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Victoria's wetlands 2009–2011: statewide assessments and condition modelling

Phil Papas and Paul Moloney

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Phil Papas and Paul Moloney

Arthur Rylah Institute for Environmental Research
123 Brown Street, Heidelberg, Victoria 3084

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Arthur Rylah Institute for Environmental Research
Department of Sustainability and Environment
Heidelberg, Victoria

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Department of Sustainability and Environment
PO Box 137
Heidelberg, Victoria 3084
Phone (03) 9450 8600
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Contents

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Summary

Victoria has adopted an integrated approach to the management of rivers, streams, estuaries and wetlands. Condition assessment is an essential part of the management of these systems. Information on condition is used to inform policy, assess risks to the values of rivers, estuaries and wetlands, determine management priorities, set targets and monitor the longer-term trends in condition.

This report presents the findings of an assessment of the condition of Victoria's wetlands. The objectives of the assessment were to:

- evaluate the condition of high-value and representative wetlands
- assess the influence of a range of wetland attributes on wetland condition including climate, water regime, landscape context, water source, wetland phase and land tenure
- identify key threats to the wetlands assessed
- develop and test mathematical models to predict wetland condition using remotely derived variables.

The Index of Wetland Condition (IWC) was developed to assess the condition of Victoria's wetlands in 2005, and was calibrated in 2007. The IWC has 13 variables that measure six aspects (sub-indices) of wetland condition: the wetland catchment, physical form, hydrology, water properties, soils, and biota (see Table below).

Sub-index	Measure
Wetland catchment	1. Percentage of land in different land use intensity classes adjacent to the wetland 2. Average width of the buffer 3. Percentage of wetland perimeter with a buffer
Physical form	4. Percentage reduction in wetland area 5. Percentage of wetland where activities (excavation and landforming) have resulted in a change in bathymetry
Hydrology	6. Severity of change in water regime
Water properties	7. Activities leading to nutrient enrichment to the wetland 8. Evidence of a change in salinity
Soils	9. Percentage and severity of wetland soil disturbance
Biota	Wetland vegetation quality assessment based on: 10. critical lifeforms 11. presence of weeds 12. indicators of altered processes 13. vegetation structure and health

Two statewide assessments of wetland condition using the IWC have been undertaken in Victoria. In total, 827 wetlands have been assessed, which is approximately 6% of the naturally occurring, non-alpine wetlands in the state. The first assessment was made between spring 2009 and autumn

2010 following a period of extended drought. This assessment focused on 587 high-value wetlands, which is 39% of those listed under the Ramsar convention, Directory of Important Wetlands in Australia (DIWA) and high-value wetlands in the Wimmera region (i.e. the Edenhope wetlands). The second assessment was made between spring 2010 and autumn 2011 after a period of widespread and severe flooding. This assessment focused on 240 wetlands, which is 2% of Victoria's naturally occurring non-alpine wetlands. These were selected to represent the range of Victorian wetland types. Future wetland condition assessments are scheduled to be undertaken at eight-year intervals.

Condition of high-value and representative wetlands

Mean overall condition and subindex scores, except for biota, were significantly higher for the high-value wetlands than the representative wetlands. This is most likely because threats and sources of threat were less prevalent or more effectively managed at the high-value wetlands.

Over half (56%) of the high-value wetlands assessed were in good or excellent condition overall and only 14% were in poor or very poor condition. A similar proportion (51%) of representative wetlands were in excellent or good condition, although a considerably larger proportion (25%) were in poor or very poor condition. The number of high-value wetlands in good condition was surprising given that this assessment occurred at the end of a period of unprecedented drought. The results may reflect the resilience of these wetlands to drought, the effectiveness of management interventions, or both. The proportion of wetlands with soils in very poor condition was three times larger in representative wetlands than in high-value wetlands, and the proportion of catchments in very poor condition was twice as great for representative wetlands than for high-value wetlands. However, proportionally fewer representative wetlands had very poor hydrology compared to high-value wetlands. This is because there were many river-fed, high-value wetlands with an altered hydrology and one or more related threat sources.

Condition of wetlands among attributes

At the representative wetlands, a larger proportion of seasonal wetlands were in poor condition, compared to permanent wetlands. Seasonal wetlands are likely to be more exposed and vulnerable to threats than permanent wetlands because they are more accessible and amenable to activities such as grazing and cultivation.

The condition of high-value and representative wetlands (including alpine wetlands) was better on public land than on private land. This again was a likely response to threats, as most threats are less prevalent on public land.

For both high-value and representative wetlands, the condition of those with no water present was significantly poorer than those that contained some water. A *post hoc* examination of subindex condition showed that, of all subindices, biota was the most important factor in these lower overall condition scores. Not surprisingly, it appears that the condition of wetland vegetation was affected by dry conditions.

Wetlands fed by groundwater and local runoff were more likely to be in better condition than those fed by rivers. This is probably because of the high exposure of river-fed wetlands to alterations in hydrology from several sources, such as river regulations and the obstruction of natural inlets and outlets. Wetlands fed entirely or in part by an artificial channel were in poorest condition, but there were few of these wetlands.

Although there was not a simple linear relationship between wetland size and condition, smaller wetlands were more likely to be in poor condition than larger wetlands. This trend was evident for high-value wetlands smaller than 300 ha, and for representative wetlands smaller than approximately 50 ha.

Threats and sources of threat

Over half of the high-value and representative wetlands assessed were subjected to at least one threat. However, threats were more prevalent at representative wetlands than at high-value wetlands. The exception was altered hydrology, where proportionally more high-value wetlands than representative wetlands were affected (see Table below).

Threat	High-value wetlands (% affected)	Representative wetlands (% affected)
Altered hydrology	46	32
Soil disturbance	19	38
Degraded water quality	15	28
Reduced wetland area	14	26
Altered wetland form	6	12

The most prevalent threat sources at high-value wetlands were livestock grazing, driving of vehicles on the wetland, and excavation of the wetland bed. For the representative wetlands the most prevalent were non-point source runoff, livestock grazing, pugging by livestock and feral animals, excavation of the wetland bed, alteration of the flow regime of the water source, and alteration of the topography (e.g. levelling). All threat sources (except two that were uncommon) were two to ten times more prevalent at wetlands on private land than at wetlands on public land.

Modelling wetland condition

Modelling procedures were tested using total IWC condition scores from the high-value and representative wetland assessments and variables that could affect wetland condition (e.g. land use) and be measured remotely for any wetlands on the Wetland 1994 inventory.

None of the models successfully predicted more than 50% of the condition categories of the test data. The modelling results demonstrate that the information contained in the remote sensed variables was not sufficient to classify wetland condition. The relationships between these variables and wetland condition could be too complex and variable among wetlands to enable good predictions. For example, the relationship between wetland catchment land use and wetland condition will be complex because of the influence of the wetland catchment topography and geology, climate, wetland water source and wetland type.

Recommendations for further work

The following recommendations may improve the prediction outcomes:

- Base the modelling on a coarser classification (i.e. poor and not poor). Ensure there are additional wetlands in poor condition included to increase the sample size of this category. These additional wetlands may be obtained from quality-controlled IWC assessments from other programs such as Wetland Tender.
- Use updated spatial data as it becomes available to attribute wetlands.

- Construct models to predict individual subindex scores instead of overall condition. If successful it may be possible to construct an overall condition model from these subindex models.
- Include a variable for wetland type derived from the new Victorian wetland classification system when it has been completed.

1 Introduction

1.1 Victoria's wetlands and threats to them

In Victoria, wetlands are defined as areas, whether natural, modified or artificial, subject to permanent, periodic or intermittent inundation, which hold static or very slowly moving water, and develop, or have the potential to develop, biota adapted to inundation and the aquatic environment (DSE 2005). They can be broadly classed as shallow and temporary or deep and more permanent, and as freshwater or saline. There are more than 12 800 natural wetlands in Victoria, with a total area of more than 530 000 ha (Table 1, Figure 1). They are diverse in nature and include permanent lakes, seasonal lakes, floodplain wetlands, alpine bogs, mangroves, mudflats and seagrass areas. There also at least 3000 artificial wetlands, including farm dams, reservoirs, sewage treatment ponds and saltworks. It is estimated that almost 4000 natural wetlands (201 000 ha) in Victoria have been lost since European settlement (DSE 2007a,b) (Table 1, Figures 1 and 2).

Table 1. Broad wetland types in Victoria, with their land tenure and loss since European settlement.

	Current number and area (% of total)		% of current wetland numbers by tenure (average area)		Number and area lost since European settlement (% lost)	
Wetland type	**Number**	**Area (ha)**	**Public land**	**Private land**	**Number**	**Area (ha)**
Shallow freshwater wetlands	9140 (71%)	168 077 (32%)	19% (53 ha)	81% (10 ha)	3532 (28%)	95 443 (31%)
Deep freshwater wetlands	2303 (18%)	141 126 (26%)	55% (102 ha)	45% (12 ha)	349 (12%)	91 055 (37%)
Saline wetlands	1373 (11%)	221 210 (42%)	44% (349 ha)	56% (14 ha)	44 (3%)	14 676 (7%)
Total	12816	530 413	28% (120 ha)	72% (11 ha)	3925 (23%)	201 175 (26%)

Wetlands are resilient and adaptive but are subject to many threats, particularly altered water regimes caused by changes to the flow regime of their water source, water extraction, water disposal or modifications to wetland inlets and outlets. Other threats include altered physical form (altered wetland form, reduced wetland area), poor water quality (e.g. elevated salinity, nutrients, turbidity), degraded habitats (soil disturbance) and invasive flora and fauna (aquatic and terrestrial) (Table 2).

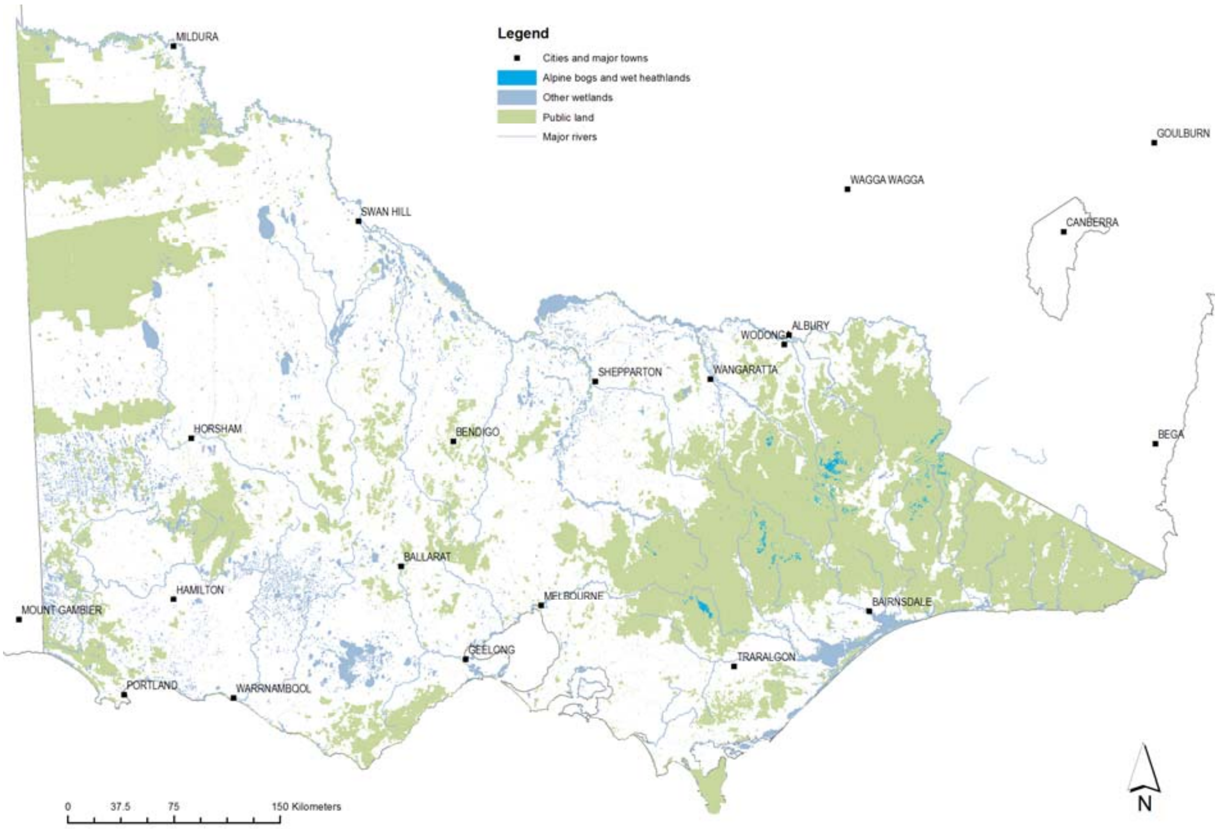

Figure 1. Present-day wetlands in Victoria, based on the Wetland 1994 inventory (DSE 2007a) and the alpine and wet heathland inventory (DSE 2010).

