State of the catchments 2010

Wetlands

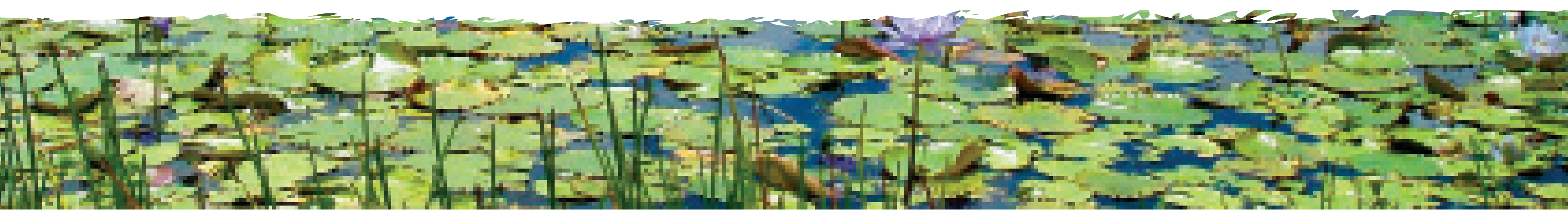
Technical report series

Monitoring, evaluation and reporting program

Assessing the extent and condition of wetlands in NSW: Project report

Sonia Claus
Sarah Imgraben
Kirsty Brennan
Alex Carthey
Benjamin Daly
Rachel Blakey
Eren Turak
Neil Saintilan

Office of Environment and Heritage



Monitoring, evaluation and reporting program
Technical report series

Native vegetation
Native fauna
Threatened species
Invasive species
Riverine ecosystems
Groundwater
Marine waters
Wetlands
Estuaries and coastal lakes
Soil condition
Land management within capability
Economic sustainability and social well-being
Capacity to manage natural resources

Published by:

Office of Environment and Heritage
59 Goulburn Street, Sydney NSW 2000
PO Box A290, Sydney South NSW 1232
Phone: (02) 9995 5000 (switchboard)
Phone: 131 555 (environment information and publications requests)
Phone: 1300 361 967 (national parks, climate change and energy efficiency information, and publications requests)
Fax: (02) 9995 5999
TTY: (02) 9211 4723
Email: info@environment.nsw.gov.au
Website: www.environment.nsw.gov.au

Report pollution and environmental incidents
Environment Line: 131 555 (NSW only) or info@environment.nsw.gov.au
See also www.environment.nsw.gov.au

This publication may be cited as:

Claus S, Imgraben S, Brennan K, Carthey A, Daly B, Blakey R, Turak E & Saintilan N 2011, *Assessing the extent and condition of wetlands in NSW: Project report,* Monitoring, evaluation and reporting program, Technical report series, Office of Environment and Heritage, Sydney.

ISBN 978 1 74293 337 5
OEH 2011/0716
September 2011

Acknowledgements

The authors wish to acknowledge the contribution of the following people to the NSW Wetlands Monitoring, Evaluation and Reporting program:

- Neil Saintilan, Joanne Ling, John Patten, Alex Meehan, Alison Curtin, Mike Maher, Jennifer Spencer, Tim Ralph, Hugh Smith, Kerrylee Rogers, Eren Turak, Louise Goggin, Henning Holburg and Hugh Robertson from Office of Environment and Heritage, Department of Premier and Cabinet
- Lana Heydon, Mike Ronan and David Scheltinga of Queensland Department of Environment and Resource Management (QLD DERM)
- Ben Gawne and Amina Price from Murray–Darling Freshwater Research Centre (MDFRC)
- Ben Maddox, Sam Davis and Andrew Kennedy from NSW Department of Primary Industries (NSW DPI), Department of Trade and Investment, Regional Infrastructure and Services
- Michael Healey and Maxine Rowley from NSW Office of Water (NOW), Department of Primary Industries
- Brendan Edgar from National Land and Water Resources Audit (NLWRA)
- Ben Fee and Glen Scholz South Australia Department of Land, Water and Biodiversity Conservation (SA DWLBC)
- Peter Nelson NSW Department of Planning and Infrastructure (DOP).

Contents

Figures

Tables

Summary

The State of the catchments (SOC) 2010 reports are one of the key reporting mechanisms under the monitoring, evaluation and reporting (MER) strategy for natural resources in NSW. One of the measures of the success of this strategy is the progress made towards the achievement of the state-wide targets for the condition of natural resource assets. The target for wetland assets is: 'By 2015, there is improvement in the condition of important inland lacustrine and palustrine wetlands, and the extent of those wetlands is maintained'.

The first SOC report for wetlands provided baseline information on the status of 280 individual wetlands (from 189 wetland complexes) in the 13 catchment management authority (CMA) regions. The individual assessments of each wetland used available data about their condition, and the pressures they face. In conjunction with the compilation of these assessments, a conceptual framework was developed for assessing trends in the status of wetlands. This framework relies on the development of a functional typology of wetlands and conceptual models, which link pressures and drivers to the condition of various components of wetland ecosystems.

The sites selected for the SOC report represent the most important wetlands across NSW. This includes all wetlands identified under international conventions and treaties (eg Ramsar and bilateral migratory bird agreements) and those listed in Australia's Directory of Important Wetlands (DIWA). The indicators used to assess which wetlands were most important were selected by referring to the conceptual models of wetland function, and relied on existing datasets.

A major limitation of the first SOC reports was that there was very little suitable data – especially on the condition of wetland components – to provide reliable assessments of the status of important wetlands across the state. There were also imbalances in the representation of different types of wetlands during site selection, resulting in biases in aggregated scores of wetland condition for CMA regions and the state. Other major limitations were that there were inconsistencies and inadequacies in the methods used for determining wetland extent, and that the assessment methods could not account for multiple alternative states of wetland condition.

The conceptual framework, which includes the identification of wetland types for NSW, and associated methods developed will be helpful for assessing the status of wetlands for future SOC reports. Thirty-four broad wetland types were assessed based on whether they were lacustrine (lake-like) or palustrine (swamp or marsh-like), as well as on their climate and water source. When specific information on hydrological regime and water or vegetation type was incorporated, the potential number of wetland types increased to 54. Three types of conceptual models of wetland function were developed: wetland type models, disturbance and stressor models, and dry-phase models. Also as part of this framework, a series of field methods were proposed.

The baseline data, the condition and pressure scores calculated for CMA regions and the state, and the conceptual framework represent substantial progress towards the assessment of lacustrine and palustrine wetlands at broad spatial scale in NSW. However, there are still some important practical steps and knowledge gaps that need to be addressed. The conceptual framework needs to be expanded beyond representing individual wetlands. It should also include quantification of the amount of change that can be detected within each reporting period and within 10-year planning intervals, together with the uncertainty associated with the detected changes.

1. Introduction

In 2010, 13 SOC reports were released by the Department of Environment, Climate Change and Water (DECCW, now Office of Environment and Heritage [OEH]) to report on the condition of and pressures on 11 natural resource assets and two community targets (OEH, 2011). These assessments provide baseline information on natural resource assets, which can then be used to determine trends in asset condition as part of a state-wide monitoring program. The 13 state-wide targets were recommended by the NSW Natural Resources Commission (NRC) and formed part of the NSW State Plan (NSW Government, 2006). The wetlands natural resource asset, which is the subject of this report, was assigned the following natural resource management (NRM) state-wide target:

'By 2015 there is an improvement in the condition of important wetlands, and the extent of those wetlands is maintained'.

In accordance with the principles of the NSW Natural Resources MER strategy 2010–2015, (DECCW 2010) OEH was given the responsibility to monitor the State's wetlands, report on the status and trends of resource condition for these and evaluate progress towards the state-wide target.

This report aims to:

- describe and evaluate the methods used to generate the first SOC reports on the status of important wetlands in NSW
- establish a conceptual framework for assessing trends in status and progress towards the state-wide target for 2015.

Three other reports support this main report as follows:

- Assessing the extent and condition of wetlands in NSW: Supporting report A – Conceptual framework
- Assessing the extent and condition of wetlands in NSW: Supporting report B – Development of a condition assessment index
- Assessing the extent and condition of wetlands in NSW: Supporting report C – Assessment results for all regions.

2. Background

For the purposes of MER in NSW, wetland assets are those areas that fit the following definition (adapted from Coward in 1979):

- Inundated permanently, periodically or intermittently with non-flowing water
- Supporting plants and animals that are adapted to and dependent on living in wet conditions for at least part of their lifecycle
- Having a substratum consisting of predominantly un-drained soils that are saturated, flooded or ponded long enough to develop anaerobic conditions in the upper layers.

Under the NSW MER, there are five 'water'-based themes:

- riverine ecosystems
- groundwater
- marine ecosystems
- wetlands
- estuaries and coastal lakes.

All five water-based themes contain wetland systems. The wetlands theme is confined to lacustrine and palustrine wetlands, and is defined as follows.

Lacustrine wetlands: large, non-tidal, open, water dominated systems (ie lakes) larger than 8 hectares (ha), which are situated in a topographic depression or on a dammed river channel. They lack trees, shrubs, persistent emergents, emergent mosses and lichens covering greater than 30 per cent of the wetland surface area. Lacustrine systems less than 8 ha may be included if the water depth in the deepest part of the basin exceeds 2 m at low water.

Palustrine wetlands: all non-tidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens. Traditionally these wetlands have been known as swamps, marshes, bogs and fens. These wetlands can occur on river floodplains, in conjunction with lacustrine or riverine systems or in depressions on the landscape.

The wetland assessment methods used for the first SOC reports in NSW followed an evaluation of the previous methods used both in Australia (see review by Conrick 2007) and overseas (eg Fennessy et al. 2004; US Environmental Protection Agency [EPA] 2002; Clarkson et al. 2004) to assess wetlands. While state-wide programs already exist in Victoria (Papas & Holmes 2005) and QLD (QLD DERM 2011), assessments in NSW have been confined to relatively small parts of the state such as the Hawkesbury–Nepean area of Sydney (Sainty & Jacobs 1997) and floodplain wetlands in southern sections of the Murray–Darling Basin (Spencer et al. 1998; Baldwin et al. 2005).

3. Assessment and monitoring methods

The main steps in assessing extent and condition of important wetlands in NSW to provide baseline information for wetlands for the first SOC reports, is described below. The wetland typology and conceptual models of wetland function which underpinned components of these models are detailed in Assessing the extent and condition of wetlands in NSW: Supporting report A – Conceptual framework.

3.1 Site selection

The wetland sites to be assessed in the NSW Wetlands MER program were selected using a series of steps identified in Figure 1. At least 10 wetlands were selected in each CMA region for assessment. Initially all appropriate RAMSAR and DIWA wetlands were selected. If more than 10 important sites were listed in a CMA region, the list was shortened, making sure the following were included:

- At least one of each wetland type (see Assessing the extent and condition of wetlands in NSW: Supporting report A – Conceptual framework, for wetland typology)
- Wetlands which were highlighted in DIWA as good examples of that type of wetland
- Wetlands which have Japan-Australia Migratory Bird Agreement, China-Australia Migratory Bird Agreement, and Republic of Korea-Australia Migratory Bird Agreement species
- Wetlands which have threatened or endangered species or communities.

If fewer than 10 sites were listed in a CMA region, CMAs were given the opportunity to add sites of regional significance. Due to the varying size, total wetland extent and protection status of the different regions used in the NSW MER program, numbers of wetlands selected for assessment varied from eight (Sydney Metropolitan) to 26 (Murrumbidgee). The draft list was circulated to all CMAs for comment and all comments were taken into consideration when compiling the final site list (Appendix 1).

