Testing the Framework for the Assessment of River and Wetland Health in New South Wales wetlands

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Published by:
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ISBN 978 1 74293 356 6
OEH 2011/0779
September 2011

Cover photo: Gwydir wetlands – J Spencer, OEH

Australian Government
National Water Commission

This project was funded by the Australian Government through the National Water Commission’s Raising Water Standards Program.

Summary

The Framework for the Assessment of River and Wetland Health (FARWH) aims to facilitate nationally comparable regional assessments of river and wetland health across Australia at the scale of surface water management areas (SWMAs).

All previous trials of FARWH were confined to river systems. In this first application to wetlands, five SWMAs in New South Wales were assessed: Murray, Murrumbidgee, Hunter, Karuah and Manning. Existing wetland maps for these areas did not adequately cover major wetland types, so one of the first steps taken in this trial was to complete wetland mapping. A total of 30 296 wetlands with a surface area of 468 143 hectares were mapped in this process.

Attributes of the mapped wetlands, including climatic variables, soil types, elevation, wetland area, ratio of area to wetland perimeter, and the furthest distance between the wetland and any point in its catchment, were used to develop wetland typology by applying multivariate classification techniques. A single typology was developed for the Hunter, Karuah and Manning SWMAs, where five wetland types were defined. The typology for the Murray SWMA also defined five wetland types, while the one developed for the Murrumbidgee SWMA defined seven wetland types.

The data available for assessing wetland condition in any of the SWMAs was limited, allowing assessments to be made for only three of the six FARWH themes: catchment disturbance, water quality, and fringing zone. Catchment disturbance was assessed using the Wetland Catchment Condition Index (WCCI), which was the average of three indices: an index of local land use surrounding the wetland; an index of all local anthropogenic disturbances in the vicinity of the wetland; and an index of cumulative disturbances in the entire catchment of the wetland. Water quality was assessed using the Wetland Water Quality Index (WWQI), which was derived from measurements of electrical conductivity, pH and turbidity. The condition of the fringing zone was assessed using the Fringing Zone Structural Index (FZSI), which measured the extent of woody vegetation in the fringing zone. The WCCI and FZSI were calculated for all wetlands, but the WWQI was calculated for only the small number of wetlands in each SWMA for which suitable water quality data was available. The reference condition was set at 0 for the WWCI and at the index value of least disturbed wetlands for the FZSI. For the WWQI, the reference condition was determined by extrapolating from the median value for observations that were in the interquartile range of disturbance (WCCI).

Index values were aggregated by averaging index values for all wetlands, weighted by wetland area. Aggregation was performed for each of the SWMAs for each wetland type separately and then for all wetlands, regardless of type. Aggregated values were also calculated for subcatchments of two different sizes (small and large) in the Hunter SWMA and for large subcatchments only in the four other SWMAs. These aggregations were performed only for the WCCI and the FZSI and were not type-specific. The SWMA-level aggregated values for the indices (WCCI, WWQI and FZSI) were integrated to generate a single Wetland Condition Index (WCI) for each SWMA.

The overall condition of the five SWMAs measured by the WCI suggested that the wetlands of the Karuah SWMA were in the best condition (0.78) and those of the Murrumbidgee SWMA were in the worst condition (0.37). The Murray SWMA (0.49) was also assessed to be in poor condition, while the Hunter (0.59) and the Manning (0.63) were assessed to be in better condition than both the Murray and the

Murrumbidgee. The distinctions among the SWMAs were greater for water quality and fringing zone condition than for catchment condition. Wetland type influenced condition assessments for all three themes and in all SWMAs, but this influence appeared to be greatest in the Murrumbidgee SWMA and for water quality. Aggregations performed at the subcatchment level showed greater variation among subcatchments in fringing zone condition compared with catchment disturbance. In the Hunter SWMA, large variations in condition were observed both for the small subcatchments and the larger ones.

This trial has shown that better data and wetland mapping, and further development of indices are needed before the FARWH can be used to generate useful broadscale assessments of wetland health in NSW. Nevertheless, great progress towards this goal has been made in this trial, including the development of wetland mapping methods that can be applied across Australia with limited resources, procedures for selecting reference wetlands, development of regional wetland classifications using remotely derived data, and methods for assessing catchment condition, fringing zone condition and water quality for wetlands at broad spatial scales.

Successful implementation of a wetland assessment program in NSW will require the development of broadscale monitoring programs, especially for biota and water quality, as well as improvement of wetland mapping and the development and validation of ecologically meaningful wetland typologies. These necessary next steps are outlined in an implementation plan for a FARWH-based, statewide wetland assessment program in NSW.

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Introduction

The National Framework for the Assessment of River and Wetland Health (FARWH) was developed as part of the Australian Water Resources (AWR) 2005 project funded by the Raising National Water Standards (RNWS) Program. The Australian Government's $250 million RNWS Program, administered by the National Water Commission (NWC), supports the implementation of the National Water Initiative (NWI) by funding projects that are improving Australia's capacity to measure, monitor and manage our water resources (Norris et al. 2007). The Australian Government NWC is managing the implementation of the NWI, which has been signed by the Commonwealth and all states and territories. It is Australia's blueprint for national water reform to improve water management across the country. The overall objective of the NWI, which includes a range of water management issues and encourages the adoption of best-practice approaches, is to achieve a nationally compatible market and a regulatory and planning-based system for managing surface and groundwater resources for rural and urban use that optimises economic, social and environmental outcomes.

The primary aim of the FARWH was to enable locally relevant, comprehensive assessments of river and wetland health to be comparable across jurisdictions. FARWH uses a referential approach, assuming that ecosystem health can be measured in the currency of ecological integrity (Karr and Dudley 1981), which may be defined as the degree of departure from a reference condition (Schofield and Davies 1996; Reynoldson et al. 1997; Norris and Thoms 1999).

FARWH uses six key components that are appropriate for assessing river and wetland health, all of which are considered to represent ecological integrity:

1. physical form
2. water quality and soils
3. aquatic biota
4. hydrological disturbance
5. fringing zone
6. catchment disturbance.

To achieve nationally consistent reporting, the default spatial scale of assessments and reporting in FARWH was set as surface water management areas (SWMAs) (Norris et al. 2007). These are typically large river catchments. In the Murray–Darling Basin the SWMAs often have similar boundaries to those of the catchment management authorities (CMAs), but in eastern New South Wales typically several SWMAs are included in one CMA region. Some of the NSW catchments were divided into regulated and unregulated SWMAs. For this trial we have combined these into a single region.

This report presents findings of the RNWS-funded project, *Testing the Framework for the Assessment of River and Wetland Health (FARWH) in New South Wales Wetlands*.[1] The objectives of the project, listed in the inception report, were as follows:

- develop a framework to achieve comparable assessment of wetlands across CMA regions and SWMAs in NSW, using the FARWH
- apply the framework to existing data from selected regions in NSW

[1] www.nwc.gov.au/www/html/461-farwh-in-nsw.asp?intSiteID=1

- based on the results of this trial, identify data requirements to assess the ecological health of wetlands at the scales of the entire state, CMA region and SWMAs
- identify modifications to and directions for the FARWH and wetlands monitoring, evaluation and reporting (MER) programs for NSW (i.e. using outcomes from objectives 1–3)
- communicate the process and outcomes of the trial to stakeholders.

To meet these objectives, it was necessary to address some key issues that relate to the application of the FARWH to wetlands. These issues include spatial scales of reporting, definition of reference conditions, selection of indices to represent the different components of the ecosystems, methods for integrating and aggregating different indices, sensitivity analyses, range standardisation and managing missing data. We attempt to address each of these issues in relation to selected wetlands in NSW, with the expectation that the results can be readily applied in other parts of Australia. The main steps taken during this project are shown in Figure 1.

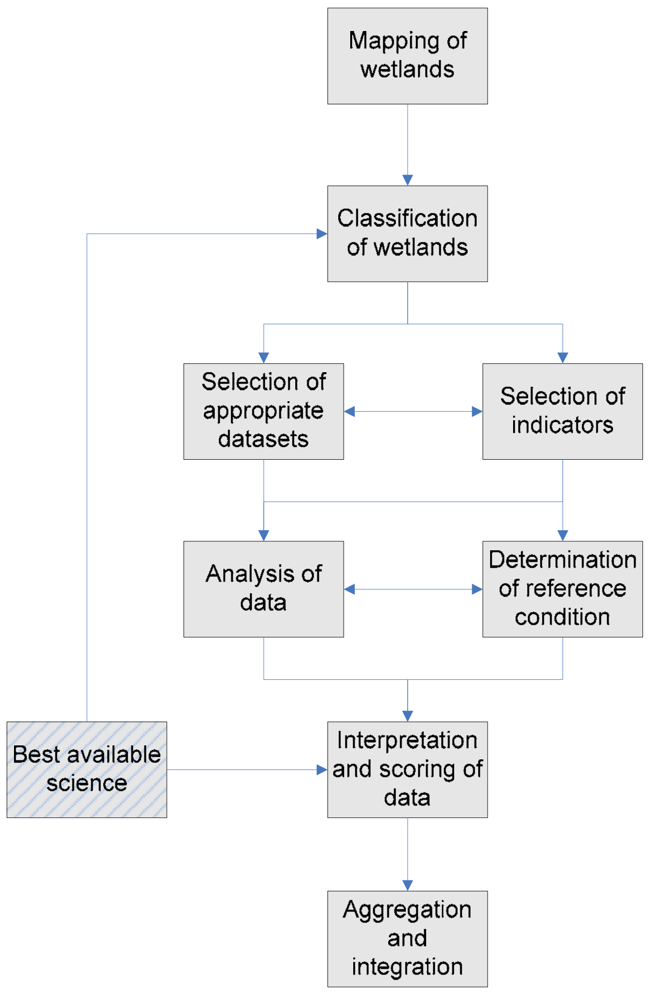

Figure 1: Overview of the components and framework used to apply the FARWH to wetlands in NSW

Methods

Scope of the trial

Definition of wetlands

Wetlands were defined by Cowardin et al. (1979) as:

- being 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 life cycle
- having a substratum consisting of predominantly undrained soils that are saturated, flooded or ponded long enough to develop anaerobic conditions in the upper layers.

Riverine estuarine and marine wetlands were excluded from the trial.

FARWH themes assessed

A major constraint of this trial was the availability of suitable data. Hence the themes were chosen in accordance with existing data that was readily available for analysis. Three of the six FARWH themes were assessed in this trial:

- catchment disturbance
- fringing zone
- water quality.

Trial areas

Five SWMAs in NSW were chosen to be included in this trial (Figure 2):

- Murray (NSW part only)
- Murrumbidgee
- Hunter
- Karuah
- Manning.

The SWMAs were chosen to make best use of the available data and include a range of catchment sizes, environmental conditions, wetland types and pressures. Table 1 describes the environmental and socioeconomic features of each SWMA.

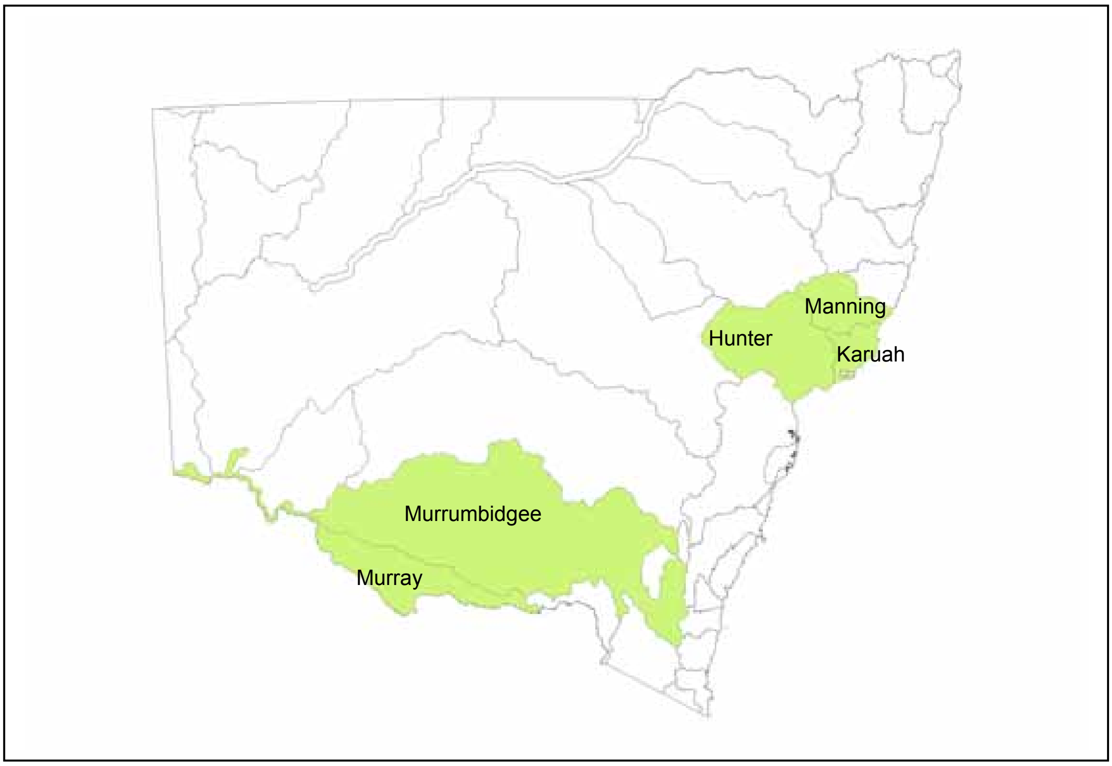

Figure 2: The SWMAs chosen for the trial of FARWH in NSW wetlands

Table 1: Overview of SWMAs chosen for NSW FARWH trial *

SWMA	Catchment size (km^2)	Water resource development	Human population	Climate	Av. annual rainfall range (mm)	Pressures
Hunter	21 500	High	~600 000	Coastal temperate to upland	650–1100	Power generation, coal mining, heavy industry, irrigated agriculture, urban infrastructure, fisheries.
Karuah	4500	Low	~65 000	Coastal subtropical and temperate with small upland component	950–1300	Beef cattle production, open cut mining, tourism, recreational fishing.
Manning	8190	Low	~45 000	Coastal subtropical to upland	850–1500	Dairy production, oyster farming, coal mining, gravel extraction, agriculture, forestry, fisheries.
Murray	37 197	Over-developed	~75 000	Temperate to semi-arid	350–650	Agriculture, e.g. rice, wool, dairy, wheat, beef, lamb, grapes, citrus. Also tourism and recreation.
Murrumbidgee	85 580[2]	Over-developed	~545 000	Alpine to semi-arid	350–1500	Irrigated agriculture – rice production, viticulture, horticulture.

* Water resource development categories represent the magnitude of water use as a percentage of sustainable flow regime (surface water) and sustainable yield (groundwater): low: <30%; moderate: 30–70%; high: 70–100%; and over-developed: 100% (*Australian natural resources atlas 2009*).

