fishing | | | | | | | | | | | | | | ✓ | ✓ | | ✓ | Not directly measured |
| **Recreation (including tourism)** | | | | | | | | | | | | | | | | | | Threat too inspecific? |
| **Climate change** | ✓ | ✓ | | | | ✓ | | ✓ | | | | | ✓ | | | | ✓ | |
| **Sedimentation** | | ✓ | ✓ | | ✓ | | ✓ | | | ✓ | | | ✓ | | | | | |
| **Wind and water erosion** | | ✓ | ✓ | | ✓ | | ✓ | | | | | | | | | | | |

Twelve indicators were identified as high priority to provide information on threats to wetlands within the South Coast Region, and data is available to inform all of these – either through the South Coast Wetland Monitoring Program or the South Coast Wetlands Conservation Program. This puts the South Coast Region in a strong position to implement the next phase of the National Wetland Indicators process.

### *Information Gaps*

The South Coast Wetland Monitoring Program includes almost 70 wetlands over a wide geographic area, making it the most comprehensive wetland monitoring project in the region. However, logistical restraints prevented the identification of aquatic invertebrates to the species level. This limits the information provided by the data and the way in which this is interpreted. Detailed surveys of aquatic invertebrates at the lowest taxonomic level for a smaller number of wetlands would be beneficial. This program also does not monitor waterbirds or other wetland vertebrates, however the data collected on other indicators may still give a comprehensive picture of wetland condition.

### *Planned future work*

The South Coast Wetland Monitoring Program, run by DoW, finished in 2008 monitoring may be continued into the future at some of these sites (T. Calvert, pers. comm.).

Wetland management plans, developed as part of the South Coast Wetland Conservation Program, are to be implemented by Green Skills within the next few months by providing on-ground support for wetland fencing, revegetation and weed control programs. Due to limited resources, management actions will be implemented only for prioritised wetlands (T. Frodsham pers. comm.).

An application will be made to fund continuation of the IAI RCM project. Provided the application is successful, surveys will continue on an annual basis. The project also aims to facilitate and encourage the development of monitoring programs for individual wetlands, or groups of wetlands (G. Daniel pers. comm.).

## South West Region

### *Survey and monitoring programs*

Wetland monitoring is being undertaken by DEC at 40 wetlands in the South West Region as part of a wetland inventory project funded under the Natural Heritage Trust (NHT) and the National Action Plan for Salinity and Water Quality (NAP) via the South West Catchments Council (SWCC) (Podesta 2007; Department of Environment and Conservation 2009). The monitoring is now in its third year. The initial project 'Wetland Mapping, Classification and Evaluation Program for Priority Wetlands, South West Western Australia' commenced in 2006 at 13 wetland sites throughout the Swan Coastal Plain in the south west region. The on-going project 'Mapping, Classification and Evaluation of Wetlands', increased the number of sites to 40 wetlands. The monitoring program aims to understand and document the baseline condition of the selected wetlands, which were chosen to meet a range of criteria such as representativeness of habitat, function, processes, biodiversity, scientific and cultural values. Parameters recorded include vegetation cover and condition, water quality, and waterbird and invertebrate diversity.

The Peel-Yalgorup System comprises the Peel Inlet and Harvey estuary, wetlands of Lakes McLarty and Mealup, the Yalgorup National Park environment (saline lakes) and sections of fringing dryland. The Peel-Yalgorup System was originally designated as a Ramsar site in 1990. This was extended in 2001 to include additional wetlands, bringing the total area of the Ramsar site to 26,530 ha. Since its listing, the Ramsar site has faced significant pressures relating to the rapidly expanding population of nearby Mandurah, including the opening of the Dawesville Channel in 1994. A Management Plan and an Ecological Character Description (ECD) have been prepared for the Peel-Yalgorup Ramsar Site (Hale and Butcher 2007; Hale and Butcher 2008a). These two documents detail previous monitoring which has occurred within the Peel-Yalgorup System (summarised in Table 8).

The Vasse-Wonnerup wetlands were also nominated as a Ramsar site in 1990. In 2000, this Ramsar site was extended and now covers 1,115 ha and includes the Wonnerup Inlet, the Vasse and Wonnerup estuaries (lagoons) and lower reaches along the Sabina and Abba rivers. The wetlands are a significant habitat and breeding site for large numbers of waterbirds. While there is currently no comprehensive monitoring program for the Vasse-Wonnerup Ramsar Site, a number of monitoring, rehabilitation and restoration programs have been conducted by various organisations within the Vasse-Wonnerup wetlands. In general, these have been related to water quality monitoring, however, sampling methodologies have differed making comparison of results difficult. Details of these programs are presented in the Ecological

Character Description of the Vasse-Wonnerup Ramsar Site and are summarised in Table 8 (Wetland Research & Management 2007). DEC has been monitoring several locations throughout the Vasse-Wonnerup and Benger wetland on a monthly basis since September 2007. This monitoring is guided by the ECD and is due to be completed in December 2008.

The Swan Coastal Plain Waterbirds study extended from Lancelin (in the Northern Agricultural Region) to Bunbury (in the South West Region). As most of the area covered by the study was contained within the South West and Perth Regions, parameters measured as part of the project are included in both Table 8 and Table 11. The Swan Coastal Plain Waterbirds project investigated the relationships between environmental characteristics and waterbird usage at 251 wetlands of the Swan Coastal Plain (SCP) (Storey *et al.* 1993). The study was designed to incorporate a variety of wetland types. The aim of the project was to "*quantify the extent of waterbird use of different wetland types on the SCP, identify important wetlands for waterbirds, and examine the pattern of use (i.e. seasonal movements/habitat for different parts of the life cycle such as breeding or moulting) of different wetland types by waterbirds*". To this end, the Royal Australasian Ornithologists Union (RAOU) conducted waterbird surveys with the assistance of volunteers. Officers from DEC (then CALM) measured environmental conditions (Table 8).

Sampling of wetlands in the South West region was also undertaken as part of the Inland Aquatic Integrity Resource Condition Monitoring project monitoring and survey work as part of the Salinity Action Plan (including the South West Wetland Monitoring Program) and annual counts of waterfowl. As these projects included sampling wetlands over several NRM regions, they have been described in detail only once in this paper (South Coast region – p. 16).

Some more targeted monitoring of specific wetland vertebrates is also taking place in the South West region, and this is listed below, but has not been included in Table 8 due to insufficient detail:

- Frogs (*Geocrinia* sp.) – contact Kim Williams, DEC Bunbury
- Bitterns – contact Nicole Lincoln, DEC Bunbury

**Table 8: Wetland monitoring and inventory projects for the South West Region**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Name of project** | | Wetland Mapping, Classification and Evaluation Program | Peel-Yalgorup Ramsar Site | Vasse-Wonnerup Wetlands Ramsar Site | Swan Coastal Plain Waterbirds | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfowl counts in south west WA |
| **Monitoring or inventory?** | | Monitoring | Monitoring | Monitoring | Monitoring | Monitoring | Inventory / Monitoring | Inventory | Inventory |
| **Duration of project** | | 2006 - 2008 | | 2007 - 2008 | 1989 - 1992 | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-1992 |
| **Organisation(s) responsible** | | DEC | Peel-Harvey Catchment Council | DEC | DEC, RAOU | DEC | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | | |
| **Catchment disturbance** | *Disturbance in the catchment* | ND | DC: Changes in land use associated with rising population (Mandurah) since 1990 | DC: Estimates of percentage land clearing | ND | ND | ND | ND | ND |
| **Physical form and processes** | *Change in wetland area* | ND | ND | DC: Reduced area (less flooding due to floodgates) | DC | DC (limited): Detailed bathymetry for some sites | ND | ND | ND |
| | *Change in wetland topography* | ND | DC: Bathymetry, geomorphology. Some dredging | DC: Original (1965) bathymetry data | DC: Width of wading zone | DC (limited): Detailed bathymetry for some sites | DC (limited): Detailed bathymetry for 4 lakes: Toolibin, Dumbleyung, Towerrining, Coyrecup | ND | ND |

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|---|---|---|---|---|---|---|---|---|---|
| **Name of project** | | Wetland Mapping, Classification and Evaluation Program | Peel-Yalgorup Ramsar Site | Vasse-Wonnerup Wetlands Ramsar Site | Swan Coastal Plain Waterbirds | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfowl counts in south west WA |
| **Monitoring or inventory?** | | Monitoring | Monitoring | Monitoring | Monitoring | Monitoring | Inventory / Monitoring | Inventory | Inventory |
| **Duration of project** | | 2006 - 2008 | | 2007 - 2008 | 1989 - 1992 | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-1992 |
| **Organisation(s) responsible** | | DEC | Peel-Harvey Catchment Council | DEC | DEC, RAOU | DEC | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | | |
| | *Soil disturbance* | ND | DC: Soil composition<br>DC: Potential ASS | DC: Rapid assessment of propensity for bed and bank erosion | ND | ND | ND | DC: Observations recorded | ND |
| **Hydrological disturbance** | *Physical modification to hydrology* | ND | DC: Construction of Dawesville Channel in 1994 | DC: Significant changes to surface hydrology. - estuaries act as compensating basins since installation of floodgates (1908) | DC: Number of drains | ND | DC: 'Impacts on wetlands' including drains, dams, etc., identified using ortho-photographs | DC: Observations recorded | ND |

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|---|---|---|---|---|---|---|---|---|---|
| **Name of project** | | Wetland Mapping, Classification and Evaluation Program | Peel-Yalgorup Ramsar Site | Vasse-Wonnerup Wetlands Ramsar Site | Swan Coastal Plain Waterbirds | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfowl counts in south west WA |
| **Monitoring or inventory?** | | Monitoring | Monitoring | Monitoring | Monitoring | Monitoring | Inventory / Monitoring | Inventory | Inventory |
| **Duration of project** | | 2006 - 2008 | | 2007 - 2008 | 1989 - 1992 | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-1992 |
| **Organisation(s) responsible** | | DEC | Peel-Harvey Catchment Council | DEC | DEC, RAOU | DEC | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | | |
| | *Changes to water regime* | DC: Depth measured at fixed reference point (as depth or distance to edge of surface water) | DC: Water depth | DC: Water depth (recorded periodically 1927 - 1992, then more regularly); estuary floodgates logger data (1998 – 2004) | DC: Water depth (at gauge) and permanence | DC: wetland depths (depth-gauge), rainfall. September and November | DC: Surface and groundwater depths<br>DC: 'Wetness' index derived from satellite imagery analysis has been developed for most of the Wheatbelt | DC (limited): Maximum depth sampled | DC: wetland depths, rainfall |
| **Water and soil quality** | *Turbidity regime* | DC | DC | DC: Few historical data on TSS (ND on seasonal variability); seasonal (May - Nov), fortnightly sampling since 2006 (20 sites) | DC | ND | DC (lab) | DC | ND |

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|---|---|---|---|---|---|---|---|---|---|
| **Name of project** | | Wetland Mapping, Classification and Evaluation Program | Peel-Yalgorup Ramsar Site | Vasse-Wonnerup Wetlands Ramsar Site | Swan Coastal Plain Waterbirds | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfowl counts in south west WA |
| **Monitoring or inventory?** | | Monitoring | Monitoring | Monitoring | Monitoring | Monitoring | Inventory / Monitoring | Inventory | Inventory |
| **Duration of project** | | 2006 - 2008 | | 2007 - 2008 | 1989 - 1992 | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-1992 |
| **Organisation(s) responsible** | | DEC | Peel-Harvey Catchment Council | DEC | DEC, RAOU | DEC | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | | |
| | *Salinity regime* | DC: EC, field salinity, TSS | DC (limited): Collected by the Lake Mealup Preservation Society (unpublished), 1987 – 1994; Lake McLarty data from a small number of spot samples | DC: EC, TSS, salinity (fortnightly Aug - May 1996 - 2006, and Feb - Dec 2006); additional survey in Nov 2006; Fortnightly monitoring in Vasse and Wonnerup exit channels, the Deadwater and lower Vasse River | DC (TDS) | DC: EC, salinity (lab). September and November | DC: EC, salinity | DC | ND |
| | *pH* | DC | DC (limited): Collected by the Lake Mealup Preservation Society (unpublished), 1987 – 1994; Lake McLarty data from few spot samples | DC: EC (fortnightly Feb - Dec 2006) | DC | ND | DC | DC | ND |

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|---|---|---|---|---|---|---|---|---|---|
| **Name of project** | | Wetland Mapping, Classification and Evaluation Program | Peel-Yalgorup Ramsar Site | Vasse-Wonnerup Wetlands Ramsar Site | Swan Coastal Plain Waterbirds | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfowl counts in south west WA |
| **Monitoring or inventory?** | | Monitoring | Monitoring | Monitoring | Monitoring | Monitoring | Inventory / Monitoring | Inventory | Inventory |
| **Duration of project** | | 2006 - 2008 | | 2007 - 2008 | 1989 - 1992 | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-1992 |
| **Organisation(s) responsible** | | DEC | Peel-Harvey Catchment Council | DEC | DEC, RAOU | DEC | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | | |
| | *Soil properties* | ND | DC: Potential ASS (2006) | DC: Actual and potential ASS | ND | ND | ND | DC: Sediment samples for composition | ND |
| **Fringing zone** | *Change in fringing zone* | ND | ND | DC (rivers only?): Vegetation data and maps for Vasse-Wonnerup | DC: Vegetation structure; percent wetland buffered and width of buffer | ND | ND | ND | ND |