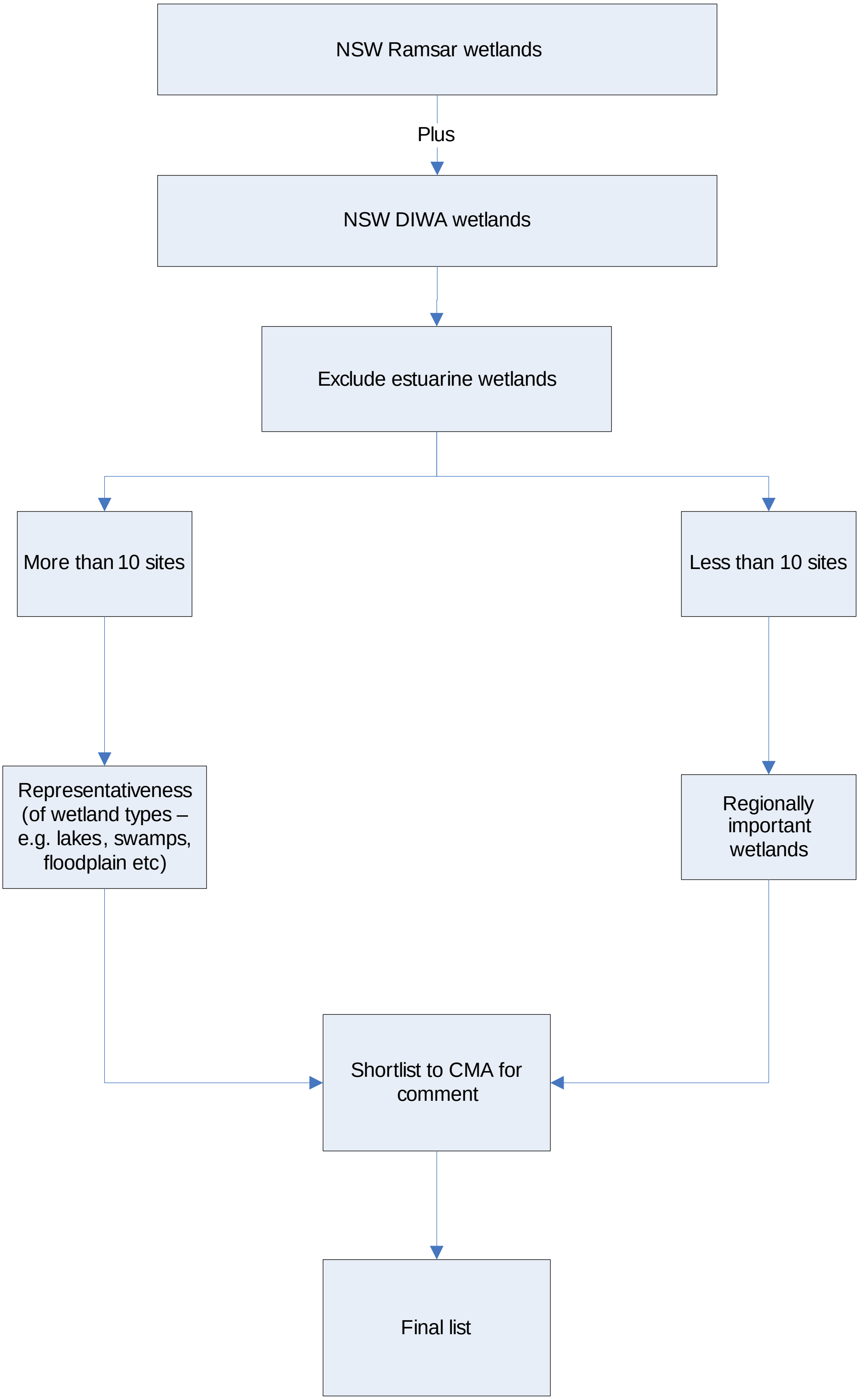


Figure 1: Steps used to select sites for the NSW Wetlands MER program

3.2 Mapping wetland extent, fringing zone and hydrological catchment

3.2.1 Wetland extent

In accordance with the wetland definition described in the previous section, wetland extent was defined as the frequently wetted area and the wetland dependent ecosystem that surrounds it (National Land and Water Resources Audit [NLWRA] 2007). As a comprehensive wetland mapping layer of high enough resolution that encompasses all wetland types and distinguishes between riverine, lacustrine and palustrine systems does not exist for NSW, the extent of each wetland selected for assessment as part of the NSW Wetlands MER program was determined by carrying out an inventory of the best available mapping for each wetland site. The sources of wetland spatial data include the following:

- OEH
- DIWA
- Ramsar
- State Environmental Planning Policy 14 (SEPP14)
- Land and Property Information (LPI)
- Geoscience Australia
- Murray–Darling Basin Commission
- WetlandCare.

3.2.2 Fringing zone

The wetland fringing zone contributes to wetland ecosystem health through direct provision of habitat and connectivity for native species, and indirectly as a protective or buffer zone for wetland ecosystems from impacts to water quality, soil erosion and edge effects (Wang & Yin 2008).

For the NSW Wetlands MER program, the fringing zone of a wetland was defined in the following ways:

- A 200 m buffer was used to represent fringing zone where wetlands were less than 2000 ha in area
- A buffer of 400 m was used for wetlands greater than 2000 ha in area
- For wetlands that were located in large floodplain complexes without discrete wetland boundaries (eg Macquarie Marshes) no fringing zone was used; instead the floodplain boundary was used as the fringing zone in further analyses.

3.2.3 Hydrological catchment

The NLWRA defines a wetland catchment as:

'The zones surrounding a wetland that may provide protection and/or filtration, and the surrounding landscape which directs water flow into the wetland. The catchment boundaries are defined by local geomorphology on the surface, and by both local and regional surface and groundwater basin boundaries' (NLWRA 2007).

This considers not only different scales of measurement, but surface and groundwater components. For the NSW Wetlands MER program, only the surface hydrological catchment of the wetland sites was determined using the best available drainage networks, contour lines and a flow direction map. The flow direction map was created using 25 m digital elevation model (DEM) and hydrology tools within ArcGIS 9.2 (Environmental Systems Research Institute Inc [ESRI] 2006). Ten-metre contours, CMA region boundaries and drainage line mapping were used in conjunction with the flow direction map to create the hydrological catchments.

3.3 Indicators

3.3.1 Selection of indicators using conceptual models

Whilst data availability and resources impeded the use of specific pressure and condition indicators for each wetland type in this assessment, the disturbance and stressor conceptual models (see Assessing the extent and condition of wetlands in NSW: Supporting report A – Conceptual framework), developed for three overall wetland disturbances (catchment disturbance, hydrological disturbance and habitat disturbance) were used to select pressure and condition indicators for NSW wetlands in general.

This process is illustrated below for catchment disturbance. The conceptual diagram (Figure 2) is initially used to identify important pressures on the wetland system and ecosystem responses. Next, the ecosystem responses are linked to changes in condition in a flowchart (Figure 3). Suitable indicators have then been assigned to the pressures and the changes in condition, forming the pressure and condition indicators used for the NSW Wetlands MER program.

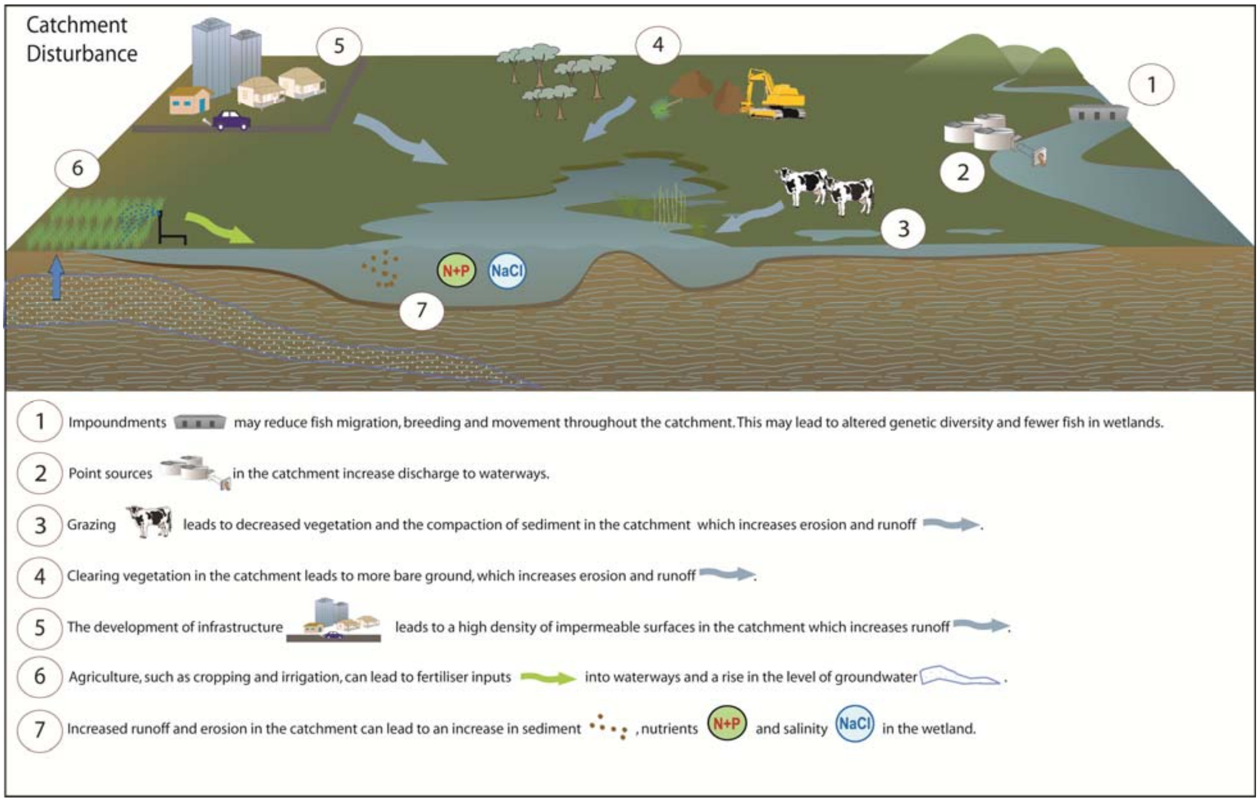
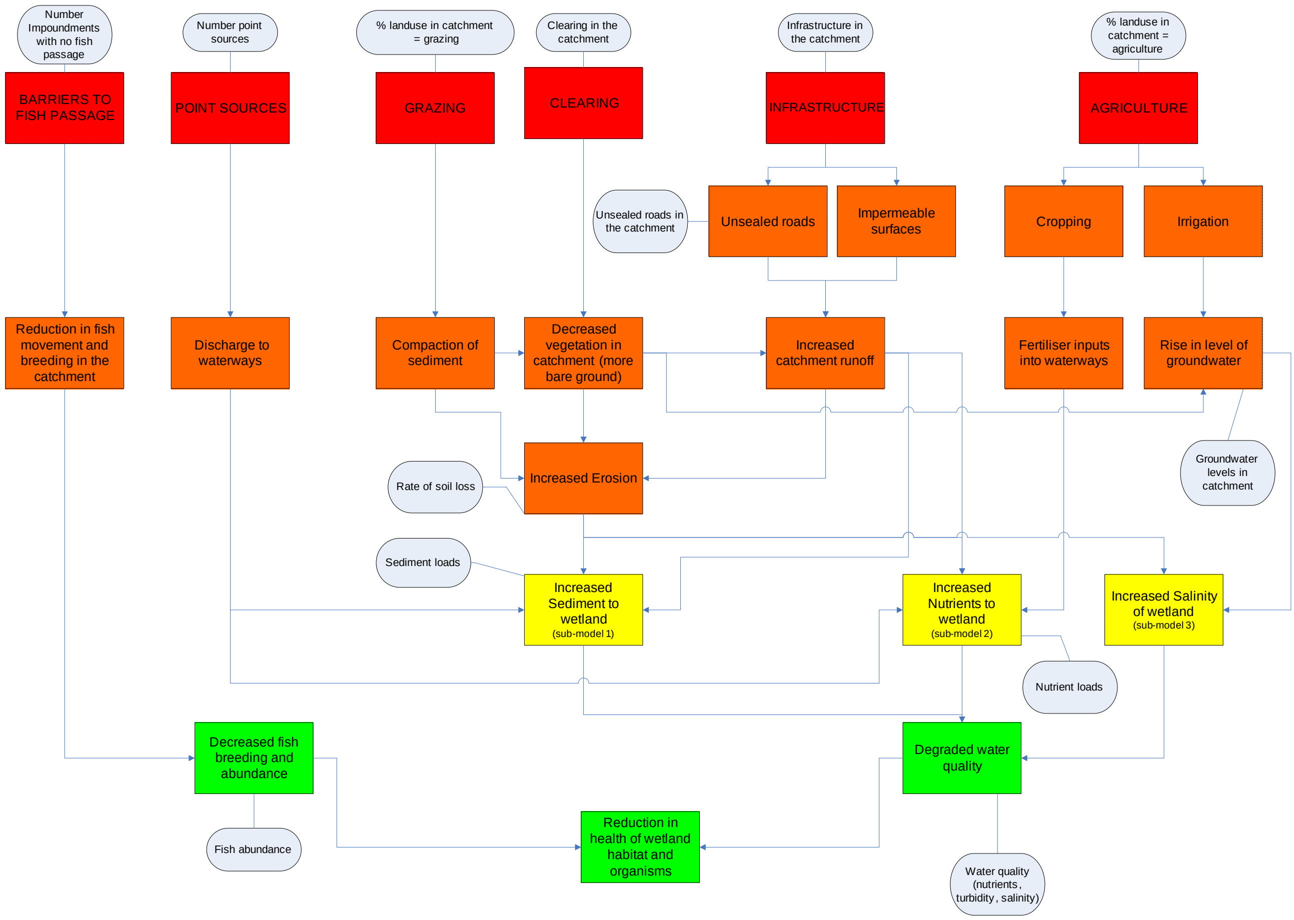