Mapping

There is consensus at a state and national level that wetland-extent mapping is an essential precursor to any wetland condition assessment (DEWHA 2008; EPA 2005). While wetland datasets exist for NSW (Kingsford et al. 2004), they were not considered appropriate for the trial, as they were of relatively coarse resolution (30–80 m), focused on floodplain wetland systems, did not distinguish between river-fed wetland types and riverine channels, and were delineated to represent the wettest periods. This meant that wetlands of different types and river channels could be represented within a single wetland extent, complicating assignment of the typology. As such, new wetland-extent maps were generated for each SWMA during the trial.

There were two major constraints in undertaking this exercise:

- The maps had to make use of ecologically important features of wetlands but could not be reliant on field assessments.
- The maps had to rely on existing and primarily remotely sensed data.

As such, resource-intensive assessments of wetland extent, such as that applied by the Queensland Wetlands Program (DERM 2010), were not possible for this trial. However, this mapping exercise has built on existing maps, adding further detail and generating a more consistent and comprehensive wetland coverage for the trial SWMAs.

To generate the maps, individual wetlands were delineated within the Murray, Murrumbidgee, Karuah, Hunter and Manning SWMAs. This task used a similar methodology as the Wetlands Mapping and Classification Methodology in Queensland (EPA 2005), tailored to make use of existing NSW datasets. The process for developing these maps is illustrated in
Figure 3 and outlined below.

Process 1—Collation of relevant data layers

Relevant data to inform the wetland mapping process was compiled, including:

- existing wetland data layers (Kingsford et al*.* 2004; Green and Alexander 2006)
- vegetation mapping of the western plains (Benson et al. 2006)
- high-resolution spatial imagery (SPOT 5 2008 and ADS40 2008)
- digital elevation models (DEMs) (LiDAR DEM 10 m resolution, Shuttle Radar Topographic Mission (SRTM) DEM 90 m resolution)
- Landsat 5 imagery (cb3, bd6, ch2) over 20 years (1988–2008), with 10–12 images per year
- spatial extents of each SWMA (Hunter, Karuah, Manning, Murrumbidgee and Murray).

All datasets were clipped to each of the five SWMAs to ease processing.

Process 2—Manual quality control and editing of existing wetland layers

Existing wetland layers were checked and edited, using the latest high-resolution imagery available (SPOT 5 2008 or ADS40 2008). Main rivers and associated anabranches were extracted from the wetland dataset by overlaying the Sustainable Rivers Audit (SRA) (MDBC 2008) river network data layers and extracting polygons.

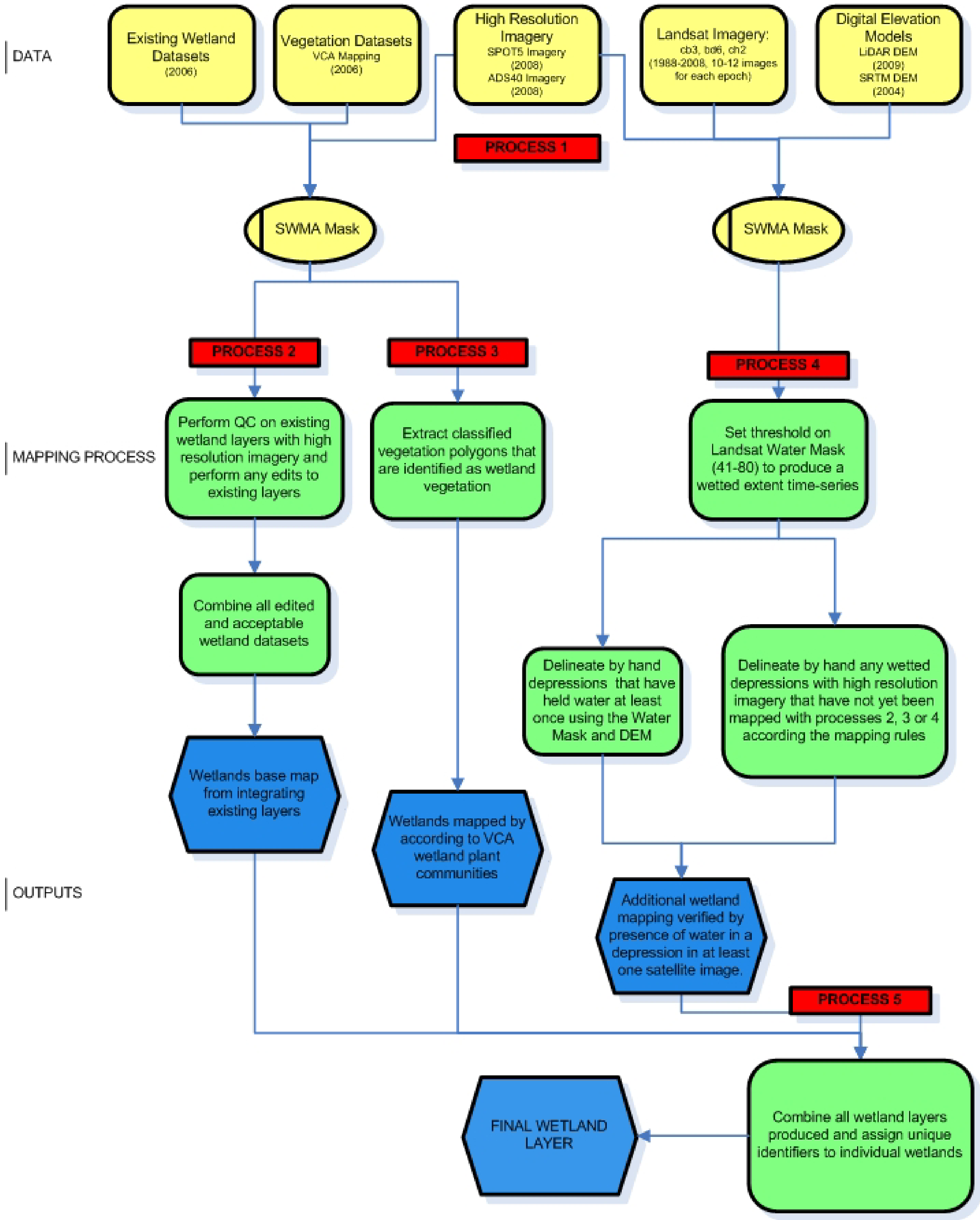

Figure 3: The five processes for developing wetland extent maps for each SWMA

This was performed manually, because automated selection and extraction excluded many of the billabongs along the edges of the river. Floodplain channels that did not form part of the SRA drainage network were not excluded from the dataset. High-resolution imagery was also used to assist delineation of any extra wetlands, which were identified by other sources, including topographic maps.

Output: Wetlands base map from existing wetland layers.

Process 3—Extracting wetland information from vegetation mapping

Wetland-specific vegetation mapping was extracted from existing mapping of the Western Plains (Benson et al. 2006) in consultation with John Benson (Royal Botanic Gardens, Sydney).

Output: Wetland layer with plant communities attributed to each polygon.

Process 4—Applying water mask to Landsat images across a 20-year time frame

All possible Landsat multispectral satellite images available within the Office of Environment and Heritage (OEH) archive were obtained (1988–2008, approximately 10–12 for each epoch), radiometrically corrected, orthocorrected and processed, using the 'water mask' method developed by Danaher and Collett (2006). A threshold for 'wetness', or standing water, was set at a range of 41–80 to identify the pixel values in the image histogram that will be extracted.

These layers were combined to produce a layer of all areas that had been wet at least once over the 10-year period. This layer was checked for accuracy and edited using high-resolution imagery (SPOT 5 2008 and/or ADS40 2008) and DEMs (LiDAR 2009, Shuttle Radar Topography Mission (SRTM) (2004)), using the following rules (illustrated in Figure 4):

- Eliminate all areas of obvious irrigated agriculture.
- Eliminate all very small (<0.5 ha) farm dams identified as wet areas that were circular or square.
- Retain/add wet areas with a distinct wetland shape.

Effort was made to include modified wetlands because of their potential value for biodiversity (Wassens et al. 2007; Hazell et al. 2001). As such, farm dams larger than 0.5 ha were retained, as well as areas containing vegetation that could be identified as hydrophytes.

Output: Wetland layer identified from satellite imagery showing extent of wetting.

Process 5—Final wetland layer

All wetland datasets were combined to form a single spatial layer and individual wetlands, as identified by distinct boundaries or by different biotic composition (inferred from vegetation mapping), and assigned unique identifiers. Wetlands occurring on the border between two SWMAs (e.g. the Murray and the Murrumbidgee SWMAs) were assigned to one SWMA only.

Output: A single, final wetland layer for each of the five SWMAs.

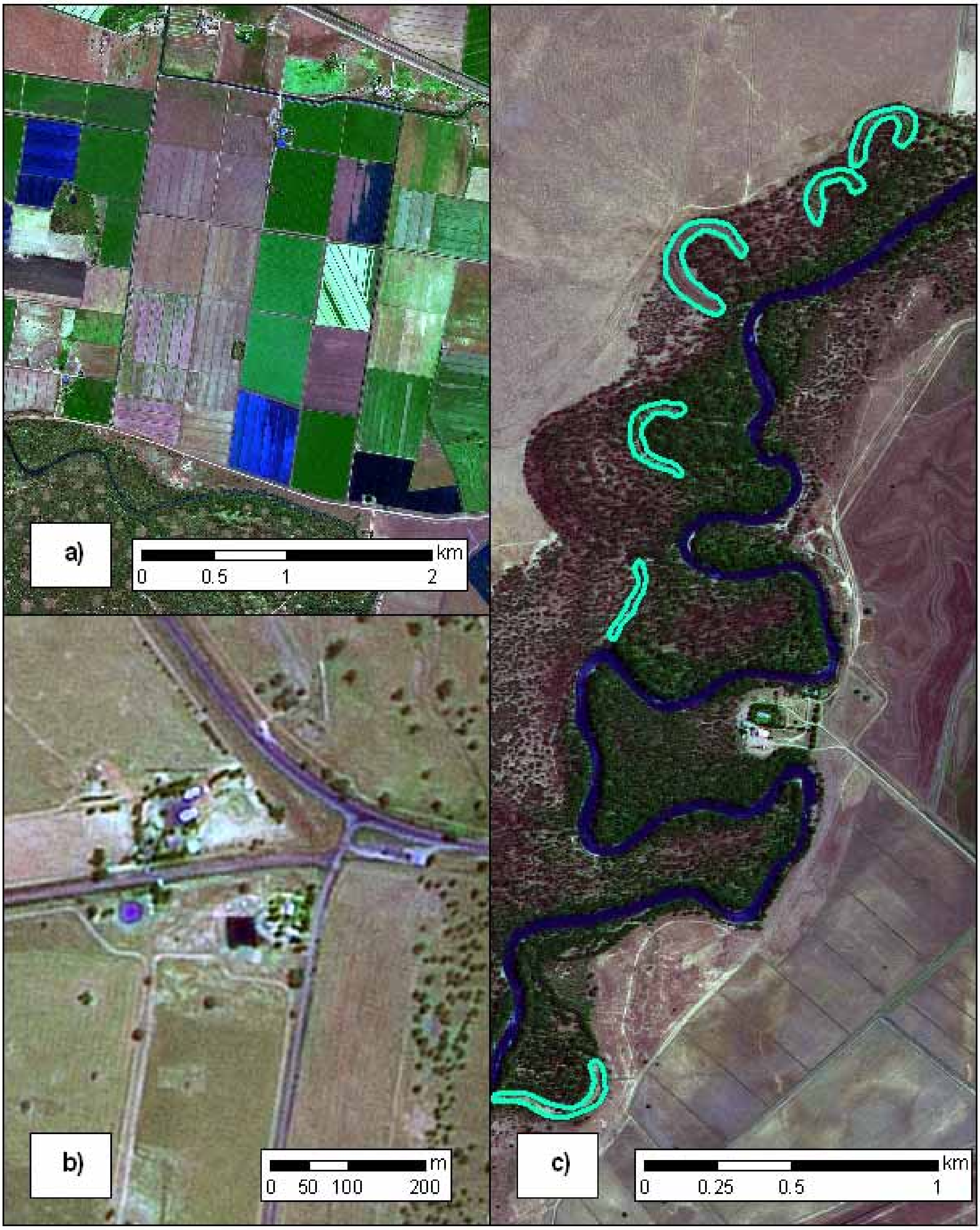

Figure 4: Imagery (SPOT 5 2008) within the Murrumbidgee SWMA illustrating rules for wetland delineation

Subsets show typical examples of: a) irrigated agriculture; b) small farm dams; and c) distinct wetland shapes outlined in turquoise adjacent to the main river channel.

Limitations of mapping methods

The wetland-extent mapping completed for the FARWH trial made the best use of available datasets and remote imagery in the absence of resources for a more intensive, field-validated methodology (DERM 2010).

As a large proportion of wetlands in NSW vary in their level of wetness through different seasons, hydrological regimes and management actions, wetland boundaries that portray a single extent should not be assumed to sufficiently represent the character of highly variable wetlands. However, for this exercise, quantitative information about wetland location and extent was required as a precursor to developing wetland types and conducting wetland health assessments. Seasonality and fluctuations in wetland extent should be considered further in future for their implications in monitoring wetland extent or wetland loss.

As a variety of datasets were used to delineate wetlands, the final dataset comprised data with a range of spatial resolutions, spatial coverages and source data. This problem is not unique to this trial, and using a range of data sources to inform wetland mapping is an accepted technique (DSEWPaC 2011). Disparity in different representations of wetland extent between datasets was accounted for, where possible, by manually checking and editing final wetland layers for consistency, using recently acquired high-resolution imagery (SPOT and/or ADS40).

Alignment of FARWH wetland mapping to draft national standards

The draft standard and guidelines for the mapping and classification of wetlands (aquatic ecosystem) in Australia are being prepared by the Department of Sustainability, Environment, Water, Population and Communities. The guidelines were not available at the time of the FARWH trial, but a working draft has been made available to OEH in order to review FARWH's agreement with the national standards.

Data collation: The FARWH trial has made use of all the key data layers specified by the draft national standard, including remotely sensed imagery, water-body mapping derived from imagery in vector format with multitemporal outputs, drainage and existing vector water-body mapping, vegetation mapping, topographic mapping, soils mapping and other datasets.

Scale and data quality:

- **Minimum mapping unit:** FARWH wetland mapping was undertaken at the minimum mapping unit required for the landscape (0.25 ha at a scale of 1:25 000 for intensive land-use areas, high density of discrete wetland areas and site/regional scale mapping products).
- **Horizontal position accuracy:** The horizontal accuracy, based on the scale and pixel resolution of data layers used, and the scale at which visual interpretation was performed, is considered to be within the positional accuracy standards of ±25 m, although root-mean-square error values were not calculated for the maps.
- **Vertical position accuracy:** Digital elevation and digital terrain models used for the project were accurate within ±10 m maximum (for LiDAR DEM) and ±90m maximum (for SRTM DEM).
- **Producer's accuracy and data verification:** This accuracy measurement involves validation, using randomised in-field sampling and expert opinion. This would be a resource-intensive process that was not accounted for in the costing of the FARWH trial, but may be a useful precursor to implementing the FARWH framework nationally.