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|---|---|---|---|---|---|---|---|---|---|
| **Name of project** | | Wetland Mapping, Classification and Evaluation Program | Peel-Yalgorup Ramsar Site | Vasse-Wonnerup Wetlands Ramsar Site | Swan Coastal Plain Waterbirds | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfowl counts in south west WA |
| **Monitoring or inventory?** | | Monitoring | Monitoring | Monitoring | Monitoring | Monitoring | Inventory / Monitoring | Inventory | Inventory |
| **Duration of project** | | 2006 - 2008 | | 2007 - 2008 | 1989 - 1992 | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-1992 |
| **Organisation(s) responsible** | | DEC | Peel-Harvey Catchment Council | DEC | DEC, RAOU | DEC | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | | |
| **Biota** | *Change in wetland vegetation* | DC: Vegetation quadrats (% cover, stem numbers)<br>DC: Vegetation condition (and floristics) | DC: Benthic vegetation (sea grasses) and macroalgae<br>DC: Littoral vegetation | DC: Broadscale vegetation mapping surveys in 1973, 1980, 1996<br>DC: Vegetation and flora surveys of area Mar - Apr 1980 and 2000<br>DC: Satellite thermal imagery used to estimate rates of vegetation clearing 1990 - 2000 | DC: Vegetation structure, macrophyte cover and biomass | ND | ND suitable for use for indicator | DC: Vegetation presence/absence, condition and community composition | DC: dominant vegetation type |
| | *Change in invertebrates* | DC: Invertebrates (macro- & micro-); live-picking to 60 minutes in 2006 and 2007, live-picking to 200 | DC (limited): Invertebrates (MI?); Summer 2000: Lake McLarty survey ND for Lake Mealup<br>DC: | DC: MI Presence/absence, abundance (log10 scale), ID to species (or genus) Surveys in spring 1989, 2001, 2005<br>DC: Large | DC: Invertebrates | ND | DC: Invertebrate diversity and community composition | DC: ID to species | ND |

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|---|---|---|---|---|---|---|---|---|---|
| **Name of project** | | Wetland Mapping, Classification and Evaluation Program | Peel-Yalgorup Ramsar Site | Vasse-Wonnerup Wetlands Ramsar Site | Swan Coastal Plain Waterbirds | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfowl counts in south west WA |
| **Monitoring or inventory?** | | Monitoring | Monitoring | Monitoring | Monitoring | Monitoring | Inventory / Monitoring | Inventory | Inventory |
| **Duration of project** | | 2006 - 2008 | | 2007 - 2008 | 1989 - 1992 | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-1992 |
| **Organisation(s) responsible** | | DEC | Peel-Harvey Catchment Council | DEC | DEC, RAOU | DEC | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | | |
| | | species in 2008; ID to species | Thrombolite communities DC (limited): Large inverts (e.g. crabs) | invertebrates, e.g. crayfish, prawns (no quantitative studies) | | | | | |

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|---|---|---|---|---|---|---|---|---|---|
| **Name of project** | | Wetland Mapping, Classification and Evaluation Program | Peel-Yalgorup Ramsar Site | Vasse-Wonnerup Wetlands Ramsar Site | Swan Coastal Plain Waterbirds | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfowl counts in south west WA |
| **Monitoring or inventory?** | | Monitoring | Monitoring | Monitoring | Monitoring | Monitoring | Inventory / Monitoring | Inventory | Inventory |
| **Duration of project** | | 2006 - 2008 | | 2007 - 2008 | 1989 - 1992 | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-1992 |
| **Organisation(s) responsible** | | DEC | Peel-Harvey Catchment Council | DEC | DEC, RAOU | DEC | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | | |
| | *Change in vertebrates* | DC: WB surveys. Waterbirds were distinguished from wetland birds<br>DC: Opportunistic frog sightings and calls recorded<br>DC: Opportunistic sighting of other fauna (scats, tracks, impacts) | DC: WB surveys 1981 - 1985<br>DC: Fish - estuarine and marine species | DC: Fish abundance, relative density<br>DC: WB foraging and breeding habitats. Annual aerial surveys Sep/Oct 1960s - 70s. Annual surveys 1981 - 85 (2 - 4 weekly in each season, except winter 1981 - 82). Aerial & ground surveys in March 1986 - 91, additional counts in Nov 1989 – 91. Surveys 1998 - 2000 | DC: WB abundance (every 3 months for 2 years), clutch and brood size<br>DC: Fish | ND | DC: Waterbirds | DC: Waterbirds<br>DC: Frog observations | DC: waterbird counts |
| | *Change in introduced species* | ND | ND | DC (limited): Introduced fish and weeds (e.g. *Typha*, | ND | ND | ND | DC: Weeds<br>DC: Observations | ND |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Name of project** | | Wetland Mapping, Classification and Evaluation Program | Peel-Yalgorup Ramsar Site | Vasse-Wonnerup Wetlands Ramsar Site | Swan Coastal Plain Waterbirds | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfowl counts in south west WA |
| **Monitoring or inventory?** | | Monitoring | Monitoring | Monitoring | Monitoring | Monitoring | Inventory / Monitoring | Inventory | Inventory |
| **Duration of project** | | 2006 - 2008 | | 2007 - 2008 | 1989 - 1992 | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-1992 |
| **Organisation(s) responsible** | | DEC | Peel-Harvey Catchment Council | DEC | DEC, RAOU | DEC | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | | |
| | | | | arum lily) | | | | of ferals (scats, tracks, habitat disturbance) | |
| | *Change in algae* | DC: Chlorophyll - a,b,c; phaeophytin | DC?: Phytoplankton | DC: Chlorophyll-a,b,c; phaeophytin; phytoplankton (fortnightly Aug-May 1996 - 2006, monthly 2006 - 08); Nov 2006: abundance & distribution of vascular macrophytes & macroalgae, inc. cyanophytes | DC: Chlorophyll-a, phaeophytin -a | ND | DC: Chlorophyll-a,b,c; phaeophytin | DC: Chlorophyll-a,b,c | ND |

[1] ND – No data [2] DC – Data collected [3] EC – Electrical conductivity [4] ASS – Acid Sulphate Soils [5] MI – Macroinvertebrates [6] TSS - Total Suspended Sediments

### *Data storage*

For more information on monitoring/inventory projects in the South West Region refer to the reports or contact the persons listed in Table 9.

**Table 9: Storage of wetland monitoring and inventory datasets for the South West Region**

| Project | Data storage | Key personnel (current positions) | Relevant Report/s |
|---|---|---|---|
| Wetland Mapping, Classification and Evaluation Program (South West Catchment Council) | DEC | Wesley Manson, Environmental Officer, Wetland Section, DEC | (Podesta 2007; Department of Environment and Conservation 2009) |
| Peel-Yalgorup Ramsar Site | DEC, DoW | Amanda Willmott, Waterways & Wetlands Officer, Peel-Harvey Catchment Council | (Hale and Butcher 2007; Hale and Butcher 2008a) |
| Vasse-Wonnerup Wetlands Ramsar Site | DEC | Dr Andrew Storey, Principal Consultant, Wetland Research & Management, Joanna Hugues-dit-Ciles, Water Program Coordinator South West Catchments Council | (Wetland Research & Management 2007) |
| Swan Coastal Plain Waterbirds | DEC | Dr Andrew Storey, Principal Consultant, Wetland Research & Management | (Storey *et al.* 1993) |
| South West Wetland Monitoring Program (depth-gauged wetlands) | DEC | Jim Lane, Principal Research Scientist, Landscape Conservation Branch, Science Division DEC, Alan Clarke, Senior Technical Officer, Landscape Conservation Branch, Science Division DEC, Yvonne Winchcombe, Senior Technical Officer, Landscape Conservation Branch, Science Division DEC | (Lane *et al.* 2004) |
| Salinity Action Plan | DEC | Dr Stuart Halse, Managing Director, Bennelongia Pty Ltd, Adrian Pinder, Senior Research Scientist, Science Division, DEC | (Halse *et al.* 2003; Cale *et al.* 2004; Halse *et al.* 2004; Pinder *et al.* 2004; Pinder *et al.* 2005; Lyons *et al.* 2007) |

| Project | Data storage | Key personnel (current positions) | Relevant Report/s |
|---|---|---|---|
| Inland Aquatic Integrity Resource Condition Monitoring | DEC | Glen Daniel, Environmental Officer (Wetlands), Species and Communities Branch, DEC | (Nowicki *et al.* 2008) |
| Annual waterfowl counts in south west Western Australia | | Dr Stuart Halse, Managing Director, Bennelongia Pty Ltd Roger Jaench, Wetlands International Oceania | (Halse et al. 1992; Halse et al. 1994; Halse et al. 1995) |

### *Threats to wetlands by region/wetland type*

Table 10 shows a matrix of threats to wetlands in Western Australia against the NWI for condition, with ticks indicating that measuring a particular indicator could provide information about the corresponding threat. This allows an evaluation of which indicators might have importance in monitoring the impact of particular threats. The bold type in Table 10 indicates those threats that are known to affect wetlands in the South West Region. Shaded threats (red) are those mentioned most often in the literature for the region, and therefore inferred as the most significant threats to wetlands for each region[5]. Shaded indicators (yellow) are those which have three or more priority threats against them, and which therefore are likely to be particularly important for the region.

**Table 10: Threats to wetlands in the South West Region (in bold) against relevant NWI**

| Threat | Condition indicator: Catchment disturbance | Change in wetland area | Change in wetland topography | Soil disturbance (physical) | Physical modification to hydrology | Changes to water regime | Turbidity (light climate) regime | Salinity regime | Change in pH | Change in [sediment] properties (salinity, acidity) | Change in fringing zone | Change in wetland vegetation | Change in [aquatic] invertebrate diversity and community composition | Change in waterbird presence, breeding and abundance | Change in other wetland-dependent vertebrates presence, breeding and abundance | Change in introduced species | Change in algae | Other indicators required? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Broad-scale vegetation clearing** | ✓ | | | ✓ | | | | | | | ✓ | ✓ | | | ✓ | | | |
| **Increasing fragmentation, loss of remnants and lack of recruitment** | ✓ | | | | | | | | | | ✓ | ✓ | | | ✓ | | | |
| **Firewood collection** | | | | | | | | | | | ✓ | ✓ | | | | | | Not directly measured |
| **Grazing pressure** | ✓ | | | ✓ | | | ✓ | | | | ✓ | ✓ | | | | | | |
| **Feral animals** | | | | | | | | | | | | | | ✓ | ✓ | ✓ | | |
| **Exotic weeds** | | | | | | | | | | | ✓ | ✓ | | | | ✓ | | |
| **Altered fire regimes** | ✓ | | | | | | | | | | ✓ | ✓ | | | ✓ | | | Not directly measured |
| **Pathogens (including phytopthora)** | | | | | | | | | | | | | | ✓ | ✓ | | | Wide range possible? |
| **Secondary salinisation** | ✓ | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| **Altered hydrology (surface and ground water)** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| **Pollution (including eutrophication)** | | | | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | ✓ | |
| **Mining** | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | | | | |
| **Recreational vehicles** | | | ✓ | ✓ | ✓ | | | | | | | | | ✓ | ✓ | | | |
| **Direct human disturbance of ecosystem** | | | ✓ | ✓ | ✓ | | | | | | ✓ | ✓ | | ✓ | ✓ | | | |
| **Impacts of roads** | | ✓ | ✓ | ✓ | ✓ | | | | | | | ✓ | | ✓ | ✓ | ✓ | | |
| **Vegetation harvesting** | | | | ✓ | | | | | | | ✓ | ✓ | | | | | | |
| **Agriculture (including farm dams and infrastructure)** | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | | |
| **Acid Sulphate Soils** | | | | | | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | |

[5] Feedback on priority threats for each region is welcomed. Please contact the Wetlands Section, Department of Environment & Conservation, Kensington.

| | Condition indicator | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Catchment disturbance | Change in wetland area | Change in wetland topography | Soil disturbance (physical) | Physical modification to hydrology | Changes to water regime | Turbidity (light climate) regime | Salinity regime | Change in pH | Change in [sediment] properties (salinity, acidity) | Change in fringing zone | Change in wetland vegetation | Change in [aquatic] invertebrate diversity and community composition | Change in waterbird presence, breeding and abundance | Change in other wetland-dependent vertebrates presence, breeding and abundance | Change in introduced species | Change in algae | Other indicators required? |
| **Urban and pre-urban development** | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | ✓ | ✓ | | | | ✓ | | |
| Commercial and recreational fishing | | | | | | | | | | | | | | ✓ | ✓ | | ✓ | Not directly measured |
| **Recreation (including tourism)** | | | | | | | | | | | | | | | | | | Threat too unspecific? |
| Climate change | ✓ | ✓ | | | | ✓ | | ✓ | | | | | ✓ | | | | ✓ | |
| **Sedimentation** | | ✓ | ✓ | | ✓ | | ✓ | | | ✓ | | | ✓ | | | | | |
| **Wind and water erosion** | | ✓ | ✓ | | ✓ | | ✓ | | | | | | | | | | | |

### *Information Gaps*

Twelve indicators were identified as high priority to provide information on threats to wetlands within the South West Region, and of these, data on water quality have been most consistently collected across the different monitoring and inventory programs. Physical and hydrological indicators are not covered well either by the South West Wetlands Monitoring Program or the Wetland Mapping, Classification and Evaluation Program. There is also limited information on wetland vegetation, except at specific sites.

The Peel-Yalgorup and Vasse-Wonnerup Ramsar Site ECDs both identify several knowledge gaps for the two wetland systems. In both cases there is a need for a comprehensive, consistent approach to monitoring of both wetland systems. The Peel-Yalgorup Ramsar Site Management Plan includes a Monitoring and Evaluation Guide which aims to address these issues by providing a framework for future monitoring.

Wetland monitoring and inventory data for the South West is comprehensive in some areas, but lacks a good coverage of parameters across a wide geographic area. The longest running monitoring program is focused on a small range of parameters, and more comprehensive programs are only focused on small geographic areas. Some assessment of how representative the available information is for the South West would need to be undertaken before further implementing the NWI.

### *Planned future work*

One of the objectives of the Peel-Yalgorup Management Plan is that "*the ecological character, including services and values, is maintained or improved to achieve long term positive outcomes*" (Hale and Butcher 2007). A monitoring program is necessary to assess if the ecological character of the site is being protected. To assist in this, Limits of Acceptable Change (LAC) have been developed and will be used to interpret data collected through monitoring. As part of the management plan, a Monitoring and Evaluation Guide has been developed. The Guide aims to address knowledge gap issues by providing a framework for future monitoring and to inform the refinement and review of LAC, which can then be used to inform management. A targeted monitoring approach has been recommended and is detailed in the Monitoring and Evaluation Guide.