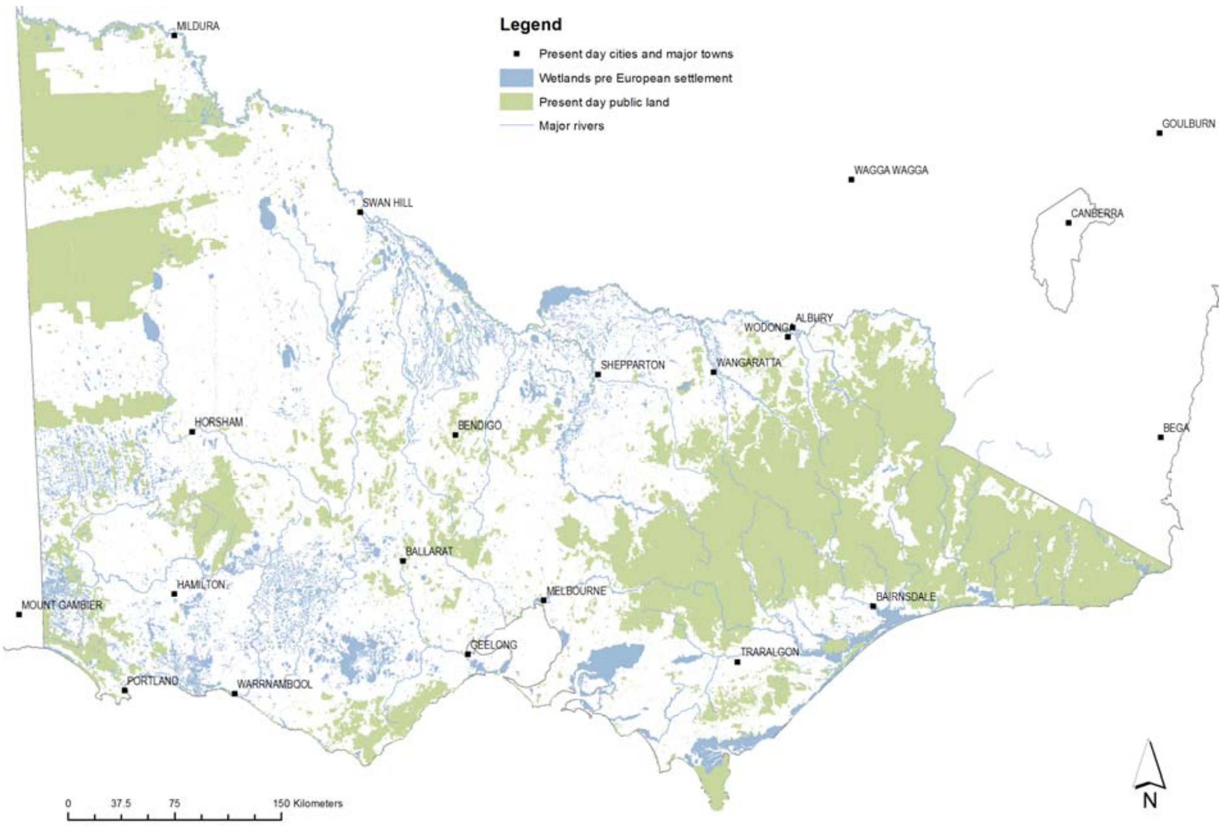

Figure 2. Wetlands in Victoria before European settlement (DSE 2007b).A pre-European map of alpine wetlands is not available.

Table 2. Wetland threats (adapted from Peters 2009).

Threat	Threat source(s)
Changed water regime	River regulation, water extraction for consumptive uses, disposal of water into wetland, wetland drainage or reduced inflows from local catchments or groundwater
Reduced wetland area	Diversion of water source, excavation, filling, levees
Altered wetland form	Excavation, landforming
Degraded water quality	Salinity from raised saline watertables, eutrophication from nutrient-rich runoff, livestock access to the wetland, turbidity from runoff
Soil disturbance	Livestock, invasive fauna (e.g carp, deer, pigs), vehicles, earthworks
Disturbance of acid sulfate soils	Changes to water levels, excavation
Invasive flora in the wetland	Inadequate preventative and/or control measures
Invasive aquatic fauna	Inadequate preventative and/or control measures
Invasive terrestrial fauna	Inadequate preventative and/or control measures

1.2 Wetland condition assessments

Condition assessment is an essential part of the management of rivers, streams and estuaries in Victoria. Information on condition is used to inform policy, assess risks to the values of these systems, determine management priorities, set targets and monitor longer-term trends in condition. Aquatic ecosystem condition assessment in Victoria is undertaken for streams and rivers (statewide assessments performed in 1999, 2004 and planned for 2013 using the Index of Stream Condition), wetlands (statewide assessments in 2009–10 and 2010–11 using the Index of Wetland Condition). Estuary condition assessment is planned (using the Index of Estuary Condition which is under development).

The first assessment of wetland condition was undertaken between spring 2009 and autumn 2010, and focused on Victoria's high-value wetlands. The second assessment was undertaken between spring 2010 and autumn 2011 and focused on wetlands that were representative of broad Victorian wetland types. Only non-marine wetlands were assessed due to the design of the Index of Wetland Condition method which was used to assess condition (see Section 2.2).

This report presents the findings of the condition assessments and specifically:

- evaluates the condition of high-value and representative wetlands
- assesses the influence of a range of wetland attributes on wetland condition including climate, water regime, landscape context, water source, wetland phase and land tenure
- identifies key threats to the assessed wetlands
- develops and tests mathematical models to predict wetland condition using remotely derived variables.

2 Methods

2.1 Site selection

2.1.1 High-value wetlands

Three groups of wetlands were selected as candidates for condition assessments because they have high conservation value and are a priority for management.

They included:

- nine of eleven sites of international importance listed under the Ramsar Convention (Ramsar Convention Secretariat 2006) (the two wholly marine sites were not included)
- 1300 wetlands contained in 29 sites listed in the Directory of Important Wetlands Australia (DIWA) (Environment Australia 2001) (marine and riverine sites were not included)
- the Edenhope wetland complex in the Wimmera region (Figure 3). This complex was included because they are regionally significant, not represented in any Ramsar site and poorly represented in DIWA.

In total, 1500 individual high-value wetlands were identified as candidates for condition assessments and of these, 700 were selected for assessment.

Selection of Ramsar wetlands

Barmah Forest and Gunbower Forest Ramsar sites consist of multiple individual wetlands but were each treated as a single wetland for the purpose of condition assessments (Table 3). To determine their overall condition, they were sub-sampled to take into account their large size and the variety of wetland types within them. Each subsample consisted of a one hectare (100 m × 100 m) plot. The number of plots identified was proportionate to the total area of each Ramsar site, so that 30 plots were located in Barmah and 24 in Gunbower (Table 4). Plots were located along access routes and, where possible, were selected to be representative of wetland categories defined in the current Victorian wetland classification system, commonly referred to as the Corrick system (Corrick and Norman 1976, 1980; Corrick 1981, 1982; see Table 5).

Table 3. Candidate wetlands in Ramsar sites selected for assessment. Ramsar sites which include marine-influenced wetlands are indicated by an asterisk.

Ramsar site	Number of candidate wetlands selected for assessment
Barmah Forest	1 (30 plots)
Edithvale–Seaford Wetlands	2
Hattah–Kulkyne Lakes	12
Gippsland Lakes*	8
Gunbower Forest	1 (24 plots)
Kerang Lakes	23
Lake Albacutya	1
Corner Inlet*	0
Port Phillip Bay and Bellarine Peninsula*	1
Western Port*	0
Western District Lakes	9
Total	**58**

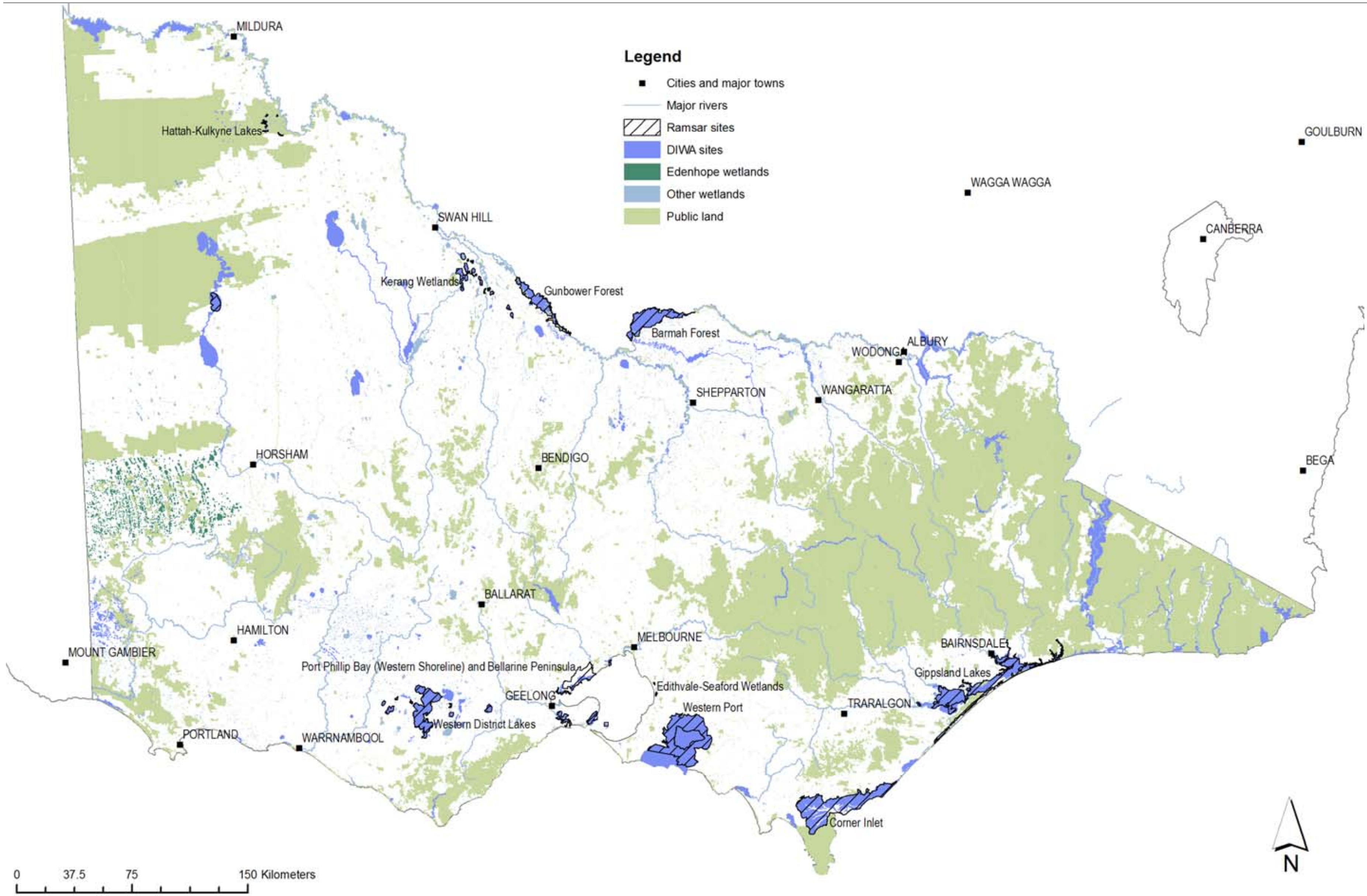

Figure 3. Location of Ramsar and DIWA sites and Edenhope wetlands.

DIWA and Edenhope wetlands

Twenty-nine DIWA sites were targeted for assessment. At DIWA sites with fewer than five wetlands, all wetlands were selected as candidates for assessment. At DIWA sites with more than five wetlands, approximately 70% of the wetlands in the site were selected as candidates for assessment, ensuring that all Corrick wetland categories at the site were represented (Table 4). Seventy-three of the 3214 Edenhope wetlands were randomly selected as candidates for assessment from each Corrick category present (Table 4).

Table 4. Summary of high-value wetlands selected for assessment.

	Number of sites	Number of individual wetlands selected for assessment
Ramsar sites	9	58
DIWA sites with ≤ 5 wetlands	7	27
DIWA sites with > 5 wetlands	22	542
Edenhope wetlands*	1	73
Total		700

* Edenhope wetlands consist of 3214 individual wetlands.

2.1.2 Representative wetlands

Identifying whether condition varies according to wetland types can inform the prioritisation of wetlands for management intervention. The objective of this assessment was to sample wetland condition of the different types of wetlands in Victoria. Several wetland attributes (climate, water regime, landscape context and salinity) were used to define wetland types for the assessment (Table 6). Attributes were consistent with those used in the Australian National Aquatic Ecosystem (ANAE) Classification (Auricht 2011) which is currently in an advanced stage of development. Wetland types are further outlined in Section 2.2.2.

The project budget allowed for the assessment of approximately 300 wetlands from the Wetland 1994 inventory and 10 wetlands from the alpine and wet heathland inventory. To allow for the likelihood that some wetlands would not be assessable (e.g. due to access difficulties), a larger list of 600 non-alpine and 20 alpine wetlands was provided to the assessors. This included wetlands from each type. The number of wetlands selected in each type was proportionate to the total number of that type in the Wetland 1994 inventory. Because of their inaccessibility, a much smaller number of alpine wetlands were selected than proportionate to the total number of that type.

Table 5. The Corrick classification system (Corrick and Norman 1976, 1980; Corrick 1981, 1982).

Category	**Subcategory**	**Depth (m)**
Sewage ponds	Undefined	Undefined
Salt works	Undefined	Undefined
Freshwater meadow These include shallow (up to 0.3 m) and temporary (less than four months duration) surface water, although soils are generally waterlogged throughout winter.	Herb-dominated Sedge-dominated Red gum-dominated Lignum-dominated	 < 0.3
Shallow freshwater marsh Wetlands that are usually dry by mid-summer and fill again with the onset of winter rains. Soils are waterlogged throughout the year and surface water up to 0.5 m deep may be present for as long as eight months.	Herb-dominated Sedge-dominated Cane grass-dominated Lignum-dominated Red gum-dominated	 < 0.5
Deep freshwater marsh Wetlands that generally remain inundated to a depth of 1–2 m throughout the year.	Shrub-dominated Reed-dominated Sedge-dominated Rush-dominated Open water Cane grass-dominated Lignum-dominated Red gum-dominated	 < 2
Permanent open freshwater Wetlands that are usually more than 1 m deep. They can be natural or artificial. Wetlands are described to be permanent if they retain water for longer than 12 months, but they can have periods of drying.	Shallow Deep Impoundment Red gum Cane grass Dead timber Black box Rush Reed Sedge Shrub Lignum	 < 2 > 2
Semi permanent saline These wetlands may be inundated to a depth of 2 m for as long as eight months each year. Saline wetlands are those in which salinity exceeds 3000 mg/L throughout the year.	Salt pan Salt meadow Salt flats Sea rush Hypersaline lake Melaleuca Dead timber	 < 2
Permanent saline These wetlands include coastal wetlands and part of intertidal zones. Saline wetlands are those in which salinity exceeds 3000 mg/L throughout the year.	Shallow Deep Intertidal flats	 < 2 > 2

Table 6. Attributes and their categories used to define wetlands types for the representative wetland assessment. Data sources and wetland attribution method for each category are also shown.