Information management: All spatial data generated as part of the FARWH trial will be maintained in the OEH *Spatial data catalogue*,[2] which maintains metadata, access, licensing and storage information.

Wetland typology

The primary purpose of undertaking a wetland classification (typology) in applying FARWH was to test whether landscape-level characteristics of wetlands were likely to influence condition assessments across SWMAs. Finding such differences would provide a strong case for type-specific reporting at that spatial scale. On the other hand, if no major differences were found this would suggest either that aggregating scores from all wetlands, regardless of type, was acceptable or that the attributes used to define the types were not appropriate.

Testing differences among wetland types at the SWMA scale requires the capacity to assign all, or a great proportion of, wetlands to a wetland type in a transparent and largely automated manner. Using a hydrogeomorphic wetland typology (see Cowardin et al. 1979) would be advantageous, because these types are likely to represent major differences in ecological processes. However, the data needed to assign the mapped wetlands in the trial SWMAs to hydrogeomorphic types was not available and could not be generated within the time frames and resource constraints of the project. For this reason, we developed bottom-up typologies for wetlands in the five SWMAs, using existing or easily generated data. To define the wetland types we used classification methods applied in the development of river typologies in NSW (see Turak and Koop 2008).

To develop the wetland typologies we first determined suitable physical, climatic and topographical variables. We then grouped similar wetland polygons for multiple variables. To do this, we used the fuzzy cluster analysis (FANNY) method and examined the outputs of the classifications, using silhouette plots (Kauffman and Rousseeuw 1990) in the R statistical package (R Development Core Team 2004). We used range-standardised variables for wetland polygons that were thought to collectively define some of the distinguishing features of wetlands at a landscape scale. Slightly different variables were used for the eastern SWMAs (Hunter, Karuah and Manning) and the western SWMAs (Murray, Murrumbidgee). Common variables were climate, elevation, wetland area and perimeter-to-area ratio. However, using only these was likely to leave out some of the local landscape influences. To help account for these in the Hunter, Manning and Karuah SWMAs we included the largest distance from source for subcatchments intersecting the wetlands as an attribute variable. In the Murray and Murrumbidgee SWMAs, soil types for each polygon, expressed as a proportion of wetland area, were used as wetland attribute variables.

The clustering algorithm used required an a priori nomination of the number of classes. As such, the analyses were conducted for different numbers of classes, starting from three. To determine the suitability of the number of classes and assess the magnitude of misclassifications we used silhouette plots (Kauffman and Rousseeuw 1990), where increasing silhouette width indicates improvement in the ability of the classification to capture variability in the data. The number of classes that gave the best overall silhouette width was chosen. Once the number of classes was decided, misclassified wetlands were assigned to their nearest neighbour and the classification was re-run with the adjusted class memberships.

[2] http://mapdata.environment.nsw.gov.au/DDWA

The large number of subcatchments in the SWMAs presented difficulties in computation and interpretation. Two different approaches were used to get around this. In the Hunter, Karuah and Manning catchments, confining the analyses to wetlands greater than 1 ha brought the wetland polygons to a manageable number (1189). In the Murray and Murrumbidgee, leaving out small wetlands was considered inappropriate because it would selectively cut the representation of some wetland types (e.g. billabongs), so only wetlands under 0.1 ha were removed and 10 per cent of the remaining wetlands were randomly selected and used for the analysis. Hence the classifications were performed with 925 polygons in the Murrumbidgee and 1408 in the Murray.

Once classification of the subset of wetlands was completed, classification-tree analysis (Breiman et al.1984) was used to allocate all wetlands to a type, using a small number of remotely derived variables. Riverine and estuarine wetlands and large dams were not allocated a wetland type, as they fall outside the definition of wetlands used for FARWH.

Indicator development

Catchment disturbance

The purpose of quantifying catchment disturbance was to provide an estimate of the magnitude of human-induced disturbances relevant to the ecological health of wetlands, whereby changes over short-to-medium time frames can be detected and distinction can be made among different SWMAs. Disturbances related to flow alterations – impoundments, levee banks and extractions – were not included as catchment disturbance because it was considered more appropriate to include those in the hydrology FARWH theme.

The following criteria were identified for a suitable indicator of catchment disturbance:

- It should capture all the major types of human-induced disturbances affecting wetland health, except for hydrological disturbances, which fall within the domain of the hydrology theme.
- It should capture both the disturbances transported from all parts of the catchment through stream flow (cumulative disturbances) and those that affect the immediate surroundings of wetlands (local disturbance).
- It should be based on an appropriate reference condition.
- It should be possible to obtain values for these indicators remotely.

In defining the indicators of catchment disturbance here, we also define the indices used to measure these indicators. At the first place, we defined the spatial units within which measurements are to be made. The spatial units we have chosen here are the national catchment boundaries (Stein 2005, 2007), which divide the landscape into small and hierarchically nested subcatchments, delineated using a 9-second DEM. This delineation makes it possible to unambiguously define the boundaries within which 'local' disturbances are measured. Here, local disturbances affecting a wetland are those that occur within the composite outer boundaries of all subcatchments that intersect with the wetland polygon. For practical reasons, we use a polygon generated in the mapping process as synonymous to a wetland. Cumulative disturbances include aggregated disturbance in all subcatchments that are hydrologically linked to the subcatchments that intersect with the wetland.

We selected the following three indicators:

- local land use: incorporates each major type of land use in the subcatchments that intersect with the wetland in accordance with their likely effects on the ecological health of wetlands
- local catchment disturbance: incorporates major types of disturbance from point and diffuse sources within local subcatchments
- cumulative catchment disturbance: aggregated values of local catchment disturbance with disturbances at all subcatchments upstream.

For the land-use indicator we used the Landuse Factor (LUF) developed by Stein et al. (2002) in which first land use is classified into seven broad types that represent different levels of threats to river ecosystems. Then the area occupied by each category in the subcatchment is calculated and the scores for all land-use types in the subcatchment are averaged after weighting by area. This land-use classification, however, was used only in the Murray and Murrumbidgee SWMAs. For the three SWMAs in the Hunter region we used a more detailed classification based on 20 land-use categories (Table 2) defined to represent not only different levels of threat to aquatic ecosystems, but also types of management actions aimed at improving the health of aquatic ecosystems and their catchments (Turak et al. 2011a). These categories were generated by grouping the 172 land-use classes identified in detailed land-use maps for the Hunter region (DECC 2007) jointly with the Hunter–Central Rivers CMA. Each of these land-use types was given a weighting to reflect the likely magnitude of impact on aquatic ecosystem health of that land use. The local land-use index for each wetland was computed by first calculating the scores for each subcatchment that intersects with the wetland and taking the average of these weighted by the area of each subcatchment.

For local catchment disturbance we used a Subcatchment Disturbance Index (SCDI) (Stein et al. 2002). The SCDI incorporates the LUF, together with three other catchment disturbance indices: Settlement Factor (SF), which accounts for the size of human population in the catchment; Infrastructure Factor (IF), which estimates the extent of roads and other major infrastructure; and Extractive Industries Factor (EF), which estimates the magnitude of disturbance in the catchment from mining and other point sources. The SCDI is the average of these four indices. The local subcatchment disturbance index for each wetland was calculated by first calculating the scores for each subcatchment that intersects with the wetland and then taking the average of these weighted by the area of each subcatchment.

The Catchment Disturbance Index (CDI) (Stein et al. 2002) is the average of the SCDI values for all nested subcatchments above a wetland, weighted by the estimated runoff from the subcatchment based on soil-moisture surplus (Stein et al. 1998, 2002) in the Hunter, Manning and Karuah SWMAs, where estimates of these variables were available for each subcatchment. In the Murrumbidgee and Murray SWMAs, where such estimates were not available, the subcatchments were weighted by area. The cumulative catchment disturbance was computed by first calculating the scores for each subcatchment that intersects with the wetland and taking the average of these weighted by the area of each subcatchment.

The local land-use, local subcatchment disturbance and cumulative catchment disturbance indices were combined into a single Wetland Catchment Condition Index (WCCI) indicating the overall catchment condition for each wetland polygon. This was computed by taking the mean of the three indices described above and subtracting this from 1.

Fringing zone

The wetland fringing zone was selected as a condition indicator because of its role in wetland ecosystem health as:

- a contributor to wetland ecosystem health by providing habitat and enhancing connectivity for a range of native species (Fischer et al. 2006)
- a protective or buffer zone for wetlands by providing protection from changing land-use regimes, including groundwater draw-down, impacts on water quality, soil erosion and edge effects (Wang and Yin 2008).

In addition, incorporating the wetland fringing zone into assessments of wetland ecosystem health compensates somewhat for the 'fuzziness' of wetland boundaries. While necessary to delineate wetlands in order to quantify extent and thus track wetland loss, it is understood that wetland boundaries fluctuate seasonally and with varying environmental conditions (Winning 1997).

For the NSW FARWH trial, the fringing zone is defined as the immediate zone around the wetland boundary containing vegetation communities that reflect the influence of continuous or intermittent water. The fringing zone was therefore defined by a 150-m buffer surrounding each of the mapped polygons. Alternative methods for delineating the zone, including differing buffer widths for different wetland types and constraining buffer size according to soil and elevation attributes, were considered (Melrose 2009). However, time and resource constraints of the study necessitated using a more general fringing zone delineation method that could be applied across the state, minimising processing time.

Scientists in Australia and overseas have identified various indicators for assessing the wetland fringing zone, including per cent of vegetation cover in the fringing zone and woody/non-woody vegetation cover in the fringing zone, vegetation species richness, classification of vegetation composition, presence of non-native species, soil moisture over time, evaporation, land-use change, extent of natural habitat, amount of gully erosion, and degree of disturbance (Castelle et al. 1992; Tiner 2004; DSE 2005; Conrick et al. 2007; Norris et al. 2007; Turrel et al. 2008; Scholz and Fee 2008).

As part of this program, a range of techniques were trialled for using remote data to assess the health of the wetland fringing zone. These included incorporating fringing zone expected values based on different local-scale wetland types, fringing zone change indices, the proportion of native species in the fringing zone, and height-based structural complexity of the fringing zone (Melrose 2009). These indices required significantly longer processing time and could not be applied to statewide-scale studies without the expense of further vegetation-mapping, plot-based surveys and/or LiDAR surveys (Melrose 2009).

As such, the FZSI was adapted from the established NWC Riparian Condition Sub-Index (RCSI) for use in wetlands (Norris et al. 2007). The FZSI represents the proportion of the fringing zone that is occupied by woody vegetation and is based on the inferred assumption that the integrity of the fringing zone declines with the proportion of woody vegetation. It should be noted that this assumption may not apply to some wetland types that do not necessarily contain woody plants in their fringing zones (e.g. lignum shrublands), which therefore may be penalised in this condition assessment. Future resources could be directed to experimentally testing the assumption that the integrity of the fringing zone declines with the proportion of woody vegetation or to furthering development of the previously mentioned alternative fringing zone condition indicators to compare to the FZSI.

The FZSI is calculated as follows:

- Woody foliage projective cover images were developed for 12 Landsat TM images from 1998–2008, using a regression model developed by Danaher et al. (2004) originally for use in the Queensland Statewide Landcover and Trees Study (SLATS) project.
- Thresholds were developed for woody vegetation areas by ‘ground-truthing’ woody foliage protective cover value ranges in known woody areas, identified using high resolution digital imagery (SPOT 5 2008 or ADS40 2008).
- The area of woody vegetation in each fringing zone was expressed as a proportion of the zone extending to the boundary of the fringing zone delineated, not including the area of side channels or within-wetland polygon area.

Water quality

We assessed water quality, using data extracted from a statewide database containing most of the water quality data collected in NSW since 1968 and from databases containing data collected in more recent wetland assessment programs (Table 2).

Water quality sampling sites recorded in these databases were matched to the mapped wetlands by intersecting the site layer with a 100 m buffer around all wetlands. The result of this mapping is shown in Table 3. There were sufficient data for only three variables: electrical conductivity, pH and turbidity.

We used mean values for all available observations within each wetland polygon to represent the value of a given variable for that wetland. The values obtained were then used to set separate reference conditions for each of the three variables, which were later combined to provide a single-condition assessment of water quality at each wetland.

Table 2: Overview of water quality data available from the main sources.

Data source	Extent	Number of sites	Time of collection
Water quality data system (Triton)	Statewide	18 54	1968–2009
Acid Sulphate Soils Assessment Program (ASSP)	MDB NSW basin-wide	422	2008–09
Rivers Environmental Restoration Project (RERP)	Gwydir (5) Macquarie (5) and Murrumbidgee (28) SWMAs	38	2007–08

Table 3: The number of water quality sampling sites that fall within wetlands and the total number of mapped wetlands in each SMWA

SWMA	WQ sites within wetlands	Total wetlands
Murray	76	14 268
Murrumbidgee	122	11 571
Hunter	30	1502
Karuah	26	343
Manning	8	519

Wetland loss

Loss-of-wetland extent through human-induced disturbance is a major threat to NSW wetlands (Kingsford et al. 2004). In the western part of the state, floodplain wetlands have been lost through agricultural development and alteration of flow regimes (Saintilain and Overton 2010). As floodplain wetlands show seasonal and other cyclical variations in their inundation extent, loss of wetlands through hydrological disturbance can be challenging to quantify. Previous studies have recommended using maximum inundation extent to compare wetland extent over time (Johnston and Barson 1993; Kingsford and Thomas 2002), and this method has detected losses of up to 59 per cent in the period 1975–98 in the Lower Murrumbidgee floodplain. These losses, in turn, have resulted in declines in wetland biota (Kingsford and Thomas 2004). In coastal areas, wetlands are likely to be lost due to climate change-related sea-level rise, resulting in significant reductions in freshwater biodiversity (Turak et al. 2011b). Models of magpie geese predict reduction and fragmentation of populations in response to decreasing wetland extent (Traill et al. 2010).

While quantifying wetland loss was out of the scope of this FARWH trial, the mapping generated during the trial provides a high-resolution snapshot of wetland extent in the five SWMAs, as at 2008, and this data could be used with appropriate methodology to track wetland-extent change and wetland loss in these areas.

Setting reference conditions and final scoring

The reference condition for the WCCI was set at 1 and the scores used were the mean values of the three indicators.