The Department of Water is currently in the process of revising a management plan for the Peel-Harvey Estuary/Peel Inlet Management Area. The monitoring program included in this management plan is designed as per the Monitoring and Evaluation Guide included in the Peel-Yalgorup Management Plan (A. Willmott pers. comm.).

The South West Catchment Council is currently developing an Investment Decision Support System (IDSS) for waterways, wetlands and estuaries in the South West region. This is being developed by Spatial Vision as a tool integrated into ArcGIS. The framework for data input is based on an attribute : threat matrix for identified assets and uses a scoring system to define appropriate management response and priority. Data to score the assets are manually entered into the system via a spreadsheet. These scores are obtained based on knowledge gained from technical reports and data sources, as well as the knowledge of water experts and representatives of local land management groups. To date, fifteen DIWA and four Ramsar listed sites have been spatially identified within the wetlands layer, and are yet to be scored (Q. Gay pers. comm.).

An application will be made to fund continuation of the IAI RCM project. Provided the application is successful, surveys will continue on an annual basis. The project also aims to facilitate and encourage the development of monitoring programs for individual wetlands, or groups of wetlands (G. Daniel pers. comm.).

## Perth Region

### *Survey and monitoring programs*

The Perth Region contains the largest concentration of people in Western Australia and, as a result, wetlands found in the region face a range of pressures associated with urbanization. Perth's population relies heavily on groundwater supply for domestic and industrial use. In order to track the effects of this water use, significant inventory and monitoring has been undertaken on wetlands occurring on the two groundwater mounds found on the Swan Coastal Plain: Gnangara and Jandakot (Table 11).

Perhaps the most comprehensive of these studies was the '40 wetlands study', undertaken by Murdoch University, which commenced in 1989 and aimed to evaluate and classify wetlands of the Swan Coastal Plain (Davis *et al.* 1993). The project provided a baseline assessment of biodiversity and information on optimal monitoring and management of wetlands. Forty-one wetlands on the Gnangara and Jandakot mounds were sampled for water chemistry and aquatic biota (Table 11).

In 1996, a further monitoring program was established for wetlands of the Jandakot groundwater mound as part of the Public Environmental Review and Environmental Management Program of the Jandakot Groundwater Scheme Stage 2. One component of the monitoring is aimed at assessing the ecological condition of wetlands located on the Jandakot mound and the possible impacts of groundwater extraction (Wild *et al.* 2004). It provides information on the status of macroinvertebrates in these wetlands and on their response(s) to changes in groundwater and wetland water levels. Ten wetlands are sampled twice-yearly (in spring and summer) for water quality, macroinvertebrates and vegetation, resulting in 15 sampling occasions over 7 years to date (however, not all wetlands have been sampled on each occasion due to low water levels). Of these ten wetlands, three are considered 'control' sites as they do not lie directly over the Jandakot mound and should therefore be less influenced by groundwater levels. The impacts of groundwater abstraction on waterbird usage and on wetland vegetation have also been monitored at wetlands on the Jandakot mound (Bamford and Bamford 1998; Ladd 1999).

Similarly, since 1995, monitoring has been conducted for wetlands located on the Gnangara groundwater mound to assess and monitor the effects of groundwater extraction as part of the Gnangara Mound Environmental Monitoring Project (Pettit and Froend 1998; Sommer and Horwitz 1999). As part of this project, water chemistry, macroinvertebrates, and fringing vegetation are sampled. Additionally, three Gnangara mound springs were

sampled in the summer of 2002 as part of a DEC survey. Invertebrates, and their associated habitats, were surveyed at all three springs but water quality was measured at only two of these due to low water levels. Wrigley *et al.* (1991) also surveyed 16 wetlands on the Gnangara Mound in November and December 1987, taking water chemistry and sediment samples.

The Swan Coastal Plain Waterbirds Study ran from 1989 to 1992 and extended from Lancelin (in the Northern Agricultural Region) to Bunbury (in the South West Region) (Storey *et al.* 1993). As the majority of the study area fell within the South West and Perth Regions, parameters measured as part of the project have been included both in Table 8 and Table 11. A more detailed description of the project is provided on page 28 (see South West Region).

More recently, Australia's branch of the WWF established the 'Wetland Watch' project, which was aimed at "*enhancing the sustainable management and conservation of wetlands on the Swan Coastal Plain*"[6]. The project focused on privately owned, high value wetlands in the Cities of Armadale and Cockburn, and the Town of Kwinana. The objectives of the project were to increase community and landowner appreciation of wetlands, to increase community and landholder capacity for management and conservation of wetlands, and to achieve long-term conservation of wetlands through the use of voluntary management agreements and conservation covenants. As most of the wetlands were damplands, and as such did not contain any surface water, the program did not involve water quality sampling and instead focused on vegetation assessment.

Various other inventory, experimental and other work has been conducted by universities on Swan Coastal Plain wetlands, but it is beyond the scope of this paper to document all of these smaller studies.

[6] http://www.wwf.org.au/ourwork/water/wetlandwatch/

**Table 11: Wetland monitoring and inventory projects for the Perth Region**

| Name of project | | 40 Wetlands Study | Jandakot Mound Groundwater Scheme | Gnangara Mound Environmental Monitoring | Gnangara Mound Spring Survey | Swan Coastal Plain Waterbirds | Wetland Watch |
|---|---|---|---|---|---|---|---|
| **Monitoring or inventory?** | | Monitoring | Monitoring | Monitoring | Inventory | Monitoring | Inventory |
| **Duration of project** | | 1989 - 1990 | 1996 - current | 1995 - current | 2002 - 2004 | 1989 - 1992 | 2004 - 2009 |
| **Organisation(s) responsible** | | Murdoch University | WRC, Murdoch University | WRC, Edith Cowan University | DEC | DEC, RAOU | WWF-Australia |
| **Theme** | **Indicator** | | | | | | |
| **Catchment disturbance** | *Disturbance in the catchment* | ND | ND | ND | ND | ND | ND |
| **Physical form and processes** | *Change in wetland area* | ND | ND | ND | ND | DC | ND |
| | *Change in wetland topography* | ND | ND | ND | ND | DC?: Width of wading zone | ND |
| | *Soil disturbance* | ND | ND | ND | ND | ND | ND |
| **Hydrological disturbance** | *Physical modification to hydrology* | ND | DC? | DC: Groundwater pumping | ND | DC: Number of drains | ND |
| | *Changes to water regime* | DC: Groundwater and wetland depth | DC: Water depth (autumn, spring and summer yearly); groundwater (annually in spring) | DC: Water depth (spring, summer/autumn 1996-1998), wetted area (annually 1995-98), groundwater, dry period (number of. weeks wetland was dry) | ND | DC: Water depth (at gauge) and permanence | ND |

| Name of project | | 40 Wetlands Study | Jandakot Mound Groundwater Scheme | Gnangara Mound Environmental Monitoring | Gnangara Mound Spring Survey | Swan Coastal Plain Waterbirds | Wetland Watch |
|---|---|---|---|---|---|---|---|
| **Monitoring or inventory?** | | Monitoring | Monitoring | Monitoring | Inventory | Monitoring | Inventory |
| **Duration of project** | | 1989 - 1990 | 1996 - current | 1995 - current | 2002 - 2004 | 1989 - 1992 | 2004 - 2009 |
| **Organisation(s) responsible** | | Murdoch University | WRC, Murdoch University | WRC, Edith Cowan University | DEC | DEC, RAOU | WWF-Australia |
| **Theme** | **Indicator** | | | | | | |
| **Water and soil quality** | *Turbidity regime* | DC (summer, winter, spring of 1989 and 1990, plus 5 wetlands on 3 - 4 weekly basis) | DC (biannually in autumn/summer and spring) | DC (FTU; biannually in autumn/summer and spring, 1996 - 1998) | DC for three springs (Dec 2002) | DC | ND |
| | *Salinity regime* | DC: Total Filterable Solids (summer, winter, spring of 1989 and 1990, plus 5 wetlands on 3 - 4 weekly basis) | DC: EC (biannually in autumn/summer and spring). | DC: Conductivity (biannually in autumn/summer and spring, 1996-1998) | DC: EC, field salinity for two springs (Dec 2002) | DC (TDS) | ND |
| | *pH* | DC (summer, winter, spring of 1989 and 1990, plus 5 wetlands on 3 - 4 weekly basis) | DC (biannually in autumn/summer and spring) | DC (biannually in autumn/summer and spring 1996-1998 | DC for 2 springs | DC | ND |
| | *Soil properties* | DC: Sediments sampled Jan and Aug 1989 | ND | DC?: ASS<br>DC: Sediment samples taken for 16 wetlands (Nov, Dec 1987) | ND | ND | ND |
| **Fringing zone** | *Change in fringing zone* | ND | DC: Major changes in vegetation, particularly weed invasions, using photo reference points (1998 - 2008)<br>DC: Tree health and vegetation status (1996 - 1998) | DC: Transects, tree health, regeneration index; annually 1995-1998 | ND | DC: Vegetation structure; percent wetland buffered and width of buffer | ND |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Name of project** | | 40 Wetlands Study | Jandakot Mound Groundwater Scheme | Gnangara Mound Environmental Monitoring | Gnangara Mound Spring Survey | Swan Coastal Plain Waterbirds | Wetland Watch |
| **Monitoring or inventory?** | | Monitoring | Monitoring | Monitoring | Inventory | Monitoring | Inventory |
| **Duration of project** | | 1989 - 1990 | 1996 - current | 1995 - current | 2002 - 2004 | 1989 - 1992 | 2004 - 2009 |
| **Organisation(s) responsible** | | Murdoch University | WRC, Murdoch University | WRC, Edith Cowan University | DEC | DEC, RAOU | WWF-Australia |
| **Theme** | **Indicator** | | | | | | |
| **Biota** | *Change in wetland vegetation* | ND | DC: Percentage cover of each aquatic habitat.<br>DC: Major changes in vegetation, particularly weed invasions, using photo reference points (1998 - 2008)<br>DC: Tree health and vegetation status (1996 - 1998) | ND | ND | DC: Vegetation structure, macrophyte cover and biomass | DC: Vegetation assessment for all wetlands, detailed flora surveys for ~10 wetlands; vegetation condition; using Natural Area Initial Assessment template |
| | *Change in invertebrates* | DC: MI in summer 1989, spring 1989 and spring 1990 | DC: MI presence and abundance using rapid bioassessment protocol; ID to family | DC: MI; ID to family (spring and autumn 1996-1998) | DC: Invertebrates for 3 springs; ID to species | DC: Invertebrates | ND |
| | *Change in vertebrates* | ND | DC: WB (three times yearly in autumn, spring and summer 1996 - 98) | ND? | ND | DC: WB abundance (every 3 months for 2 years), clutch and brood size<br>DC: Fish | ND |
| | *Change in introduced species* | ND | DC: Weeds, using photo reference points (1998 - 2008) and transects (1996 - 1998) | DC: Weediness index for fringing vegetation, annually 1995-1998 | ND | DC: Weeds | DC: Weeds |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Name of project** | | 40 Wetlands Study | Jandakot Mound Groundwater Scheme | Gnangara Mound Environmental Monitoring | Gnangara Mound Spring Survey | Swan Coastal Plain Waterbirds | Wetland Watch |
| **Monitoring or inventory?** | | Monitoring | Monitoring | Monitoring | Inventory | Monitoring | Inventory |
| **Duration of project** | | 1989 - 1990 | 1996 - current | 1995 - current | 2002 - 2004 | 1989 - 1992 | 2004 - 2009 |
| **Organisation(s) responsible** | | Murdoch University | WRC, Murdoch University | WRC, Edith Cowan University | DEC | DEC, RAOU | WWF-Australia |
| **Theme** | **Indicator** | | | | | | |
| | *Change in algae* | DC: Chlorophyll-a, phytoplankton, submerged macrophytes at 5 wetlands (Oct 1989; Feb, Jun, Aug, Nov 1990) | DC: Chlorophyll-a, phaeophytin-a (biannually in autumn/summer and spring) | DC: Chlorophyll-a (biannually in autumn/summer and spring 1996-1998) | ND | DC: Chlorophyll-a, phaeophytin-a | ND |

[1] ND – No data [2] DC – Data collected [3] EC – Electrical conductivity [4] ASS – Acid Sulphate Soils [5] MI – Macroinvertebrates [6] TSS - Total Suspended Sediments

### *Data storage*

For more information on monitoring/inventory projects in the Perth Region refer to the reports or contact the persons listed in Table 12.

**Table 12: Storage of wetland monitoring and inventory datasets for the Perth Region**

| Project | Data storage | Key personnel (current positions) | Relevant Report/s |
|---|---|---|---|
| 40 wetlands study | Murdoch University | Professor Jenny Davis, Monash University; Dr Jane Chambers, Senior Lecturer, Murdoch University | (Davis *et al.* 1993) |
| Jandakot Mound Groundwater Scheme Stage 2 | Murdoch University, WRC | Professor Jenny Davis, Monash University; Mike Bamford; *Bamford* Consulting Ecologists, Phil Ladd, Senior Lecturer, Murdoch University | (Bamford and Bamford 1998; Ladd 1999; Wild *et al.* 2004) |
| Gnangara Mound Environmental Monitoring Project | Edith Cowan University, WRC | Dr Bea Sommer, Post Doctoral Research Fellow, ECU; Associate Professor Pierre Horwitz, ECU | (Pettit and Froend 1998; Sommer and Horwitz 1999) |
| Gnangara Mound Spring Survey | DEC | Adrian Pinder, Research Scientist, Science Division, DEC | (Pinder 2004) |
| Swan Coastal Plain Waterbirds | DEC | Andrew Storey, Principal Consultant, Wetland Research & Management | (Storey *et al.* 1993) |
| Wetland Watch | WWF | Christina Mykytiuk, Wetlands Section, DEC | http://www.wwf.org.au/ourwork/water/wetlandwatch/ |

***Threats to wetlands by region/wetland type***

Table 13 shows a matrix of threats to wetlands in Western Australia against the NWI for condition, with ticks indicating that measuring a particular indicator could provide information about the corresponding threat. This allows an evaluation of which indicators might have importance in monitoring the impact of particular threats. The bold type in Table 13 indicates those threats that are known to affect wetlands in the Perth Region. Shaded threats (red) are those mentioned most often in the literature for the region, and therefore inferred as the most significant threats to wetlands for each region[7]. Shaded indicators (yellow) are those which have three or more priority threats against them, and which therefore are likely to be particularly important for the region.