Figure 2: **Example of conceptual diagram for catchment disturbance used to identify and communicate important pressures on the wetland ecosystem and ecosystem responses**



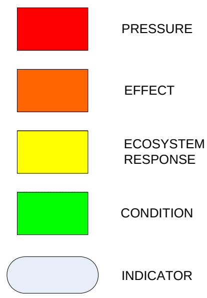


Figure 3: Example of conceptual flowchart for catchment disturbance. The pressures identified in the conceptual diagram (Figure 2) are used to relate pressures to their effects, the subsequent ecosystem response and resulting changes in condition. These changes in condition lead to selection of appropriate indicators for this disturbance

3.3.2 Pressure indicators

Catchment disturbance is defined as modifications or changes to the catchment which affect the ecological health of wetlands. The most important catchment disturbances affecting wetlands in NSW include urbanisation, agriculture, vegetation clearing, infrastructure and fire; however, the impact of these disturbances varies depending on which region the wetland is situated in.

Hydrological disturbance strongly influences the levels of nutrients entering a wetland, water and soil chemistry, vegetation patterns, the biota present and the wetland's productivity. Drainage, damming, extraction and river regulation have greatly altered the hydrologic dynamics of many NSW wetlands.

Habitat disturbance includes activities that remove or modify wetland habitats. This may occur for several reasons including infrastructure, urban development, clearing for agriculture, recreational uses and water regulation.

Table 1: List of pressure indicators and corresponding measures used in the NSW Wetlands MER program

Indicators	Measures
Catchment disturbance	Land-use in the catchment
	% of catchment cleared
	Infrastructure in the catchment
	Presence of point sources (pollution)
	Barriers without fish passage
	Total nitrogen loads
	Total phosphorus loads
Hydrological disturbance	Impoundments in the catchment
	Regulated river catchment
	Farm dam density
	Groundwater bore density
	Irrigation channel density
Habitat disturbance	% wetland in protected area
	% wetland adjoining urban area
	Recreational facilities
	Roads that cross wetland
	Roads that adjoin wetland
	Density of pigs
	Density of goats
	Density of rabbits
	Density of foxes

3.3.3 Condition indicators

Biological condition measures the response of the wetland plants and animals to pressures on the ecosystem, and includes birds, fish, invertebrates, and aquatic and fringing vegetation. It also includes estimates of the presence, abundance or health of species.

Pest species measures wetland condition in terms of the ratio of native: introduced species.

Water quality measures the condition of the water in the wetland. It includes measures such as pH, salinity and turbidity. Water in a wetland is important as it supports biota and ecological processes within the ecosystem.

Soil condition measures the physical attributes of soils in the wetland such as pH, salinity, soil moisture, erosion and modifications like channelling works.

Table 2: List of condition indicators and corresponding measures used in the NSW Wetlands MER program

Indicators	Measures
Biota	Tree health
Biota – pest species	Presence of weeds
	Ratio of invasive to native fish species
	Presence of alien fish
	Presence of feral animals
Water quality	Total nitrogen
	Total phosphorus
	Algal blooms
	Turbidity
	pH
Soil condition	pH

3.4 Development of condition assessment index

Step 1: Collection and collation of raw data

Raw data was collated from a range of sources, formats, resolutions and time periods. Due to this variability, a confidence value was assigned to each indicator by allocating categories based on the age, replication, adherence to international, national or state protocols, spatial and temporal coverage, equipment used and quality control measures implemented.

Step 2: Conversion of raw data into a score for indicator measures

Raw data for each indicator measure was first standardised by allocating categories to each measure based on indicator-specific thresholds or values. These values were converted to a scale of 1–5 where a score of 1 represented the lowest pressure and best condition and 5 represented the highest pressure and worst condition (Table 3). An example of scores for the indicator catchment disturbance in the Coopers Swamp wetland of the Murrumbidgee CMA region is provided (Table 4). This method is consistent with the QLD DERM approach (Scheltinga & Moss 2007). For the SOC 2010 reports, the scoring system adopted for the 13 state-wide targets was '5' for the best and '1' for the worst. The wetland scoring system in this report was reversed for the SOC 2010 reports. (www.environment.nsw.gov.au/soc/stateofthecatchmentsreport.htm).

Table 3: Scoring categories for condition and pressure indicators

Condition indicators	
Scoring category	**Condition of the system**
1	Excellent condition
2	Good condition
3	Fair condition
4	Poor condition
5	Very poor condition

Pressure indicators	
Scoring category	**Pressure level on the system**
1	Negligible pressure
2	Low pressure
3	Moderate pressure
4	High pressure
5	Extreme pressure

Table 4: Example of Coopers Swamp in the Murrumbidgee CMA region

Indicator	Measure	Score	Data confidence
Catchment disturbance	Land-use in the catchment	2	Low
	% of catchment cleared	5	Low
	Infrastructure in the catchment	1	Low
	Presence of point sources	1	Low
	Barriers without fishways	1	Low
	Total nitrogen loads	ND	Low
	Total phosphorus loads	ND	Low

Step 3: Aggregation of measures to form pressure and condition indicator scores

For each indicator, a pressure and condition score was calculated by taking the average of the pressure or condition scores for each measure. A final score for each indicator was then calculated by comparing the score to the values provided in Table 5, which used the 20th percentile divisions of this 1–5 data range. This gave pressure indicator and condition indicator scores for each wetland.

Table 5: Scoring thresholds for each indicator using 20th percentile divisions

Raw score	Pressure rating (score)	Condition rating (score)
≤1.8	Negligible (1)	Excellent (1)
>1.8 to ≤2.6	Low (2)	Good (2)
>2.6 to ≤3.4	Moderate (3)	Fair (3)
>3.4 to ≤4.2	High (4)	Poor (4)
>4.2	Extreme (5)	Very poor (5)

Step 4: Boosting indicator scores to account for extreme values

The unadjusted score calculated above is similar to most other measures of central tendency statistics (eg averages) in that outlying values are de-emphasised. In assessments for framework purposes, this is not necessarily desirable as extreme values can be very important regardless of the distribution of other values. For example, if five measures for a pressure category are assigned 'negligible', 'negligible', 'low', 'low' and 'extreme' respectively, it is arguable that the presence of data indicating an extreme pressure value in the last measure should be recognised beyond its influence in an average statistic, which would have the final threat pressure score marginally above a low pressure.

There are a number of arithmetic methods for addressing this issue (Turpie et al. 2002 – cited in Clayton et al. 2006). Importantly for the assessment framework, the interest is in reducing the likelihood of scores that underestimate pressure and overestimate condition rather than the opposite. This is the 'precautionary principle' in practice and infers the need for a one-tailed correction or adjustment mechanism. Therefore, a boosted score has been incorporated into the assessment, which allows for a greater influence of the maximum value (the worst condition and greatest pressure) of indicators on aggregated condition scores.

Following is a worked example of using a boosted score method of an assessment for Coopers Swamp in the Murrumbidgee CMA region:

Catchment disturbance score = 2 (average raw scores)

= 2 = low pressure

Catchment disturbance boosted score = 3.5 ([average raw scores + max score]/ 2)

= 4 = high pressure

Coopers Swamp overall pressure score = 1.95 (average of all raw pressure scores)

= 2 = low pressure

Coopers Swamp overall boosted pressure score = 3.5 ([average of all raw pressure scores] + (max score)/ 2)

= 4 = high pressure

Coopers Swamp overall condition score = 3.26 (average of all raw condition scores)

= 3 = fair condition

Coopers Swamp overall boosted condition score = 4 ([average of all raw condition scores] + max score)/ 2)

= 4 = poor condition

Step 5: Conversion of scores into overall pressure and condition score for each CMA region

For each CMA region, a pressure and condition score was calculated by taking the average of the pressure or condition scores for all wetlands within a region. The final overall pressure or condition score was converted to an overall pressure or condition rating based on the 20th percentile thresholds in Table 5. A comparison of boosted and un-boosted scores for condition and pressure indicators in the Murrumbidgee region is presented in Table 6.

Table 6: Example – overall condition assessment for Murrumbidgee region

	Score	Boosted
Catchment disturbance	3	4
Hydrological disturbance	2	2
Habitat disturbance	2	4
Overall pressure	2	4
Biota	4	4
Biota – pest species	5	5
Water quality	1	1
Soil condition	No data	No data
Overall condition	5	5

4. Evaluation and reporting

4.1 Evaluation

Evaluating the change in status and trends of natural resource assets is required as part of SOC reporting. As this was the first assessment, thus providing a baseline for future assessments, it is not yet possible to assess trends in wetland extent or condition. Developing the framework to allow effective measurement of trends in wetland condition and extent over time, and evaluation of how well NSW is progressing towards state-wide NRM targets, requires further steps. These steps are outlined in the following section.

4.2 Reporting

Using the Hunter–Central Rivers CMA region as an example, the results of the NSW Wetlands MER program assessment of extent and condition (as per the methods in the previous section) are presented.