Attribute	Categories	Category data source	Wetland attribution method
Climate	Semi-arid Temperate	Bureau of Meteorology Climate Classification of Australia spatial data with categories based on the two major groups of climate classes that cover Victoria: temperate and grassland (re-named as semi-arid).(Figure 4)	Climate spatial data intersected with Wetland 1994 inventory
Landscape context	Alpine (elevation > 1200 m)	Spatial data derived from 20 × 20 m resolution digital elevation model (DEM) (Figure 5)	Landscape context spatial data intersected with alpine bogs and wet heathlands inventory
	Upland (elevation > 500 m – 1200 m) Lowland (elevation ≤ 500 m)		Landscape context spatial data intersected with Wetland 1994 inventory
Water regime	Permanent	Corrick classification categories: permanent saline, permanent open freshwater and deep freshwater marsh (Table 5)	Wetland 1994 inventory
	Seasonal	Corrick classification categories: freshwater meadow, shallow freshwater marsh, semi-permanent saline (Table 5)	Wetland 1994 inventory
Salinity	Fresh	Corrick classification categories: permanent open freshwater, deep freshwater marsh, freshwater meadow, shallow freshwater marsh (Table 5)	Wetland 1994 inventory
	Saline	Corrick classification categories: permanent saline, semi-permanent saline (Table 5)	Wetland 1994 inventory

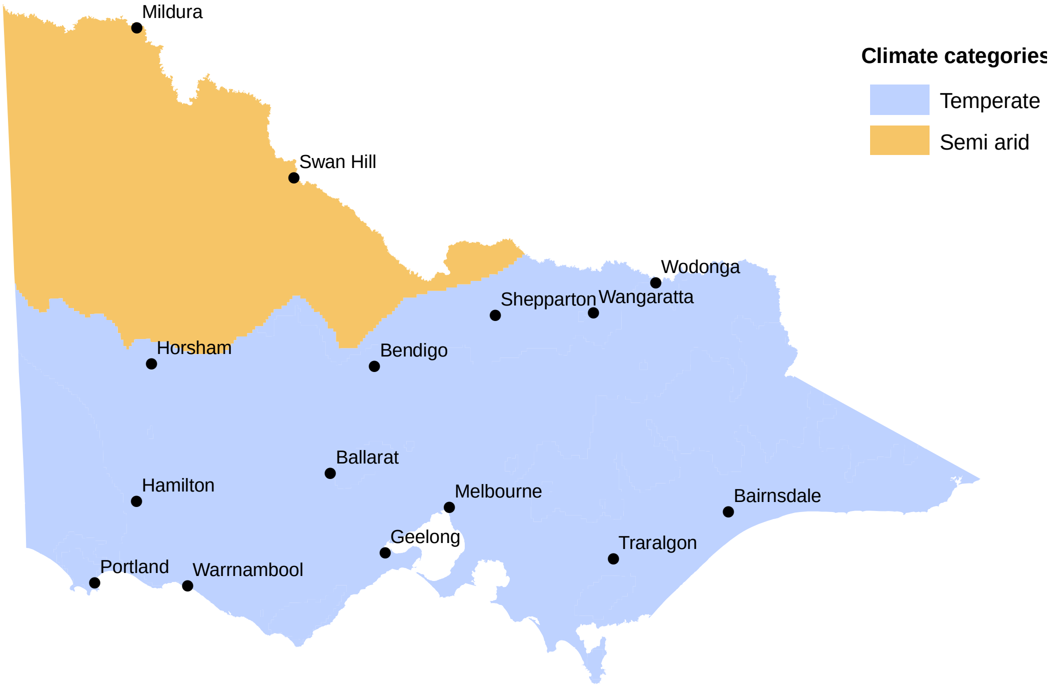

Figure 4. Köppen climate classification modified by aggregating the temperate categories.

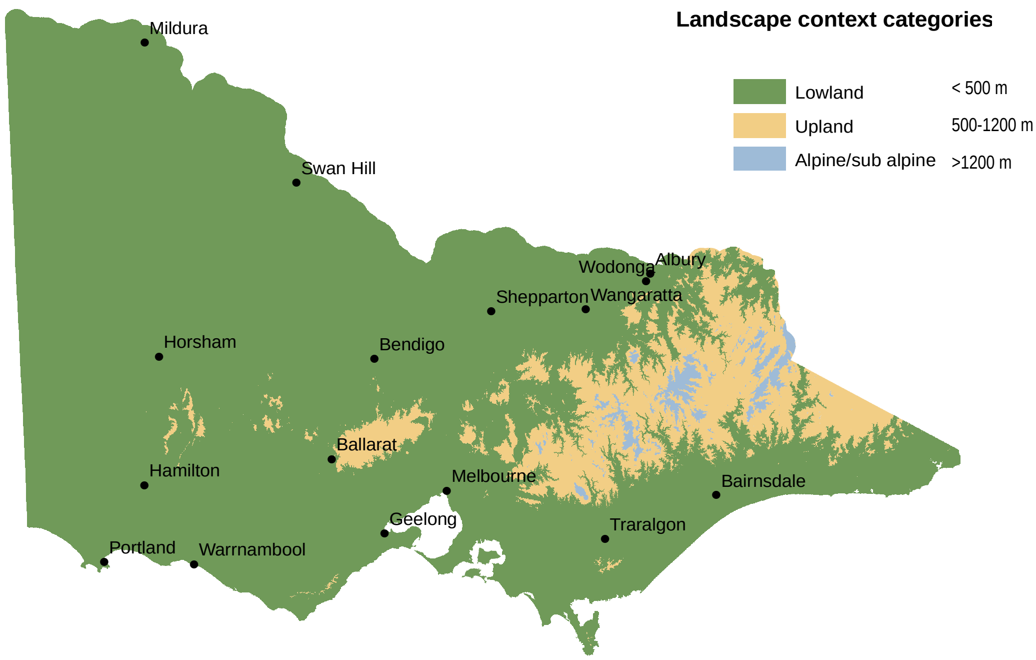

Figure 5. Landscape context categories derived from a 20 m digital elevation model.

2.2 Condition assessment method

2.2.1 IWC overview

Wetland condition assessments were undertaken using the Index of Wetland Condition (IWC), which is designed to assess the condition of natural wetlands that do not have a marine hydrological influence (DSE 2005). The IWC has six subindices based on components critical to the function of wetlands: physical form, hydrology, water properties, soils, biota, and wetland catchment. For these subindices there are 13 measures (Table 7). After testing in 2007 the IWC was calibrated and its subindices were weighted (Papas et al. 2009). Weighted subindices are tallied to produce an overall score that can be translated into one of five descriptive categories: very poor, poor, moderate, good, or excellent (Papas et al. 2009, DSE 2011).

2.2.2 Wetland condition assessments

The high-value and representative wetland assessments were undertaken by a team of two assessors using the method described in DSE (2011). The team was comprised of a wetland consultant or regional Catchment Management Authority (CMA) staff member and a botanist. All assessors were trained in the IWC method (see Papas et al. 2009). Field scheduling of consultants and botanists was facilitated by DSE and Water Technology (the lead consultant agency). Access to sites on public land was arranged through Parks Victoria, and access to wetlands on private land was arranged by the CMAs.

Table 7. Sub-indices, components and measures used in the IWC (DSE 2005).

Sub-index	Key ecological component	Measure
Wetland catchment	Wetland catchment	Percentage of land in different land use intensity classes adjacent to the wetland
	Wetland buffer	Average width of the buffer
		Percentage of wetland perimeter with a buffer
Physical form	Area of the wetland	Percentage reduction in wetland area
	Wetland form	Percentage of wetland where activities (excavation and landforming) have resulted in a change in bathymetry
Hydrology	Water regime	Severity of change in water regime
Water properties	Macronutrients (such as nitrogen and phosphorus)	Activities leading to nutrient enrichment to the wetland
	Electrical conductivity (salinity)	Evidence of a change in salinity
Soils	Soil physical properties (soil structure, texture, consistency and profile)	Percentage and severity of wetland soil disturbance
Biota	Wetland plants	Wetland vegetation quality assessment based on: • critical lifeforms • presence of weeds • indicators of altered processes • vegetation structure and health

To aid with the IWC assessment, a map of the wetland's catchment land use, its landscape context and two maps of the wetland (for annotating features such as vegetation, water structures and physical structures), were produced for each wetland from the IWC wetland mapping tool (DSE 2012b).

All assessments were based on whole wetlands except the Barmah and Gunbower Forest Ramsar sites, where, because of the size and complexity of the wetlands, assessments were performed at 30 and 24 one-hectare plots respectively (see Section 2.1.1). At these plots, biota, hydrology, soils, water property and bathymetry measures were assessed and scored at the plot scale. Wetland catchment and wetland extent measures for each plot were based on the entire Ramsar site and scored at that scale. The IWC score for each site was calculated by averaging the IWC scores obtained for each plot.

With the exception of a component of the salinity measure (assessed from the mapping tool), all measures were assessed at the wetland using field sheets contained in DSE (2011). Photos were taken of each wetland Ecological Vegetation Class (EVC) at the wetland and of the wetland itself.

IWC assessments of high-value wetlands commenced in October 2009 and concluded in April 2010. In total, 587 high-value wetlands were assessed, which was fewer than the target of 700 because of difficulties accessing some sites on private properties (Table 8, Figure 6). Approximately 70% of the sites were located on public land and 30% on private land.
IWC assessments of representative wetlands commenced in November 2010 and concluded in April 2011. Collectively, 240 wetlands were assessed across the state, fewer than the target of 300 because of difficulties accessing some sites isolated by severe flooding and problems obtaining access to wetlands on some private properties (Table 9, Figure 7). In contrast to the high-value wetland assessment, the majority of representative wetland sites (78%) were on private land.

Table 8. High-value wetlands assessed in 2009–10.

	Number of wetlands selected for assessment	Number of wetlands assessed
Ramsar sites	58	*51
DIWA sites	569	463
Edenhope wetlands	73	73
Total	700	587

* Includes Barmah and Gunbower Forest as individual sites.

Table 9. Attributes used to determine wetland types for the selection of representative wetlands, the number of wetlands from the Wetland 1994 inventory in each type, the number of candidate wetlands and the number required to reach the target of 300 non-alpine wetlands (wetland types 1–15) and 10 alpine wetlands (wetland type 16).

	Attribute							
Wetland type	**Climate**	**Landscape context**	**Water regime**	**Salinity**	**Number of wetlands**	**Candidate wetlands**	**Target wetlands**	**Number assessed**
1	temperate	lowland	permanent	saline	126	6	3	5
2	temperate	lowland	permanent	fresh	1444	68	34	33
3	temperate	lowland	seasonal	saline	678	32	16	16
4	temperate	lowland	seasonal	fresh	7036	332	166	138
5	temperate	upland	permanent	saline	31	2	1	0
6	temperate	upland	permanent	fresh	234	11	6	0
7	temperate	upland	seasonal	saline	131	6	3	0
8	temperate	upland	seasonal	fresh	1078	51	23	1
9	semi-arid	lowland	permanent	saline	11	2	2	2
10	semi-arid	lowland	permanent	fresh	414	20	10	6
11	semi-arid	lowland	seasonal	saline	395	19	9	8
12	semi-arid	lowland	seasonal	fresh	1133	53	27	21
13	semi-arid	upland	permanent	saline	1	1	0	0
14	semi-arid	upland	seasonal	saline	1	1	0	0
15	semi-arid	upland	seasonal	fresh	5	2	0	0
16	temperate	alpine	permanent	fresh	3190	20	10	10
Totals					15908	626	310	240

The IWC data, maps and photos were entered and uploaded to the IWC Data Management System (IWCDMS) by the wetland consultants and some CMA staff when the field work was completed. The IWCDMS calculates the scores for each measure and subindex and the overall score for the wetland (see Papas et al. 2009).

2.2.3 Data quality control

The IWCDMS has validation rules and checks which minimise data entry mistakes. Scores for the measures, subindices and total score are automatically calculated. The quality control measures in the IWCDMS include alerts for missing data in mandatory fields, alerts for totals which exceed maximum possible values and prevention of progress of data entry until these problems have been corrected. Despite these checks, data entry errors from the field sheets to the IWCDMS can still occur. The IWC project team checked approximately 10% of the assessment data in the IWCDMS against the field sheets for errors. Errors were detected only with the wetland water source information. In approximately 20% of the assessments checked there were two water sources identified for the wetland but only one entered in the IWCDMS. This was caused by inadequate guidance on the IWCDMS, i.e. it was not clear that more than one water source could be selected. The guidance has since been improved. Water source omissions were rectified on the IWCDMS, however resources were not available to check the water source information for the remainder of assessments. A note about this error rate has been included with the water source data that follows in this report.

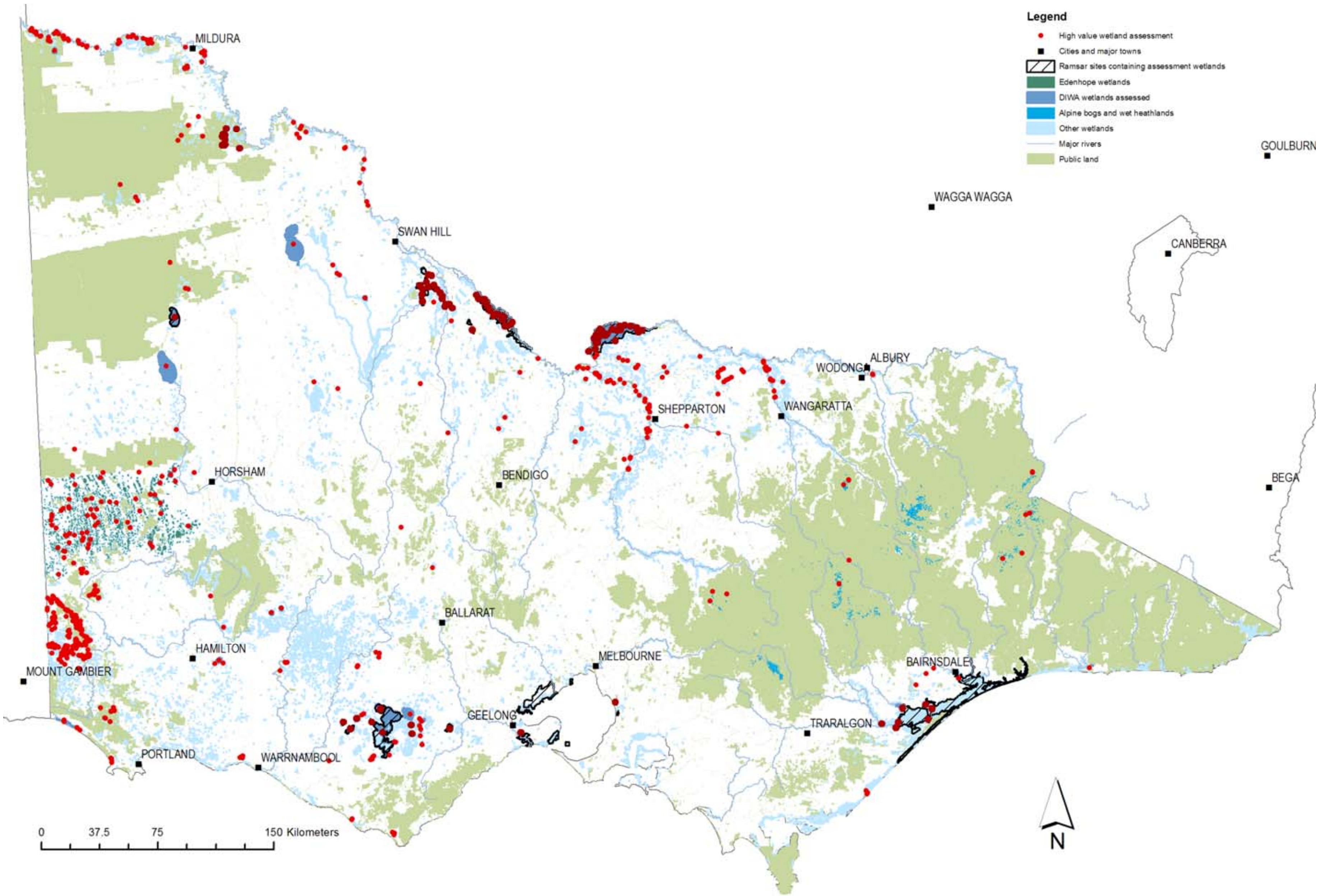

Figure 6. High-value wetlands assessed in 2009–10, with high-value wetland categories and public land shown.