The reference condition for fringing zone condition and water quality was represented by wetlands in the 1st decile of the WCCI and where there was no evidence of flow-regime disturbance. The latter was determined using a Flow-Regime Disturbance Index (FRDI) (Stein et al. 2002) and only wetlands that had 0 for the FRDI were included. Two sets of reference wetlands were selected; one of these was based on thresholds derived for all wetlands and the other used thresholds calculated separately for each wetland type.

For scoring the fringing zone condition, it was necessary to establish only the value corresponding to the highest score (1), because the lowest score was represented by 0 per cent cover of woody vegetation. For the three SWMAs in the Hunter region, the regional reference wetlands were selected by determining the 1st decile of the WCCI from all wetlands greater than 1 ha in the whole Hunter–Central Rivers CMA region (which includes the Tuggerah Lakes SWMA, in addition to the three SWMAs in this trial). The raw FZSI scores for all wetlands were then divided by the median value of the FZSI for the reference wetlands, and all values above 1 were set as 1.

The highest value for water quality variables was set in the same way as for the fringing zone. However, because water quality variables do not have a universal ‘worst value’, assigning an index value to an observation required the determination of a value corresponding to a 0 score. A very large number of observations would be needed to meaningfully assign a 0 value to any actual observation, so it is more appropriate to determine the midpoint (0.5 value) and extrapolate the distance between this point and the reference condition values backwards to determine the 0 point. The 0.5 value was set as the median water quality observation from wetlands that fall within the interquartile range of the WCCI. The WWQI was calculated as follows.

WWQI = 1 – ((Ref – Obs) / (2(Ref – Int))

where Obs = observed value to be scored
Ref = the median value for the reference sites
Int = median value for observations made at sites with catchment disturbance values that fall in the interquartile range.

In the Hunter region, the number of wetlands with water quality observations was very low (22), and on closer examination several of these were found to not be appropriate. For this reason, two modifications were made to the assessments. First, all analyses were non-type specific. Second, analyses for the three SWMAs were made together.

Aggregation of scores for individual wetlands to the entire SWMA region was done by taking the average of all values weighted by the area of the wetland. Aggregation was performed for each of the SWMAs for each wetland type separately and then for all wetlands, regardless of type. Aggregated values were also calculated for subcatchments of two different sizes in the Hunter SWMA (172 small subcatchments and 37 large subcatchments) and for large subcatchments only in the Karuah (4), Manning (7), Murrumbidgee (96) and Murray (166) SWMAs. These aggregations were performed only for the WCCI and the FZSI and were not type-specific.

The SWMA-level aggregated values for the indices (WCCI, WWQI and FZSI) were integrated to generate a single Wetland Condition Index (WCI) for each SWMA by simple taking the mean value of the three indices.

Results

Wetland maps and types

The number of discrete wetland types mapped and the total wetland area represented by these wetlands are given in Table 4.

A single wetland typology was developed for the Hunter, Karuah and Manning SWMAs, where five wetland types were identified (Figure 5). The Murrumbidgee SWMA had seven wetland types (Figure 6) and the Murray SWMA five wetland types (Figure 7).

Table 4: The surface area of each of the trial SWMAS, the area covered by the mapped wetlands and the number of individual wetlands (polygons) mapped

SWMA	Land area (ha)	Wetland area (ha)	Wetland polygons
Hunter	2 137 696	17 508	1503
Karuah	437 677	19 227	344
Manning	818 727	6613	519
Murrumbidgee River	8 310 051	177 698	9634
Murray (Hume to Border)	1 858 193	247 097	18 296

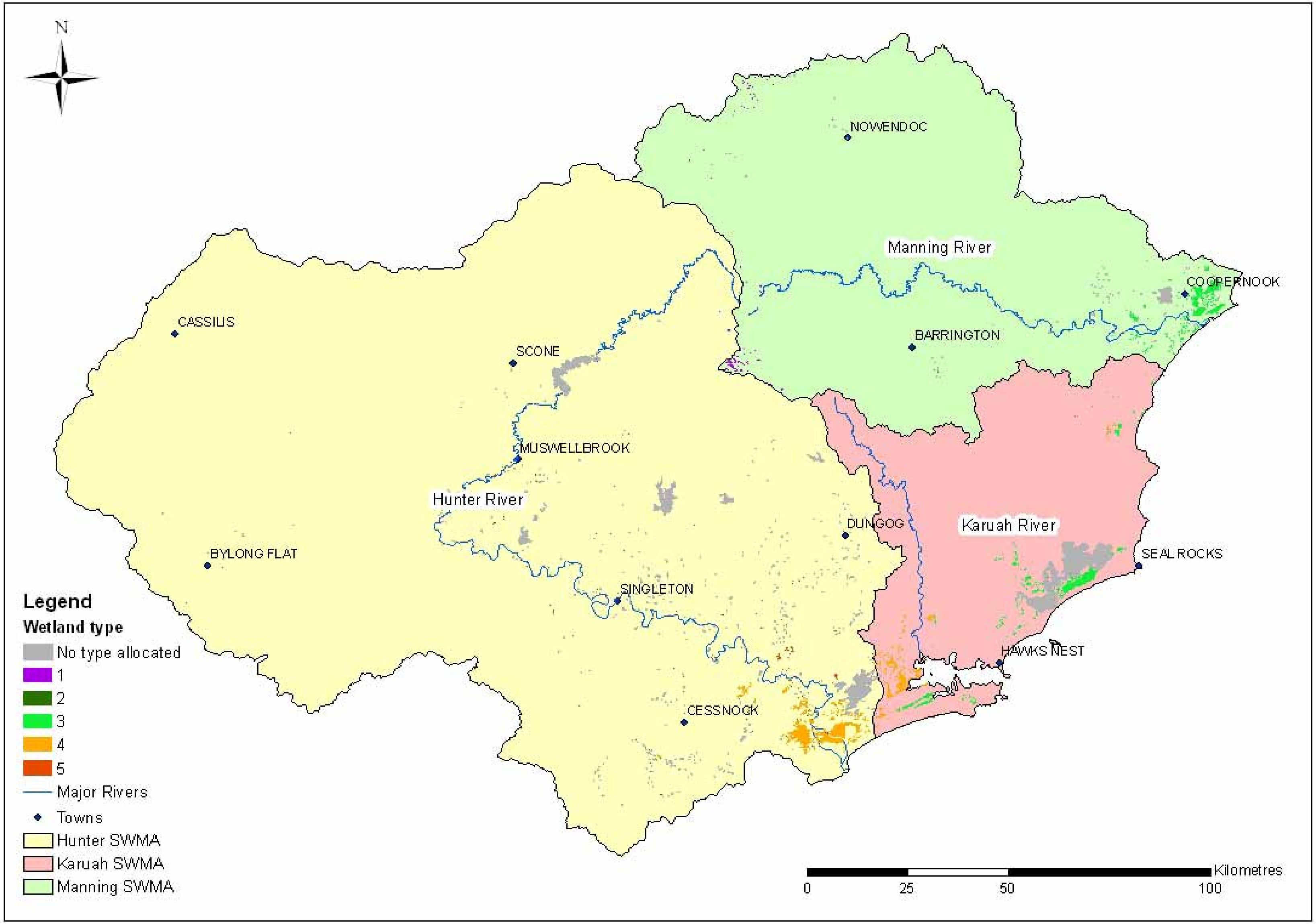

Figure 5: Wetland types (where allocated) and their extent in the Hunter, Karuah and Manning SWMAs and the main channels of the three major rivers (Hunter, Karuah and Manning)

Wetland types represent wetlands with similar physical, climatic and topographical characteristics and were derived using the FANNY algorithm. Large dams and estuarine wetlands have not been allocated a wetland type.

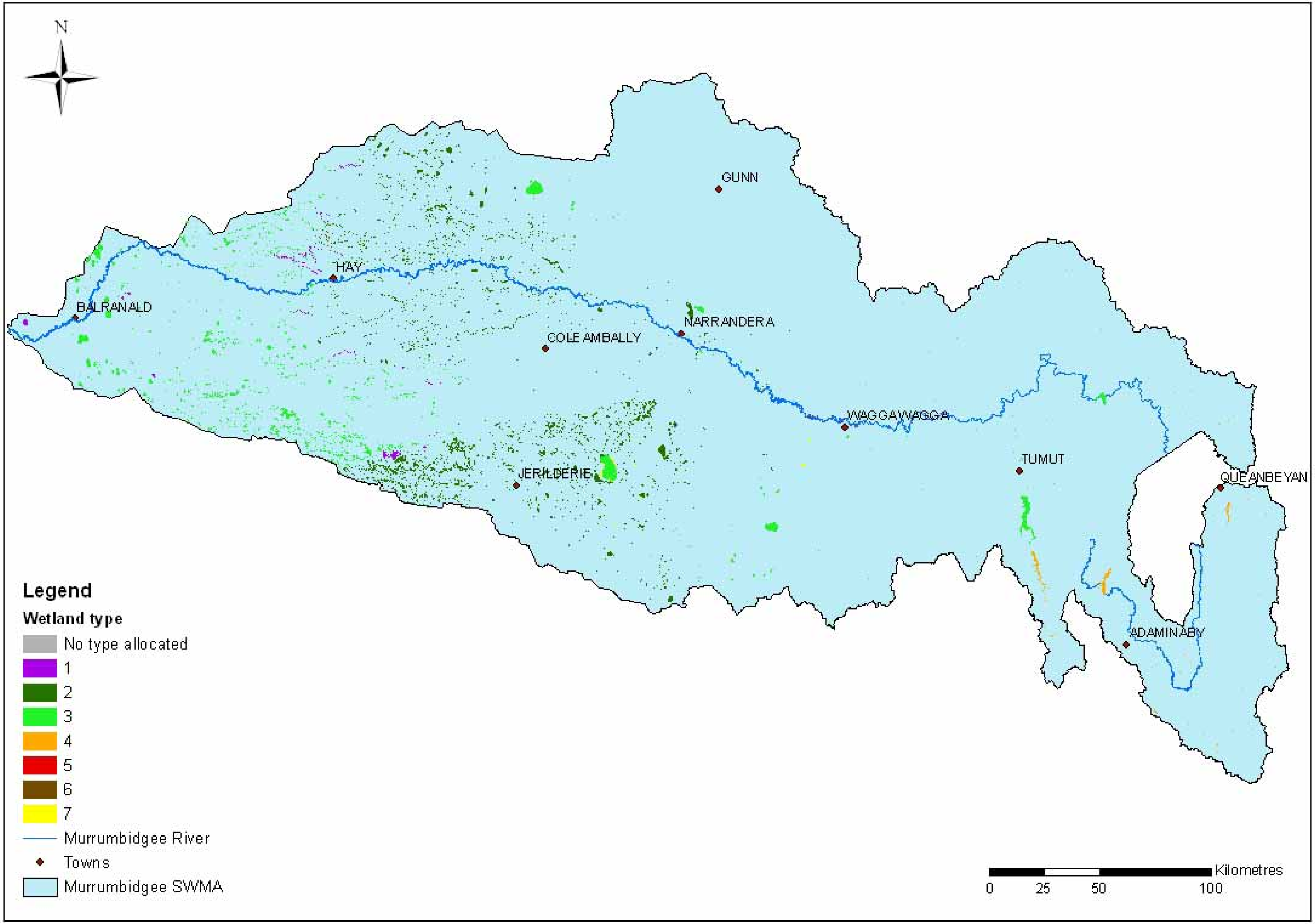

Figure 6: Wetland types (where allocated) and their extent in the Murrumbidgee SWMA and the main channel of the Murrumbidgee River
Wetland types represent wetlands with similar physical, climatic and topographical characteristics and were derived using the FANNY algorithm.

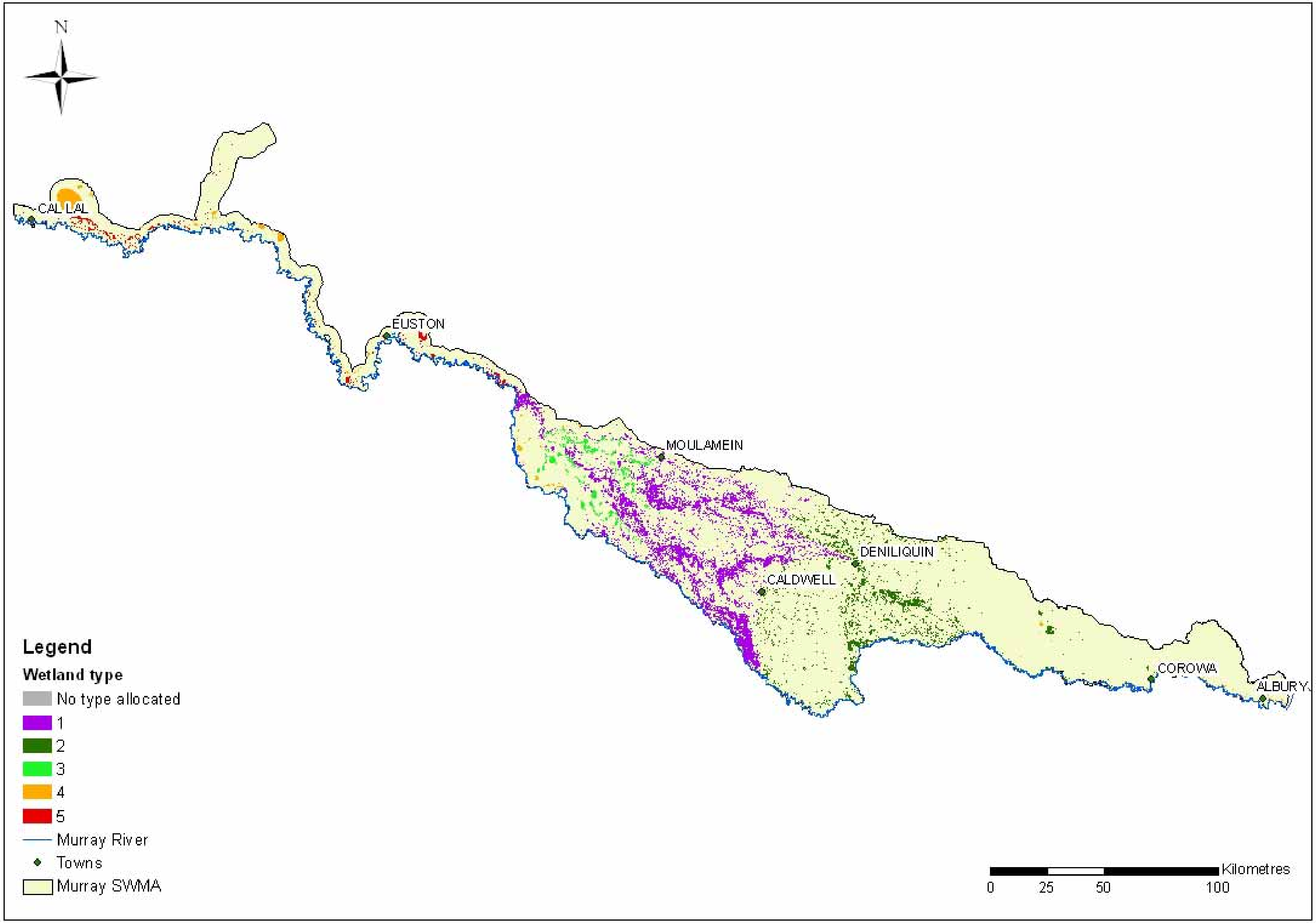

Figure 7: Wetland types (where allocated) and their extent in the Murray SWMA and the main channel of the Murray River
Wetland types represent wetlands with similar physical, climatic and topographical characteristics and were derived using the FANNY algorithm.