4.3 Wetland extent

The wetland extent, hydrological catchment area, type and location within the broader catchment management area are shown in Figure 4 and Table 7.

4.4 Wetland condition

Table 8 shows the overall condition assessment for the Hunter–Central Rivers CMA region, including boosted and un-boosted values for each pressure and condition indicator for which there were data available. Scores for each measure used to calculate the condition indices for each wetland in the CMA region are provided in Appendix 2. Full results for all CMA regions are supplied in Assessing the extent and condition of wetlands in NSW: Supporting report C – Assessment results for all regions.

Figure 4: Location and extent of wetlands assessed in the Hunter–Central Rivers CMA region

Table 7: Type, area of the wetland and area of the hydrological catchment of each wetland assessed in the Hunter–Central Rivers CMA region

Number	Site	Type	Area of wetland (km^2)	Area of hydrological catchment (km^2)
1	Barrington Top Swamps (16 swamps)	Upland bog or fen	1.77	28.65
2	Colongra Swamp	Coastal Rainfall/runoff Swamp	0.17	0.75
3	Ellalong Lagoon	Coastal Freshwater Lake	3.41	239.99
4	Hexham Swamp	Coastal Floodplain Swamp	28.49	148.87
5	Jewells Wetland	Coastal Heath Swamp	1.01	19.50
6	Myall Lakes Floodplain Swamp	Coastal Floodplain Swamp	9.68	20.37
7	Wyong Racecourse Wetlands	Coastal Rainfall/runoff Swamp	10.70	54.85
8	Cattai Wetlands	Coastal Floodplain Swamp	3.57	111.37
9	Eurunderee Lagoon	Coastal Dune Lake and Lagoon	9.59	21.33
10	Darawakh	Coastal Floodplain Swamp	1.70	20.37
11	Moffat's Swamp	Coastal Rainfall/runoff Swamp	6.42	41.50
12	Wentworth Swamp	Coastal Floodplain Swamp	5.76	189.55

Table 8: Overall condition assessment for Hunter–Central Rivers CMA region

	Not boosted		Boosted	
Catchment disturbance	2		3	
Hydrological disturbance	1		2	
Habitat disturbance	3		4	
Overall pressure	2	Low pressure	4	High pressure
Biota	No data		No data	
Biota – pest species	5		5	
Water quality	3		3	
Soil condition	No data		No data	
Overall condition	5	Very poor condition	5	Very poor condition

5. Key limitations

5.1 Site selection

The site selection was aimed at including all wetlands that had previously received institutional recognition, and at achieving equity among CMA regions with regards to the number of sites selected while limiting the total number of sites to a practical level. Consequently the selected sites may not even broadly be representative of the condition of wetlands in the CMA region. Also the number of sites in some catchments may not be adequate to generate reliable aggregated values, while in other catchments the number of sites selected may have exceeded what was required. It is currently not possible to assess whether continued assessment of the same sites will allow the detection of change in the condition of wetlands by 2015, or how much uncertainty will be associated with these assessments.

5.2 Data availability and consistency

The availability of quantitative data with state-wide coverage was a limiting factor when selecting indicators. Of all potential indicators identified, only a small number could be used. This also limited the ability to test the condition assessments with independent datasets.

5.3 Wetland extent and loss

The data used to determine wetland extent vary in resolution, temporally and in delineation methodologies. To successfully track wetland loss, a consistent method needs to be applied to all wetlands in the state.

5.4 Wetland state

The current assessment of wetland extent and condition assumes the wetlands assessed exist in a single state and are affected by different disturbances, which result in a change in wetland condition. Wetland ecosystems however are known to exist in different states (see Davis et al. 2003) and changes in states can be triggered by natural events or management actions. As such, if these triggers are known, opportunities for transition of the ecosystem into a desirable state and hazards for transition of an ecosystem into an undesirable state can be identified (Westoby et al. 1989).

The concept of multiple alternative states existing for one wetland ecosystem has been applied to shallow lake systems in WA (Davis et al. 2003). In this case different wetland states, characterised by dominant vegetation types, were identified to occur across salinity and nutrient ranges.

6. Development of a conceptual framework to guide broad-scale wetland condition assessment

The generation of the SOC reports was based on a conceptual framework and associated methods. However, due to severe data limitations and the lack of time and opportunities to collect new data, many of the benefits of this framework for broad scale assessment of wetland condition in NSW were not realised. This conceptual framework includes the identification of wetland types for NSW, the development of three types of conceptual models of wetland function, and recommended field methods. Full details of the framework are given in Assessing the extent and condition of wetlands in NSW: Supporting report A – Conceptual framework, and a summary of the main components are given below.

6.1 Wetland typology

There was a need to define types that were broad enough to include all inland wetlands across the state. Subsequently, a typology of lacustrine and palustrine wetlands was developed to facilitate the assessment of wetland condition in NSW for the MER program. At the same time the classification framework required the further splitting of types to reflect functional and morphological differences of local significance. After considering various options, the wetland classification framework developed by the QLD Department of Environment and Resource Management (QLD DERM 2011) was adopted. Key attributes for defining wetland types and the order of their application for typing wetlands (Table 9) were determined following a series of workshops in QLD and consultation of experts and representatives of CMAs across NSW.

Table 9: Attributes used for typing wetlands in NSW

Category	**Attribute**
Wetland system	Lacustrine Palustrine
Climate	Arid Semi-arid Subtropical Temperate inland Temperate upland Temperate coastal Alpine
Water source	River-fed (floodplain) Runoff/rainfall (non-floodplain – eg depressional)
Water regime	Frequently wet Periodically inundated
Water type	Fresh Saline
Vegetation	Forest/woodland Shrubland Grassland/sedgeland/herbs *Sphagnum*-dominated

NSW wetland types and the conceptual models they relate to are presented in Assessing the extent and condition of wetlands in NSW: Supporting report A – Conceptual framework, and are presented in Table 10. Code 1 identifies the broad wetland type indicating whether the wetland is palustrine or lacustrine, the climatic region it is located in, and the primary source of its water. For example, a palustrine wetland in the temperate coastal region would be classed as palustrine temperate coastal (PTC). Numbers are then given to denote whether the water source is groundwater (1), river (2) or rainfall/runoff (3). For example, a palustrine temperate coastal wetland fed by groundwater would be PTC 1. Code 2 provides greater resolution to the typology by incorporating information on water regime and vegetation/or types represented by a suffix (a-d) to Code 1. For example a lacustrine arid wetland, fed by saline groundwater, would be LA 1a.

As only a subset of value classes within each attribute are likely to be observed together in any one wetland, the number of unique wetland types is much smaller than the number of possible combination of value classes across attributes. For example an 'arid' 'sphagnum-dominated' wetland does not exist as a wetland community in NSW.

Where adequate information on the water regime vegetation/water types are not available to assign a Code 2, the wetland type will be indicated by Code 1 until observations can be completed to obtain the required information which in most cases would necessarily involve field work.

Table 10: NSW wetland types and corresponding conceptual models. The six categories are shown with their respective attributes and the corresponding conceptual models (these models provided in Assessing the extent and condition of wetlands in NSW: Supporting report A – Conceptual framework)

Climate	Type	Water source	Code 1	Water regime	Veg/water type	Code 2	Conceptual model
Arid	Palustrine	Groundwater	PA 1				GAB springs
		River-fed/ floodplain	PA 2	Periodically inundated	Sedgeland/ grassland	PA 2a	Inland floodplain swamp or Inland billabong
					Shrubland	PA 2b	
					Forest	PA 2c	
		Rainfall/runoff	PA 3				Inland rainfall/runoff swamp
	Lacustrine	Groundwater	LA 1		Saline	LA 1a	Inland saline lake
					Fresh	LA 1b	Inland freshwater lake
		River-fed/ floodplain	LA 2	Periodically inundated	Fresh	LA 2a	
		Rainfall/runoff	LA 3	Periodically inundated	Saline	LA 3a	Inland saline lake

Climate	Type	Water source	Code 1	Water regime	Veg/water type	Code 2	Conceptual model
					Fresh	LA 3b	Inland freshwater lake
Semi-arid	Palustrine	Groundwater	PSA 1				
		River-fed/ floodplain	PSA 2	Permanently wet		PSA 2a	Inland billabong
				Periodically inundated	Sedgeland/ grassland	PSA 2b	Inland floodplain swamp or Inland billabong
					Shrubland	PSA 2c	
					Forest	PSA 2d	
		Rainfall/runoff	PSA 3				Inland rainfall/runoff swamp
	Lacustrine	Groundwater	LSA 1		Fresh	LSA 1a	Inland freshwater lake
		River-fed/ floodplain	LSA 2	Permanently wet	Fresh	LSA 2a	
				Periodically inundated	Fresh	LSA 2b	
		Rainfall/runoff	LSA 3	Periodically inundated	Fresh	LSA 3a	
Temperate Inland	Palustrine	Groundwater	PTI 1				
		River-fed/ floodplain	PTI 2	Permanently wet		PTI 2a	Inland billabong
				Periodically inundated	Sedgeland/ grassland/ herbs	PTI 2b	Inland floodplain swamp or Inland billabong
					Shrubland	PTI 2c	
					Forest	PTI 2d	
		Rainfall/ runoff	PTI 3				Inland rainfall/runoff swamp
	Lacustrine	Groundwater	LTI 1				Inland freshwater lake
		River-fed/ floodplain	LTI 2	Permanently wet	Fresh	LTI 2a	

Climate	Type	Water source	Code 1	Water regime	Veg/water type	Code 2	Conceptual model
				Periodically inundated	Fresh	LTI 2b	
		Rainfall/runoff	LTI 3	Periodically inundated	Fresh	LTI 3a	
Temperate Coastal	Palustrine	Groundwater	PTC 1				Coastal dune swamp or Coastal heath swamp
		River-fed/ floodplain	PTC 2	Permanently wet	Sedgeland/ grassland/ herbs	PTC 2a	Coastal floodplain swamp
				Periodically inundated	Sedgeland/ grassland/ herbs	PTC 2b	
					Shrubland	PTC 2c	
					Forest	PTC 2d	
		Rainfall/runoff	PTC 3	Permanently wet	Sedgeland/ grassland/ herbs	PTC 3a	Coastal rainfall/runoff swamp or Coastal dune swamp or Coastal heath swamp
				Periodically inundated	Sedgeland/ grassland/ herbs	PTC 3b	
	Lacustrine	Groundwater	LTC 1				Coastal dune lake and lagoon or Coastal freshwater lake
		River-fed/ floodplain	LTC 2	Permanently wet	Fresh	LTC 2a	
				Periodically inundated	Fresh	LTC 2b	
		Rainfall/runoff	LTC 3	Permanently wet	Fresh	LTC 3a	
				Periodically inundated	Fresh	LTC 3b	
Temperate Upland (700–1800 m)	Palustrine	Groundwater	PTU 1				Upland hanging swamp or Upland bog or fen
		Rainfall/runoff	PTU 3	Permanently wet	Sedgeland/ grassland/ herbs	PTU 3a	
				Periodically inundated	Sphagnum	PTU 3b	Upland bog or fen

Climate	Type	Water source	Code 1	Water regime	Veg/water type	Code 2	Conceptual model
	Lacustrine	Groundwater	LTU 1				Upland freshwater lake
		River-fed/ floodplain	LTU 2	Permanently wet	Fresh	LTU 2a	
				Periodically inundated	Fresh	LTU 2b	
		Rainfall/runoff	LTU 3	Periodically inundated	Fresh	LTU 3a	
Alpine (>1800 m)	Palustrine	Groundwater	PAL 1				Alpine bog or fen
		Rainfall/runoff	PAL 3	Permanently wet	Sedgeland/ grassland/ herbs	PAL 3a	
				Periodically inundated	Sphagnum	PAL 3b	
	Lacustrine	Groundwater	LAL 1				Alpine glacial lake
		Rainfall/runoff	LAL 3	Permanently wet	Fresh	LAL 3a	

6.2 Conceptual models of ecosystem function for wetland types

The conceptual models of wetland function were developed in collaboration with QLD DERM, scientific experts and stakeholders, through a series of workshops to align the models with the wetland types identified in the NSW Wetlands MER program.