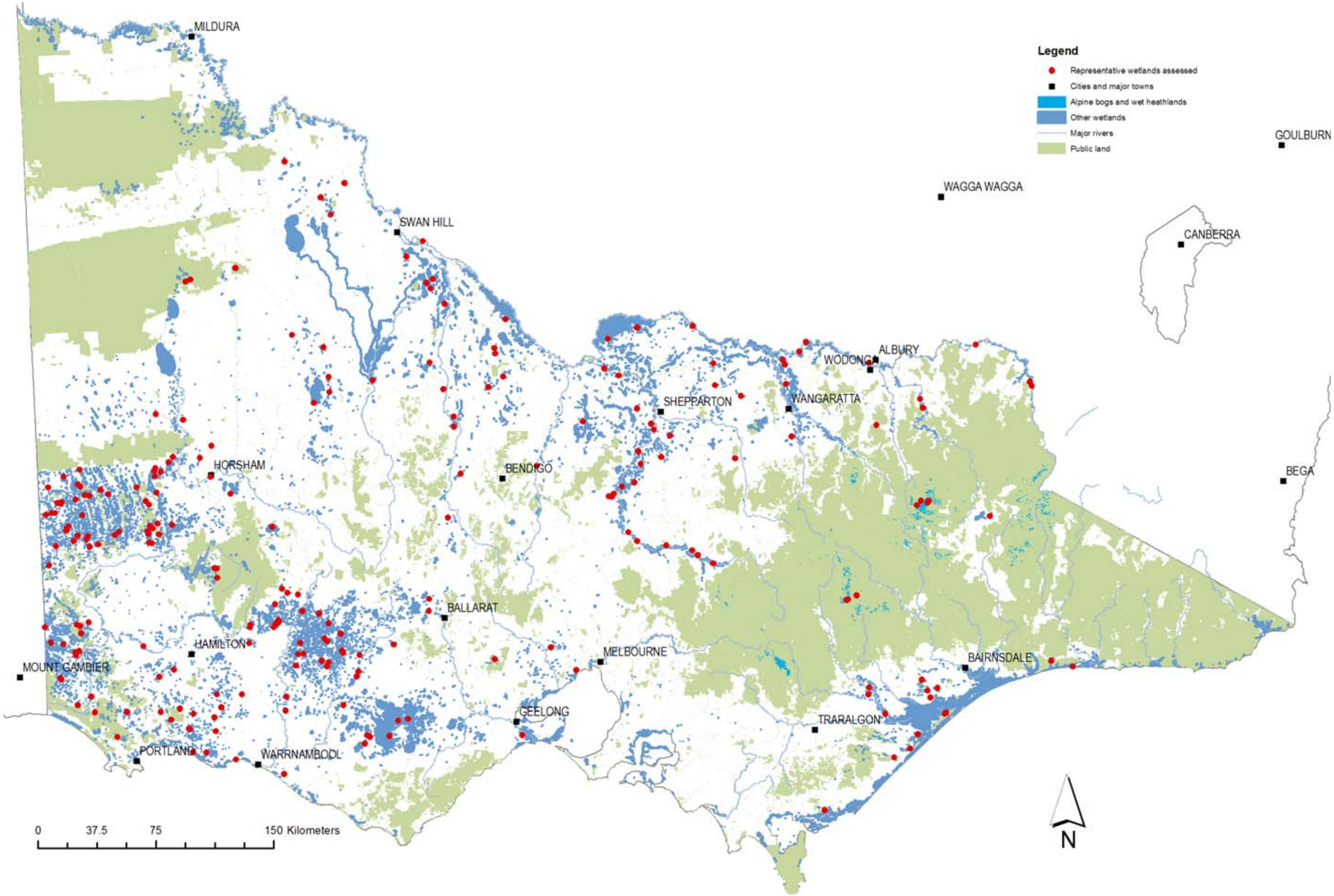

Figure 7. Representative wetlands assessed in 2010–11, with public land shown.

2.3 Data analysis

2.3.1 Condition of high-value and representative wetlands

Overall condition and condition of the subindices

The overall condition and subindex condition of the high-value and representative wetlands was summarised using Pivot tables and column charts generated in Microsoft Excel.

Comparison of wetland condition among wetland attribute categories

To inspect the distribution of wetland condition scores across various wetland groups defined by several attributes, box and whisker plots were generated using the software package *R* (R Development Core Team 2011). Attributes included wetland significance (high-value, representative, Ramsar, DIWA), wetland type (climate, water regime, landscape context, salinity), attributes from IWC assessments (water source, wetland phase) and land tenure (Table 10).

Statistical tests comparing the means of each attribute category were performed using *R*. For attributes with two categories, a Wilcoxon two-sample test was performed because the sample size of some categories was small (less than 40) and overall IWC scores were approximately normally distributed (see Tables 10 and 11). An analysis of variance (ANOVA) was performed for attributes with three or more categories and where the assumptions of normality (assessed from box plots) and equal variances were met (tested by Leven's test). Where the assumption of equal variances was not met, a non-parametric Kruskal-Wallis test was performed. A significant difference observed among three or more categories indicates that at least one category is significantly different from the others.

Relationship between wetland condition and wetland area

Scatter plots were generated using *R* to investigate whether there was likely to be a simple linear relationship between wetland area and wetland condition for the high-value and representative wetlands. A correlation matrix using overall IWC condition and wetland area was performed to generate a Pearson's correlation coefficient to determine the strength of the relationship.

2.3.2 Threats to wetlands and sources of threat

An assessment of several threats to wetlands, and source of threats, can be made using IWC subindices, measures and observations (Table 12). For this study a threat was considered to be operating at a wetland if its corresponding IWC measure or subindex condition category was very poor, poor or moderate. This was used to determine the proportion of high-value and representative wetlands subject to threats and the proportion with sources of threats.

Because the level of threat operating on public land is usually less than on private land, it was expected that this would result in generally better condition for wetlands on public land. For this reason, the proportion of wetlands with each threat was calculated for public and private land tenure separately. Because we also expected that the level of threat to the wetland's water regime could vary between wetlands that have different water sources, the proportion of wetlands with each threat was calculated for each of the water sources separately.

Table 10. Wetland attributes used to group wetlands to inspect variation in wetland condition for the high-value and representative wetlands. The number of wetlands in each attribute category is also shown.

Attribute	Categories	No. of high-value wetlands	No. of representative wetlands
Climate	Semi-arid	57	35
	Temperate	530	206
Landscape context	Alpine	11	10
	Upland	4	1
	Lowland	572	230
Water regime	Permanent	271	58
	Seasonal	316	183
Salinity	Fresh	553	210
	Saline	34	32
Water source[1]	River or stream	220	40
	Groundwater	66	12
	Surface runoff	256	183
	Artificial channel	18	5
	River/Groundwater	3	0
	River/Artificial Channel	19	0
	Groundwater/Artificial Channel	2	0
	Groundwater/Artificial Channel/River	2	0
Land tenure[2]	Public	393	189
	Private	204	52
Wetland phase	Full	45	49
	Filling	46	22
	Receding	195	115
	No water present	287	44
	Not applicable (peatland sites)	14	11

[1] A small percentage of these data were not entered correctly onto the IWCDMS (see Section 2.2.3)

[2] Data obtained by intersecting the Wetland 1994 inventory with the public land spatial data (DSE 2012).

Table 11. Number of high-value and representative wetlands assessed in each wetland type. Note: no wetlands of types 13-15 were assessed (see Table 9).

Wetland type group	Attribute				Number of wetlands	
	Climate	Landscape context	Water regime	Salinity	High-value	Representative
1	temperate	lowland	permanent	saline	20	5
2	temperate	lowland	permanent	fresh	140	33
3	temperate	lowland	seasonal	saline	23	16
4	temperate	lowland	seasonal	fresh	230	138
8	temperate	upland	seasonal	fresh	4	1
9	semi-arid	lowland	permanent	saline	3	2
10	semi-arid	lowland	permanent	fresh	98	6
11	semi-arid	lowland	seasonal	saline	11	8
12	semi-arid	lowland	seasonal	fresh	57	21
16	temperate	alpine	permanent	fresh	11	10
Total					587	240

Table 12. Threats to wetlands and their corresponding IWC measures and activities and the IWC activities that correspond to the threat sources.

Threat	IWC measure and subindices that corresponds to the threat	Activities recorded by the IWC that corresponds to the threat source
Reduced wetland area	Reduction in wetland area	
Altered wetland form	Severity of change to wetland bathymetry	Excavation of wetland (e.g. dam)
		Landforming (e.g. levelling)
Altered hydrology	Hydrology subindex score (severity of change to wetland water regime)	Change to wetland water source flow regime
		Obstruction of wetland inlets
		Obstruction of wetland outlets
		Drainage of water from the wetland
		Water disposal into wetland
		Extraction of water from the wetland
		Activities that raise the water level (e.g. levee construction)
		Activities that increase groundwater height
		Activities that decrease groundwater height
Degraded water quality	Water properties subindex score (eutrophication and change in salinity)	Discharge of nutrients into wetland
		Urban drainage
		Nutrient runoff (non-point source)
		Grazing
		Aquaculture
		Increase salinity
Soil disturbance	Soils subindex score (extent and severity of soil disturbance)	Pugging by livestock and feral animals
		Cultivation
		Carp mumbling
		Trampling by humans
		Vehicle disturbance

2.3.3 Wetland condition modelling

The goal of the modelling is to be able to predict, with some confidence, the condition of wetlands where formal condition assessment has not occurred. Data mining is a common and reasonable approach to enable these predictions (Agresti 2002, Larose 2006). It is appropriate to include as much information about the sites as possible in the analysis. The information is limited to that which can be obtained through remote sensed data. Part of the rationale for including many variables is that they may indicate some important latent variables (Larose 2006). Latent variables are those that are not directly observed but may be inferred from the variables that are directly measured (usually broad scale environmental gradients). These latent variables may be associated with variables that have been measured. For instance, the biota components of the IWC score can not be remotely sensed, but may be associated to some of the latent variables. If the models predict wetland condition well this could inform the nature of these latent variables.

The IWC are ordinal scores and therefore ordinal analysis has been used. There are several different types of ordinal regression and classification techniques in the relevant literature (Guisan and Harrell 2000, Liu et al. 2005, Pinto Da Costa et al. 2010). It was unclear which technique(s) would produce the best predictions hence several techniques were explored.

The modelling methods explored were:

- Ordinal response classification tree using an ordinal impurity function (Piccarreta 2008, Archer 2010).
- Continuation ratio ordinal regression using a logit link function (Hosmer and Lemeshow 2000). This method fits a series of logistic regressions, and can be attempted in both ascending and descending order with different results. Each regression is conditional on cumulative probabilities, as follows (for ascending; the opposite for descending):

  $$\Pr(IWC > \text{"Poor"})$$
  $$\Pr(IWC > \text{"Moderate"} \mid IWC \geq \text{"Moderate"})$$
  $$\Pr(IWC = \text{"Excellent"} \mid IWC \geq \text{"Good"})$$

  The model with the smallest Bayesian information criterion (BIC) was selected at each stage.
- Frequentist ordered probit regression using the cumulative link with flexible thresholds (Agresti 2002, Christensen 2011), which attempts to fit a single model to the data, with cut-offs estimated to separate each class. The model with the lowest BIC was selected.
- Support vector machine (SVM) using ν classification (Karatzoglou et al. 2004, Pinto Da Costa et al. 2010). This is a kernel-based learning algorithm. A combination of continuation ratio and SVM approaches was used.
- Bayesian analysis using ordered probit regression (Kruschke 2011, Martin et al. 2011). It is similar to the ordinal regression with a cumulative link, but uses a Bayesian rather than frequentist approach.

The steps for building and testing the models were as follows:

1. IWC high-value wetland and representative wetland datasets were collated, checked for errors and wetlands with missing data removed.
2. A principal components analysis (PCA) of the individual IWC measures was performed to identify those which best correlated with wetland condition. From these, remote sensed surrogate variables were selected.
3. Additional variables that may predict wetland condition were identified.

4. Data for all the variables identified in steps 2 and 3 were obtained from spatial datasets for all assessment wetlands.
5. Models were built by first randomly splitting IWC data into training and testing data. The models were calibrated using the training data, while their ability to predict was assessed using the testing data.

1. Sites and condition data used for model development

The preliminary analysis for the model and the model development was based on IWC scores and categories for 860 wetlands from the first and second statewide assessments. As only 10 sites had an IWC category of Very Poor, the Very Poor and Poor categories were combined, and referred to as Poor. Although IWC assessment data from other programs (e.g. Wetland Tender) were available, they were not used because their quality could not be assessed.

2. Principal components analysis and selecting remote sensed variables

To identify the most suitable spatial variables to predict wetland condition during modelling, a principal components analysis (PCA) (Clarke 1993) based on overall IWC condition scores and IWC measures (see Table 7) was performed. The PCA was undertaken using the PCA module of the PRIMER software package (Clarke and Gorley 2006). Only measures that could be obtained or approximated from spatial datasets could be used to build the predictive model, so surrogate variables for water regime and biota were not included in the PCA analysis.