Despite the fact that the Perth Region is so heavily populated, additional information on threats is required to accurately complete this matrix. This will require input from regional staff and organisations. This is likely to result in additional threats and indicators being identified as a priority for this region.

**Table 13: Threats to wetlands in the Perth Region (in bold) against relevant National Wetland Indicators**

| Threat | Condition indicator: Catchment disturbance | Change in wetland area | Change in wetland topography | Soil disturbance (physical) | Physical modification to hydrology | Changes to water regime | Turbidity (light climate) regime | Salinity regime | Change in pH | Change in [sediment] properties (salinity, acidity) | Change in fringing zone | Change in wetland vegetation | Change in [aquatic] invertebrate diversity and community composition | Change in waterbird presence, breeding and abundance | Change in other wetland-dependent vertebrates presence, breeding and abundance | Change in introduced species | Change in algae | Other indicators required? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Broad-scale vegetation clearing** | ✓ | | | ✓ | | | | | | | ✓ | ✓ | | | ✓ | | | |
| Increasing fragmentation, loss of remnants and lack of recruitment | ✓ | | | | | | | | | | ✓ | ✓ | | | ✓ | | | |
| Firewood collection | | | | | | | | | | | ✓ | ✓ | | | | | | Not directly measured |
| **Grazing pressure** | ✓ | | | ✓ | | | ✓ | | | | ✓ | ✓ | | | | | | |
| **Feral animals** | | | | | | | | | | | | | | ✓ | ✓ | ✓ | | |
| **Exotic weeds** | | | | | | | | | | | ✓ | ✓ | | | | ✓ | | |
| **Altered fire regimes** | ✓ | | | | | | | | | | ✓ | ✓ | | | ✓ | | | Not directly measured |
| Pathogens (including phytopthora) | | | | | | | | | | | ✓ | ✓ | | ✓ | ✓ | | | Wide range possible |
| **Secondary salinisation** | ✓ | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| **Altered hydrology (surface and ground water)** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | ✓ | |
| **Pollution (including eutrophication)** | | | | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | ✓ | |
| Mining | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | | | | |

[7] Feedback on priority threats for each region is welcomed. Please contact the Wetlands Section, Department of Environment & Conservation, Kensington.

| | Condition indicator | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Catchment disturbance | Change in wetland area | Change in wetland topography | Soil disturbance (physical) | Physical modification to hydrology | Changes to water regime | Turbidity (light climate) regime | Salinity regime | Change in pH | Change in [sediment] properties (salinity, acidity) | Change in fringing zone | Change in wetland vegetation | Change in [aquatic] invertebrate diversity and community composition | Change in waterbird presence, breeding and abundance | Change in other wetland-dependent vertebrates presence, breeding and abundance | Change in introduced species | Change in algae | Other indicators required? |
| **Recreational vehicles** | | | ✓ | ✓ | ✓ | | | | | | | | | ✓ | ✓ | | | |
| **Direct human disturbance of ecosystem** | | | ✓ | ✓ | ✓ | | | | | | ✓ | ✓ | | ✓ | ✓ | | | |
| **Impacts of roads** | | ✓ | ✓ | ✓ | ✓ | | | | | | | ✓ | | ✓ | ✓ | ✓ | | |
| Vegetation harvesting | | | | ✓ | | | | | | | ✓ | ✓ | | | | | | |
| Agriculture (including farm dams and infrastructure) | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | | |
| Acid Sulphate Soils | | | | | | ✓ | | | ✓ | ✓ | | | ✓ | | | | | |
| **Urban and pre-urban development** | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | ✓ | ✓ | | | | ✓ | | |
| Commercial and recreational fishing | | | | | | | | | | | | | | ✓ | ✓ | | ✓ | Not directly measured |
| Recreation (including tourism) | | | | | | | | | | | | | | | | | | Threat too unspecific |
| Climate change | ✓ | ✓ | | | | ✓ | | ✓ | | | | | ✓ | | | | ✓ | |
| **Sedimentation** | | ✓ | ✓ | | ✓ | | ✓ | | | ✓ | | | ✓ | | | | | |
| Wind and water erosion | | ✓ | ✓ | | ✓ | | ✓ | | | | | | | | | | | |

### *Information Gaps*

Wetlands of the Perth Region have been extensively sampled since the late 1980s. Comprehensive baseline data is available for assessing changes to wetlands over time. However, there may be some difficulties in comparing data due to differences in sampling methodologies.

Although fringing and terrestrial vegetation has been widely studied, there is a need to focus more on submerged aquatic plant communities in order to understand wetland ecosystem dynamics (J. Davis pers. comm.). Information on these is currently minimal. Aquatic vegetation is central to the ecology of a wetland as it provides habitat within the wetland. The inclusion of data collection of aquatic vegetation in future wetlands projects is recommended.

Only one indicator was identified as high priority to provide information on threats to wetlands within the Perth Region. However, it should be noted that when additional threats data become available, other indicators are likely also to be highlighted. There has been very little monitoring or inventory data collected on this one indicator (change in other wetland-dependent vertebrates presence, breeding and abundance), and this may need to be redressed if monitoring schemes are to collect the information necessary to understand the impact of priority threats.

### *Planned future work*

The Perth Region NRM (formerly called the Swan Catchment Council) is planning to prepare a Biodiversity Conservation Plan for the Perth Region, which would replace the Bush Forever scheme that currently identifies regionally-significant bushland areas for protection.

An application will be made to fund continuation of the IAI RCM project. Provided the application is successful, surveys will continue on an annual basis. The project also aims to facilitate and encourage the development of monitoring programs for individual wetlands, or groups of wetlands (G. Daniel pers. comm.).

## Northern Agricultural Region

### *Survey and monitoring programs*

Five main wetland projects have been implemented in the Northern Agricultural Region. These include a biodiversity survey carried out in the Buntine Marchagee Natural Diversity Recovery Catchment, a DEC survey of mound springs in the Three Springs area, WWF-Australia's 'Balancing Agricultural Production and Conservation in Wetlands of the Gingin Shire' (BAPC Wetlands) project, and the Inland Aquatic Integrity Resource Condition Monitoring and Salinity Action Plan projects implemented by DEC (Table 14).

The main threat facing the Buntine-Marchagee Recovery Catchment (BMRC) is salinity, and as such it was nominated as a Natural Diversity Recovery Catchment under the State Salinity Strategy. The main objective of the BMRC is to "*maintain the 2006 richness, distribution, abundance and condition of biodiversity assets threatened by salinity within the Buntine-Marchagee catchment for the next 20 years*"(Department of Environment and Conservation 2008a). To achieve this goal, 20 monitoring wetlands were established to provide a baseline understanding of these biodiversity assets (Table 14). The wetlands were selected to provide a geographical spread along the main braided drainage system, and were the best examples of relatively intact remnant fringing vegetation. Due to low water levels, only eight of the twenty wetlands were sampled by DEC (then the Department of Conservation and Land Management) in November 2003 for water chemistry and aquatic invertebrate fauna. All twenty wetlands were sampled by the University of Western Australia (UWA) in 2004, and again in 2005 with the addition of an extra wetland.

The Tumulus Spring project involved a survey of five organic mound springs on the Dandaragan Plateau in the Shire of Three Springs (Pinder and Pennifold 2001). The survey was part of an assessment of a proposal to list the mound spring invertebrates as a Threatened Ecological Community. To this end, aquatic invertebrates were collected and water chemistry was sampled (Table 14).

The 'Balancing Agricultural Production and Conservation in Wetlands of the Gingin Shire' (BAPC Wetlands) project was one of six pilot projects initiated by WWF-Australia (Roache 2008). The project aimed to engage private landholders to improve native vegetation management by conserving high-value remnant wetlands on their farms. Seven landholders on nine properties signed Voluntary Management Agreements, with management actions

focusing on fencing of wetlands and associated vegetation. On-site visits were conducted as part of the project and included fauna and flora surveys, as well as soil and water testing.

Sampling of wetlands in the Northern Agricultural region was also undertaken as part of: the Inland Aquatic Integrity Resource Condition Monitoring project; monitoring and survey work as part of the Salinity Action Plan (including the South West Wetland Monitoring Program); and for annual waterfowl counts. As these projects included sampling wetlands over several NRM regions, they have been described in detail only once in this paper (see South Coast Region – p. 16).

**Table 14: Wetland monitoring and inventory projects for the Northern Agricultural Region**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Project title** | | Buntine-Marchagee Recovery Catchment | Three Springs Tumulus Spring Survey | BAPC in Wetlands of the Gingin Shire | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfowl counts in south west WA |
| **Monitoring or inventory?** | | Inventory | Inventory | Inventory | Monitoring | Inventory / Monitoring | Inventory | Inventory |
| **Duration of project** | | 2003-2005 | 2001-2005 | 2006-2008 | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-1992 |
| **Organisation(s) responsible** | | DEC, UWA | DEC | WWF-Australia | DEC | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | |
| **Catchment disturbance** | *Disturbance in the catchment* | ND | ND | ND | ND | ND | ND | ND |
| **Physical form and processes** | *Change in wetland area* | ND | ND | DC: Wetland area (ha) | DC (limited): Detailed bathymetry for some sites | DC: Mapping at a resolution of 1:100 000 | ND | ND |
| | *Change in wetland topography* | ND | ND | DC | DC (limited): Detailed bathymetry for some sites | ND | ND | ND |
| | *Soil disturbance* | ND | ND | DC? (trampling due to grazing) | ND | ND | DC: Observations recorded | ND |
| **Hydrological disturbance** | *Physical modification to hydrology* | ND | ND | ND | ND | DC: 'Impacts on wetlands' including drains, dams, etc., identified using orthophotographs | DC: Observations recorded | ND |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Project title** | | Buntine-Marchagee Recovery Catchment | Three Springs Tumulus Spring Survey | BAPC in Wetlands of the Gingin Shire | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfowl counts in south west WA |
| **Monitoring or inventory?** | | Inventory | Inventory | Inventory | Monitoring | Inventory / Monitoring | Inventory | Inventory |
| **Duration of project** | | 2003-2005 | 2001-2005 | 2006-2008 | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-1992 |
| **Organisation(s) responsible** | | DEC, UWA | DEC | WWF-Australia | DEC | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | |
| | *Changes to water regime* | DC: Water depth; maximum and average (opportunistic sampling at 50 wetlands); groundwater (135 piezometers; every 5-6 weeks) | ND | ND | DC: wetland depths (depth-gauge), rainfall. September and November | DC: Surface and groundwater depths<br>DC: 'Wetness' index derived from satellite imagery analysis has been developed for most of the Wheatbelt | DC (limited): Maximum depth sampled | DC: wetland depths, rainfall |
| **Water and soil quality** | *Turbidity regime* | DC | DC | DC? | ND | DC (lab) | DC | ND |
| | *Salinity regime* | DC: EC (opportunistic sampling at 50 wetlands) | DC: EC, TDS (lab), field salinity | DC | DC: EC, salinity (lab). September and November | DC: EC, salinity | DC | ND |
| | *pH* | DC (opportunistic sampling at 50 wetlands) | DC | DC? | ND | DC | DC | ND |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Project title** | Buntine-Marchagee Recovery Catchment | Three Springs Tumulus Spring Survey | BAPC in Wetlands of the Gingin Shire | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfowl counts in south west WA |
| | **Monitoring or inventory?** | Inventory | Inventory | Inventory | Monitoring | Inventory / Monitoring | Inventory | Inventory |
| | **Duration of project** | 2003-2005 | 2001-2005 | 2006-2008 | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-1992 |
| | **Organisation(s) responsible** | DEC, UWA | DEC | WWF-Australia | DEC | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | |
| | *Soil properties* | DC: Presence and thickness of salt crust | ND | DC: Soil testing | ND | ND | DC: Sediment samples for composition | ND |
| **Fringing zone** | *Change in fringing zone* | DC: Fringing vegetation, aquatic vegetation | ND | DC: Vegetation/flora surveys | ND | ND | ND | ND |
| **Biota** | *Change in wetland vegetation* | DC: Vegetation sampled at 27 wetlands in 2004 (baseline); vegetation condition was scored; changes in community composition (principally ground cover | ND | DC: Vegetation condition, structure (height, cover), floristic composition | ND | ND suitable for use for indicator | DC: Vegetation presence/absence, condition and community composition | DC: dominant vegetation type |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Project title** | | Buntine-Marchagee Recovery Catchment | Three Springs Tumulus Spring Survey | BAPC in Wetlands of the Gingin Shire | South West Wetland Monitoring Program | Salinity Action Plan | Inland Aquatic Integrity Resource Condition Monitoring | Annual waterfowl counts in south west WA |
| **Monitoring or inventory?** | | Inventory | Inventory | Inventory | Monitoring | Inventory / Monitoring | Inventory | Inventory |
| **Duration of project** | | 2003-2005 | 2001-2005 | 2006-2008 | 1977 - ongoing | 1997 – 2003 / ongoing | 2008-2009 | 1988-1992 |
| **Organisation(s) responsible** | | DEC, UWA | DEC | WWF-Australia | DEC | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | |
| | *Change in invertebrates* | DC: Invertebrates divided into 'permanent and temporary' as opposed to 'macro and micro'; ID to species | DC: Invertebrates collected, ID to species | DC: Fauna surveys | ND | DC: Invertebrate diversity and community composition | DC: ID to species | ND |
| | *Change in vertebrates* | DC: WB<br>DC: Frogs (aural)<br>DC: Fish (one species found) | ND | DC: Fauna surveys | ND | DC: Waterbirds | DC: Waterbirds<br>DC: Frog observations | DC: Waterbird counts |
| | *Change in introduced species* | ND | ND | DC: Weeds, feral animals | ND | ND | DC: Weeds<br>DC: Observations of introduced fauna (scats, tracks, habitat disturbance) | ND |
| | *Change in algae* | DC: Chlorophyll-a | ND | ND | ND | DC: Chlorophyll-a,b,c; phaeophytin | DC: Chlorophyll-a,b,c | ND |

[1] ND – No data [2] DC – Data collected [3] EC – Electrical conductivity [4] ASS – Acid Sulphate Soils [5] MI – Macroinvertebrates [6] TSS - Total Suspended Sediments

### *Data storage*

For more information on monitoring/inventory projects in the Northern Agricultural Region refer to the reports or contact the persons listed in Table 15.