Catchment disturbance

The SWMA-scale condition assessments using the WCCI were varied, with the Karuah SWMA assessed as being in the best condition and the Murray and Murrumbidgee SWMAs as being in similar condition and poorer than the eastern SWMAs; however, catchment condition varied among wetland types within each SWMA (Table 5).

Table 5: Catchment condition, number of wetlands assessed and the total surface area covered in the five trial SWMAs reported for the whole SWMA and separately for each wetland type

SWMA	Wetland type	Count	Area (ha)	WCCI
Hunter	1	7	70	0.91
	2	254	655	0.69
	3	1	2	0.75
	4	151	7775	0.69
	5	110	708	0.66
	All	523	9210	0.69
Karuah	2	13	24	0.85
	3	140	3347	0.92
	4	114	2223	0.87
	All	267	5594	0.9
Manning	1	81	902	0.87
	2	21	39	0.81
	3	202	4226	0.78
	4	2	24	0.74
	5	4	10	0.69
	All	310	5200	0.79
Murray	1	5290	77521	0.66
	2	2806	45319	0.61
	3	660	13 577	0.51
	4	455	6138	0.41
	5	744	9273	0.54
	All	10 090	153 488	0.62
Murrumbidgee	1	55	6179	0.66
	2	4950	77 284	0.59
	3	3131	45 144	0.65
	4	359	2863	0.73
	5	348	455	0.61
	6	16	402	0.60
	7	109	1144	0.59
	All	9345	133 487	0.62

Fringing zone

The condition of the fringing zone measured, using the FZSI, also varied greatly among the SWMAs (Table 6), with wetlands in the Murrumbidgee assessed as having very low FZSI values and those in the Karuah as having high values. Assessments were made, first using single regional reference wetlands for the whole SWMA, and then using reference wetlands for each type separately. The number of wetlands assessed for each type and the total surface area of these are also given.

Table 6: FZSI value reported separately for wetland types

SWMA	Type	Wetlands	Area (ha)	FZSI (regional reference)	FZSI (type specific reference)
Hunter	1	7	70	0.88	0.9
	2	242	621	0.66	0.69
	3	1	2	0.12	0.11
	4	133	5376	0.48	0.48
	5	105	694	0.38	0.61
	All			0.49	
Karuah	2	13	24	0.67	0.71
	3	131	2898	0.87	0.87
	4	107	2073	0.87	0.86
	All			0.87	
Manning	1	78	884	0.63	0.64
	2	21	39	0.4	0.45
	3	175	2875	0.5	0.49
	4	2	24	0.45	0.45
	5	4	10	0.33	0.62
	All			0.53	
Murray	1	5290	77 521	0.40	
	2	2806	45 319	0.38	
	3	660	13 577	0.25	
	4	455	6138	0.24	
	5	744	9273	0.28	
	All	10090		0.36	
Murrumbidgee	1	39	6179	0.20	
	2	3683	77 284	0.10	
	3	2085	45 144	0.13	
	4	358	2863	0.34	
	5	111	455	0.32	
	6	16	402	0.17	
	7	83	1144	0.04	
	All			0.12	

When the condition of the fringing zone was assessed separately for each wetland type there was considerable variation among the types (Table 6). In the Hunter, Karuah and Manning SWMAs, for most wetland types there was little difference between using the regional reference condition and the type-specific reference condition, but the difference was very large in one SWMA (Hunter) for wetland type 5. In the Murrumbidgee and Murray SWMAs, using a reference value was not possible because woody vegetation cover was too variable and too low (median values of 0.16 for Murrumbidgee and 0.41 for Murray) to meaningfully assign a value. This probably reflects the large amount of clearing that has taken place in these regions, as well as the result of some climatic variability. For example, in more arid areas the fringing zone would be expected to have less woody vegetation that in other areas.

Water quality

Because of the very small number of water quality assessments in the Karuah, Manning and Hunter SWMAs, aggregations for the WWQI were made for all three SWMAs (Table 7). Meaningful type-specific assessments of the WWQI were possible only in the Murrumbidgee SWMA, where there were water quality sites in wetlands from five types. However, type 7 included only two water quality sites, so this result is probably not very useful. In the Hunter region (Hunter, Karuah and Manning SWMAs), type 1 and 4 had results for just one wetland each, with all other results being from 11 wetlands in type 3.

The overall water quality condition was highest in the Hunter, Karuah and Manning SWMAs, with the Murray having a slightly lower value. The lowest aggregated WWQI was in the Murrumbidgee, where there was substantial variation among the type-specific assessments.

Table 7: WWQI for different types of wetlands in Hunter, Karuah and Manning SWMAs

SWMA	Wetland type	Count	Area (ha)	WWQI
Hunter, Karuah and Manning	1	1	66	0.57
	3	11	1300	0.56
	4	1	6	0.33
	all	13	5333	0.58
Murray	1 (all)	26	500	0.50
Murrumbidgee	2	43	1645	0.29
	3	23	2221	0.40
	4	11	26	0.53
	5	5	17	0.22
	7	2	2	0.19
	all	84	3910	0.36

Integration of themes

When the results for the three themes were combined to obtain integrated results for the trial SWMAs, represented by the WCI, the wetlands in the Karuah SWMA were shown to be in the best condition and those of the Murrumbidgee to be in the poorest (Figure 8).

The aggregated results for each theme and wetland type in the five trial SWMAs (Figures 9–13) show the influence of the different themes and wetland types on the overall assessments in Figure 8. For example, the poor condition of the Murrumbidgee SWMA appears to be greatly influenced by water quality and fringing zone condition, for which some wetland types within this SWMA had extremely low values (Figure 9).

Figure 8: The WCI representing the integrated wetland condition assessments for the five trial SWMAs

The WCI was calculated by taking the mean of the three condition indices WCCI, FZSI and WQI.

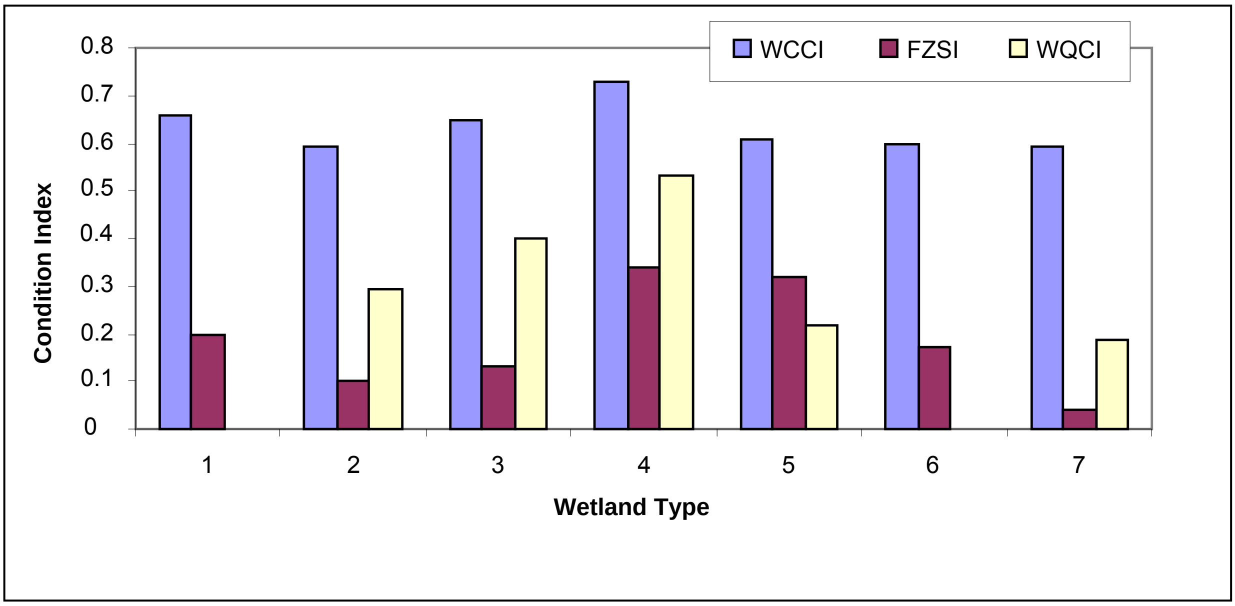

Figure 9: Condition assessments for each wetland type in the Murrumbidgee SWMA using the three condition indices WCCI, FZSI and WWQI

The Murray SWMA, which showed similar catchment condition values to the Murrumbidgee SWMA, was assessed as having much better water quality and slightly better condition than the fringing zone (Figure 10).

Because all water quality sites in the Murray SWMA were confined to wetland type 1, which had the least disturbed catchments, the aggregated water quality assessments may be an overestimate of the water quality of wetlands in the Murray SWMA, and this could be a major influence on the magnitude of the differences in the integrated catchment-wide, wetland health assessments given for the Murray and Murrumbidgee SWMAs in Figure 8.

The very low results for the fringing zone condition observed in the Hunter SWMA (Figure 11) is misleading because it represents a single wetland. The overall influence of the three themes on results and variation among wetland types for the Hunter SWMA (Figure 11) and Manning SWMA (Figure 12) seems quite similar.

The Karuah, however, is distinguished from the other SWMAs by having very high values for the fringing zone condition, which for wetland type 4 equalled the catchment disturbance value (Figure 13). This contrasts with the results for all other SWMAs and wetland types in this trial, because they consistently have much higher values for catchment condition compared with fringing zone condition.

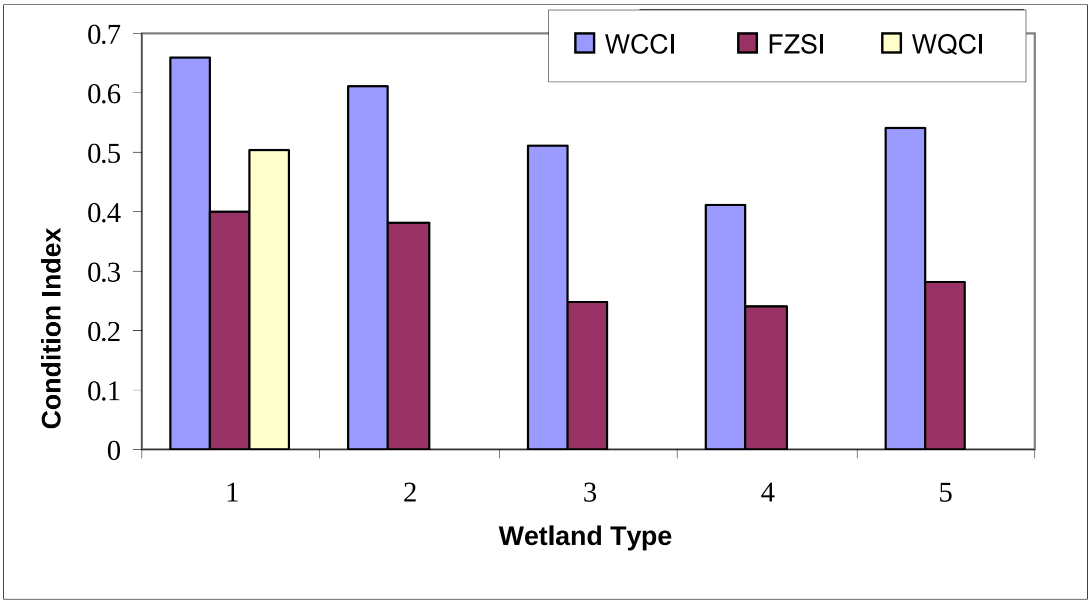

Figure 10: Condition assessments for each wetland type in the Murray SWMA using the three condition indices WCCI, FZSI and WWQI

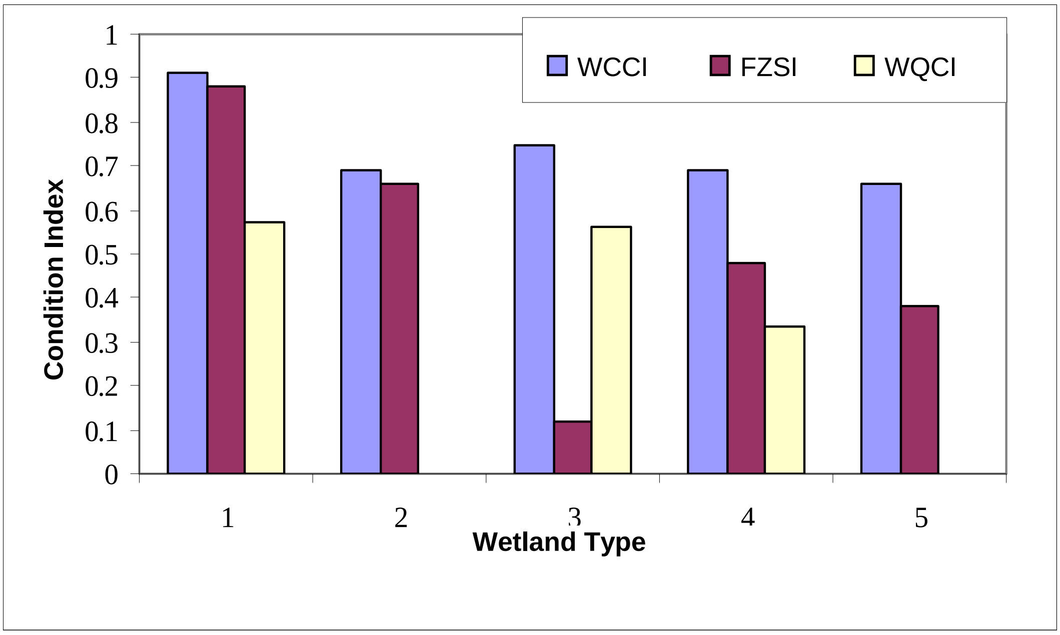

Figure 11: Condition assessments for each wetland type in the Hunter SWMA using the three condition indices WCCI, FZSI and WWQI