Of the five PCA axes tested, approximately 60% of the data variance was captured by PCA axes 1 and 2 (Figure 8). This was the only combination of PCA axes in which a condition gradient was evident. In PCA components 1 and 2, wetland buffer, land use intensity, nutrients, wetland area and bathymetry were most influential in describing the principal components (Table 13). However, the wetland buffer, land use intensity and nutrient enrichment measures showed the best alignment with condition gradient (Figure 8). These (and related or surrogate variables) were therefore considered to be the most suitable to include in the model.

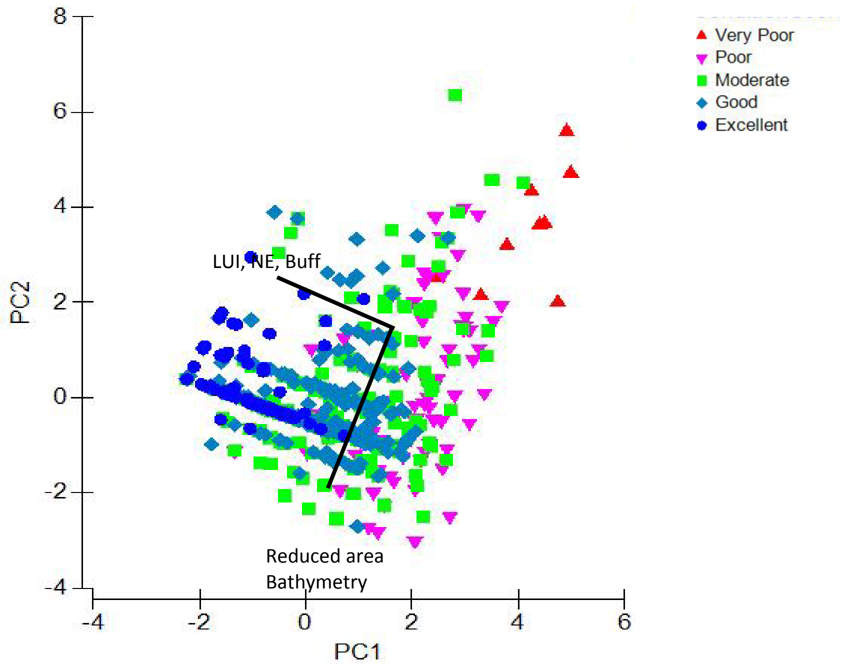

Figure 8. PCA plot of assessment wetlands. Different colours and symbols represent different condition categories of individual wetlands. Black lines show the direction of influence for measures that exert the most influence on the patterning of wetlands in the PCA: LUI (land use intensity), NE (nutrient enrichment), Buff (wetland buffer), reduced area and bathymetry.

Table 13. PCA coefficients (influence on the principal components). Measures with a coefficient greater than 40% are underlined. See Figure 9 for additional information.

Variable	Principal component 1	Principal component 2
Wetland buffer	<u>0.549</u>	0.223
Land use intensity	<u>0.563</u>	0.240
Wetland area	0.285	<u>0.607</u>
Bathymetry	0.294	<u>0.630</u>
Nutrient enrichment	<u>0.449</u>	0.143
Salinity	0.111	0.328

Note: Cumulative variance explained by PCA 1 and 2 = 58.5%.

3. Selecting additional variables that may predict wetland condition

In addition to the variables identified in PCA, other variables that could influence or inform wetland condition were included in the modelling. These included wetland size, salinity and water source. Broad scale variables such as geographic location and climate were included to detect processes operating at broad scales. To test for any effects associated with extreme drought or flood that might have occurred during the high-value and representative wetland assessments, a rainfall deficit variable was included. This was calculated from the deviation from mean rainfall in the three years preceding the IWC assessments. Three years was considered an adequate time period to capture any effects on wetland condition associated with drought and flood (Table 14). Landscape context was not used as a variable as there were too few wetlands in the alpine category (n = 20) and upland category (n = 6).

Table 14. Additional variables used in the modelling and their expected relationship with condition.

Variable	Relationship with condition
Salinity	Threat levels may differ between fresh and saline wetlands for several reasons, e.g. freshwater wetlands are more attractive for livestock grazing and saline aquifers feeding saline groundwater wetlands are unlikely to be exploited for consumptive purposes
Size	In most cases larger wetlands are likely to be exposed to fewer threats
Water source	Threat levels may differ among wetlands with different water sources
Geographic location	A broad scale variable (unlike land use which operates at a fine scale) which may be useful for detecting processes operating at broad scales
Climate	A broad scale variable (unlike land use which operates at a fine scale) which may be useful for detecting processes operating at broad scales
Rainfall and rainfall deficit	Tests for effects associated with extreme drought or flood

4. Obtaining data for the model variables

Land use intensity / nutrients

Variables derived from land use spatial data were used as a surrogate for land use intensity and nutrients. Land use intensity data from the IWC assessments was not used in the modelling because these data are not available on a statewide scale.

Land use spatial data was taken from a surrogate wetland catchment or 'zone of influence', defined as the zone within 250 m of the wetland boundary. Data from actual wetland catchments was preferred, but these have not been delineated for the majority of Victorian wetlands. Two hundred and fifty metres was selected as the surrogate catchment to be consistent with the IWC's land use intensity measure. The source of the land use data for the surrogate wetland catchments was the Victorian Land Use Information System (VLUIS). This is a hierarchical land use classification based on Australian Evaluation Property Classification codes (Victorian Government 2009, DPI 2010). There are three levels in the hierarchy. A combination of individual and aggregated land use classes in the second level of the hierarchy was considered most suitable for modelling purposes. The aggregated categories were (a) national parks and nature reserves, (b) residential, commerce and community, and (c) mining and industrial. Individual classes were agricultural cropping, livestock grazing, mixed farming and grazing, and forestry. Land use data was obtained for the assessment wetlands by performing a spatial intersect of the surrogate wetland catchments with the VLUIS level 2 data using ArcMap9.3, and then aggregating land use categories (Table 15).

Several indices based on land use were also reviewed for applicability as modelling variables. An Australian-based index derived from impacts on wetlands from land uses adjacent to wetlands (Papas et al. 2008, 2009) was unsuitable because the present VLUIS categories are significantly different to those used in the index and there was insufficient time in the study to apply the framework to the VLUIS categories. Other methods developed elsewhere include a metric derived from land use, wetland buffer characteristics and an assessment of potential site stressors (Miller et al. 2006), an index based on land cover, vegetated buffer and the extent of human-induced hydrologic alteration (Lopez and Fennessy 2002), and an index based on non-renewable energy consumed per unit area of land use within a wetland catchment (Brown and Vivas 2005). The method of Brown and Vivas (2005), called the Landscape Development Intensity Index (LDII), was considered suitable as a model variable because its land use categories could be aligned to VLUIS and it is the most extensively used of all the methods. Its applications include identifying human disturbance gradients (Brown and Vivas 2005), validating wetland condition assessment methods (Mack 2006, Reiss 2006) and developing biological indicators for wetlands (Brown et al. 2001, Brown 2003, Lane 2003).

The LDII is calculated by first determining the percentage of a land use in the zone of influence for a wetland (usually the surrogate 250 m zone), then multiplying each percentage by a coefficient derived from energy consumption for that land use (Appendix 1, Table A1). It was possible to assign coefficients for the majority of VLUIS land use categories (Appendix 1, Table A2).

LDII scores were calculated for the zone of influence for all wetlands used in modelling process using the following formula:

$$LDI_{Total} = \sum \%LU_i * LDI_i$$

Where:
LDI_{Total} = LDI ranking for landscape unit
$\%LU_{\text{i}}$ = percent of the total area of influence in land use i
LDI_{i} = landscape development intensity coefficient for land use i

<u>Water source</u>

Water source data were collected during IWC assessments, but spatial data based on remote sensing was used to derive water source because this would be the data used to generate wetland condition predictions for the remaining Wetland 1994 inventory wetlands. Groundwater input was assigned using an attribute of the potential groundwater-dependent ecosystem (GDE) dataset and a floodplain spatial dataset, based on the assumptions that (a) wetlands on floodplains have the river as their primary water source, and (b) wetlands with shallow watertables in areas identified as potential GDEs have groundwater as their primary water source.

The GDE spatial dataset was derived from remote sensing, and was partially validated using groundwater height data and local scale studies where available; see Dresel et al. (2010) for details on validation. It is largely a modelled product and requires further validation, but it has a statewide coverage unlike other groundwater datasets and distinguishes shallow from deep watertables. Assessment wetlands were identified as having groundwater as their primary water source if they overlay potential GDEs with a shallow watertable (less than 5 m from the surface). Attribution was performed by a spatial intersect of the assessment wetlands with a shallow watertable. The GDE dataset is likely to over-predict the area of potential GDEs (Dresel et al. 2010). Future modelling should consider new refined GDE datasets which have since become available.

River-fed wetlands were identified as wetlands on river floodplains. Because floodplains are not comprehensively identified and mapped in Victoria at present, several methods of defining their extent were assessed. A three kilometre buffer applied on streams greater than 4th order (using the Strahler classification) based on the Stein stream network (Stein 2007) was the most representative of floodplains, using air photos as validation (Figure 9). A spatial dataset of these floodplains was generated and used to attribute the assessment wetlands as floodplain or non-floodplain. Due to the fixed 3 km buffer imposed on streams, the dataset may over represent floodplain wetlands in the upper parts of catchments and under represent floodplain wetlands in the lower parts of catchments. Future modelling should consider new refined floodplain datasets which are currently in development.

<u>Other variables used in the model development</u>

- Salinity — Corrick salinity categories were used to define two salinity categories: fresh and saline (Table 5). These data was obtained from the Wetland 1994 inventory.
- Climate — Temperate and semi-arid climate categories modified from the Kőppen climate classification (Figure 4). The climate data for the assessment wetlands was obtained by intersecting the climate spatial data with the Wetland 1994 inventory.
- Wetland size — Data were obtained from the Wetland 1994 inventory.
- Rainfall deficit — Spatial data were obtained from the Bureau of Meteorology. The rainfall deficit data for the assessment wetlands was obtained by intersecting the rainfall deficit spatial data with the Wetland 1994 inventory.

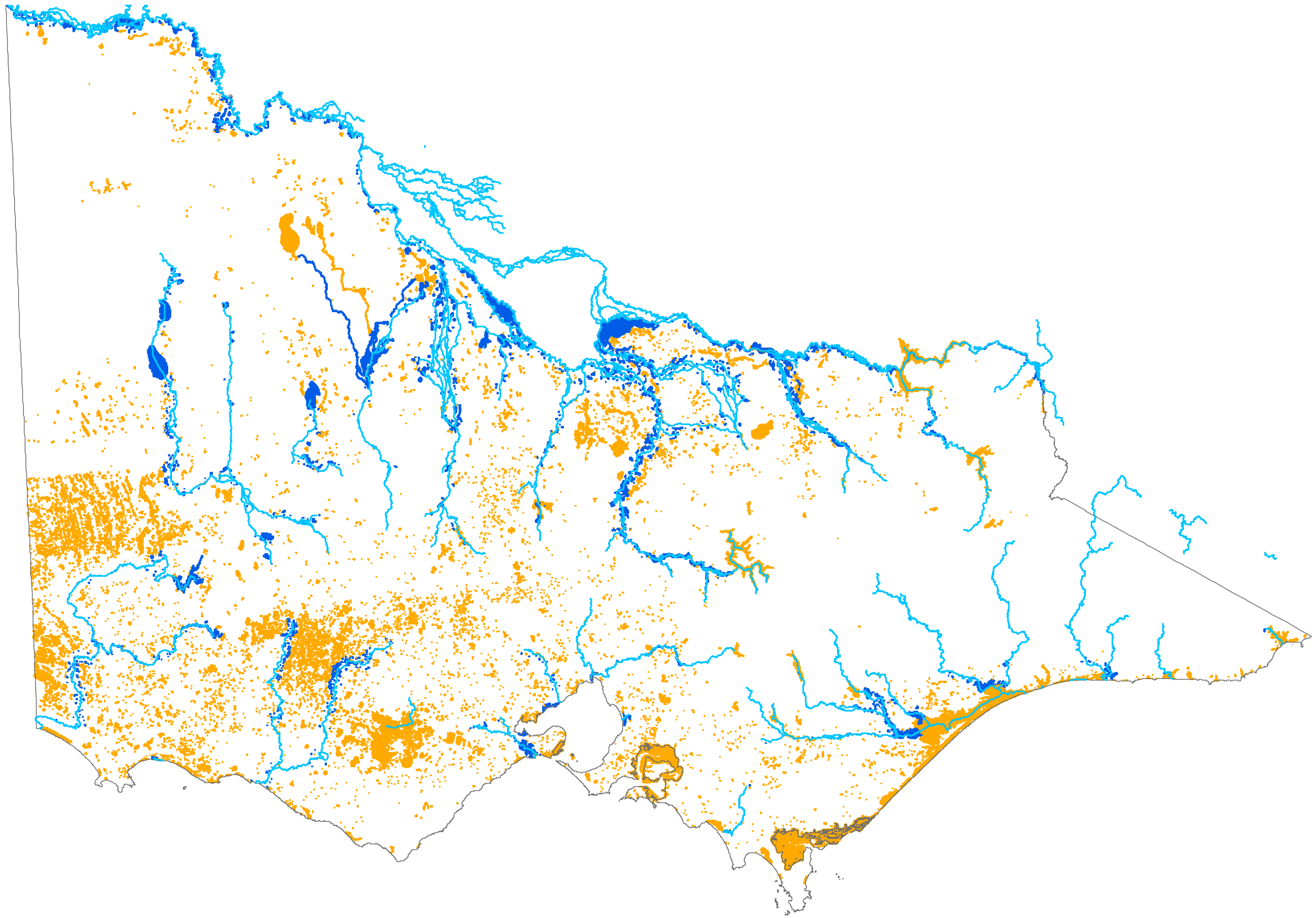

Figure 9. Map of floodplain wetlands (blue), non-floodplain wetlands (yellow) and streams greater than the 4th order (light blue). Stream order is based on the Strahler classification system. Stream data was derived from the NCSED database (Stein et al. 2011).

Table 15. Variables used in the modelling, their definition and data source.