**Table 15: Storage of wetland monitoring and inventory datasets for the Northern Agricultural Region**

| Project | Data storage | Key positions (current personnel) | Relevant Report(s) |
|---|---|---|---|
| Buntine-Marchagee Recovery Catchment | DEC | Jodie Watts, Recovery Catchment Officer, Geraldton, DEC | (Lynas *et al.* 2006; Department of Environment and Conservation 2008a) |
| Three Springs Tumulus Spring Survey | DEC | Adrian Pinder, Senior Research Scientist, Science Division, DEC | (Pinder and Pennifold 2001) |
| BAPC in Wetlands of the Gingin Shire | WWF-Australia | Michael Roache, Threatened Species Network Regional Manager, WWF-Australia | (Roache 2008) |
| South West Wetland Monitoring Program (depth-gauged wetlands) | DEC | Jim Lane, Principal Research Scientist, Landscape Conservation Branch, Science Division DEC, Alan Clarke, Senior Technical Officer, Landscape Conservation Branch, Science Division DEC, Yvonne Winchcombe, Senior Technical Officer, Landscape Conservation Branch, Science Division DEC | (Lane *et al.* 2004) |
| Salinity Action Plan | DEC | Dr Stuart Halse, Managing Director, Bennelongia Pty Ltd, Adrian Pinder, Senior Research Scientist, Science Division, DEC | (Halse *et al.* 2003; Cale *et al.* 2004; Halse *et al.* 2004; Pinder *et al.* 2004; Pinder *et al.* 2005; Lyons *et al.* 2007) |
| Inland Aquatic Integrity Resource Condition Monitoring | DEC | Glen Daniel, Environmental Officer (Wetlands), Species and Communities Branch, DEC | (Nowicki *et al.* 2008) |
| Annual waterfowl counts in south west Western Australia | | Dr Stuart Halse, Managing Director, Bennelongia Pty Ltd Roger Jaench, Wetlands International Oceania | (Halse et al. 1992; Halse et al. 1994; Halse et al. 1995) |

*Threats to wetlands by region/wetland type*

Table 16 shows a matrix of threats to wetlands in Western Australia against the NWI for condition, with ticks indicating that measuring a particular indicator could provide information about the corresponding threat. This allows an evaluation of which indicators might have importance in monitoring the impact of particular threats. The bold type in Table 16 indicates those threats that are known to affect wetlands in the Northern Agricultural Region. Shaded threats (red) are those mentioned most often in the literature for the region, and therefore inferred as the most significant threats to wetlands for each region[8]. Shaded indicators (yellow) are those which have three or more priority threats against them, and which therefore are likely to be particularly important for the region.

**Table 16: Threats to wetlands in the Northern Agricultural Region (in bold) against relevant NWI**

| Threat | Catchment disturbance | Change in wetland area | Change in wetland topography | Soil disturbance (physical) | Physical modification to hydrology | Changes to water regime | Turbidity (light climate) regime | Salinity regime | Change in pH | Change in [sediment] properties (salinity, acidity) | Change in fringing zone | Change in wetland vegetation | Change in [aquatic] invertebrate diversity and community composition | Change in waterbird presence, breeding and abundance | Change in other wetland-dependent vertebrates presence, breeding and abundance | Change in introduced species | Change in algae | Other indicators required? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Broad-scale vegetation clearing** | ✓ | | | ✓ | | | | | | | ✓ | ✓ | | | ✓ | | | |
| **Increasing fragmentation, loss of remnants and lack of recruitment** | ✓ | | | | | | | | | | ✓ | ✓ | | | ✓ | | | |
| **Firewood collection** | | | | | | | | | | | ✓ | ✓ | | | | | | Not directly measured |
| **Grazing pressure** | ✓ | | | ✓ | | | ✓ | | | | ✓ | ✓ | | | | | | |
| **Feral animals** | | | | | | | | | | | | | | ✓ | ✓ | ✓ | | |
| **Exotic weeds** | | | | | | | | | | | ✓ | ✓ | | | | ✓ | | |
| **Altered fire regimes** | ✓ | | | | | | | | | | ✓ | ✓ | | | ✓ | | | Not directly measured |
| **Pathogens (including phytopthora)** | | | | | | | | | | | ✓ | ✓ | | ✓ | ✓ | | | Wide range possible |
| **Secondary salinisation** | ✓ | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| **Altered hydrology (surface and ground water)** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| **Pollution (including eutrophication)** | | | | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | ✓ | |
| **Mining** | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | | | | |
| **Recreational vehicles** | | | ✓ | ✓ | ✓ | | | | | | | | | ✓ | ✓ | | | |
| **Direct human disturbance of ecosystem** | | | ✓ | ✓ | ✓ | | | | | | ✓ | ✓ | | ✓ | ✓ | | | |
| Impacts of roads | | ✓ | ✓ | ✓ | ✓ | | | | | | | ✓ | | ✓ | ✓ | ✓ | | |
| Vegetation harvesting | | | | | | | | | | | | | | | | | | |

[8] Feedback on priority threats for each region is welcomed. Please contact the Wetlands Section, Department of Environment & Conservation, Kensington.

| | Condition indicator | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Catchment disturbance | Change in wetland area | Change in wetland topography | Soil disturbance (physical) | Physical modification to hydrology | Changes to water regime | Turbidity (light climate) regime | Salinity regime | Change in pH | Change in [sediment] properties (salinity, acidity) | Change in fringing zone | Change in wetland vegetation | Change in [aquatic] invertebrate diversity and community composition | Change in waterbird presence, breeding and abundance | Change in other wetland-dependent vertebrates presence, breeding and abundance | Change in introduced species | Change in algae | Other indicators required? |
| **Agriculture (including farm dams and infrastructure)** | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | | |
| Acid Sulphate Soils | | | | | | ✓ | | | ✓ | ✓ | | | ✓ | | | | | |
| Urban and pre-urban development | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | ✓ | ✓ | | | | ✓ | | |
| Commercial and recreational fishing | | | | | | | | | | | | | | ✓ | ✓ | | ✓ | Not directly measured |
| Recreation (including tourism) | | | | | | | | | | | | | | | | | | Threat too unspecific? |
| Climate change | ✓ | ✓ | | | | ✓ | | ✓ | | | | | ✓ | | | | ✓ | |
| **Sedimentation** | | ✓ | ✓ | | ✓ | | ✓ | | | ✓ | | | ✓ | | | | | |
| Wind and water erosion | | ✓ | ✓ | | ✓ | | ✓ | | | | | | | | | | | |

***Information Gaps***

Limited wetland monitoring and inventory has occurred in the Northern Agricultural Region, and the work that has taken place has been quite restricted in geographic extent. No broad-scale inventory of wetlands has been undertaken in the region. The most comprehensive monitoring work to date has been implemented within the Buntine-Marchagee Catchment. The Three Springs Tumulus Spring survey was limited to only one type of wetland (mound springs) and focused on aquatic invertebrates. The WWF-Australia (BAPC Wetlands) project covered a very limited geographical area as it included only wetlands found on nine private properties within the Shire of Gingin. Both the Tumulus Spring Survey and the BAPC Wetlands project involved once-off sampling.

There is therefore a need to expand the geographical extent of wetland inventory in the Northern Agricultural Region and, where possible, to build on the baseline data currently available by establishing long-term monitoring.

Four indicators were identified as high priority to provide information on threats to wetlands within the Northern Agricultural Region, and of these, data on three (change in fringing zone; change in wetland vegetation; change in other wetland-dependent vertebrates presence, breeding and abundance) has been collected as both part of the Buntine-Marchagee monitoring and the BAPC wetland project. Data on the remaining indicator (catchment disturbance) is much harder to build into monitoring programs, and may need to be supplied through a separate process, such as the development of Catchment Disturbance Indices (discussed in Sim *et al.* 2008).

***Planned future work***

An application will be made to fund continuation of the IAI RCM project. Provided the application is successful, surveys will continue on an annual basis. The project also aims to facilitate and encourage the development of monitoring programs for individual wetlands, or groups of wetlands (G. Daniel pers. comm.).

## Rangelands Region

### *Survey and monitoring programs*

The Rangelands Region covers 90% of the state. A number of wetland monitoring and inventory projects have been undertaken throughout the region, but large areas still remain unsurveyed.

Several surveys have been implemented by DEC in the Pilbara Sub-region (Table 17). These include the Pilbara Surface Water, Mound Spring and Marsh surveys, and the IAI RCM project. The surveys aimed to provide baseline information on biodiversity of the Pilbara Region and nature conservation priorities, and to provide a framework for future monitoring.

As part of the Pilbara Surface Water survey, 94 wetlands were sampled in autumn and in spring for water chemistry and biota. The Pilbara Spring survey involved sampling organic mound springs for aquatic invertebrates and water chemistry to determine stygofauna diversity. As part of the Pilbara Marsh study, Mandora Marsh and Fortescue Marsh were surveyed for waterbirds, invertebrates and water chemistry.

Several studies were also implemented in the Kimberley Sub-region (Table 17). DEC has conducted water chemistry and biodiversity surveys at five sites at the Victoria-Bonaparte mudflats (in February and April 1993) (Halse *et al.* 1996) and at organic mound springs between 1999 and 2001 (Black 2004). Numerous sites were sampled at Lake Gregory between October 1989 and August 1993 (Halse *et al.* 1998). The University of Western Australia has also been sampling Kimberley wetlands since 2001 (Storey and Lynas 2007). The monitoring sites are primarily located in the Ord River catchment with some sites in the Pentecost and Keep River catchments. The Shire of East Wyndham has also been conducting monitoring of the macroinvertebrates and water quality of Lake Kununurra and Lily Creek Lagoon as part of the Ribbons of Blue program.

WWF-Australia initiated a project titled 'Establishing priorities for wetland conservation and management in the Kimberley' (Vernes 2007). The project collated existing information on wetlands from twelve catchments to generate baseline information, which could then be used to advise future planning and management of wetlands in the Kimberley. All the available knowledge was used to identify priority wetlands for future monitoring and management. Field visits were made to assist in the prioritisation process. Wetlands were chosen to capture a range of wetland types, values, threats and uses spread

over several catchments. A total of thirty-one surveys were conducted over six catchments (Table 17).

Two surveys were conducted by DEC in the Midwest Sub-region (Table 17). Between the winters of 1994 and 1995, fifty-six sites were sampled at fifty-three wetlands of the Carnarvon Basin (Halse *et al.* 2000). Most wetlands were sampled twice (in winter and in summer) but not all wetlands contained water on both sampling occasions. The aim of the survey was to inventory the waterbird and aquatic invertebrate fauna of the wetlands, and to correlate the occurrence of these fauna with the physical and chemical properties of the wetlands. In 2007, the wetlands of the Hutt River Catchment were surveyed for biodiversity and water quality (Quinlan *et al.* in prep.).

DEC has conducted a survey of wetlands in the Goldfields under the NHT funded project titled "Nomination and improved documentation of Nationally Important Wetlands in under-represented IBRA regions of Western Australia". The study focused on invertebrates found in the inland arid zone (desert) areas of WA (Table 17).

Sampling of wetlands in the Rangelands region was also undertaken as part of the Inland Aquatic Integrity Resource Condition Monitoring project. As this project included sampling wetlands over several NRM regions, it has been described in detail only once in this paper (see South Coast region – p. 16).