The conceptual models of wetland types attempt to provide a representation of the knowledge of the functioning of wetlands that is relevant to NRM. They integrate the current understanding of ecosystem dynamics, identify critical functional processes and threats, and illustrate connections between indicators and ecological processes (Gross 2003). Models can be used as a basis for discussion or planning (Roman & Barret 1999), and help identify gaps in knowledge and prioritise areas that require further research or monitoring. Conceptual models can be presented in many forms such as diagrams, tables and flow-charts and may have accompanying narratives or contextual information.

A well-constructed conceptual model provides a scientific framework for a monitoring program and justification for the choice of indicators (Gross 2003). In the case of a multi-stakeholder monitoring program such as the NSW MER program, a conceptual model can also provide a forum for stakeholders to reach a common understanding of the system that is being investigated (Hierl et al. 2007).

The NSW Wetlands MER program uses a combination of two types of wetland conceptual models: control models and stressor models.

Control models conceptualise the actual influences, feedbacks and interactions responsible for system dynamics (Gross 2003). This type of model can help crystallise users' understanding of the way in which systems operate, including linkages among the different ecosystem components.

Stressor models can be used to communicate the relationship between pressures, ecosystem components, effects and indicators (Gross 2003). The purpose of this type of model is to illustrate the key sources of stress on a system, along with the ecological responses of that system (and in some cases how responses can be monitored). A pressure is the activity (anthropogenic or natural) that causes a change to the stressor. The ecosystem response and condition is how the ecosystem responds to the change in the stressor. A stressor is identified as something that when changed directly affects the wetland. The indicators are measures of either ecosystem condition, or measures of the pressures on the ecosystem, that may help to assess the condition of and pressure to a wetland.

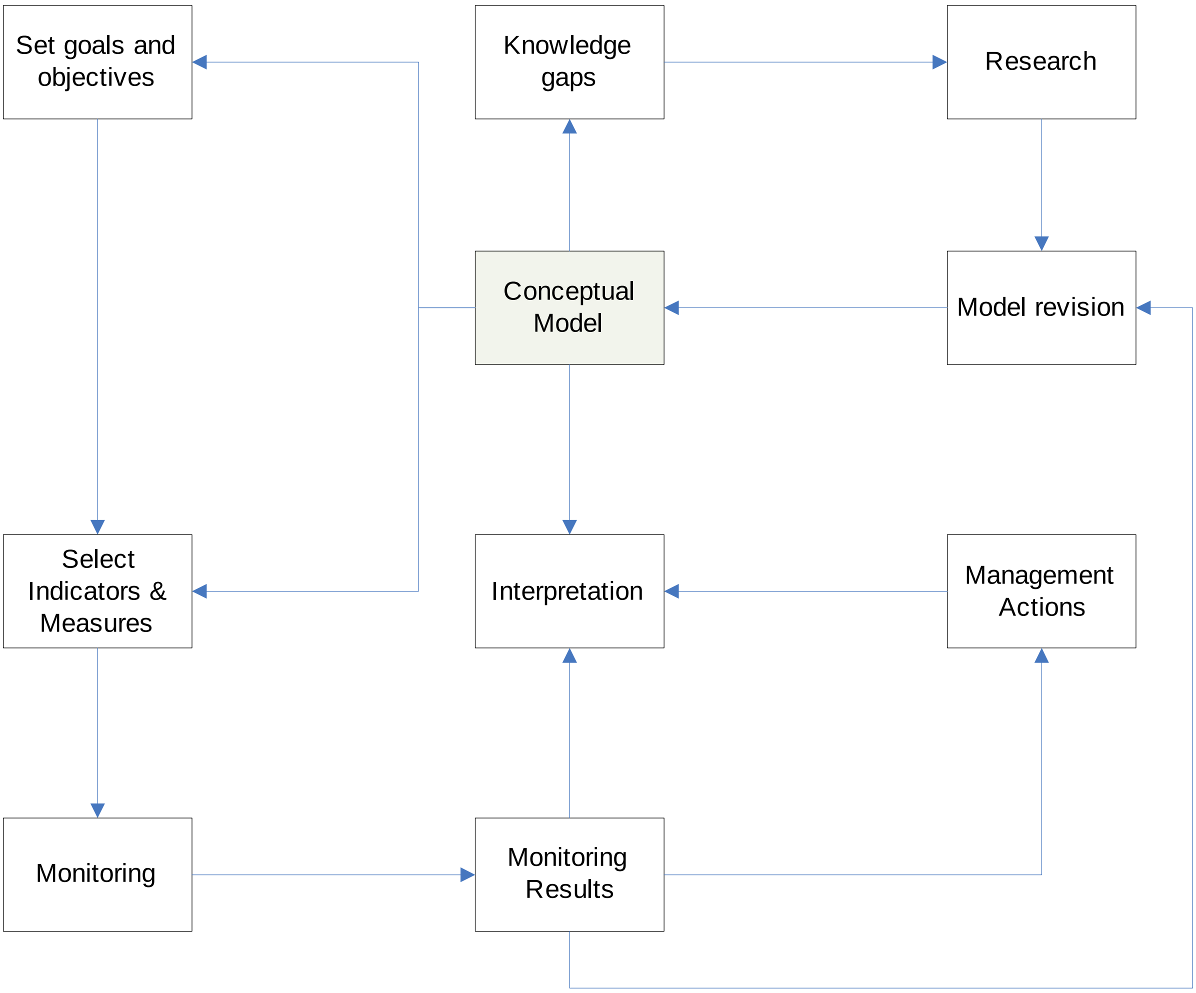


Figure 5: Linkages between conceptual models and the wider monitoring program (adapted from Fischenich 2008)

Conceptual models developed as part of the NSW wetlands MER program were used to:

- identify key links between drivers, stressors, and system responses
- identify an understanding of how the processes, threats and system dynamics differ between wetland types (and climatic regions)

- facilitate selection and justification of indicators
- simplify complex environmental systems.

The conceptual models may be used in future MER assessments to:

- help interpret monitoring data (specific to different wetland types) and identify acceptable levels of change
- communicate results to CMAs and other technical and non-technical audiences
- highlight knowledge gaps
- inform the development of quantitative, predictive models which relate pressure indicators to condition.

A workshop was held with regional CMAs to identify ways in which they envisage using the conceptual models. The main regional uses identified from this workshop were:

- as a tool for justifying monitoring and on-ground works within the CMA region (to the Board, managers etc.), by other natural resource managers and local councils
- to identify knowledge gaps relating to wetland systems within a CMA region, which may help to prioritise research or funding allocations
- to show linkages between state-wide programs and CMA activities
- for education of the wider community, local councils and CMA staff
- to guide management actions, and to act as a supplement to numerical models to assess project benefits and impacts
- to show where endangered ecological communities (EECs) and threatened species may reside by identifying ecosystem processes which support them
- to help interpret the catchment report cards produced by state themes under MER.

Three groups of conceptual models were developed as part of the NSW Wetlands MER program; these included wetland type models, disturbance and stressor models and dry-phase models.

6.2.1 Wetland type models

For each wetland type, the following conceptual models have been developed:

- A flowchart, describing the ecosystem drivers and physiological/biological features that result in these habitat components, links between ecosystem drivers and other systems are also included (eg influences of riverine systems on floodplain wetlands)
- A flowchart describing the ecosystem drivers and habitat components
- A conceptual diagram where ecosystem processes are related to ecosystem response. In addition each diagram shows the key pressures for the wetland type (eg agriculture, point sources) with the stressors they influence (eg pest species, nutrients).

Some particularly dynamic wetland types (eg inland floodplain swamps) include several conceptual diagrams to describe the different phases of the wetland system (eg wet, drying, dry).

6.2.2 Disturbance and stressor models

Three overarching disturbance indicators were identified as important to NSW wetlands in general. These were:

- catchment disturbance
- hydrological disturbance
- habitat disturbance.

For each disturbance, a conceptual diagram was developed to identify and communicate important pressures on the wetland ecosystem and ecosystem responses. Pressures identified as important to NSW wetlands were:

- climate change
- urbanisation
- infrastructure
- clearing
- grazing
- agriculture
- recreation
- barriers to fish passage
- rainfall/runoff diversion
- surface and groundwater extraction
- river regulation
- point sources
- fire.

Stressors, which can impact on the ecosystem when influenced by pressures, were identified in the conceptual diagram for each disturbance group. These included:

- sediment
- nutrients
- salinity
- pH
- pest species.

Finally, the pressures identified in the conceptual diagram for the disturbance group were used to relate pressures to their effects, the subsequent ecosystem response and resulting changes in condition, in a flowchart. These changes in condition informed selection of appropriate indicators for each disturbance group.

6.2.3 Dry-phase models

Wetlands are dynamic ecosystems that experience wetting and drying cycles over different temporal scales. A wetland can have very different characteristics, and consequently require different indicators when dry, particularly if the period between inundation periods is long. For example, during a wet-phase indicators may include fish, aquatic vegetation and water quality. The absence of these parameters during a dry-phase would not necessarily mean that the ecosystem is in poor health; rather, it may simply be an artifact of the lack of water.

While it is preferable and easier to assess condition of wetland ecosystems in their wet phase, there may be opportunities to monitor indicators of condition of dry wetlands and the potential of the ecosystem to support healthy wetland habitat when inundation occurs. For example, diversity of biotic propagules (the resting stages of animals and plants) in dry wetland soils has been identified as an indicator of wetland salinity (Skinner et al. 2001).

As such, a conceptual diagram and flowchart was developed to outline important ecosystem processes operating in the dry wetland system, and to select potential indicators to monitor them.

6.3 Potential methods for collection of data to be used in condition assessments

Methods for collecting physical and biological data from NSW wetlands were developed (see Assessing the extent and condition of wetlands in NSW: Supporting report A – Conceptual framework). They are designed to complement the NSW Wetlands MER program by enabling state agencies, catchment managers or local councils to collect standardised, relevant information about wetlands which can be integrated into future condition assessments. In addition, field methods may be used by CMAs, local councils or interest groups to collect information about specific wetlands or for a specific purpose. The field methods do not provide information about how the data may be used to inform condition assessments.

7. Further development of the conceptual framework and practical steps for SOC reporting

The baseline data, the condition and pressure scores calculated for CMA regions and the state, and the conceptual framework developed for the first SOC reports represent substantial progress towards the assessment of lacustrine and palustrine wetlands at broad spatial scales in NSW. However, there are still some important gaps that need to be addressed and practical steps to be taken. The conceptual framework needs to be expanded beyond representing individual wetlands, and should include quantification of the amount of change that can be detected within each reporting period and within 10-year planning intervals, together with the uncertainty associated with the detected changes. Some of the steps recommended for the development of the next SOC reports in relation to the wetlands target in NSW are described below.