Rationale for selecting variable	Variable surrogate	Variable used in the Model	Definition	Data source
Variables identified from the PCA	Land use intensity/ Nutrient enrichment	Public	Proportion of the wetland catchment* that is publicly owned	Public land spatial data
		Nature	Proportion of the wetland catchment that is classified natural using VLUIS	Victorian Land Use Information System (VLUIS) categories 91, 93, 95, 96, 99
		ResComEtc	Proportion of the wetland catchment classified as residential, commercial or community	VLUIS categories 10–15, 21–24, 60, 64, 74, 78, 79, 81–84
		MinInd	Proportion of the wetland catchment classified as mining or industrial	VLUIS categories 30–32, 40–41, 48, 63, 65, 69
		LU51	Proportion of the wetland catchment classified as agricultural cropping	VLUIS
		LU52	Proportion of the wetland catchment classified as livestock grazing	VLUIS
		LU53	Proportion of the wetland catchment classified as mixed farming and grazing	VLUIS
		LU57	Proportion of the wetland catchment that is classified as forestry VLUIS	VLUIS
		LDII	Land use development intensity index	Based on Brown and Vivas (2005) using VLUIS categories
Variables which may predict condition	Salinity	Salinity	Salinity concentration of wetland: fresh or saline	Corrick classification
	Climate	Climate	Climate zone	Modified Köppen climate classification
		Rainfall	Long term mean rainfall	Bureau of Meteorology rainfall data
	Geographic location	VicgridEast	Location of wetland using Vicgrid referencing	Wetland 1994 inventory
		VicgridNorth	Location of wetland using Vicgrid referencing	Wetland 1994 inventory
	Wetland size	lnWetHect	Natural logarithm of the wetland size in hectares	Wetland 1994 inventory
	Water source	River	Is the wetland part of a floodplain?	Floodplain wetlands spatial data
		Groundwater	Is the wetland likely to have groundwater influence?	Groundwater dependant ecosystems spatial data
Effect of drought and flood		RainIndex	Mean rainfall in the three years preceding observation as a percentage difference of the long term mean rainfall	Bureau of Meteorology rainfall data

* The wetland catchment used in the study is a 250 m zone from the boundary of the wetland

5. Building the models

The analysis was conducted using *R* (R Development Core Team 2011) using packages referenced with each method's description.

To compare the accuracy of the models, several statistics were calculated for each method: the misclassification error rate (MER) (Pinto Da Costa et al. 2010), Goodman and Kruskal's γ-statistic, Somer's D statistic (Agresti 2002), Spearman's ρ-statistic, and the Kendall rank correlation τ-statistic (Kendall 1938). The MERs measure the proportion of observations that were wrongly classified, therefore the closer to zero the better. Goodman and Kruskal's γ measures the strength of association of the cross-tabulated data. It is a measure of rank-order correlation. A score of 1 is perfect agreement, –1 is perfect inversion, and 0 is an absence of association. It is often used where there are many ties in the data set. Somer's D statistic is an extension of Goodman and Kruskal's γ in which the variables are designated as independent and dependent. However, not all misclassifications are equal when dealing with ordinal data. For example, misclassifying an Excellent as Poor is much worse that than misclassifying it as Good. Spearman's ρ measures the correlation of the ranked results and takes the magnitude of the error into account. It effectively measures how close the data are to a straight line; the closer to one the better. It does, however, depend on the choice of values to represent each class. Different values can result in different correlations. Kendall's τ does not depend on the value, as it measures agreement in relative ranking. Each statistic has its merits and limits, so all were included.

The sensitivity and the specificity of each class was also be calculated for each method. Sensitivity is the proportion of the class that were correctly predicted. Specificity is the proportion that are not from the class that were correctly not allocated to that class.

The accuracy and robustness in predicting the IWC category for the testing data was used to determine the best method. The statistics infer the reliability of the methods.

3 Results

3.1 Overall condition and condition of the subindices

3.1.1 High-value wetlands

Twenty-four percent of the high-value wetlands assessed were in excellent condition, 32% in good condition, 30% in moderate condition, 14% in poor condition and 1% in very poor condition (Table 16). Half the wetlands assessed had good or excellent scores for wetland catchment. However, for 27% of wetlands, the wetland catchment was in very poor condition. The majority of wetlands (86%) had largely unaltered physical form and 66% had moderate to excellent hydrology, but 33% were scored as very poor. Water properties scores for most wetlands (85%) were good or excellent. Soils in about 80% of wetlands were relatively undisturbed. Thirty percent of the wetlands assessed had an excellent or good score for native vegetation, but for 70% the vegetation was scored as moderate to very poor condition.

Overall, 65% of high-value wetlands on public land and 39% on private land were in good or excellent condition (Figure 10). There were more wetlands in excellent condition on public land than private land at the subindex level for the biota, soils, wetland catchment, physical form and water properties subindices (Figures 10–13).

Table 16. Condition category distribution for high-value wetlands (% of wetlands in each category) for each IWC sub-index and total IWC.

	Condition category				
IWC subindex	**Very poor (%)**	**Poor (%)**	**Moderate (%)**	**Good (%)**	**Excellent (%)**
Wetland catchment	27	15	9	10	39
Physical Form	1	1	4	8	86
Hydrology*	33	–	13	–	53
Water Properties	1	2	12	47	38
Soils	5	5	9	14	67
Biota (vegetation)	24	23	23	16	14
Total IWC	1	13	30	32	24
Number of wetlands	6	77	177	189	139

* The hydrology measure had three possible condition categories only.

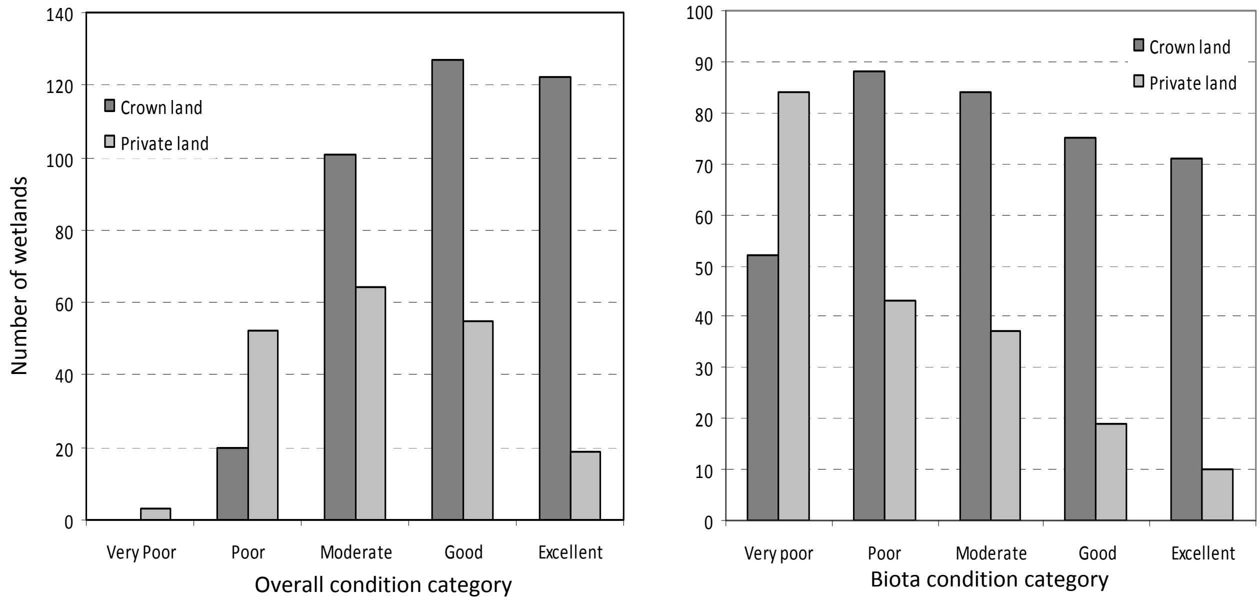

Figure 10. Distribution of wetlands across condition categories for overall condition (left) and biota subindex condition (right) for high-value wetlands on public land and private land.

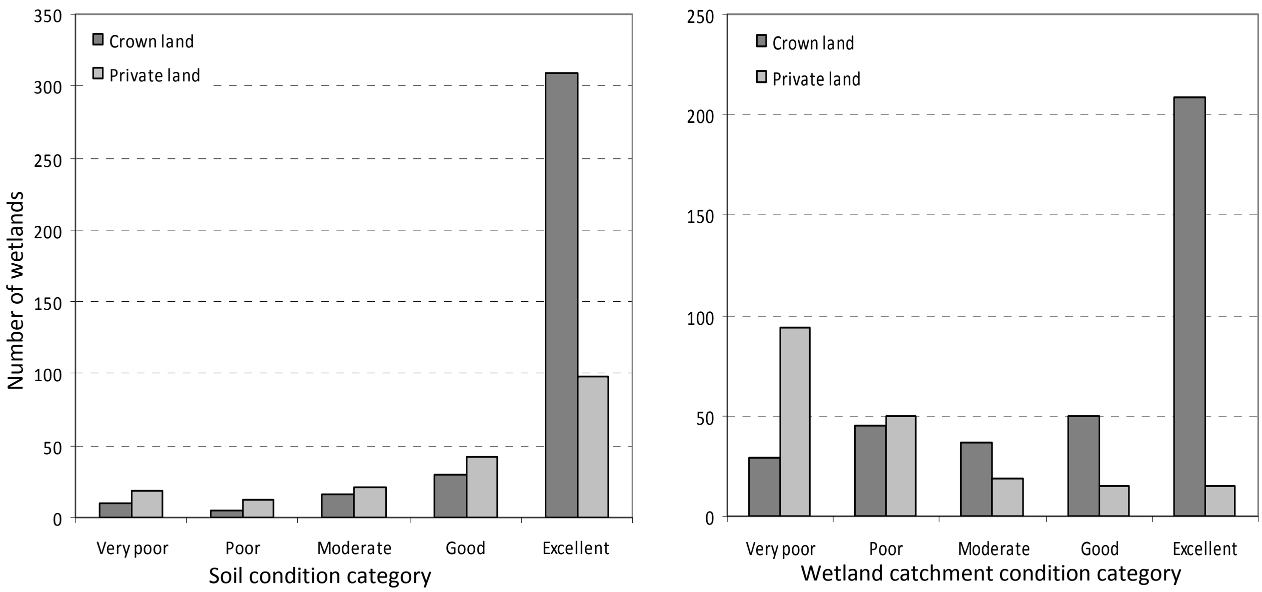

Figure 11. Distribution of wetlands across condition categories for soil subindex condition (left) and wetland catchment subindex condition (right) for high-value wetlands on public land and private land.

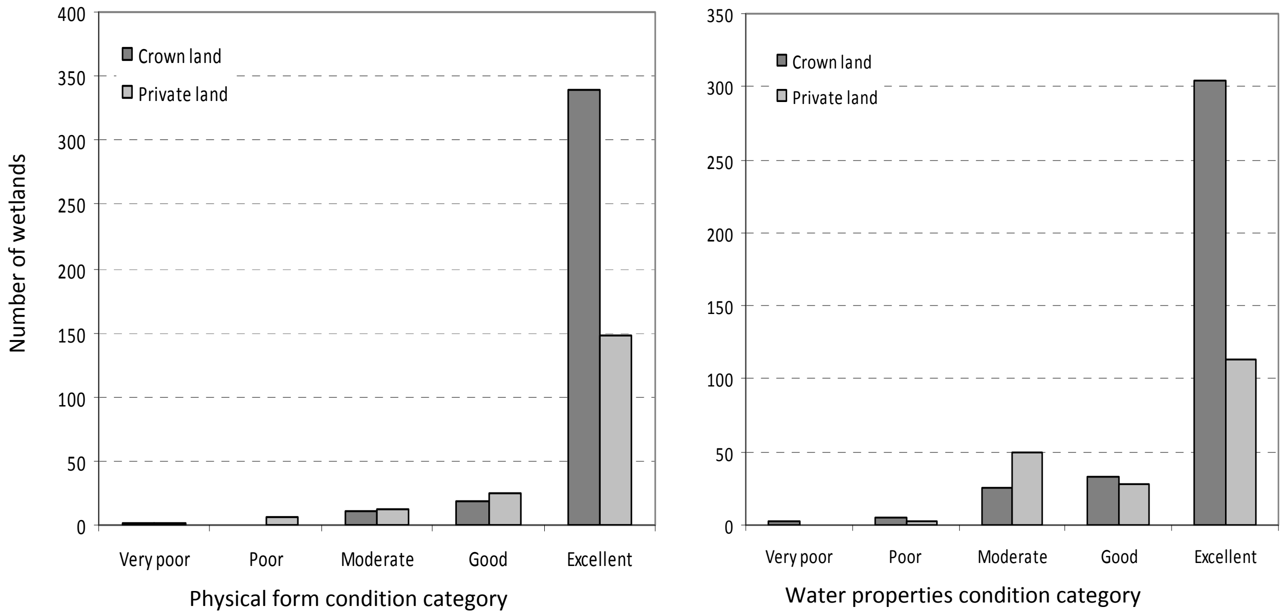

Figure 12. Distribution of wetlands across condition categories for physical form subindex condition (left) and water properties subindex condition (right) for high-value wetlands on public land and private land.

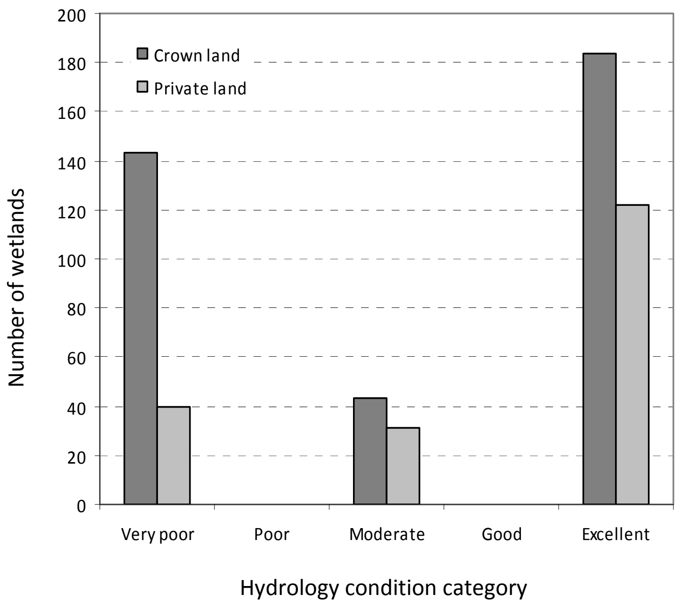

Figure 13. Distribution of wetlands across condition categories for hydrology subindex condition for high-value wetlands on public land and private land. Note: at the time of the high-value wetland assessment, the hydrology assessment contained three condition categories.