**Table 17: Wetland monitoring and inventory projects for the Rangelands Region**

| | | Several regions | Pilbara | | | Kimberley | | | | | | Midwest | | Goldfields |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Name of project** | | Inland Aquatic Integrity Resource Condition Monitoring | Pilbara Surface Water Survey | Pilbara Spring Study | Pilbara Marsh Study | Victoria-Bonaparte Mudflat | Lake Gregory | Kimberley Sites | Kimberley Mound Spring Survey | Priorities for Wetland Conservation & Management | Lake Kununurra and Lily Creek Lagoon | Carnarvon Basin Survey | Hutt Catchment Survey | Desert / Goldfields Wetlands Survey |
| **Monitoring or inventory?** | | Inventory | Inventory | Inventory | Inventory | Inventory | Monitoring | Monitoring | Inventory | Inventory | Monitoring | Inventory | Inventory | Inventory |
| **Duration of project** | | 2008 - 2009 | 2003 - 2007 | 2001 | 2000 | 1993 | 1989 - 1993 (intermittent) | 2001- ongoing | 1999 - 2001 | 2005 - 2007 | ? | 1994 - 2001 | 2007 | 2004 |
| **Organisation(s) responsible** | | DEC | DEC | DEC | DEC | DEC | DEC | UWA | DEC | WWF-Australia | Shire of East Wyndham | DEC | DEC | DEC |
| **Theme** | **Indicator** | | | | | | | | | | | | | |
| **Catchment disturbance** | *Disturbance in the catchment* | ND | ND | ND | ND | ND | ND | ND | ND | DC: Catchment land use | ND | ND | ND | ND |
| **Physical form and processes** | *Change in wetland area* | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| | *Change in wetland topography* | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| | *Soil disturbance* | DC: Observations recorded | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| **Hydrological disturbance** | *Physical modification to hydrology* | DC: Observations recorded | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| | *Changes to water regime* | DC (limited): Maximum depth sampled | DC: Depth at gauge | ND | ND | DC: Depth at gauge | ND | ND | ND | ND | ND? | DC: Estimated maximum water depth | ND | ND |
| **Water and soil quality** | *Turbidity regime* | DC | DC: 94 wetland sites sampled twice: autumn and spring | DC: 6 springs sampled once | DC | ND | DC: Oct 1989-Aug 1993 | ND | DC: Up to 3 sample sites per spring | DC | DC (Ribbons of Blue methodology) | DC | DC | ND |
| | *Salinity regime* | DC | DC: TDS (lab), EC, field salinity; 94 wetland sites sampled twice: autumn and spring | DC: EC (6 springs each sampled once) | DC (limited): EC (field) – one datapoint | ND | DC: TDS (lab), EC; numerous sites sampled Oct 1989 - Aug 1993 | ND | DC: Up to 3 sample sites per spring | DC: EC, field salinity | DC (Ribbons of Blue methodology) | DC: TDS (lab), EC (field) | DC: EC, TDS (lab), field salinity | ND |
| | *pH* | DC | DC: 94 wetland sites sampled twice: autumn and spring | DC: 6 springs sampled once | DC (limited): One datapoint | ND | DC: numerous sites sampled Oct 1989 - Aug 1993 | ND | DC: Up to 3 sample sites per spring | DC | DC (Ribbons of Blue methodology) | DC | DC | ND |
| | *Soil properties* | DC: Sediment samples for composition | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| **Fringing zone** | *Change in fringing zone* | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Biota** | *Change in wetland vegetation* | DC: Vegetation presence/absence, condition and community composition | ND | ND | ND | ND | ND | ND | ND | DC: Vegetation assessment – basic floristics of aquatic and surrounding vegetation, disturbance, weed presence/absence | ND | ND | ND | ND |
| | *Change in invertebrates* | | DC: Invertebrates (ID to species; 94 wetland sites sampled twice: autumn and spring) | DC: Invertebrates (ID to species; six springs each sampled once) | DC: Invertebrates (one sample per marsh) | DC: Invertebrates (at five sites) | DC: Invertebrates (benthic and planktonic; numerous sites Oct 1989 - Aug 1993) | DC: Invertebrates | DC: Invertebrates (Up to 3 sample sites per spring) | DC: MI (ID to family) | ND | DC: Invertebrates (macro and micro; ID to species). | DC: Invertebrates | DC: Invertebrates |
| | *Change in vertebrates* | DC: Waterbirds<br>DC: Frog observations | DC: WB, 94 sites sampled twice: autumn and spring | ND | DC: WB | DC: WB (aerial and ground surveys) in Feb and April 1993 | DC: WB over several years | ND | ND | DC: WB counts/abundance<br>DC (limited): Fish breeding sites<br>DC: Crocodile habitat | ND | DC: WB | DC: WB | ND |
| | *Change in introduced species* | DC: Weeds<br>DC: Observations of introduced fauna (scats, tracks, habitat disturbance) | ND | ND | ND | ND | ND | ND | ND | DC | ND | ND | ND | ND |
| | *Change in algae* | DC: Chlorophyll-a,b,c | DC: Submerged macrophyte biomass and cover; emergent macrophyte cover; chlorophyll-a,b,c; phaeophytin-a (94 sites sampled twice: autumn, spring) | ND | ND | ND | DC (limited): Chlorophyll-a | ND | ND | DC: Phytoplankton | ND | DC: Chlorophyll-a; Phaeophytin-a | DC: Chlorophyl-a,b,c; phaeophtyin-a | ND |

[1] ND – No data [2] DC – Data collected [3] EC – Electrical conductivity [4] ASS – Acid Sulphate Soils [5] MI – Macroinvertebrates [6] TSS - Total Suspended Sediments

### *Data storage*

For more information on monitoring/inventory projects in the Rangelands Region refer to the reports or contact the persons listed in Table 18.

**Table 18: Storage of wetland monitoring and inventory datasets for the Rangelands Region**

| Project | Data storage | Key positions (current personnel) | Relevant Report/s |
|---|---|---|---|
| Inland Aquatic Integrity Resource Condition Monitoring | DEC | Glen Daniel , Environmental Officer (Wetlands), Species and Communities Branch, DEC | (Nowicki *et al.* 2008) |
| Pilbara Surface Water Survey | DEC | Dr Stuart Halse, Managing Director, Bennelongia Pty Ltd, Adrian Pinder, Senior Research Scientist, Science Division DEC Jane McRae, Science Director, Bennelongia Pty Ltd | Unpublished |
| Pilbara Spring Study (stygofauna) | DEC | Dr Stuart Halse, Managing Director, Bennelongia Pty Ltd, Mike Scanlon, Project Director, Bennelongia Pty Ltd, Jim Cocking Project Director, Bennelongia Pty Ltd | Unpublished |
| Pilbara Marsh Study | DEC | Dr Stuart Halse, Managing Director, Bennelongia Pty Ltd, Mike Scanlon, Project Director, Bennelongia Pty Ltd, Jim Cocking, Project Director, Bennelongia Pty Ltd | Unpublished |
| Victoria-Bonaparte mudflat monitoring | DEC | Dr Stuart Halse, Managing Director, Bennelongia Pty Ltd, Dr Russell Shiel, University of Adelaide, Grant Pearson, Project Director, Bennelongia Pty Ltd | (Halse *et al.* 1996) |
| Lake Gregory | DEC | Dr Stuart Halse, Bennelongia Pty Ltd Environmental Consultants | (Halse *et al.* 1998) |
| Kimberley Sites | DEC/UWA | Dr Andrew Storey, Principal Consultant, Wetland Research & Management | (Storey and Lynas 2007) |
| Kimberley Mound Spring Survey | DEC | Dr Stuart Halse, Managing Director, Bennelongia Pty Ltd, Sally Black, Mike Scanlon, Director, Bennelongia Pty Ltd, Jim Cocking Bennelongia Pty Ltd | (Black 2004) |
| Establishing Priorities for Wetland Conservation and Management in the Kimberley | WWF | Tanya Vernes, Project Officer, WWF | (Vernes 2007) |

| Project | Data storage | Key positions (current personnel) | Relevant Report/s |
|---|---|---|---|
| Lake Kununurra and Lily Creek Lagoon | DoW | Katya Tripp, Projects Officer, Shire of Wyndham, East Kimberley | None |
| Carnarvon Basin Survey | DEC | Dr Stuart Halse, Managing Director, Bennelongia Pty Ltd | (Halse *et al.* 2000) |
| Hutt Catchment Survey | DEC | Adrian Pinder, Senior Research Scientist, Science Division DEC | (Quinlan *et al.* in prep.) |
| Desert/Goldfields Wetlands Survey (Nomination and improved documentation of Nationally Important Wetlands in under-represented IBRA regions of Western Australia) | DEC | Jim Lane, Principal Research Scientist, Landscape Conservation Branch, Science Division DEC, Alan Clarke, Senior Technical Officer, Landscape Conservation Branch, Science Division DEC | (Environment Australia 2001) |
| Salinity Action Plan | DEC | Dr Stuart Halse, Managing Director, Bennelongia Pty Ltd, Adrian Pinder, Senior Research Scientist, Science Division, DEC | (Halse *et al.* 2003; Cale *et al.* 2004; Halse *et al.* 2004; Pinder *et al.* 2004; Pinder *et al.* 2005; Lyons *et al.* 2007) |

***Threats to wetlands by region/wetland type***

Table 19 shows a matrix of threats to wetlands in Western Australia against the NWI for condition, with ticks indicating that measuring a particular indicator could provide information about the corresponding threat. This allows an evaluation of which indicators might have importance in monitoring the impact of particular threats. The bold type in Table 19 indicates those threats that are known to affect wetlands in the Rangelands Region. Shaded threats (red) are those mentioned most often in the literature for the region, and therefore inferred as the most significant threats to wetlands for each region[9]. Shaded indicators (yellow) are those which have three or more priority threats against them, and which therefore are likely to be particularly important for the region.

**Table 19: Threats to wetlands in the Rangelands Region (in bold) against relevant NWI**

| | | **Condition indicator** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Catchment disturbance | Change in wetland area | Change in wetland topography | Soil disturbance (physical) | Physical modification to hydrology | Changes to water regime | Turbidity (light climate) regime | Salinity regime | Change in pH | Change in [sediment] properties (salinity, acidity) | Change in fringing zone | Change in wetland vegetation | Change in [aquatic] invertebrate diversity and community composition | Change in waterbird presence, breeding and abundance | Change in other wetland-dependent vertebrates presence, breeding and abundance | Change in introduced species | Change in algae | Other indicators required? |
| **Threat** | **Broad-scale vegetation clearing** | ✓ | | | ✓ | | | | | | | ✓ | ✓ | | | ✓ | | | |
| | Increasing fragmentation, loss of remnants and lack of recruitment | ✓ | | | | | | | | | | ✓ | ✓ | | | ✓ | | | |
| | Firewood collection | | | | | | | | | | | ✓ | ✓ | | | | | | Not directly measured |
| | **Grazing pressure** | ✓ | | | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ | | | | | |
| | **Feral animals** | | | | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| | **Exotic weeds** | | | | | | | | | | | ✓ | ✓ | | | | ✓ | | |
| | **Altered fire regimes** | ✓ | | | | | | | | | | ✓ | ✓ | | | ✓ | | | Not directly measured |
| | Pathogens (including phytopthora) | | | | | | | | | | | ✓ | ✓ | | ✓ | ✓ | | | Wide range possible |
| | **Secondary salinisation** | ✓ | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| | **Altered hydrology (surface and ground water)** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| | **Pollution (including eutrophication)** | | | | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | ✓ | |
| | **Mining** | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | | | | |
| | **Recreational vehicles** | | | ✓ | ✓ | ✓ | | | | | | | | | ✓ | ✓ | | | |
| | **Direct human disturbance of ecosystem** | | | ✓ | ✓ | ✓ | | | | | | ✓ | ✓ | | ✓ | ✓ | | | |
| | Impacts of roads | | ✓ | ✓ | ✓ | ✓ | | | | | | | ✓ | | ✓ | ✓ | ✓ | | |
| | Vegetation harvesting | | | | ✓ | | | | | | | ✓ | ✓ | | | | | | |
| | Agriculture (including farm dams and infrastructure) | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | | |
| | Acid Sulphate Soils | | | | | | ✓ | | | ✓ | ✓ | | | ✓ | | | | | |

[9] Feedback on priority threats for each region is welcomed. Please contact the Wetlands Section, Department of Environment & Conservation, Kensington.

| | | Condition indicator | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Catchment disturbance | Change in wetland area | Change in wetland topography | Soil disturbance (physical) | Physical modification to hydrology | Changes to water regime | Turbidity (light climate) regime | Salinity regime | Change in pH | Change in [sediment] properties (salinity, acidity) | Change in fringing zone | Change in wetland vegetation | Change in [aquatic] invertebrate diversity and community composition | Change in waterbird presence, breeding and abundance | Change in other wetland-dependent vertebrates presence, breeding and abundance | Change in introduced species | Change in algae | Other indicators required? |
| | **Urban and pre-urban development** | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | ✓ | ✓ | | | | ✓ | | |
| | **Commercial and recreational fishing** | | | | | | | | | | | | | | ✓ | ✓ | | ✓ | Not directly measured |
| | **Recreation (including tourism)** | | | | | | | | | | | | | | | | | | Threat too unspecific? |
| | Climate change | ✓ | ✓ | | | | ✓ | | ✓ | | | | | ✓ | | | | ✓ | |
| | **Sedimentation** | | ✓ | ✓ | | ✓ | | ✓ | | | ✓ | | | ✓ | | | | | |
| | Wind and water erosion | | ✓ | ✓ | | ✓ | | ✓ | | | | | | | | | | | |

### *Information Gaps*

Four indicators were identified as high priority to provide information on threats to wetlands within the Rangelands Region, and none of these are very well covered by past or existing survey and monitoring programs. This is a significant data gap, but this is not unexpected for a region as large as the Rangelands. Ideally, threats need to be broken down by sub-region to facilitate a better gap analysis.

The inventory projects that have been conducted throughout the Rangelands have provided baseline information for a large number of wetlands over a wide geographic area. However, the sites are not necessarily representative of the region or of particular sub-regions. These initial projects would need to be extended into longer-term monitoring to enable application of indicators of change.

### *Planned future work*

The project 'Establishing priorities for wetland conservation and management in the Kimberley' collated information on Kimberley wetlands from desktop studies, field research and community consultation. The resulting report (Vernes 2007) presents the major issues facing wetlands of the area and identifies suggested areas for future investment. Some specific recommendations for management actions and monitoring are outlined, but are yet to be implemented.

An application will be made to fund continuation of the IAI RCM project. Provided the application is successful, surveys will continue on an annual basis. The project also aims to facilitate and encourage the development of monitoring programs for individual wetlands, or groups of wetlands (G. Daniel pers. comm.).

# Part Two - Wetland classification systems and conceptual model development

## *Introduction and purpose*

The classification of wetlands into groups with similar characteristics can be useful for many purposes including inventory, monitoring, and ecological modelling. In their review of wetland inventory and classification in Australia, Pressey and Adam (1995) broadly define wetland classification as 'any attempts, intuitive or numerical, to group wetlands with common characteristics or to identify the types of environments and biota they contain'. Dividing wetlands into discrete and recognisable groupings also facilitates reporting at regional, State and National Scales. Moreover, the classification system(s) most appropriate for different types of reporting are likely to vary depending on the resolution of information required and the aims of the project.

As discussed by Pressey and Adam (1995), each classification scheme is a 'tool' to 'understand variation for a particular management or conservation purpose and should be developed specifically…'. It is therefore unlikely that the same system will be appropriate for different geographic areas, and for purposes as different as facilitating wetland mapping versus the development of conceptual models of wetland type.

Wetland classification is relevant to the trial of NWI in Western Australia, as it is likely that different suites of indicators will be relevant to different wetland types, making an understanding of these types, and the selection of the appropriate typology integral to the implementation of NWI in WA. This is discussed further in the section on conceptual models (p. 83).