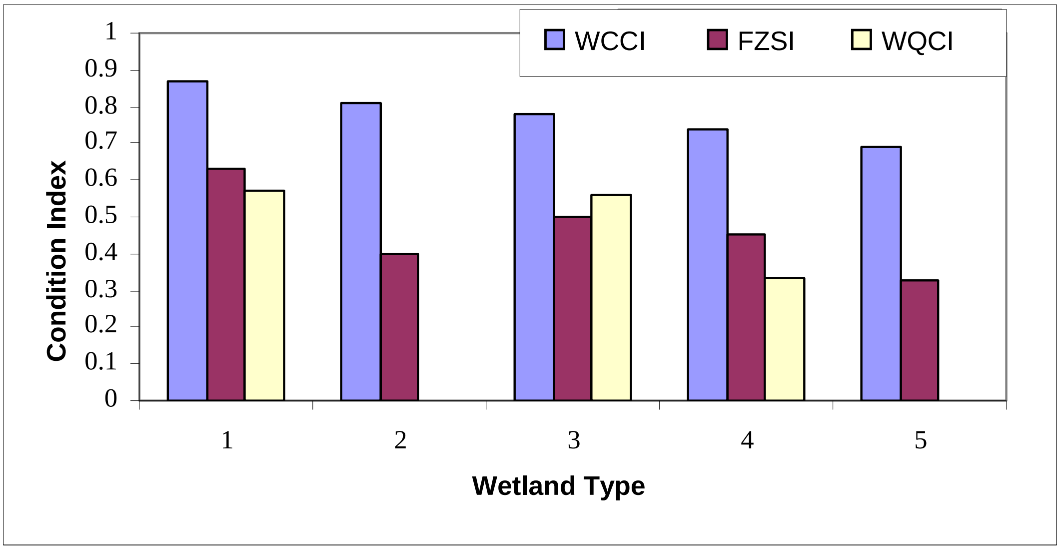

Figure 12: Condition assessments for each wetland type in the Manning SWMA using the three condition indices WCCI, FZSI and WWQI

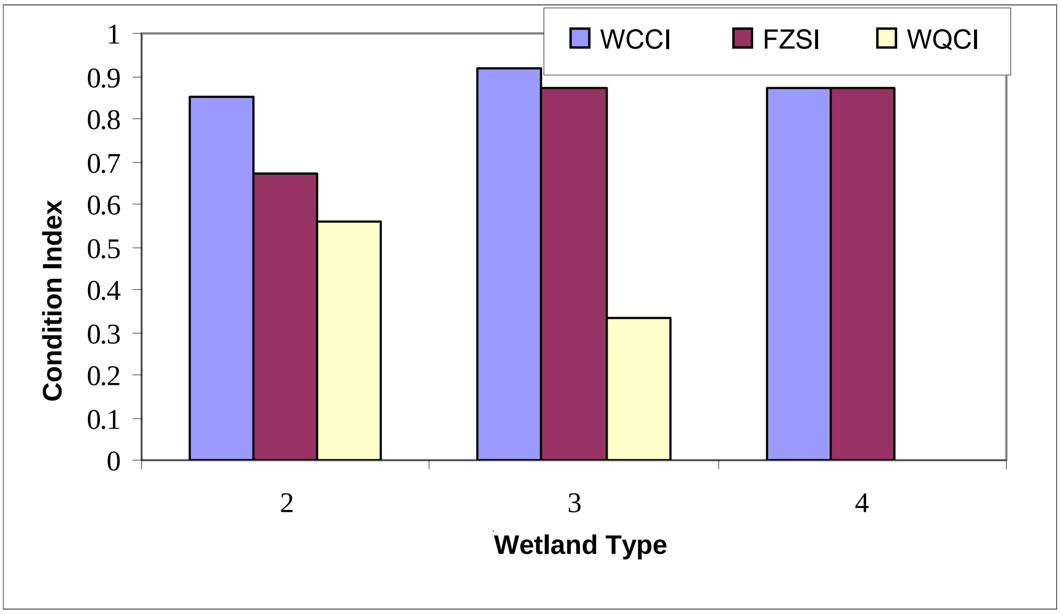

Figure 13: Condition assessments for each wetland type in Karuah SWMA using the three condition indices WCCI, FZSI and WWQI

Spatial scales of aggregation and reporting

Outputs were generated through aggregation at two levels of finer spatial scales for the Hunter SWMA for FZSI (Figures 14 and 16) and WCCI (Figures 15 and 17) and one level at a finer scale for the Karuah, Manning, Murrumbidgee and Murray SWMAs. These showed that the magnitude of variation in the value of the aggregated condition indices depended on both the index in question and on the SWMA.

Within the Hunter SWMA, the fringing zone condition of wetlands varied considerably for the different spatial scales examined: the entire SWMA, large subcatchment resolution and small subcatchment resolution (Table 6, Figures 14 and 16). The catchment condition appears to vary considerably less across spatial scales (Figures 15 and 17).

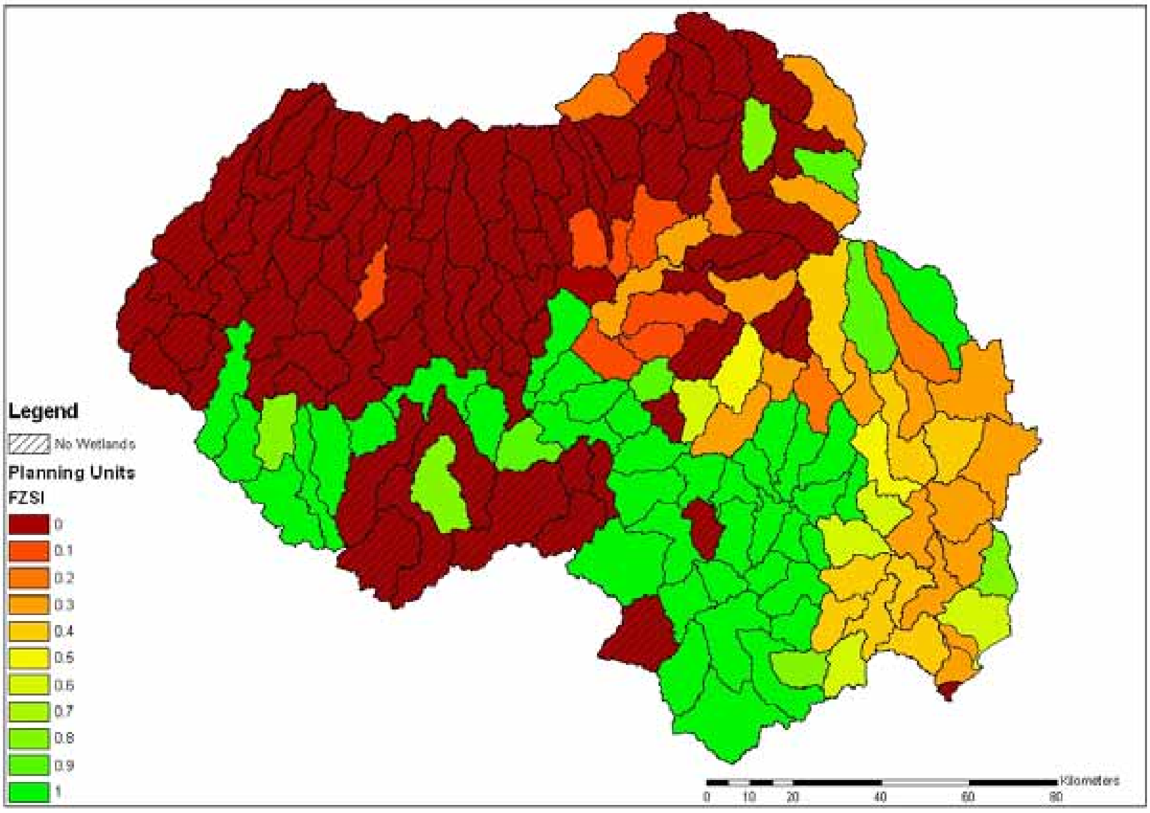

Figure 14: FZSI for 172 small subcatchments used for water planning in the Hunter SWMA

FZSI represents the proportion of wetland fringing zone containing woody vegetation, where a value of 0 indicates an absence of woody vegetation in the fringing zone, and a value of 1 indicates a fringing zone with close to 100% woody vegetation. Wetland FZSI values were averaged for each subcatchment, and subcatchments containing no wetlands are indicated with diagonal hatching.

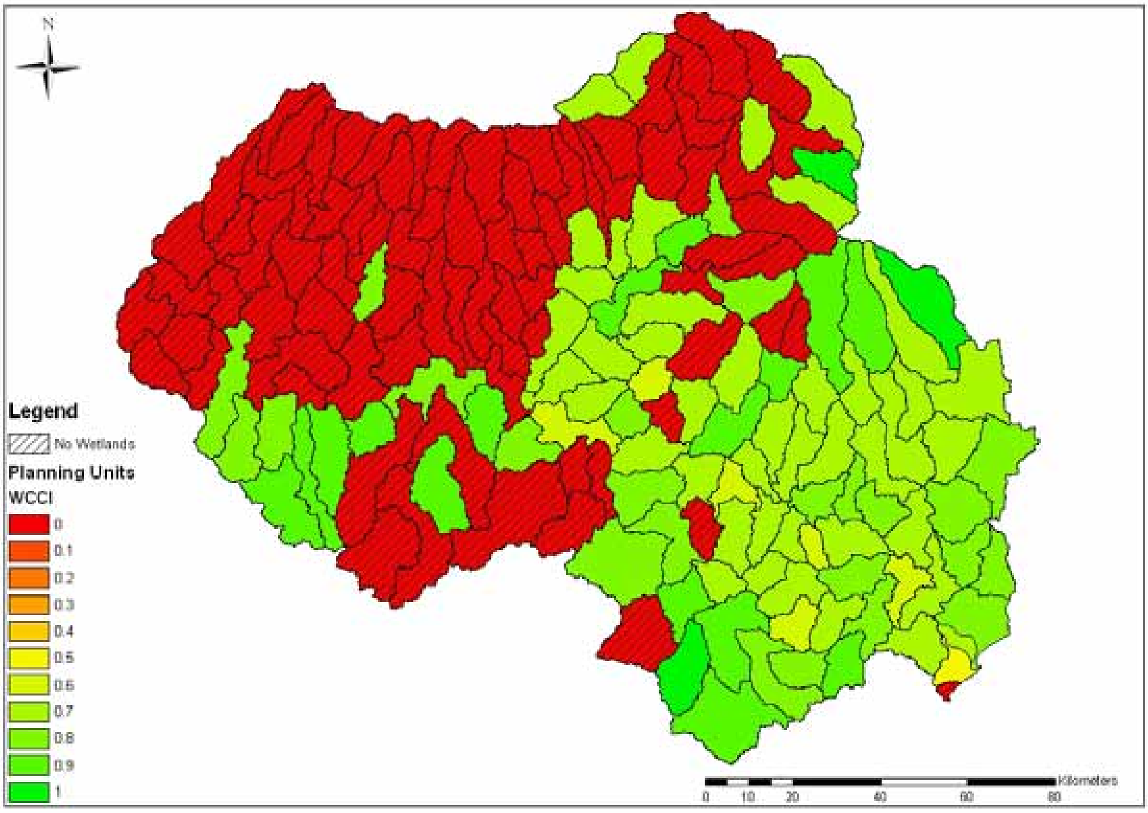

Figure 15: WCCI for the 172 small subcatchments used for water planning in the Hunter SWMA

WCCI represents the condition of a wetland's catchment, where a value of 0 indicates a highly disturbed catchment and a value of 1 indicates a minimally disturbed catchment. Wetland WCCI values were averaged for each subcatchment, and subcatchments containing no wetlands are indicated with diagonal hatching.

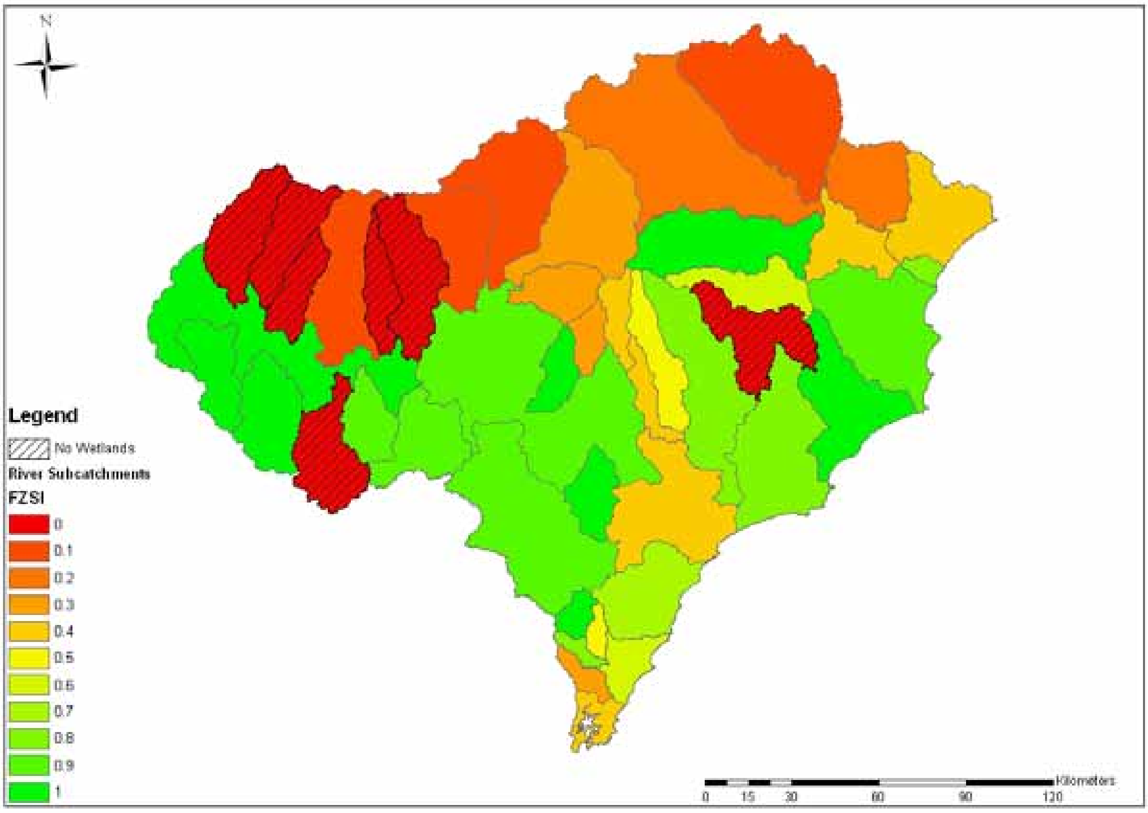

Figure 16: FZSI for the large subcatchments in the Hunter Karuah and Manning SWMAs

FZSI represents the proportion of wetland fringing zone containing woody vegetation, where a value of 0 indicates an absence of woody vegetation in the fringing zone, and a value of 1 indicates a fringing zone with close to 100% woody vegetation. Wetland FZSI values were averaged for each subcatchment, and subcatchments containing no wetlands are indicated with diagonal hatching.