3.1.2 Representative wetlands

Approximately half of the wetlands assessed were in good or excellent condition overall, while one quarter were in poor or very poor condition (Table 17). Nearly 50% of wetlands had a wetland catchment in very poor condition. The majority of wetlands had largely unaltered physical form (78%). Water properties scores were good or excellent for most (73%) wetlands. Soil condition was excellent for 50% of wetlands but very poor for 15%. Biota was in poor or very poor condition for almost half of the wetlands.

Overall, 88% of wetlands on public land and 40% of those on public land were in good or excellent condition (Figure 14). There were more wetlands in excellent condition on public land than private land at the subindex level for the biota, soils, wetland catchment, physical form and water properties subindices (Figures 14-17).

Table 17. Condition category distribution (% of wetlands in each category) for each IWC sub-index and total IWC for representative wetlands.

	Condition category				
IWC subindex	**Very poor (%)**	**Poor (%)**	**Moderate (%)**	**Good (%)**	**Excellent (%)**
Wetland catchment	49	14	9	9	19
Physical form	2	3	7	10	78
Hydrology	25	-	7	25	43
Water properties	1	4	23	52	20
Soils	15	5	18	12	50
Biota (vegetation)	28	20	18	21	14
Total IWC	4	22	24	31	20
Number of wetlands	10	52	56	74	48

* The hydrology measure was updated prior to commencement of the representative wetland assessment with four possible condition categories.

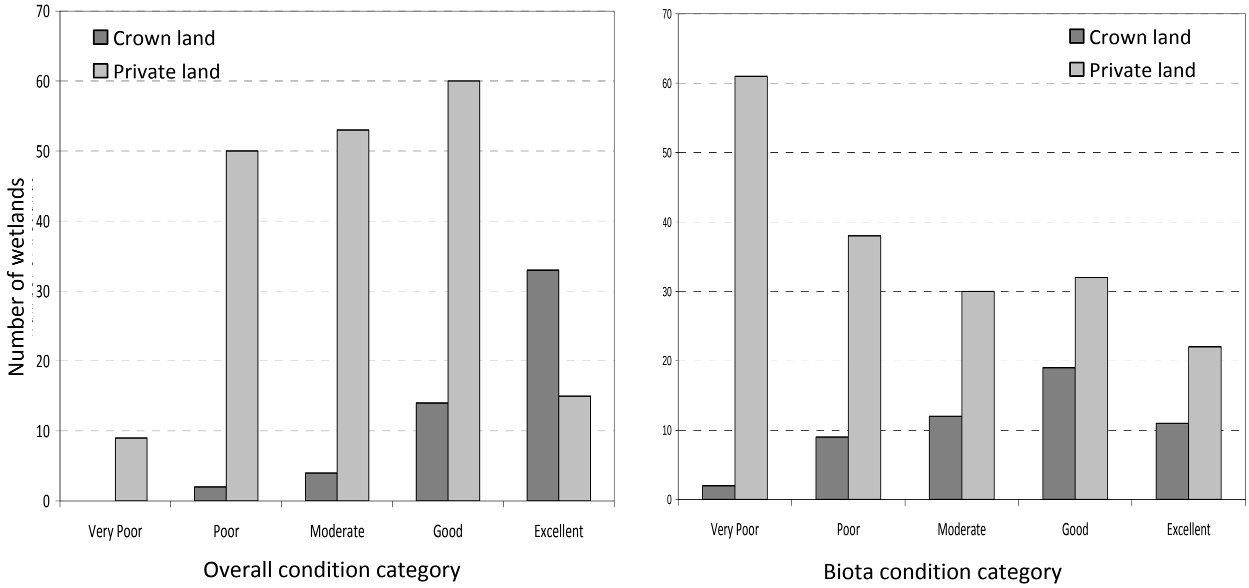

Figure 14. Distribution of wetlands across condition categories for overall condition (left) and biota subindex condition (right) for representative wetlands on public land and private land.

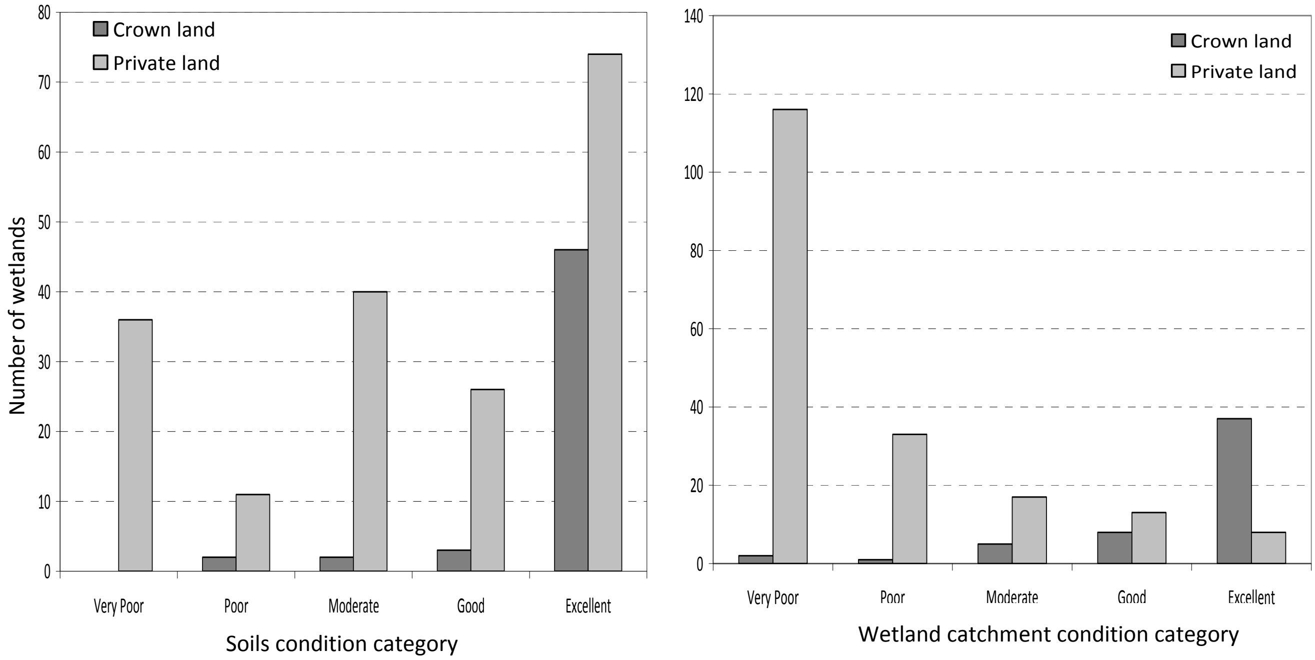

Figure 15. Distribution of wetlands across condition categories for soils subindex condition (left) and wetland catchment subindex condition (right) for representative wetlands on public land and private land.

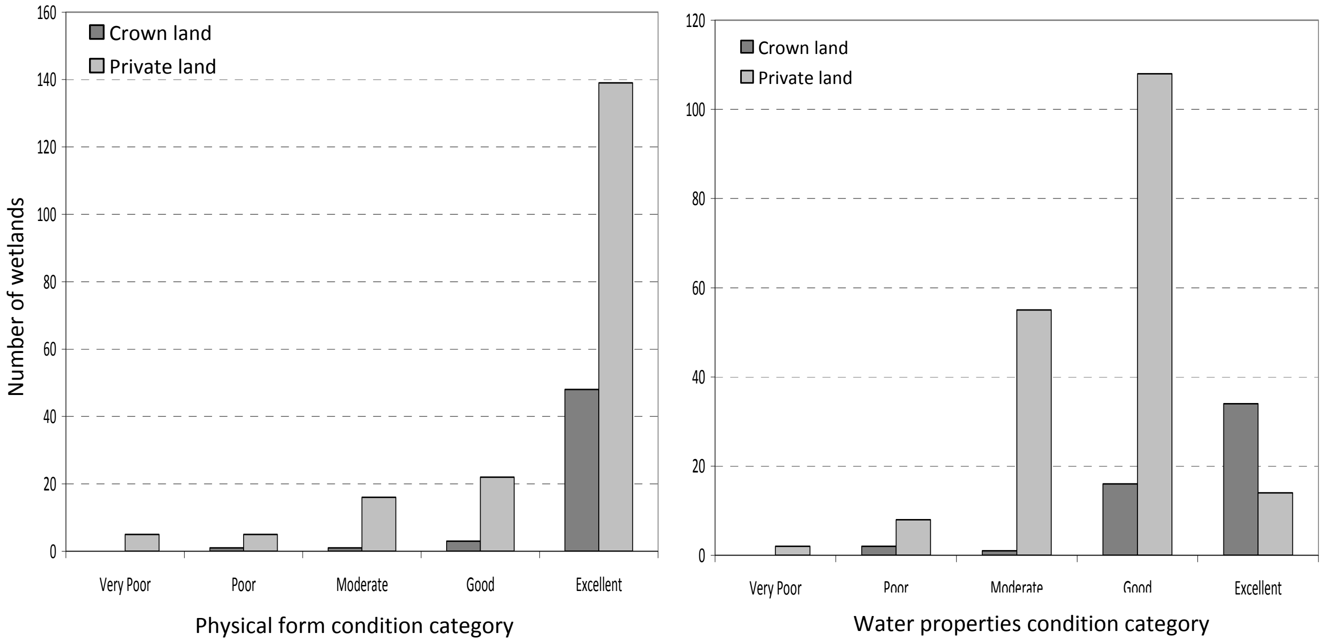

Figure 16. Distribution of wetlands across condition categories for the physical form subindex condition (left) and water properties subindex condition (right) for representative wetlands on public land and private land.

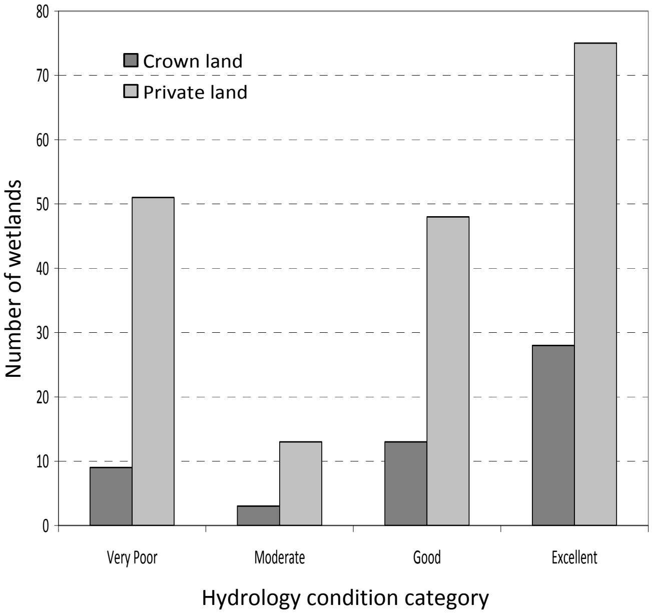

Figure 17. Distribution of wetlands across condition categories for the hydrology subindex for wetlands on public land and private land.

3.2 Comparison of wetland condition among wetland attribute categories

3.2.1 High-value wetland categories

Figures 18–21 show the range of overall IWC scores and subindex scores for the high-value wetland categories for comparison. Where there is a significant difference among group means, as determined by a Kruskal-Wallis test, the *p*-value is reported in square brackets in the figure caption using the following annotation: < 0.001 = ***, < 0.01 = **, < 0.05 = *, > 0.05 = NS (not significant).

The overall condition of Ramsar wetlands was significantly lower than DIWA and Edenhope wetlands (Figure 18). This was due largely to the low hydrology subindex scores of the Ramsar wetlands (Figure 19). Wetland catchment subindex scores for the DIWA wetlands exhibited a greater range and included wetlands with higher scores than the Edenhope and Ramsar wetlands (Figure 20). A larger proportion of Edenhope wetlands had higher water properties subindex scores, compared to DIWA and Ramsar wetlands (Figure 20). There were no significant differences in the biota, physical form and soils subindex scores among the groups.

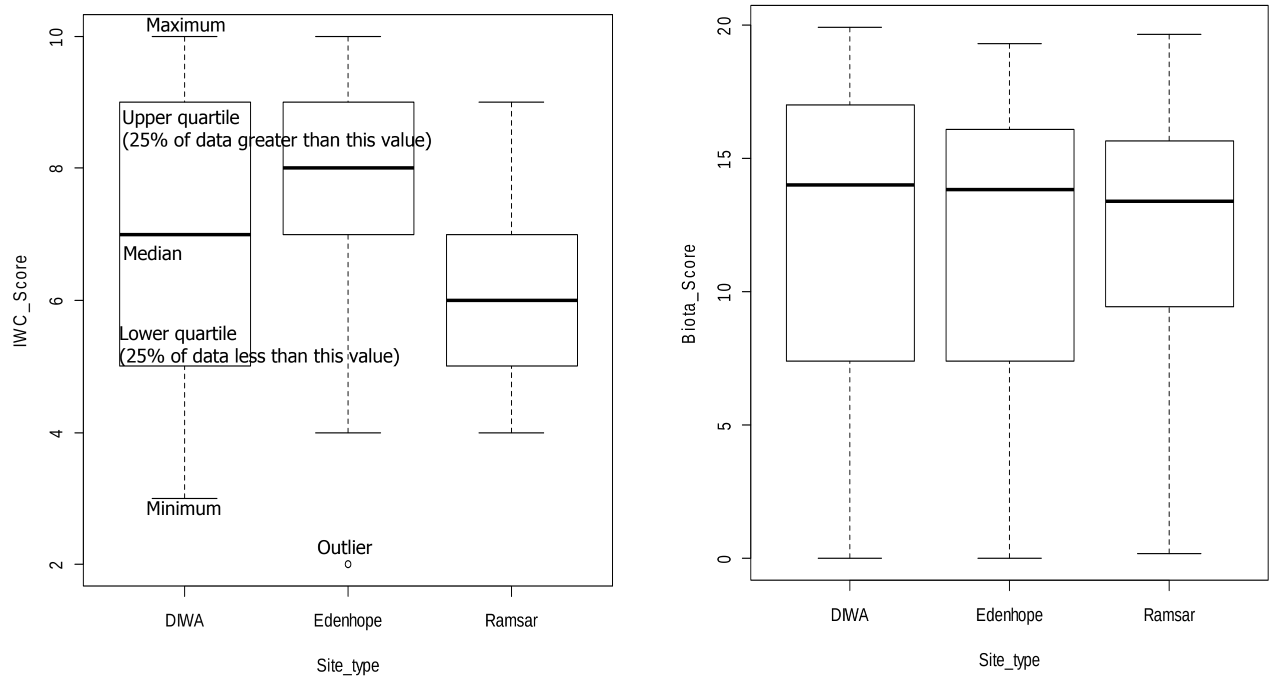

Figure 18. Box and whisker plot showing IWC overall scores [**] (left) and biota subindex scores [NS] (right) for high-value wetland categories. Features of the plot are shown to aid interpretation.