The first objective of Part Two of this discussion paper is to examine similarities and differences between four wetland classification systems with practical or potential relevance to wetlands in Western Australia. These are:

- the Geomorphic Wetlands Classification system (Semeniuk and Semeniuk 1995) adopted for use by the Western Australian Government;
- the Queensland Wetland Habitat Typology (EPA Queensland Wetland Programme 2008a), developed as an overarching framework for wetlands in different climatic zones of Queensland, and potentially the rest of Australia;
- the Classification of Wetlands and Deepwater Habitats of the United States (Cowardin *et al.* 1979), the terminology from which has been

broadly adopted by the Australian Federal Government for use across Australia;

- and the Northern Territory Arid Zone Wetland Classification (Duguid *et al.* 2007), which is an example of an ecologically-based classification system with some relevance to Western Australian wetlands, despite its restricted geographic scope.

It is important to note at the outset that these four classification systems have been developed for very different purposes, making them difficult to compare. We are not intending to conclude that one system is better than others but to show similarities and differences between them so that this information can be used for future decision-making. We have tried to include a 'translation tool' (Table 20) to facilitate comparison between the wetland classes in the different systems. Geomorphic Wetland Classification System categories are compared with the lowest (most detailed) applicable level of each of the other three classification systems. In all cases, only broad comparisons could be made, due to the differences in level of detail, content and construction of the four classification systems.

**Table 20: Comparison of wetland classification categories in the 'Wetlands and Deepwater Habitats of the US' classification, the Queensland Wetland Habitat Typology and the Northern Territory arid zone wetlands classification with the Geomorphic Wetland Classification system**

| **Geomorphic Wetland Classification (Semeniuk and Semeniuk 1995)** | **Wetlands and deepwater habitats of the US (Cowardin *et al.* 1979)** | **Queensland Wetland Habitat Typology (EPA Queensland Wetland Programme 2008a)** | **NT arid zone wetlands (Duguid *et al.* 2007)** |
|---|---|---|---|
| Lake | Lacustrine | Lacustrine<br>Permanent | N/A<br>All wetlands covered by the classification are temporary |
| Sumpland | Palustrine | Palustrine<br>Non-permanent | Basins – forming natural wetlands |
| Dampland | Palustrine | Palustrine<br>Non-permanent | Basins – forming natural wetlands<br>Not open water |
| Playa | Lacustrine | Lacustrine<br>Non-permanent | Basins – forming natural wetlands |
| River | Riverine | *Not covered* | Water courses |
| Creek | Riverine | *Not covered* | Water courses |
| Wadi | Riverine | *Not covered* | Water courses |

| **Geomorphic Wetland Classification (Semeniuk and Semeniuk 1995)** | **Wetlands and deepwater habitats of the US (Cowardin *et al.* 1979)** | **Queensland Wetland Habitat Typology (EPA Queensland Wetland Programme 2008a)** | **NT arid zone wetlands (Duguid *et al.* 2007)** |
|---|---|---|---|
| Trough | Riverine | *Not covered* | Water courses |
| Floodplain | Palustrine | Palustrine<br>Non-permanent<br>Floodplain | Flats |
| Palusplain | Palustrine | Palustrine<br>Non-permanent | Flats |
| Barlkarra | *Not covered* | *Not covered* | Flats |
| Paluslope | Palustrine | Palustrine<br>Non-permanent<br>Non-floodplain | Upland spring/seepage (if groundwater derived) |
| Palusmont | *Not covered* | *Not covered* | Upland spring/seepage (if groundwater derived) |

## *Description of the four wetland classification systems*

The Western Australian Government has adopted the Geomorphic Wetlands Classification System (Semeniuk and Semeniuk 1995) for wetland management specifically related to wetland delineation (mapping) at regional and State levels. This system is a non-hierarchical top-down classification system based on physical ecosystem drivers, primarily hydrology and geomorphology (Table 21). Wetland categories derived from the Geomorphic Wetlands Classification System are shown in Table 22. The system also provides for modifiers against the basic classification system, including water quality (salinity category), vegetation distribution and wetland size (Semeniuk and Semeniuk 1995).

**Table 21: Comparison of wetland classification system characteristics**

| **Characteristic** | **Geomorphic Wetlands Classification (Semeniuk and Semeniuk 1995)** | **Wetlands and deepwater habitats of the US (Cowardin *et al.* 1979)** | **Queensland Wetland Habitat Typology (EPA Queensland Wetland Programme 2008a)** | **NT arid zone wetlands (Duguid *et al.* 2007)** |
|---|---|---|---|---|
| Purpose | *"…this approach to the classification of wetlands is based on the two major factors which determine the existence of all wetlands, i.e. landform and water…has the potential to bring out the underlying, unifying features of wetlands that occur in diverse physiographic and climatic settings."* | *"…to describe ecological taxa, arrange them in a system useful to resource managers, furnish units for mapping, and provide uniformity of concepts and terms."* | *"…provide further resolution for wetlands, beyond this (Cowardin et al. 1979) system level, to a type level that is both broad enough to cover the state of Queensland but also allows for identification and grouping of key ecological and physical processes within wetlands of each climatic zone."* | *"…classification that usefully distinguishes the wetland types in the arid NT…"* using ecological parameters. |
| Bottom-up or Top-down | Top-down | Top-down | Top-down | Top-down |
| Classification system type (Hale and Butcher 2008b)[1]<br>• Unstructured<br>• Driver<br>• Biological<br>• Holistic | Driver-based | Holistic | Holistic | Holistic |
| Hierarchical? | No | Yes | No | Semi<br>Open-ended hierarchy |

| Characteristic | Geomorphic Wetlands Classification (Semeniuk and Semeniuk 1995) | Wetlands and deepwater habitats of the US (Cowardin *et al.* 1979) | Queensland Wetland Habitat Typology (EPA Queensland Wetland Programme 2008a) | NT arid zone wetlands (Duguid *et al.* 2007) |
|---|---|---|---|---|
| Appropriate for conceptual model development? | Needs additional descriptors, e.g. water colour, climatic zone | Models already exist, although intended to be very broad and not region-specific | Needs additional information from scientific literature and consultation | Yes, but geographic area very restricted |
| Meets HCAVE[2] criteria for classification system? | No | No | No | No |
| Wetland types included | 13 wetland categories | 5 wetland systems: (marine, estuarine, riverine, lacustrine and palustrine); 56 wetland classes | 45 wetland types (restricted to Queensland) | 71 wetland types (restricted to arid NT) |

[1] **Unstructured:** unstructured lists based on compilations; **Driver:** based on abiotic drivers of aquatic ecosystems; principally geomorphology; and/or hydrology; **Biological:** bottom-up classifications based predominantly on species or communities; and **Holistic:** based on a combination of drivers and responses and including both abiotic and biotic components (Hale and Butcher 2008b).

[2] High Conservation Value Aquatic Ecosystems (HCAVE) (Hale and Butcher 2008b).

**Table 22: Wetland categories derived from the Geomorphic Wetlands Classification System (Semeniuk and Semeniuk 1995)**

| Water longevity | 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 |

The Geomorphic Wetlands Classification System has been endorsed for use as Western Australia's primary wetland classification in the context of mapping and delineation of wetlands, and has considerable value in this context. However, additional ecological detail is often required when classifying wetlands to understand biological and ecological trends and patterns, and in these instances the Geomorphic Wetlands Classification System may not be the most suitable scheme. Ecologists often tend to use novel schemes developed for a particular purpose. Such schemes may be based on an understanding of a particular aspect of wetlands such as diversity, condition, or which values or function is most important. Schemes may also be tailored to particular geographic areas. A good example of an ecologically-focused scheme that captures the necessary detail to understand a range of wetland drivers (not just physical drivers) and that would allow the development of tailored ecological conceptual models is the Northern Territory arid zone wetlands classification system (Duguid *et al.* 2007).

However, the detail inherent in the Northern Territory arid zone wetlands classification system also makes it unwieldy for use over large areas, as it would require the input of detail that may not be available for many largely unsurveyed areas in Western Australia, and would also result in too many wetland categories to allow simple cross-referencing. This type of detailed scheme could be used for particular focus areas, with other schemes that have a broader focus and can be applied at either a regional, state or Australia-wide scale layered on top.

In order to assist wetland inventory and management across Australia, an overarching framework is required to help facilitate a comparison of wetland types and reporting on condition, extent and distribution in all of the different Australian States and Territories. A framework such as this would not be intended to replace state-based systems but to link them. It would need to be simple to apply, so that no significant additional work would be required to assign wetlands to these categories.

"*A major requirement of a contemporary classification system to be used at a State or national level is that different wetland types be identified using desktop techniques such as remote sensing and data trawling. It is also critical that information collected on wetlands using different classification systems can be "translated" for the purpose of establishing a more complete picture of different wetland types for monitoring purposes, and to provide for a level of data comparability once assessments have been undertaken*"(EPA Queensland Wetland Programme 2008b).

As part of the Queensland Wetland Programme (QWP), a partnership with the Australian Federal Government, the Queensland EPA has developed such a framework, called the 'Wetland Habitat Typology – Palustrine and

Lacustrine Wetlands', to cover two major ecological systems of wetlands. Definitions of these ecological systems, based on Cowardin *et al.* (1979), are presented in Table 23. At this stage the Wetland Habitat Typology applies only to Queensland, however the South Australian and New South Wales Governments have taken steps towards adapting it for wetlands within their jurisdictions (M. Coote pers. comm.).

Table 21 shows a comparison of the major characteristics of each of the four classification systems being compared in this document. The Geomorphic Wetland Classification system is driver-based and assumes that ecological characteristics of wetlands flow on from the key physical drivers of landform and hydrology. There is no climatic division made between wetland types. The Cowardin *et al.* (1979) system is a broad classification scheme based around 'ecological systems' and is designed to cover a wide range of geographic areas. The Australian Federal Government has largely adopted the terminology used in this classification system, rather than the entire system itself. The Queensland Wetland Habitat Typology is designed to use desktop data and categorise wetlands by a number of parameters including climatic zone, water type and vegetation type. The Northern Territory arid zone wetland classification system is very detailed and provides a useful level of ecological information, but covers only a restricted geographic area.

**Table 23: Descriptions of ecological systems of wetlands (Cowardin *et al.* 1979; EPA Queensland Wetland Programme 2008b)**

| Ecological system | Description of wetlands included in system |
|---|---|
| Marine | coastal wetlands including rocky shore |
| Estuarine | including deltas, tidal marshes and mangrove swamps |
| Riverine | wetlands along rivers and streams |
| Lacustrine | wetlands associated with lakes |
| Palustrine | marshes, swamps and bogs |
| Reservoirs | including water storage areas, excavations, wastewater ponds, irrigation channels, rice fields, canals |
| Subterranean[a] | inland subterranean wetlands |

[a] In this paper we have adopted the definition of subterranean wetlands from (Duguid *et al.* 2007) "underground water-filled spaces in rock with macroscopic invertebrates".

Table 24 shows a detailed comparison of the parameters considered by each of the four classification systems. All four systems use landform and hydrology as core characteristics, but vary in the level of detail they include, and in which other parameters are included as core characteristics.

**Table 24: Comparison of core (primary) and descriptor (secondary) characteristics used to classify wetlands using the Geomorphic Wetland Classification system (Semeniuk and Semeniuk 1995), the Wetlands and Deepwater Habitats of the US classification (Cowardin *et al.* 1979), the Queensland Wetland Habitat Typology (EPA Queensland Wetland Programme 2008a) and the Northern Territory arid zone wetland classification (Duguid *et al.* 2007)**

| Classification system | Climate | Ecological system | Geomorphology /Landform | Upland/lowland | Size | Hydrology | Water source | Wetland depth | Substrate | Vegetation structure | Vegetation distribution | Representative flora | Water quality - salinity | Water quality - pH | Representative fauna |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Semeniuk and Semeniuk (1995)** | — | — (used in some of the category names) | **Core** | — | Descriptor | **Core** | — | — | — | — | Descriptor | — | Descriptor | — | — |
| **Cowardin *et al.* (1979)** | — | **Core** (doesn't include subterranean systems) | **Core** | — | Descriptor for Lacustrine and Palustrine | **Core** | — | Descriptor for Lacustrine and Palustrine | **Core** | Part of 'class' with substrate | — | Descriptor | Descriptor | — | Descriptor |
| **Queensland Wetland Habitat Typology** | **Core** | **Core** (only Lacustrine and Palustrine included) | **Core** (broad) | — | — | **Core** (broad) | — | — | **Core** (soils only, additional detail not currently used) | **Core** (broad) | — | Not currently used | **Core** | **Core** | — |
| **NT arid zone wetlands** | — | — | **Core** (additional detail for Springs) | Descriptor for Channels | — | **Core** Channel, Spring additional hydrology detail | Descriptor for artificial wetlands | — | — | Descriptor for Flats | Descriptor for Basins | — | Descriptor for Basins and Springs | — | — |

## *Conceptual models*

The development of conceptual models for different wetland types is one of the next stages in the process of implementing the use of NWI in Western Australia, and this requires an understanding of the ecology behind each 'type'. "*…the ecological basis of the selection of condition indicators is derived from conceptual models that identify key wetland ecological and physical drivers and pressures. Indicators are the means by which the condition of a wetland can be assessed but it is not sufficiently robust to simply select them from a standard list. There needs to be an understanding of the individual wetland in terms of its physical, biological and chemical processes, and indicators should be selected to reflect the changes that may occur to a wetland under different impacts*" (Conrick *et al.* 2007).

Ideally, the use of a wetland classification system that encapsulates all of this information would facilitate the development of conceptual models. However, currently not all of this information is often included in wetland classifications. The tradeoff is that once sufficient information is included in a classification/typology to facilitate conceptual model development, it then becomes so detailed that it is unwieldy for use over large areas (e.g. NT arid zone wetlands classification). This once again supports the use of several 'layers' of classification, from very broad to more detailed.

Often there is a scientific understanding associated with different 'ecological wetland types', even if these are not rigidly set into a defined classification system. These ecological wetland types each have a characteristic biota, wetting and drying dynamic and key set of processes which define them. These are the kinds of information that are required for the development of useful ecological conceptual models. Table 25 outlines the ecological wetland types occurring in each region of Western Australia. These have been documented from expert knowledge of members of the Science Division of DEC, as well as DEC Regional Ecologists. Table 25 outlines the ecological wetland types occurring in each region and their equivalent classes in the Geomorphic Wetlands Classification System.