7.1 Placing individual wetlands in a landscape context: modelling of disparate observations using spatially continuous remote sensing data

Reporting against state-wide targets requires wetland assessments to be undertaken at large spatial scales. The wetland assessment methods developed for the first SOC reports focused on assessing individual wetlands with heavy reliance on field collected data. There is a need to further develop the conceptual framework of wetland assessments for two main reasons:

1. The lack of field collected data is likely to continue to be a major problem for wetlands as there are no apparent funding sources for large-scale field collections of data in wetlands across NSW in the foreseeable future.
2. Valid and reliable assessments of trends in wetland condition (which ideally would also provide meaningful assessments for trends in the condition for individual wetlands) require methods of site selection (including the number of sites selected) and aggregation to be adjusted to the magnitude of change to be detected and the precision needed. A possible solution lies in the effective use of remote sensing data in two major ways:
   a) Characterisation of measured attributes (eg hydrology, land-use, topography) of wetlands across various spatial scales and at given time intervals
   b) Modelling of attributes observed on the ground at a small number of locations (eg biodiversity, water quality) to generate spatially continuous layers based on remotely derived predictor variables.

Modelling methods exist, which may enable the generation of condition assessments for wetlands using patchy biological data (which were collected for a wide variety of purposes using a variety of methods and at varying time intervals). One such method is Generalized Dissimilarity Modelling (GDM) (Ferrier et al. 2007) which allows mapping of compositional turnover of biological assemblages over large areas, and the derivation of predicted condition measures for biota at any give location based on remotely derived environmental data and disturbance assessments. In this way, the best use of existing state datasets (eg NSW Atlas of Wildlife, Yeti database) can be made where the potential for field work is limited.

7.2 Tracking wetland loss

Further refining of wetland extent state-wide and developing techniques to track wetland loss over time should be continued. Methods to delineate wetlands at the state level have been developed for NSW and QLD (Turak et al. 2011b; Kingsford et al. 2004; QLD DERM 2010) and remote sensing techniques have been used to measure wetland loss over a 23-year period in Lower Murrumbidgee (Kingsford & Thomas 2002). Methods developed to track wetland loss need to be sensitive enough to separate wetland loss through hydrological or habitat modification from seasonal and other cyclical variations in their inundation extent (ie in floodplain wetlands), and to detect wetland loss through emerging threats (ie loss of freshwater wetlands due to climate change related sea-level rise). Emerging methods and technologies (eg LiDAR, Synthetic Aperture Radar, high resolution satellite imagery) are being reviewed by OEH for their potential to track change in wetland extent at a state-wide level.

7.3 Data collection for additional indicators

Many of the indicators proposed under the conceptual framework could not be used, as data were not available. Further methods recommended were limited to visual observations of physical attributes of wetlands and structural attributes of wetland biological communities without comparable quantitative observations. Compiling or collection of data for these indicators should be considered as part of the further development to the MER strategy for wetlands.

7.3.1 Proposed indicators for which no data were available

During the MER program, a number of indicators were reviewed for their potential as pressure and condition indicators. However, due to lack of data, many of these were not used in the current assessment. Potential indicators are discussed in Assessing the extent and condition of wetlands in NSW: Supporting report B – Development of a condition assessment index; field methods for collecting data to inform some of the proposed indicators are outlined in Assessing the extent and condition of wetlands in NSW: Supporting report A – Conceptual framework.

7.3.2 Macroinvertebrates

Aquatic invertebrates can be useful in biological monitoring of lacustrine and palustrine wetlands (Baldwin et al. 2005; US EPA 2002) as they occupy various levels position in wetland food webs, are often abundant and ubiquitous, and display a great range of responses pollutants and other stressors. However, to use them successfully for this purpose there is a need to overcome difficulties associated with their high spatial variability, and the expertise and time needed for taxonomy and identification (Baldwin et al. 2005). A preliminary protocol for collecting state-wide wetland macroinvertebrate data for use in wetland condition assessment has been prepared by OEH.

7.3.3 Frogs

Frogs have a varied lifecycle involving dependence on several different aspects of an environment (ie their semi-permeable skin makes them sensitive to pollutants, they are dependent on a broad range of food sources, and they generally have small geographic ranges) (Wake & Vredenburg 2008). The larvae of most species are fully aquatic and can be sensitive to water pollution and changed regimes (De John Westman et al. 2010). The status of frog communities in NSW is therefore of interest as a possible indicator of wetland health. A preliminary protocol for collecting state-wide wetland frog data, for use in wetland condition assessment, has been prepared by OEH.

7.4 Linking management actions with wetland assessment

7.4.1 Incorporating management actions into conceptual models

The conceptual disturbance and stressor conceptual models developed for the NSW Wetlands MER program (see Assessing the extent and condition of wetlands in NSW: Supporting report A – Conceptual framework) used expert knowledge to link management action to different pressures under the three disturbances: catchment disturbance, hydrological disturbance and habitat disturbance. As these models are non-quantitative, the relationship between management actions and change in wetland condition cannot be determined. However, emerging techniques are using conceptual models to generate quantitative outputs for management actions. For example, state-and-transition models have been used with Bayesian networks to quantitatively predict the probability of transition of vegetation into alternative states as a result of a variety of management actions (Rumpff et al. 2011).

7.4.2 Predicting management influence on biodiversity condition, the whole landscape framework

New methods for making quantitative estimates of the biodiversity benefits or losses of alternative management scenarios on biodiversity condition across large landscapes are in development by OEH and have been trialled in the Hunter–Central Rivers and Murrumbidgee CMA regions (Turak et al. 2011). These methods involve establishing a relationship between environmental and disturbance variables and biodiversity condition, based on quantitative biotic data from different wetland taxa. Management actions are then related to quantifiable changes in disturbance variables and these relationships can be used to test impacts of management actions on biodiversity at a range of spatial scales. In addition to alternative management scenarios, the impacts of large-scale changes such as climate change and hydrological disturbance on biodiversity at a regional or state-wide scale can be assessed.

8. References

Baldwin DS, Nielsen DL, Bowen PM & Williams J 2005, *Recommended Methods for Monitoring Floodplains and Wetlands*, MDBC Publication No. 72/04.

Clarkson BR, Sorrell BK, Reeves PN, Champion PD, Partridge TR & Clarkson BD 2004, *Handbook for monitoring wetland condition,* Coordinated monitoring of New Zealand wetlands.

Conrick D 2007, *Scoping Study for Monitoring Wetland Extent and Condition,* QLD Department of Natural Resources and Water.

Cowardin LM, Carter V, Golet FC & LaRoe ET 1979, *Classification of the wetlands and deepwater habitats of the United States,* US Department of the Interior, Fish and Wildlife Service, Washington DC.

Davis J, McGuire M, Halse SA, Hamilton D, Horwitz P 2003, 'What happens when you add salt: predicting impacts of secondary salinisation on shallow aquatic ecosystems by using an alternative-states model', *Australian Journal of Botany,* vol. 51, pp. 715–724.

DECCW 2010, New South Wales Natural Resource Monitoring. Evaluation and Reporting Strategy 2010–2015, NSW Department of Environment, Climate Change and Water.

De John Westman A, Elliot J, Kim C, Van Aggelen G & Bishop CA 2010, 'Effects of environmentally relevant concentrations of endosulfan, azinphosmethyl, and diazinon on Great Basin Spadefoot (*Spea intermontana*) and Pacific Treefrog (*Pseudacris regilla*)', *Environmental Toxicology and Chemistry*, vol. 29, no. 7, pp. 1604–1612.

ESRI 2006, ArcGIS 9.2 software, ESRI, US.

Fennessy MS, AD Jacobs & ME Kentula 2004, *Review of Rapid Methods for Assessing Wetland Condition EPA/620/R-04/009,* US Environmental Protection Agency, Washington DC.

Ferrier S, Manion G, Elith J & Richardson K 2007, 'Using generalised dissimilarity modelling to analyse and predict patterns of beta-diversity in regional biodiversity assessment', *Diversity and Distributions,* vol. 13, pp. 252–264.

Fischenich JC 2008, 'The Application of Conceptual Models to Ecosystem Restoration', *Ecosystem Management and Restoration Research Program Report,* ERDC/EBA TN-08-1.

Gross JE 2003, *Developing Conceptual Models for Monitoring Programs*, US National Park Service Discussion Paper [http://science.nature.nps.gov/im/monitor/ConceptualModels.cfm].

Hierl LA, Franklin J, Deutschman DH & Regan HM 2007, *Developing Conceptual Models to Improve the Biological Monitoring Plan for San Diego's Multiple Species Conservation Program,* report for California Department of Fish and Game.

Kingsford RT, Brandis K, Thomas R, Crighton P, Knowles E & Gale E 2004, 'Classifying landform at broad spatial scales: the distribution and conservation of wetlands in New South Wales, Australia', *Marine and Freshwater Research,* vol. 55, pp. 17–31.

Kingsford RT & Thomas RF 2002, 'Use of satellite image analysis to track wetland loss on the Murrumbidgee River floodplain in arid Australia, 1975–1998', *Water Science and Technology,* vol. 45, no. 11, pp. 45–53.

NLWRA 2007, *Assessment of data requirements and availability to address natural resource condition and trend indicators; Part A: Project Report,* National Land and Water Resources Audit, Canberra.

NSW Government 2006, *NSW State Plan Chapter 6: Environment for living,* Premier's Department, Sydney, viewed 9 May 2011 [www.stateplan.nsw.gov.au/sites/default/files/pdf/Chapter6_Environment_for_Living2006.pdf] .

OEH 2011, State of Catchment reports online, Office of Environment and Heritage, Sydney, viewed 9 May 2011 [www.environment.nsw.gov.au/soc/stateofthecatchmentsreport.htm]

Papas P & Holmes J 2005, *Index of Wetland Condition: Conceptual Framework and Selection of Measures,* Department of Sustainability and Environment, Victoria.

QLD DERM 2010, *Queensland Wetland Definition and Delineation Guideline,* Queensland Government, Brisbane [www.epa.qld.gov.au/wetlandinfo/site/WetlandDefinitionstart/WetlandDefinitions/definitionguide.html].

QLD DERM 2011, *Wetland info Lacustrine and Palustrine typology,* QLD Department of Environment and Resource Management, viewed 9 May 2011 [www.epa.qld.gov.au/wetlandinfo/site/WetlandDefinitionstart/WetlandDefinitions/Typologyintro/Typology.htm].

Roman CT & Barrett NE 1999, *Conceptual Framework for the Development of Long-term Monitoring Protocols at Cape Cod National Seashore*, USGS Patuxent Wildlife Research Centre, Cooperative National Park Studies Unit, University of Rhode Island.

Rumpff L, Duncan DH, Vesk PA, Keith DA & Wintle BA 2011, 'State-and-transition modelling for Adaptive Management of native woodlands', *Biological Conservation,* vol. 144, no. 4, pp. 1244–1235.

Sainty GR & Jacobs SWL 1997, *Hawkesbury–Nepean wetland assessment*, Hawkesbury–Nepean Catchment Management Trust, Sydney.

Scheltinga DM & Moss A 2007, *A framework for assessing the health of coastal water: a trial of the national set of estuarine, coastal and marine indicators in Queensland*, draft final report, Queensland EPA.

Skinner R, Sheldon F & Walker KF 2001, 'Propagules in dry wetland sediments as indicators of ecological health: effects of salinity', *Regulated Rivers: Research and Management,* vol. 17, pp. 191–197.

Spencer C, Robertson AI & Curtis A 1998, 'Development and testing of a rapid appraisal wetland condition index in south-eastern Australia', *Journal of environmental management,* vol. 54, no. 2, pp.143–159.