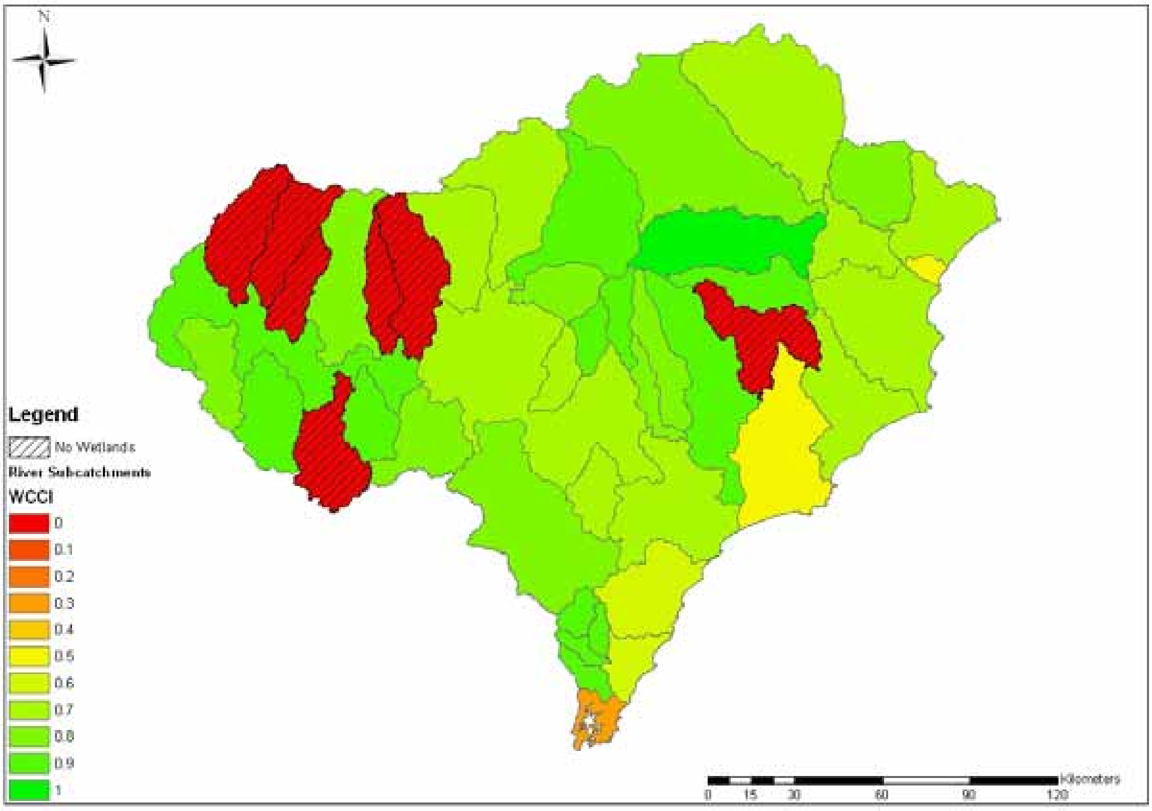

Figure 17: WCCI for large subcatchments in the Hunter, Karuah and Manning SWMAs

WCCI represents the condition of a wetland's catchment, where a value of 0 indicates a highly disturbed catchment and a value of 1 indicates a minimally disturbed catchment. Wetland WCCI values were averaged for each subcatchment, and subcatchments containing no wetlands are indicated with diagonal hatching.

Within the Murray and Murrumbidgee SWMAs, however, a distinction between the magnitude of variation in the condition of the fringing zone and catchment was not evident (Figures 18–21). Within both SWMAs and for both themes, a small number of subcatchments showed very different values from the remainder which varied within a very small range.

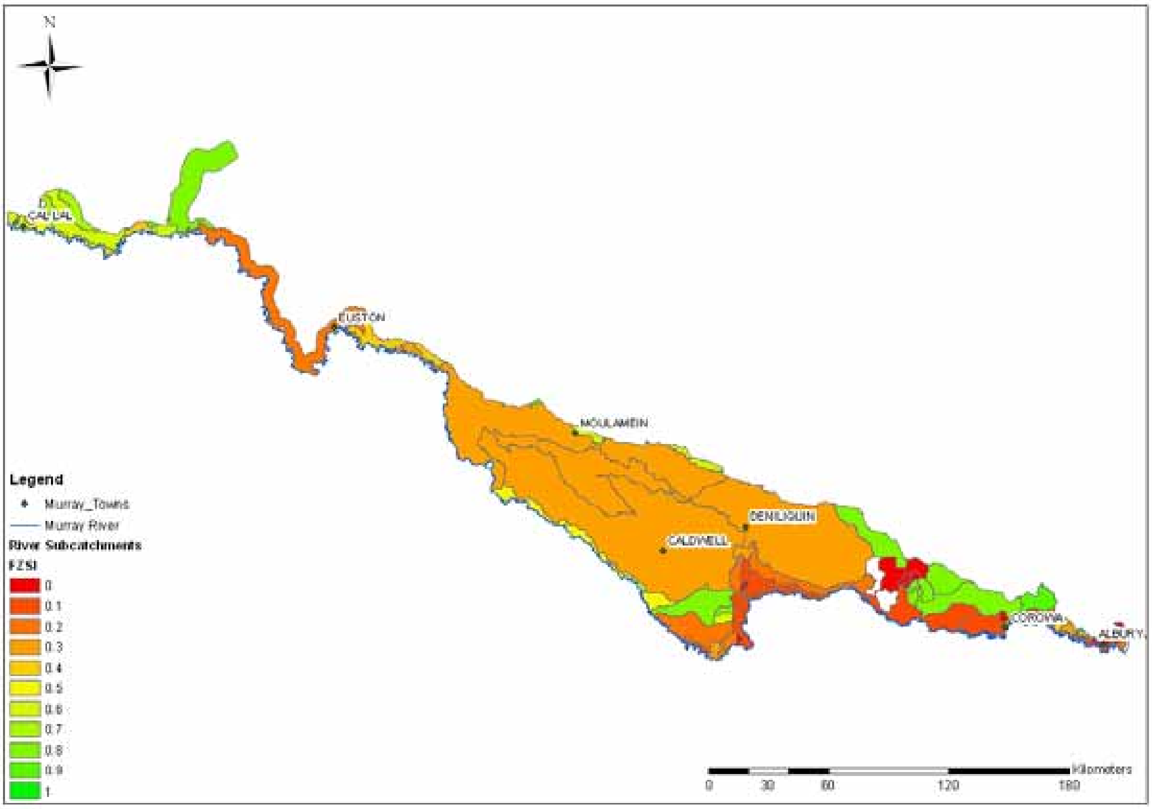

Figure 18: FZSI for subcatchments of the Murray SWMA

FZSI represents the proportion of wetland fringing zone containing woody vegetation, where a value of 0 indicates an absence of woody vegetation in the fringing zone, and a value of 1 indicates a fringing zone with close to 100% woody vegetation. Wetland FZSI values were averaged for each subcatchment, and subcatchments containing no wetlands are indicated with diagonal hatching.

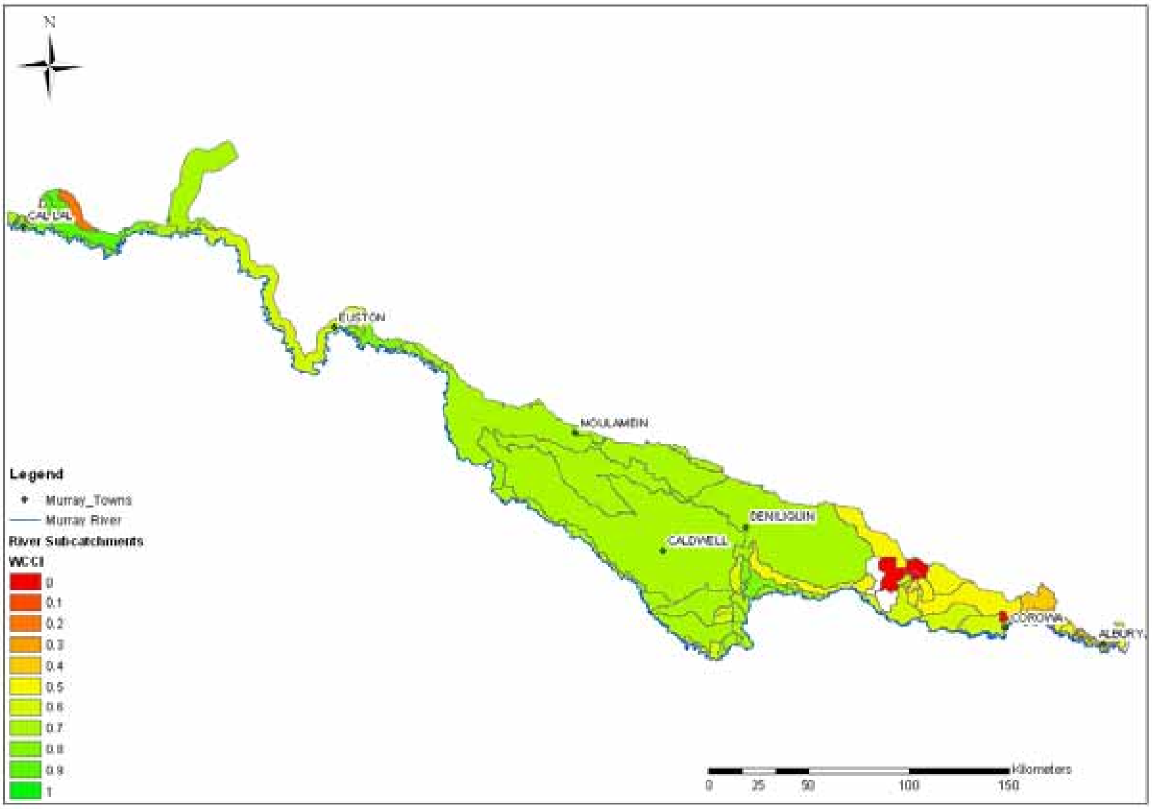

Figure 19: WCCI for subcatchments of the Murray SWMA

WCCI represents the condition of a wetland's catchment, where a value of 0 indicates a highly disturbed catchment and a value of 1 indicates a minimally disturbed catchment. Wetland WCCI values were averaged for each subcatchment, and subcatchments containing no wetlands are indicated with diagonal hatching.

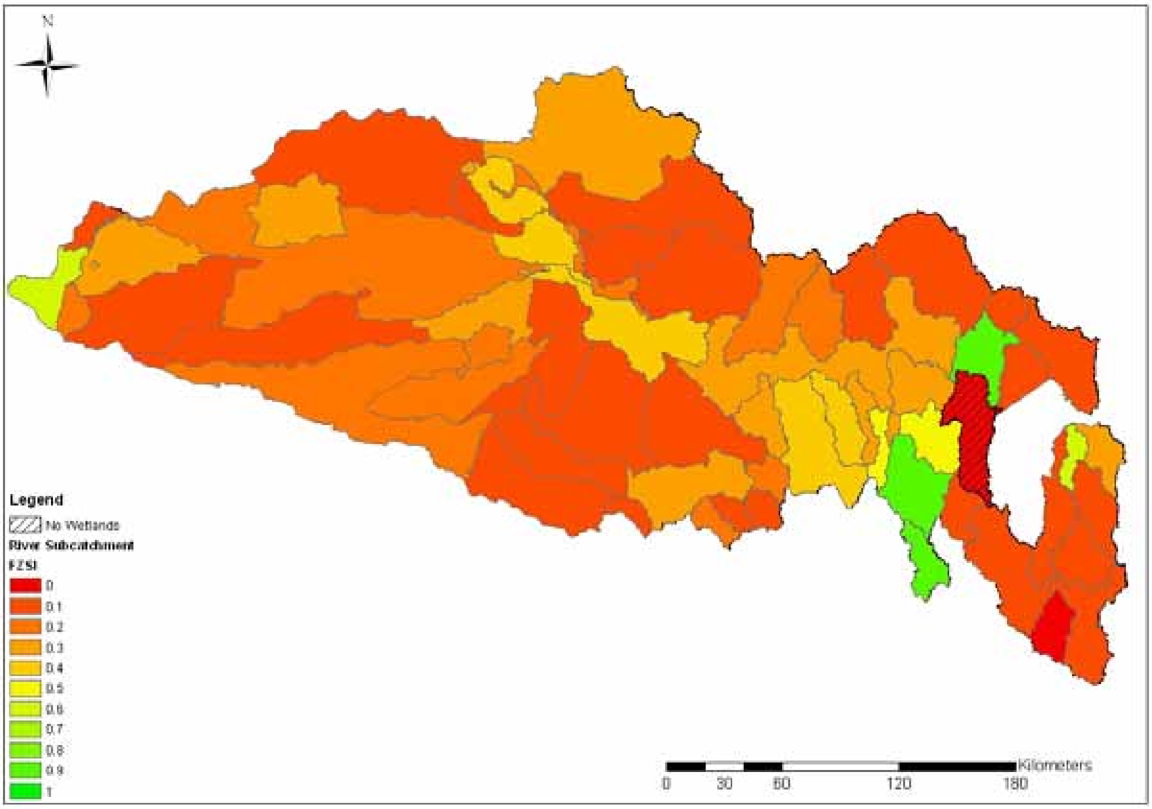

Figure 20: FZSI for subcatchments of the Murrumbidgee SWMA

FZSI represents the proportion of wetland fringing zone containing woody vegetation, where a value of 0 indicates an absence of woody vegetation in the fringing zone, and a value of 1 indicates a fringing zone with close to 100% woody vegetation. Wetland FZSI values were averaged for each subcatchment, and subcatchments containing no wetlands are indicated with diagonal hatching.