There are significant benefits in using a formal wetland classification system to name conceptual models of wetland type, as it provides a systematic approach and can assist in a clear understanding of what the key characters of each type may be. However, the information contained in the ecological wetland type descriptions is extremely valuable from a scientific and management viewpoint and should not be disregarded.

Conceptual model development has not yet commenced in Western Australia, and some of these issues will need to be resolved as part of this process.

## The Queensland approach to conceptual model development

One of the functions of the Queensland Wetland Habitat Typology is to provide a framework for the development of conceptual models for wetland types.

"*The wetland types resulting from this typology will form the basis of a series of conceptual models that will provide a visualisation of the latest scientific understanding of the ecological and physical processes operating in these systems. These conceptual models will also feed into the system of indicators that is being developed by the EPA for lacustrine and palustrine wetlands"* (EPA Queensland Wetland Programme 2008a).

Although the typology is very broad in scale, the basic wetland types resulting from the system can be used as a basis for developing conceptual models, and then additional detail in the form of scientific information from literature and expert opinion is also incorporated. The models are reviewed and workshopped to ensure their accuracy (EPA Queensland Wetland Programme 2008c).

The initial models developed using the typology are still relatively generalised, and do not include regional or local level detail. It is intended that these generalised models can be used to develop more detailed models for particular systems (EPA Queensland Wetland Programme 2008b), mirroring the 'stacking' of classifications/typologies.

**Note: The Queensland Wetland Programme (QWP) webpage (Queensland EPA 2008) is currently being updated to better reflect the linkages between the wetland typology, development of conceptual models and the NWI process (L. Heydon pers. comm.) and the location of this webpage may be updated once it is finalised.**

The QWP are also developing a series of 'stressor models' that depict elements of the wetland environment and landscape that can be altered by human activity, causing stress to the wetland ecosystem (Queensland EPA 2008). These include:

- Bacteria
- Biota
- Conductivity
- Connectivity
- Habitat
- Hydrology
- Litter

- Nutrients
- Organic matter
- Pests
- pH
- Sediments
- Toxicants
- Water temperature

These types of conceptual models can provide a valuable insight into how particular stressors may affect wetland function and biodiversity. However, they are not tailored to particular wetland types. There may be a need for linkages between ecological knowledge about the impacts of stressors on wetlands in general, and on-ground understanding of key threats to particular wetland types in the different regions of Western Australia to help further understand which indicators are important for which wetlands.

**Table 25: Ecological wetland types in Western Australian regions (A. Pinder pers. comm. with details confirmed/added by regional ecologists)**

| Broad ecological wetland type | Primary descriptor | Secondary descriptor | Geomorphic Wetland category | South West Region | Perth Region | South Coast Region | Avon Region | Northern Agricultural Region | Rangelands Region | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Pilbara | Kimberley | Midwest | Goldfields |
| **Swamps/marshes** | Tree-dominated | *Eucalyptus* | Sumpland/ dampland | Y | Y | Y | Y | Y | ? | Y | N | N |
| | Tree-dominated | *Melaleuca* | " | Y | Y | Y | Y | Y | N | Y | Y | N |
| | Tree-dominated | *Banksia littoralis* | " | Y | N | Y | N | N | N | N | N | N |
| | Tree-dominated | Other (e.g. *Casuarina*, *Acacia*) | " | Y? | ? | Y (and *Kunzea*, *Astartea*, *Homalspermum*, *Callistachys*, *Pericalymma*) | Y | Y? | Y | ? | N | N |
| | Heath-dominated | *Allocasuarina*, *Taxandria* | " | Y | N | Y | N | N | N | N | N | N |
| | Sedge/emergent macrophyte-dominated | Cane grass | " | N | N | N | Y | N | Y | N | Y | Y? |
| | Sedge/emergent macrophyte-dominated | *Typha*/*Baumea* | " | Y | Y | Y | Y | Y | but fed by springs | Y | N | N |
| | Sedge/emergent macrophyte-dominated | Other Cyperaceae | " | Y | Y | Y (*Evandra aristata*) | Y | Y | but fed by springs | Y | N | N |
| | Sedge/emergent macrophyte-dominated | Rushes | " | Y | N | Y | N | N | N | N | N | N |
| | Salt marsh | | N/A (marine) | Y (Peel-Harvey, samphire flats, e.g. Lake Unicup) | Y (parts of Swan estuary) | Y (estuarine samphire) | Y | Y (e.g. north of Hutt) | Y | ? (coastal) | N | N |
| **Springs** | Mound springs | organic | N/A | N | Y | N | N | Y (Three Springs) | N | Y | ? | ? |
| | Mound springs | inorganic | N/A | N | N | N | N | N | N | N | N | N |
| | Other | | ? | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| | Tufa-dominated (calcium carbonate deposit) http://en.wikipedia.org/wiki/Tufa | | ? | Y | ?Y (e.g. microbial thrombolite and mat communities, and possibly some small tufa rim-pool type springs) | Y | N | N | N | ? | N | N |
| **Palusplain/ sumpland** | | | Palusplain/ sumpland | Y | Y | Y | Y (samphire flats) | Y | N | N | N | N |
| **Damplands** | | | Dampland | Y | Y | Y | Y (samphire flats) | Y | N | N | N | N |

| Broad ecological wetland type | Primary descriptor | Secondary descriptor | Geomorphic Wetland category | South West Region | Perth Region | South Coast Region | Avon Region | Northern Agricultural Region | Rangelands Region | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Pilbara | Kimberley | Midwest | Goldfields |
| **Claypans** | Vegetated | | Sumpland | Y | Y | Y | Y | Y | Y | Y (south) | Y | Y |
| | Non-vegetated | | Sumpland | Y | Y (seasonal) | N | Y | Y | Y | Y (south) | Y | Y |
| **Lakes** | Naturally saline (playas) | | Playa | Y (wandoo-jarrah fringe, Lake Unicup) | Y | Y | Y | Y | N | N | Y | Y |
| | Fresh—brackish | | Lake | Y | Y | Y | Y | Y | Y (very few) | Y (e.g. Lake Gregory) | Y | Y |
| **Artificial** | Reservoirs | farm dams | N/A | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| | Reservoirs | water supply reservoirs | N/A | Y | Y | Y | Y | Y | Y | Y | N | Y |
| | Reservoirs | ornamental lakes | N/A | Y | Y | Y | N | N | N | N | N | Y |
| | Reservoirs | salt fields | N/A | N | N | N | N | ? | Y | Y | N | Y |
| | Reservoirs | canals/irrigation channels | N/A | N | Y | Y (drains) | Y (drains) | N | N | Y | N | N |
| **Riverine** | Rivers/streams Include floodplains? | | River, Creek, Wadi, Trough | Y | Y | Y | Y | Y | Y | Y | ? (rarely flowing) | ? (ephemeral - Ponton Creek) |
| | Pools in dry rivers | | ? | N | Y | Y | N | Y | Y | Y | Y | Y |
| | Gorge/plunge pools | | ? | Y (few, e.g. Kent River) | Y (small ones) | Y | N | ? (Murchison Gorge) | Y | Y | Y | Y (Central Ranges bioregion) |
| **Rock pools** | Gnamma pools/ holes (ephemeral pools on granite) | | Dampland | Y | Y (on rock outcrops) | Y | Y | Y | Y | Y? | Y | Y |
| | deep rockbed pools in creeks | | River/creek | N | ? | Y | N | ? | Y | Y? | Y | Y |
| **Coastal lagoons** | | | N/A | Y | Y (e.g. Peel – Yalgorup) | Y (e.g. Wilsons Inlet) | N | Y (e.g. Hutt, Jurien suite) | N | Y | N | N |
| **Subterranean** | | | N/A | Y | Y | N? | N | Y | Y (e.g. Barrow Island, Cape Range) | Y | N | Y? |

## The way forward for Western Australia

In order to implement the NWI for extent, distribution and condition in Western Australia, the following tasks remain as a high priority:

- Check regional detail – information about available data, parameters recorded, and importantly, about threats to wetlands, all needs to be checked and confirmed by regional staff from agencies and NRM organisations;

- Complete gap analysis – once threats and data information has been checked, the final gap analysis can be updated, highlighting areas where additional data may be required. However, until a wetland typology is confirmed, tailoring of indicators to regions and wetland types cannot be completed;

- Decide on adoption or adaptation of Queensland Wetland Habitat Typology and/or other classification system – the development of a 'layered' approach to wetland classification in Western Australia, in which several typologies overlay each other, is likely to be required. The Queensland Wetland Habitat Typology approach could be modified for use in Western Australia, allowing some consistency in national reporting;

- Incorporate ecological detail into wetland classification – the typology/classification used for the development of conceptual models will need to contain accurate ecological information. Consensus will need to be reached on the appropriate approach to achieving this. Some possible options are:

    - Development of an ecological classification system for WA (or focus regions as required);

    - Addition of ecological detail into Geomorphic Wetlands Classification System;

    - Tailoring of the Queensland Wetland Habitat Typology at finer scales to incorporate necessary ecological detail.

- Use the ecological classification derived from the above process to develop conceptual models for each wetland type. If wetland types occur in other parts of Australia (or are similar to wetland types from other areas), conceptual models that have already been developed may be able to be modified for Western Australia;

- Use typology, conceptual models, threat and stressor information and gap analysis, to refine our understanding of which indicators are relevant to particular regions and wetland types for Western Australia.

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# Appendix One – consultation list

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Alison Beard, David Cale, Michael Coote, Glen Daniel, Christina Denton, Justine Lawn, John Lizamore, Adrian Pinder, Catherine Prideaux, Holly Smith (Wetlands Section, Department of Environment and Conservation), Graeme Behn (Remote Sensing Section, Department of Environment and Conservation).


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| Calvert, Tracy | Project Manager, Albany, DoW | 28 July 2008 |
| Cossart, Robert | Waterways Coordinator, DoW | 4 August 2008 |
| Cowan, Mark | Principal Ecologist, Rangelands, Science Division, DEC | 12 August 2008 |
| Cundy, Melissa | Conservation Officer (Wetlands), Midwest Region, DEC | 10 August 2008 |
| Davis, Jennifer | Professor, Monash University | 8 October 2008 |
| English, Val | Principal Ecologist, Species and Communities, DEC | 19 September 2008 |
| Frodsham, Tim | Wetlands Project Manager, Green Skills Inc. | 30 June 2008 |
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| Heydon, Lana | Wetlands Program, Queensland EPA | 8 October 2008 |
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| Humphries, Bill | WA Museum | 18 September 2008 |
| Lane, Jim | Principal Research Scientist, Busselton, DEC | 9 December 2008 |
| Lincoln, Nicole | Conservation Officer, Busselton, DEC | 10 July 2008 |
| Massenbauer, Tilo | Recovery Catchment Officer, Esperance, DEC | 29 July 2008 |
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| Mitchell, David | Regional Leader Nature Conservation, Swan Region, DEC | 15 August 2008 |
| Mykytiuk, Christina | Environmental Officer, Wetlands Section, DEC | 17 September 2008 |
| Palmer, Duncan | Senior Natural Resource Management Officer, East Kimberley, DoW | 1 August 2008 |
| Suzac, Robert | Technical Officer, Science Division, DEC | 11 August 2008 |
| Tripp, Katya | Projects Officer, Shire of Wyndham East Kimberley | 22 July 2008 |

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| Willmott, Amanda | Waterways and Wetlands Officer, Peel-Harvey Catchment Council | 10 September 2008 |

# Appendix Two – National Wetland Indicators, reference conditions and possible measures

| Theme | Indicator | Reference condition | Possible measures |
|---|---|---|---|
| **Catchment disturbance** | Disturbance in the catchment | Pre-European | Land use<br>Infrastructure<br>Land cover change |
| **Physical form and processes** | Change in wetland area | Change from reference date | Percentage reduction in wetland area<br>Loss in area of original wetland |
| | Wetland topography – change through erosion, excavation, banks and levees, deposition or rehabilitation | Change from reference date | Percent of the wetland where activities have resulted in a change in wetland topography (or bathymetry)<br>Percentage change in bathymetry |
| | Soil disturbance – change through physical disturbance, compaction or cultivation | Change from reference date | Change in the physical surface of the soil through disturbance<br>Percentage and severity of wetland soil disturbance<br>Substrate disturbance |
| **Hydrological disturbance** | Physical modification to hydrology in-flow, drainage and extraction (catchment and wetland scale) | Pre-European | Severity of activities that change the water regime<br>Impact of man-made structures |
| | Changes to water regime, including broad scale and wetland scale groundwater contribution | Pre-European | Requires more development and expert advice on appropriate measures |
| **Water and soil quality** | Turbidity regime | Requires expert advice. Ideally pre-European, or an estimate of what this may have been. | Requires expert advice on appropriate methodology |
| | Salinity regime | Requires expert advice. Ideally pre-European, or an estimate of what this may have been | Requires expert advice on appropriate methodology |

| Theme | Indicator | Reference condition | Possible measures |
|---|---|---|---|
| | pH | Requires expert advice. Ideally this would be pre-European, or an estimate of what this may have been | Requires expert advice on appropriate methodology – issues with diurnal variability.<br>pH measured in situ with a hand-held meter |
| | Soil properties – change in salinity, acidity | Requires expert advice. Ideally this would be pre-European, or an estimate of what this may have been | Requires expert advice on appropriate methodology |
| **Fringing zone** | Change in fringing zone | Pre-European | Presence of an intact fringing zone<br>Percentage of the fringing zone that is intact<br>Percentage of natural and exotic vegetation |
| **Biota** | Change in wetland vegetation | Change from reference date | Change in vegetation structure<br>Change in vegetation 'health'<br>Change in vegetation extent |
| | Change in invertebrate diversity and community composition | Change from reference date | Change in invertebrate species/family composition<br>Change in invertebrate species/family diversity |
| | Change in vertebrates (fish, frogs, reptiles, birds, mammals) presence, breeding and abundance | Change from reference date | Change in species composition<br>Change in species diversity<br>Change in species abundance |
| | Change in introduced species (weeds and ferals) | Change from reference date | Requires expert advice on appropriate methodology |
| | Change in algae | Change from reference date | Requires expert advice on appropriate methodology |