Turak E, Ferrier S, Barrett T, Mesley E, Drielsma M, Manion G, Doyle G, Stein J & Gordon G 2011a, 'Planning for persistence of river biodiversity: exploring alternative futures using process-based models', *Freshwater Biology*, vol. 56, pp. 39–56.

Turak E, Melrose R, Islam T, Imgraben S & Blakey R 2011b, *Testing the Framework for the Assessment of River and Wetland Health (FARWH) in New South Wales wetlands,* Milestone 5 Final Report, DECCW for the Australian National Water Commission.

US EPA 2002, *Methods for Evaluating Wetland Condition: Introduction to Wetland Biological Assessment,* Office of Water, US Environmental Protection Agency, Washington, DC.

Wake DB & Vredenburg VT 2008, 'Are we in the midst of a sixth mass extinction? A view from the world of amphibians', *Proceedings of the National Academy of Sciences of the United States of America,* vol. 105(SUPPL. 1), pp. 11466–11473.

Wang W & Yin C 2008, 'The boundary filtration effect of reed-dominated ecotones under water level fluctuations', *Wetlands Ecology and Management*, vol. 16, pp. 65–76.

Appendix 1: **List of final sites selected for the NSW Wetlands MER program**

CMA region	Number	Site	Ramsar	DIWA	DIWA Code
Border Rivers–Gwydir	1	Gwydir Wetlands	yes	yes	NSW008
	2	Boobera Lagoon		yes	NSW095
	3	Pungbougal Lagoon		yes	NSW095
	4	Mother of Ducks Lagoon (New England Wetland)		yes	NSW023
	5	Racecourse Lagoon (New England Wetland)		yes	NSW023
	6	Barbers Lagoon			
	7	Baroona Billabong			
	8	Clarevaux Lagoon			
	9	Crooked Lagoon			
	10	Gooroo Lagoon			
	11	Kettleys Waterhole			
	12	Lake Tullimba			
	13	Little Bumble Lagoon			
	14	Maynes (Yarrangooran) Lagoon			
	15	Rocky Dam			
	16	Second Lagoon			
	17	Woondoona Lagoon			
Central West	1	Macquarie Marshes	yes	yes	NSW009
	2	Buckinguy Swamp			
	3	Cudgegong Lagoon			
	4	Goolgotha Lake			
	5	JC Walker Reservoir			
	6	Meryon Cowal			
	7	Moonachie Cowal			
	8	Oberon Wetlands			
	9	Old Harbour Lagoon			
	10	Rylstone Dam			
	11	Spring Creek Lagoon			
	12	Windmill Creek Lagoon			
Hawkesbury–Nepean	1	Blue Mountains Swamps (six swamps)		yes	NSW072
		Asgard Swamp			
		Cedar Head Swamp			
		Corral Swamp			
		Glenraphael Swamp			
		Notts Swamp			
		Sassafras Swamp			
	2	Boyd Plateau Bogs (10 swamps)		yes	NSW074
		Belarah Swamp			
		Boyd Hill Swamp			
		Dingo Swamp			
		Jensens Swamp			
		Little Dingo Swamp			

CMA region	Number	Site	Ramsar	DIWA	DIWA Code
		Little Morong Bog			
		Morong Swamp			
		Mumbedah Swamp			
		Roly Whalans Swamp			
		Wheengee Whungee Swamp			
	3	Lake Bathurst		yes	NSW066
	4	The Morass		yes	NSW066
	5	Longneck Lagoon		yes	NSW083
	6	Paddys River Swamps (four swamps)		yes	NSW082
		Hanging Rock Swamp			
		Long Swamp			
		Mundego Swamp			
		Stringray Swamp			
	7	Pitt Town Lagoon		Yes	NSW087
	8	Thirlmere Lakes (five lakes)		Yes	NSW091
		Baraba Lake			
		Couridjah Lake			
		Gandangarra Lake			
		Nerrigorang Lake			
		Werri-Berri Lake			
	9	Wingecarribee Swamp		Yes	NSW093
Hunter–Central Rivers	1	Barrington Top swamps (11 swamps)		yes	NSW025
		Black Swamp			
		Bobs Swamp			
		Brumlow Swamp			
		Burraga Swamp			
		Edwards Swamp			
		Horse Swamp			
		Kerripit Swamp			
		Little Murray Swamp			
		Polblue Swamp			
		Saxby Swamp			
		Upper Polblue Swamp			
	2	Colongra Swamp		Yes	NSW134
	3	Ellalong Lagoon		yes	NSW136
	4	Hexham Swamp		yes	NSW138
	5	Jewells Wetland		Yes	NSW183
	6	Myall Lakes Floodplain Swamps		yes	NSW033
	7	Wyong Racecourse Wetlands		yes	NSW143
	8	Cattai Wetlands			
	9	Eurunderee Lagoon			
	10	Darawahk Swamp			
	11	Moffat’s Swamp			
	12	Wentworth Swamp			

CMA region	Number	Site	Ramsar	DIWA	DIWA Code
Lachlan	1	Booligal Wetlands		yes	NSW043
	2	Cuba Dam		yes	NSW044
	3	Great Cumbung Swamp		yes	NSW045
	4	Lachlan Swamps		yes	NSW047
	5	Lake Brewster		yes	NSW048
	6	Lake Cowal		yes	NSW040
	7	Wilbertroy Wetlands		yes	NSW040
	8	Lake Merrimajeel		yes	NSW049
	9	Murrumbidgil Swamp		yes	NSW049
	10	Merrowie Creek			NSW051
	11	Lake Cargelligo			
	12	Robsar Lagoon			
	13	Wilga Lagoon			
Lower Murray Darling	1	Darling Anabranch Lakes (nine lakes) Little Lake Milkengay Lake Mindona Lake Nearie Lake Nialia Lake Popiltah Lake Popio Lake Travellers Lake Yelta Lake		yes	NSW020
	2	Menindee Lakes (nine lakes) Lake Bijijie Lake Cawndilla Lake Copi Hollow Lake Pamamaroo Lake Menindee Lake Spectacle Lake Speculation Lake Tandure Lake Wetherall		yes	NSW010
	3	Dry Lake			
	4	Gol Gol Lake			
	5	Gol Gol Swamp			
	6	Lake Benanee			
	7	Lake Caringay			
	8	Lake Victoria			
	9	Pomona Wetland			
	10	Purda Billabong and Pink Lake			
	11	Neilpo Station Wetlands			
	12	Thegoa Lagoon			
	13	Wombalano Wetland			

CMA region	Number	Site	Ramsar	DIWA	DIWA Code
Murrumbidgee	1	Big Badja swamp		yes	NSW063
	2	Black Swamp		yes	NSW042
	3	Coopers Swamp 2		yes	NSW042
	4	Coopers Swamp		yes	NSW064
	5	Dudal Corner Swamp (Doodle Corner Swamp)		yes	NSW113
	6	Fivebough Swamp	yes	yes	NSW15
	7	Lake George		yes	NSW067
	8	Lowbidgee Floodplain		yes	NSW021
	9	Lower Mirrool Creek Floodplain		yes	NSW050
	10	Micalong Swamp		yes	NSW068
	11	Monaro Lakes (four lakes)		yes	NSW069
		Killmacoola Lake			
		Long Lake			
		O'Neils Lake			
		Muddah Lake			
	12	Tuckerbil Swamp	yes	yes	NSW054
	13	Tomneys Plain		yes	NSW131
	14	Yaouk Swamp		yes	NSW070
	15	Bulgari Lagoon			
	16	Coononcoocabil Lagoon			
	17	Currawananna Lagoon			
	18	Darlington Lagoon			
	19	Flowerdale Lagoon			
	20	Gobbagombalin Lagoon			
	21	Kelvin Grove Lagoon			
	22	McKennas Lagoon			
	23	Mundowney Lagoon			
	24	Riverslie Lagoon			
	25	Sheepwash Lagoon			
Murray	1	Koondrook and Pericoota Forests		yes	NSW046
	2	Kosciusko Alpine Lakes (four lakes)		yes	NSW002
		Khancoban Lake			
		Lake Albina			
		Lake Cootapatamba			
		Murray 2 Pondage			
	3	Millewa Forest		yes	NSW053
	4	Werai Forest		yes	NSW056
	5	Wakool – Tullakool Evaporation Basins		yes	NSW055
	6	Walla Walla Swamp (Gum Swamp)		yes	NSW114
	7	Back Creek Lagoon			
	8	Cooks Lagoon			
	9	Jingera Jingera Lagoon			
	10	Kensal Green Lagoon			
	11	Mayfield Lagoon			
	12	Mooloomoon Lagoon			

CMA region	Number	Site	Ramsar	DIWA	DIWA Code
	13	Mungabarina Lagoon			
	14	Normans Lagoon			
	15	North Dale Lagoon			
	16	Quatta Quatta Lagoon			
	17	Sheep Dip Lagoon			
	18	Smiths Lagoon			
	19	Snake Island Lagoon			
	20	Woorooma Lagoon			
Namoi	1	Goran Lake		yes	NSW005
	2	Goran Swamp			
	3	Eulah Lagoon			
	4	Euromlin Lagoon			
	5	Gidgin Lagoon			
	6	Gulligal Lagoon			
	7	Gunnible Lagoon			
	8	Illaroo Creek Swamp			
	9	Landry Lagoon			
	10	The Lagoons			
	11	Narrabri Lagoon			
	12	Reedy Lagoon			
	13	Round Swamp			
	14	Wigelroy Lagoon			
	15	Yarrie Lake			
Northern Rivers	1	Barley Fields Lagoon (New England Wetland)		yes	NSW023
	2	Belmore Swamp/Swan Pool		yes	NSW035
	3	Bundjalung National Park Swamps		yes	NSW026
	4	Bunyip Swamp		yes	NSW186
	5	Cowans Pond Reserve		yes	NSW107
	6	Dangars Lagoon (New England Wetland)		yes	NSW023
	7	Dumaresq Dam (New England Wetland)		yes	NSW023
	8	Everlasting Swamp, Little Broadwater and Imesons Swamp		yes	NSW030
	9	Lake Hiawatha and Minnie Water		yes	NSW031
	10	Little Llangothlin Lagoon	yes	yes	NSW022
	11	Lower Bungawalbin Wetland Complex		yes	NSW184
	12	Round Mountain Swamps (10 swamps)		yes	NSW024
		Back Creek Swamp			
		Billy Point Creek Swamp			
		Dunolly Swamp			
		Emu Swamp			
		Guy Fawkes Swamp			
		Oaky River Swamp			
		Round Mountain Swamp			
		Sandy Creek Swamp			
		Scotchman Swamp			