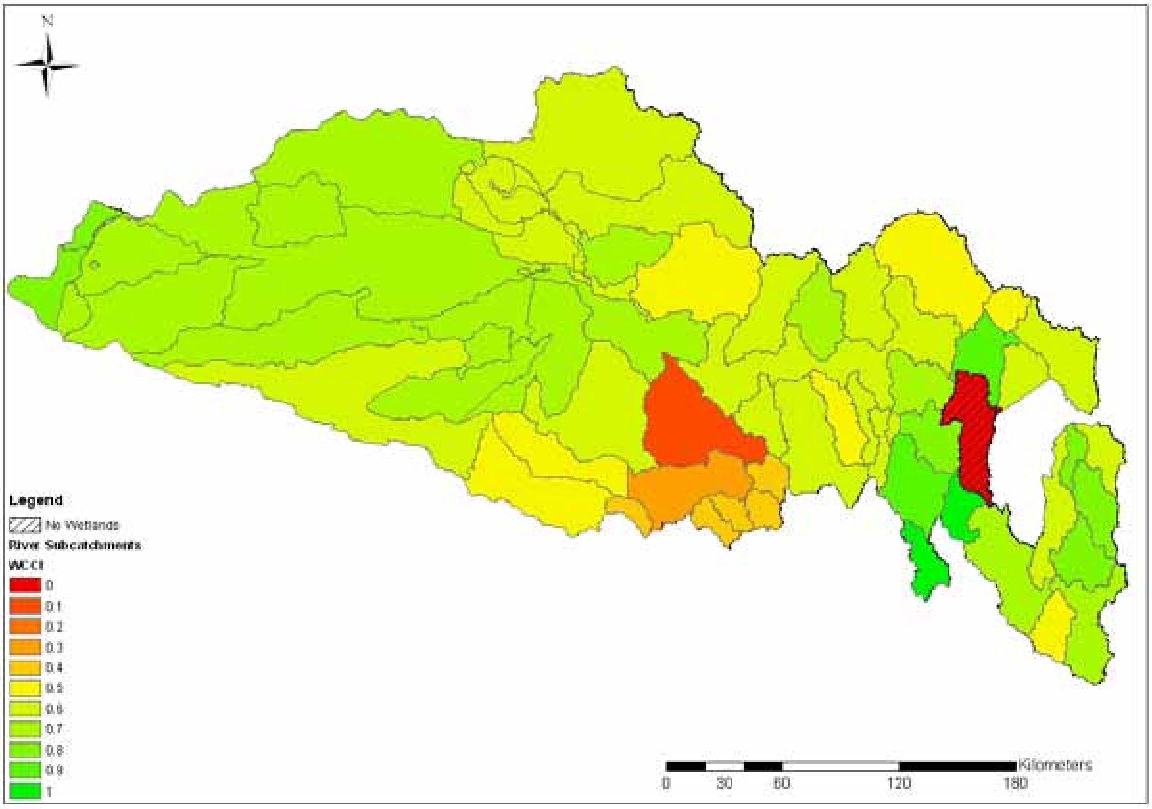

Figure 21: WCCI for subcatchments of the Murrumbidgee SWMA

WCCI represents the condition of a wetland's catchment, where a value of 0 indicates a highly disturbed catchment and a value of 1 indicates a minimally disturbed catchment. Wetland WCCI values were averaged for each subcatchment, and subcatchments containing no wetlands are indicated with diagonal hatching.

Geodatabase and applications

Geodatabase development

All spatial data generated as part of the FARWH trial is stored in a geodatabase and will be kept in the OEH *Spatial data catalogue*[3] which maintains metadata, access, licensing and storage information.

The geodatabase includes the following spatial data:

- spatial extent of wetlands identified as part of the FARWH trial in the Hunter, Karuah, Manning, Murray and Murrumbidgee SWMAs, including unique identifiers for each wetland polygon
- wetland types, derived for each SWMA, attributed to every wetland for which they were assigned
- WCCI, attributed to every spatial unit (subcatchment) within each of the five SWMAs and every wetland for which it was calculated
- FZSI, attributed to every spatial unit (subcatchment) within each of the five SWMAs and for every wetland for which it was calculated
- WWQI, attributed to every wetland for which it was calculated
- NSWVCA (NSW Vegetation and Classification project) classification of wetland plant communities attributed to individual wetlands where it is available.

This spatial data can be viewed, interrogated and combined with other data sources, using GIS software.

Applications

The FARWH trial geodatabase is a starting point for communication of FARWH assessments for wetlands across NSW. The spatial data can be used by the NWC alongside other state-level FARWH trials while reviewing the results of the FARWH trial at a national level. The datasets could also be used to compare with future-condition assessments to assess change in wetland condition or extent.

At a regional level, the datasets for each SWMA may be used by water and catchment managers to help in spatially prioritising resources, to inform location and stratification of future field assessments or monitoring programs, or to provide baseline data for regional wetland condition assessments. Data relevant to catchment managers of Hunter–Central Rivers, Murrumbidgee and Murray CMAs was generated during the trial.

Implementation plan for the assessment of wetland health

An implementation plan has been developed outlining the necessary tasks that must be completed before FARWH can be used to generate useful broadscale assessments of wetland health in NSW. The steps recommended for implementing consistent assessments of wetland health in NSW that meet FARWH requirements are represented by the specific tasks listed in Table 8. The context for these tasks, including the strengths and limitations of the current trial, are discussed in the following Discussion and Conclusions.

[3] http://mapdata.environment.nsw.gov.au/DDWA/

Table 8: Tasks that need to be completed under the implementation plan and the resources required

Task		Cost and explanation
1	Extension of the wetland mapping procedure developed during this trial to all SWMAs in NSW.	$100 000, 1 EFT
2	Ground validation of wetland maps and their refinement, based on the results obtained.	$100 000, 2 x 0.3 EFT + vehicle and other field expenses
3	Refinement of the wetland typology developed in this trial. Ideally the typology should be linked to hydrogeomorphic wetland classifications.	$30 000, 0.3 EFT
4	Typing of all mapped wetlands across NSW.	$20 000, 0.2 EFT
5	Development of rapid biological assessment protocols for wetland macroinvertebrates and frogs. Drafts of such protocols have recently been developed within OEH in NSW in conjunction with the FARWH wetlands trial, but the protocols are yet to be tested in the field.	$240 000: Combined with six 2 x 1 EFT + vehicle and other field expenses
6	Collection of water quality data (electrical conductivity, pH and turbidity) and biological data (macroinvertebrates and frogs) from minimally disturbed reference wetlands. Sites would be selected from mapped-validated, wetland polygons stratified by wetland type. The WCCI developed in this trial can be used to select reference wetlands for collecting this data.	See 5 above
7	Development of new water quality indices, a frog integrity index and a macroinvertebrate integrity index for wetlands.	$100 000, 1 EFT
8	Development of a statewide wetland monitoring program, using a stratified random sampling design where stratification is based on wetland types, and random selection of sampling sites on validated wetland maps. Data collected from pilot trials can be used to determine minimum sample size needed from each wetland type within each SWMA for the sampling program.	$300 000–$500 000, each sampling round repeated every 3 years, 2–4 EFT + field expenses

Discussion

This trial of the FARWH for NSW wetlands has generated recommendations for setting up wetland health monitoring programs in NSW and other parts of Australia. However, there were some major constraints in this trial that can probably be addressed only by research and basic method development.

In this trial we addressed the three themes for which there was sufficient prior-method development and for which some data was available. There were two main reasons for excluding the other themes from the trial. The biota theme was not attempted because there were no suitable datasets to work with, even though there was a suite of methods that could be applied (see Norris et al. 2007). In contrast, physical form and hydrology were excluded because there were no methods that could be applied readily, even though both themes offered the possibility of making assessments from available, remotely derived data. There is no doubt that hydrology has a critical influence on the condition of wetland ecosystems, and obtaining assessments for that theme would be a high priority in any statewide or national program. Early investigations in the trial, however, made it clear that development of this theme alone would require resources well beyond what was available for the trial. It would require an integration of groundwater flow models, streamflow models and runoff models to address processes affecting all wetlands, including those that are fed primarily by rainwater, groundwater or river flows. Data availability may not be a major constraint for such an exercise due to increasingly accessible, remotely sensed data and emerging analysis techniques (Gondwe et al. 2010). Similarly, hydrological modelling techniques have made major advances (e.g. Littleboy et al. 2009). However, the integration of various models to produce hydrological-disturbance assessment methods, based on suitable reference conditions that can be applied to all wetland types, is a major task and would require substantial resources.

This trial explored how broadscale wetland assessments might vary if applied to individual wetland types instead of all wetlands. This required the assignment of a wetland type to each of the wetland polygons, which we achieved by generating a bottom-up typology based on morphological attributes that could be derived remotely within the resource and time constraints of the project. The results clearly showed that the catchment-wide patterns in condition are likely to vary greatly among wetland types. The Australian National Aquatic Ecosystem (ANAE) classification (Auricht 2010) may provide an alternative way of quickly assigning wetland types to the mapped polygons, but this work is still under development and was not available for application during the trial.

One of the important shortcomings of the trial was that the existing and substantial methodology used to assess the condition of individual wetlands in Australia could not be applied. The most developed of these is the Victorian Index of Wetland Condition (DSE 2005), which is assessed through in situ observations made at individual wetlands using rigorous assessment protocols. The lack of such data for the wetlands of NSW necessitated a very different approach for the trial. Broadscale assessments of wetland health based on field observations require a substantial commitment of resources and time. This is because the number of wetlands that should be sampled, and the sampling frequency required to fully account for differences among wetland types and temporal variability, is likely to be very large and thus prohibitively costly. It may be possible to extrapolate data collected from a smaller subset to unsurveyed wetlands using remotely derived data, but there has not been sufficient progress in modelling methods to achieve this in the near future.

This trial was unable to directly address wetland loss. This is because FARWH does not explicitly incorporate the assessment of ecosystem extent although, intuitively, there is likely to be a significant correlation between historic wetland loss and catchment disturbance. Direct measures of wetland extent are needed so that activities that lead to the restoration of wetlands (and hence an increase in extent) or their loss can be considered alongside those that improve or degrade wetlands to provide a more complete assessment of wetland management across planning regions. The mapping generated as part of the FARWH trial provides a high-resolution snapshot of wetland extent in the five SWMAs as at 2008. This data could be used with appropriate methodology to track wetland-extent change and wetland loss in these areas.

Conclusions

This is the first trial of the FARWH for wetlands in Australia and was resourced only for processing existing data, with no possibility of catchment-scale collection of field data. Hence our recommendations for a wetland health assessment program in NSW and elsewhere were dependent on the available data, its quality, and the outcomes of the trial application of the FARWH approach to this data. Our trial has demonstrated that there is still much to be done in terms of data collection and the development of concepts and methods before an adequate wetland health assessment program can be developed that meets the requirements of FARWH. The trial has generated outputs for only three of the six FARWH themes. This is the minimum number of themes required for reporting under FARWH, and it would be imprudent to proceed with such reporting at this stage because there is not enough evidence to show that reliable assessments can be obtained for these three themes, even if better data was available. However, in the course of this trial we have taken major steps towards integrating wetland assessments into FARWH. The key outcomes are as follows:

- **Wetland mapping methods that can be applied across Australia with limited resources.** We applied these to five SWMAs across NSW.
- **Procedures for selecting reference wetlands, using catchment-disturbance assessments and development of regional wetland classifications, using remotely derived data.** We applied these in the five trial SWMAs. These reference wetlands provide obvious locations for new wetland monitoring programs in the five SWMAs, including biological monitoring programs, which would generate the data needed for the biota theme to be added to wetland assessments under FARWH.
- **Methods for estimating catchment disturbance and fringing zone condition.** We applied these to the five SWMAs.
- **A process for assessing the adequacy of water quality data from wetlands.** Together with the selection of reference wetlands and the wetland typology this provides a strong foundation for water quality monitoring in wetlands across NSW.
- **Demonstration of the importance of type-specific reporting of wetland condition and a framework for achieving this.** This was done using a bottom-up typology developed through numerical classification of wetlands, based on their physical attributes. This typology can readily be replaced by alternative typologies such as the ANAE classification (Auricht 2010).

This trial has highlighted some major obstacles faced in the broadscale assessments of wetland condition in NSW and other parts of Australia. Probably the most significant of these is the lack of comprehensive mapping and changes in wetland extent. Another major obstacle is the absence of consistently collected biological data from wetlands. Because of this, the type of broadscale assessments of biological condition now possible for rivers in all Australian states and territories cannot yet be performed for wetlands in NSW. The dearth of suitable water quality data from wetlands also presents a major obstacle. Only a fraction of the extensive water quality data available in NSW was of any use for wetland assessments, and those were generally clumped in a small number of wetlands, leaving very large gaps in the geographic distribution of observations.

This trial has provided a basis for addressing some of these gaps efficiently, and an implementation plan has been developed to assess wetland health across NSW. Monitoring programs for biota and water quality, based on random selection of wetlands stratified by the mapped wetland types, could be initiated immediately in the five SWMAs. Completion of the mapping for all other SWMAs and the development of typologies for these areas could also be done relatively quickly. However, the relevance of the typologies developed here for ecological function, the composition of biological assemblages in wetlands and natural resource management is unknown. It would be preferable to either eventually replace these typologies with functional, hydrogeomorphic typologies or link the two classifications.

Glossary

ADS40 imagery	High-resolution imagery acquired using a Leica ADS40 Airborne Digital Sensor.
AWR	Australian Water Resources – the baseline assessment of water resources at the beginning of the National Water Initiative.
CDI	Catchment Disturbance Index
CMA	Catchment management authority – CMAs exist in NSW primarily to enable regional communities to participate in resource management of their catchment.
DEM	Digital Elevation Model – a dataset that provides information about elevation and topographical features across a landscape.
FANNY	Fuzzy cluster analysis
FARWH	The National Framework for the Assessment of River and Wetland Health – developed as part of the Australian Water Resources 2005 project to enable locally relevant, comprehensive assessments of river and wetland health to be comparable across jurisdictions.
FRDI	Flow-regime Disturbance Index
Fringing zone	The immediate zone around the wetland boundary that contains vegetation communities reflecting the influence of continuous or intermittent water.
FZSI	Fringing Zone Structural Index – reflects the proportion of a wetland's fringing zone which is covered by woody vegetation
Geodatabase	A collection of geographic datasets of various types.
Landsat	A series of earth-observing satellites that produce multispectral imagery. Imagery from the Landsat 5 satellite was used for this project.
LiDAR	Light detection and ranging data – uses return times of actively transmitted light to gain high-resolution topographical information about a landscape.
LUF	Landuse Factor
MER	NSW Natural Resources Monitoring, Evaluation and Reporting Strategy.
NWC	National Water Commission, which is responsible for driving progress towards the sustainable management and use of Australia's water resources under our blueprint for water reform – the National Water Initiative. www.nwc.gov.au/www/html/93-roles-and-functions.asp.
NWI	National Water Initiative – Australia's enduring blueprint for water reform. Through it, governments across Australia have agreed on actions to achieve a more cohesive national approach to the way Australia manages, measures, plans for, prices, and trades water. www.nwc.gov.au/www/html/117-national-water-initiative.asp?intSiteID=1
OEH	Office of Environment and Heritage, Department of Premier and Cabinet
RCSI	Riparian Condition Sub-Index
SCDI	Subcatchment Disturbance Index
SPOT 5 imagery	Satellite imagery acquired from Satellite Pour l'Observation de la Terre (SPOT) number 5.
SRTM	Shuttle Radar Topographic Mission – an international research effort to obtain DEMs.
SWMA	Surface water management area – the default spatial scale of assessments and reporting in FARWH, as defined by Norris et al. (2007).
WCCI	Wetland Catchment Condition Index – calculated using local land use, local catchment disturbance and cumulative catchment disturbance data.
WCI	Wetland Condition Index – calculated for each SWMA by taking the mean of the three condition indices (WCCI, WWQI and FZSI).
WWQI	Wetland Water Quality Index – calculated using electrical conductivity, pH and turbidity data.

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