CMA region	Number	Site	Ramsar	DIWA	DIWA Code
		Snipe Swamp			
	13	Tuckean Swamp		yes	NSW185
	14	Upper Coldstream		yes	NSW037
Southern Rivers	1	Beercroft Peninsula (three swamps)		yes	NSW176
		Cabbage Tree Swamp			
		Currarong Creek Swamp			
		Millers Creek Swamp			
	2	Bega Swamp		yes	NSW062
	3	Blue Lake	yes	yes	NSW001
	4	Budderoo National Park and Barren Grounds Nature Reserve Heath Swamps		yes	NSW075
	5	Coomaditchy Lagoon		yes	NSW135
	6	Coomonderry Swamp		yes	NSW076
	7	Jacksons Bog		yes	NSW065
	8	Killalea Lagoon		yes	NSW079
	9	Kosciusko Lakes (two lakes)		yes	NSW002
		Club Lake			
		Hedley Lake			
	10	Lagoon Head		yes	NSW173
	11	Monaro Lakes (11 lakes)		yes	NSW069
		Avon Lake			
		Black Lake			
		Buckleys Lake			
		Burns Lake			
		Coopers Lake			
		Cootralantra Lake			
		Green Lake			
		Kiah Lake			
		Lake Bullenbalong			
		Lake Jillamatong			
		Maffra Lake			
	12	Nunnock Swamp		yes	NSW129
	13	Packers Swamp		yes	NSW130
	14	Nadgee Tributary Wetlands			NSW187
	15	Panboola Swamp (Pambula River)			NSW122
	16	Waldrons Swamp			NSW125
	17	Old Man Bed Swamp			
	18	Pedro Swamp			
Sydney Metropolitan	1	Botany Wetlands and Mill Stream		yes	NSW073
	2	O'Hares Creek Catchment (five swamps)		yes	NSW086
		Abondoned Quarry Swamp			
		Dahlia Lagoon			
		Flat Rock Swamp			
		Illuka Creek Swamp			
		Stokes Creek Swamp			

CMA region	Number	Site	Ramsar	DIWA	DIWA Code
	3	Voyager Point		yes	NSW142
	4	Lake Gillawarna			
	5	Lake Toolooma			
	6	Marley Lagoon			
	7	Warriewood Wetlands			
	8	Yeramba Lagoon			
Western	1	Blue Lake (Paroo)		yes	NSW096
	2	Bulloo Overflow		yes	NSW006
	3	Gidgee Lake		yes	NSW152
	4	Peery Lake		yes	NSW098
	5	Mullawoolka Basin		yes	NSW100
	6	Muphy's Lake		yes	NSW016
	7	Narran Lakes	yes	yes	NSW011
	8	Paroo River Distributary Channels		yes	NSW017
	9	Salisbury Lake (Altibouka)		yes	NSW007
	10	Lake Pinaroo	yes	yes	NSW057
	11	Talyawalka Anabranch and Terywynia Ck (13 lakes)		yes	NSW012
		Boolaboolka Lake			
		Brennans Lake			
		Brummeys Lake			
		Dennys Lake			
		Dry Lake			
		Eucalyptus Lake			
		Gum Lake			
		Ratcatchers Lake			
		Sayers Lake			
		Swan Lake			
		Terryaweynya Lake			
		Victoria Lake			
		Waterloo Lake			
	12	Tongo Lake		yes	NSW103
	13	Yantabangee Lake		yes	NSW104

Appendix 2: **Example of pressure and condition scores for the Hunter–Central Rivers region**

	Barrington Top Swamps	Colongra Swamp	Ellalong Lagoon	Hexham Swamp	Jewells Wetland	Myall Lake Floodplain Swamp	Wyong Racecourse Wetlands	Cattai Wetlands	Eurunderee Lagoon	Darawakh	Moffat's Swamp	Wentworth Swamp
Catchment disturbance												
Land-use in the catchment	1	3	3	3	4	1	3	3	3	1	1	3
% of catchment cleared	2	5	5	5	5	1	5	5	5	1	2	5
Infrastructure in the catchment	2	2	2	3	4	2	3	2	2	2	3	3
Presence of point sources	1	1	1	4	1	1	1	1	1	1	1	4
Barriers without fishways	1	1	2	1	1	1	1	1	1	1	1	2
Total nitrogen loads	1	ND	1	1	ND	1	ND	1	1	1	1	1
Total phosphorus loads	1	ND	1	1	ND	1	ND	1	1	1	2	1
Raw data score	1.29	2.4	2.14	2.57	3	1.14	2.6	2.00	2.00	1.14	1.57	2.71
Score (1–5)	1	2	2	2	3	1	2	2	2	1	1	3
Boosted score	1.64	3.70	3.57	3.79	4	1.57	3.80	3.50	3.50	1.57	2.29	3.86
Score (1–5)	1	4	4	4	4	1	4	4	4	1	2	4
Hydrological disturbance												
Impoundments in the catchment	1	1	4	5	1	1	1	5	1	1	1	4
Regulated river catchment	NA	NA	1	5	1	NA	NA	1	1	NA	NA	5
Farm dam density	1	1	1	2	1	1	1	1	1	1	1	2
Groundwater bore density	1	1	1	1	2	1	1	2	1	1	5	2
Irrigation channel density	1	1	1	1	1	1	1	3	1	1	2	1
Raw data score	1	1	1.6	2.8	1.2	1	1	2.4	1	1	2.25	2.8

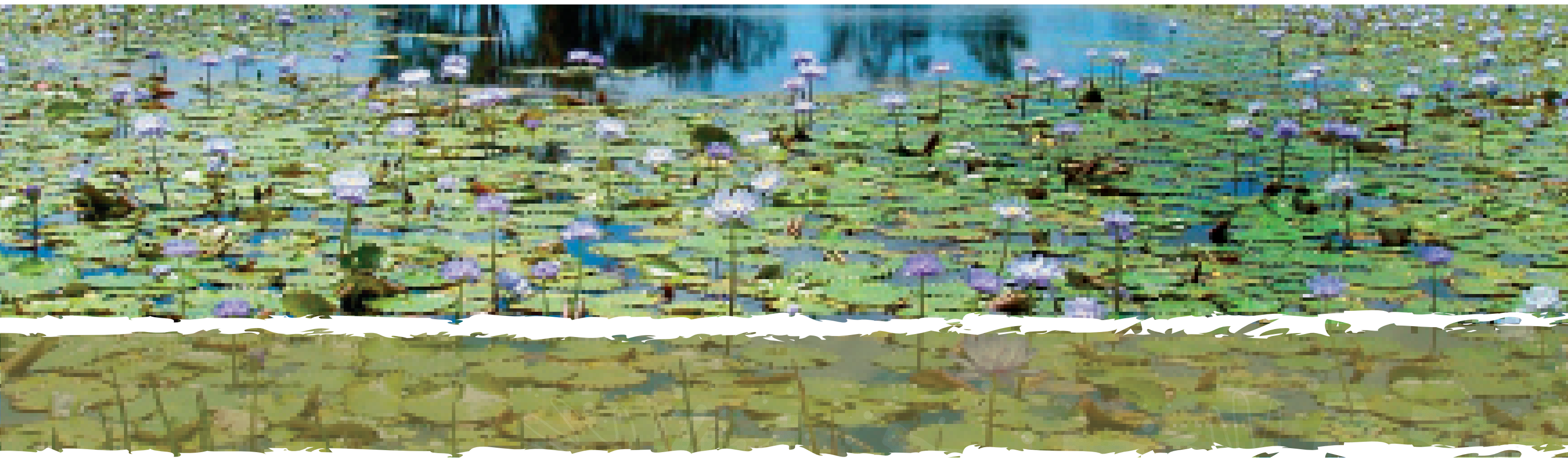
	Barrington Top Swamps	Colongra Swamp	Ellalong Lagoon	Hexham Swamp	Jewells Wetland	Myall Lake Floodplain Swamp	Wyong Racecourse Wetlands	Cattai Wetlands	Eurunderee Lagoon	Darawakh	Moffat's Swamp	Wentworth Swamp
Score (1–5)	1	1	1	3	1	1	1	2	1	1	2	3
Boosted score	1	1	2.8	3.9	1.6	1	1	3.7	1	1	3.63	3.9
Score (1-5)	1	1	3	4	1	1	1	4	1	1	4	4
Habitat disturbance												
% of wetland in protected area	1	1	1	1	1	1	3	1	3	1	1	5
% wetland adjoining urban area	1	1	2	3	3	1	3	2	1	1	1	3
Recreational facilities	2	2	4	5	4	2	5	4	5	2	5	5
Grazing	1	5	5	5	1	1	5	5	5	1	5	5
Cropping	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Roads that cross wetland	3	1	4	4	4	4	4	3	2	1	5	2
Roads that adjoin wetland	3	3	4	4	5	5	5	2	4	5	5	2
Density of pigs	5	1	1	2	1	1	1	1	1	1	1	1
Density of goats	1	1	1	1	1	1	1	1	1	1	1	1
Density of rabbits	2	2	4	2	2	2	2	2	2	2	2	4
Density of foxes	4	4	4	4	4	2	4	5	5	2	4	4
Raw data score	2.3	2.1	3	3.1	2.6	2	3.3	2.6	2.9	1.7	3	3.2
Score (1–5)	2	2	3	3	2	2	3	2	3	1	3	3
Boosted score	3.65	3.55	4	4.05	3.8	3.5	4.15	3.8	3.95	3.35	4	4.1
Score (1–5)	4	4	4	4	4	4	4	4	4	3	4	4
Overall pressure score	1.71	1.95	2.41	2.86	2.35	1.52	2.63	2.36	2.18	1.38	2.38	2.95
Score (1–5)	1	2	2	3	2	1	3	2	2	1	2	3

	Barrington Top Swamps	Colongra Swamp	Ellalong Lagoon	Hexham Swamp	Jewells Wetland	Myall Lake Floodplain Swamp	Wyong Racecourse Wetlands	Cattai Wetlands	Eurunderee Lagoon	Darawakh	Moffat's Swamp	Wentworth Swamp
Boosted score	3	3.5	3.5	4	3.5	3	4	3.5	3.5	3	3.5	4
Score (1–5)	3	4	4	4	4	3	4	4	4	3	4	4
Biota												
Tree health	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Raw data score	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Score (1–5)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Boosted score	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Score (1–5)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Biota – pest species												
Presence of weeds	5	ND	5	5	ND	ND	ND	ND	ND	ND	ND	ND
Ratio of invasive to native fish species	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Presence of alien fish	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Presence of feral animals	5	ND	5	5	ND	ND	ND	ND	ND	ND	ND	ND
Raw data score	5	ND	5	5	ND	ND	ND	ND	ND	ND	ND	ND
Score (1–5)	5	ND	5	5	ND	ND	ND	ND	ND	ND	ND	ND
Boosted score	5	ND	5	5	ND	ND	ND	ND	ND	ND	ND	ND
Score (1–5)	5	ND	5	5	ND	ND	ND	ND	ND	ND	ND	ND
Water quality												
Total nitrogen	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total phosphorus	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

	Barrington Top Swamps	Colongra Swamp	Ellalong Lagoon	Hexham Swamp	Jewells Wetland	Myall Lake Floodplain Swamp	Wyong Racecourse Wetlands	Cattai Wetlands	Eurunderee Lagoon	Darawakh	Moffat's Swamp	Wentworth Swamp
Algal blooms	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Turbidity	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
pH	ND	ND	ND	ND	ND	ND	ND	ND	ND	3	ND	ND
Conductivity	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Raw data score	ND	ND	ND	ND	ND	ND	ND	ND	ND	3	ND	ND
Score (1–5)	ND	ND	ND	ND	ND	ND	ND	ND	ND	3	ND	ND
Boosted score	ND	ND	ND	ND	ND	ND	ND	ND	ND	3	ND	ND
Score (1–5)	ND	ND	ND	ND	ND	ND	ND	ND	ND	3	ND	ND
Overall condition score	5	ND	5	5	ND	ND	ND	ND	ND	3	ND	ND
Score (1–5)	5	ND	5	5	ND	ND	ND	ND	ND	3	ND	ND
Boosted score	5	ND	5	5	ND	ND	ND	ND	ND	3	ND	ND
Score (1–5)	5	ND	5	5	ND	ND	ND	ND	ND	3	ND	ND

Note: ND = no data

NA = not assessed



www.environment.nsw.gov.au