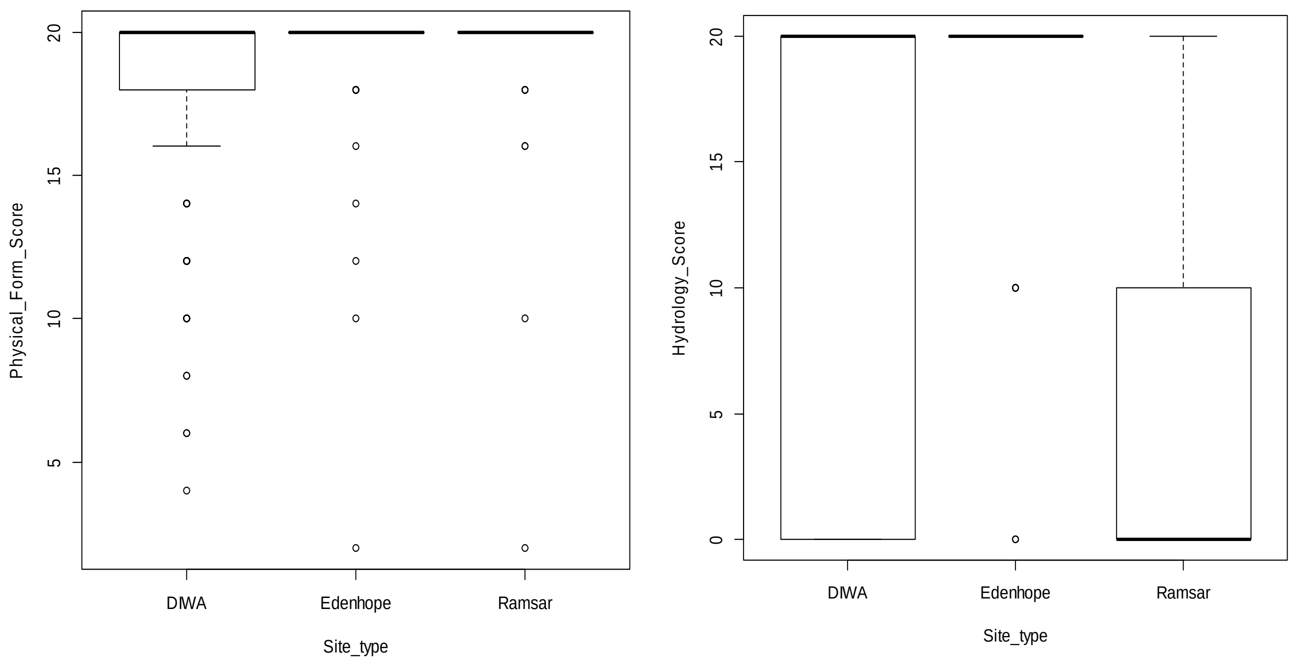

Figure 19. Box and whisker plot showing physical form subindex scores [NS] (left) and hydrology subindex scores [***] (right) for high-value wetland categories.

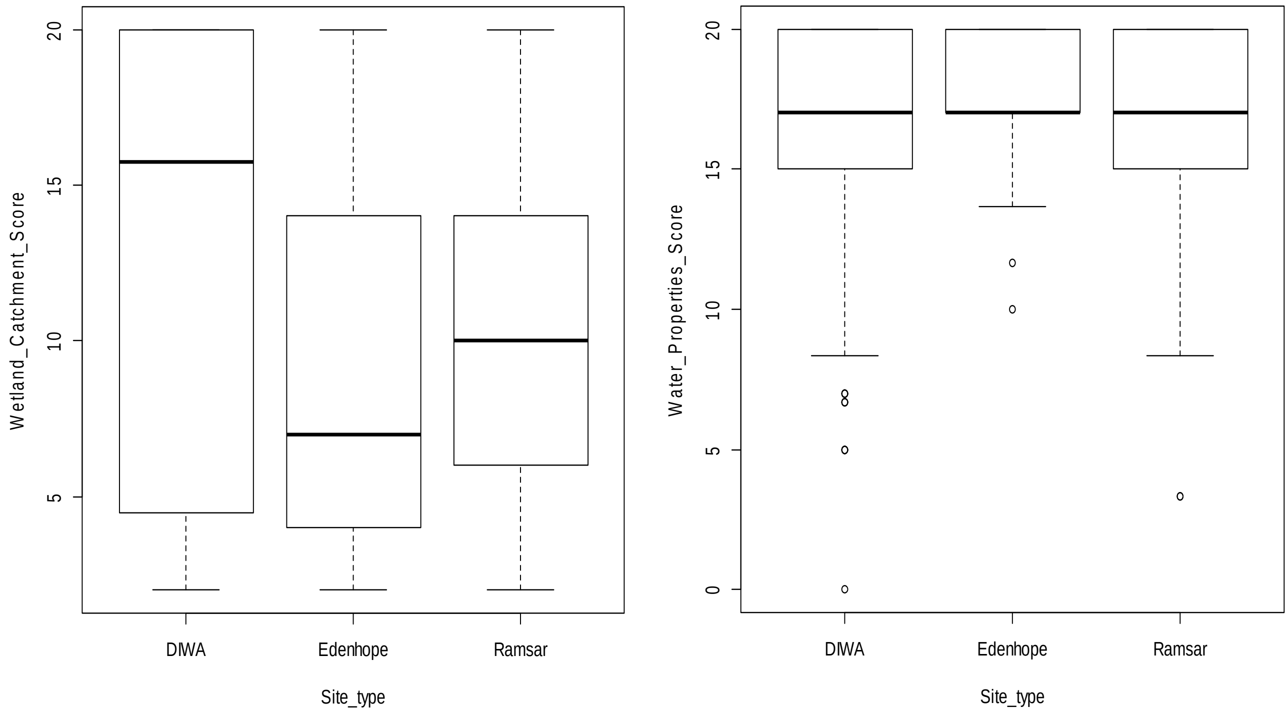

Figure 20. Box and whisker plot showing wetland catchment subindex scores [***] (left) and water properties subindex scores [***] (right) for high-value wetland categories.

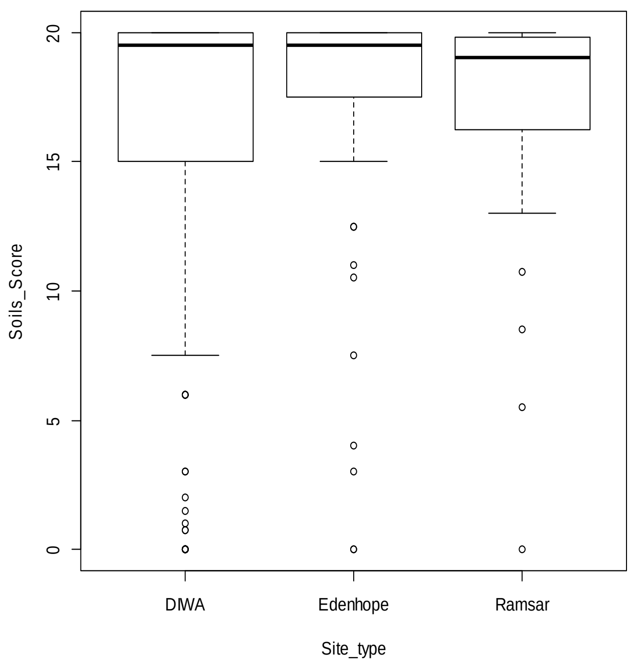

Figure 21. Box and whisker plot showing soils subindex [NS] for high-value wetland categories.

3.2.2 High-value and representative wetlands

The mean scores for the overall IWC score and all subindex scores except biota were significantly higher for the high-value wetlands than for the representative wetlands (Figures 22–25). The greatest difference among the groups occurred in the wetland catchment and water properties subindices (Figure 23). Among both wetland groups, the physical form and water properties subindex scores were least variable.

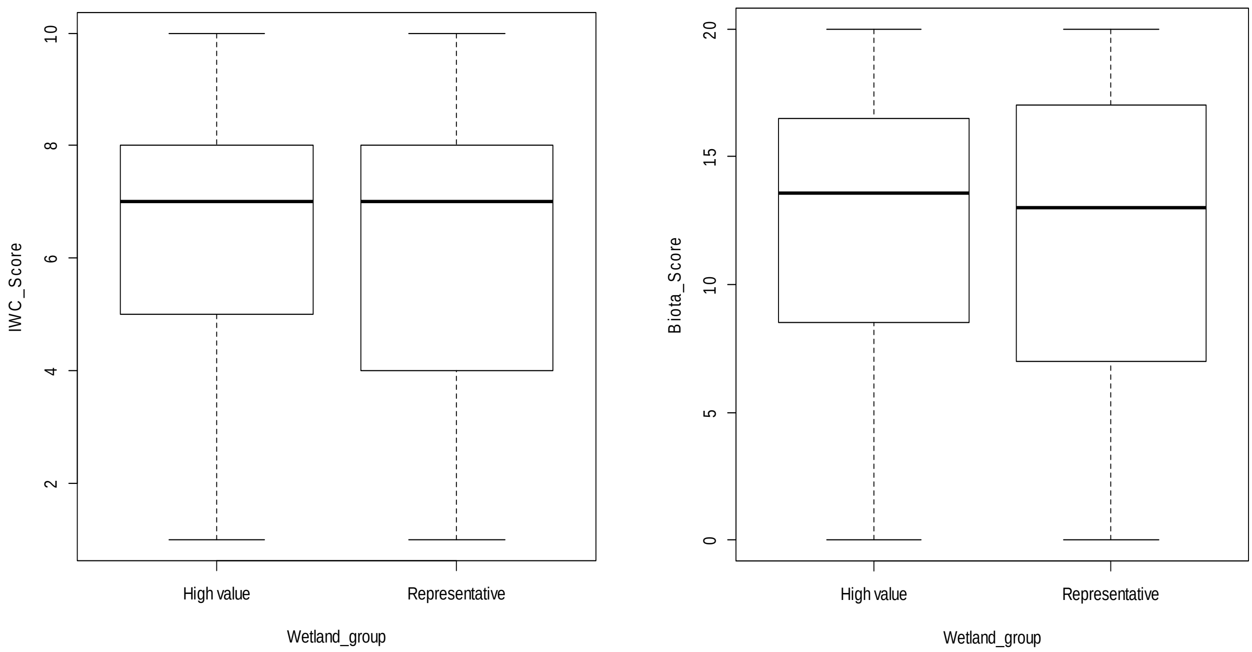

Figure 22. Box plot showing IWC overall scores [*] (left) and biota subindex scores [NS] (right) for high-value and representative wetlands.

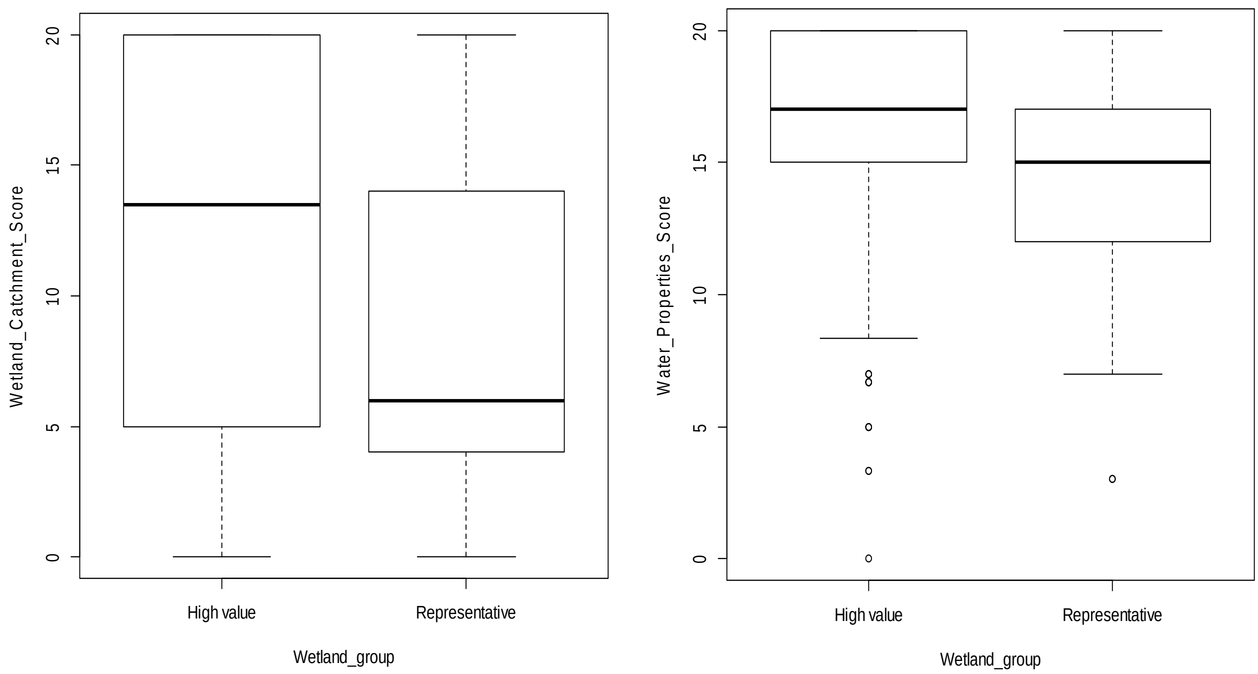

Figure 23. Box plot showing wetland catchment subindex scores [***] (left) and water properties subindex scores [***] (right) for high-value and representative wetlands.

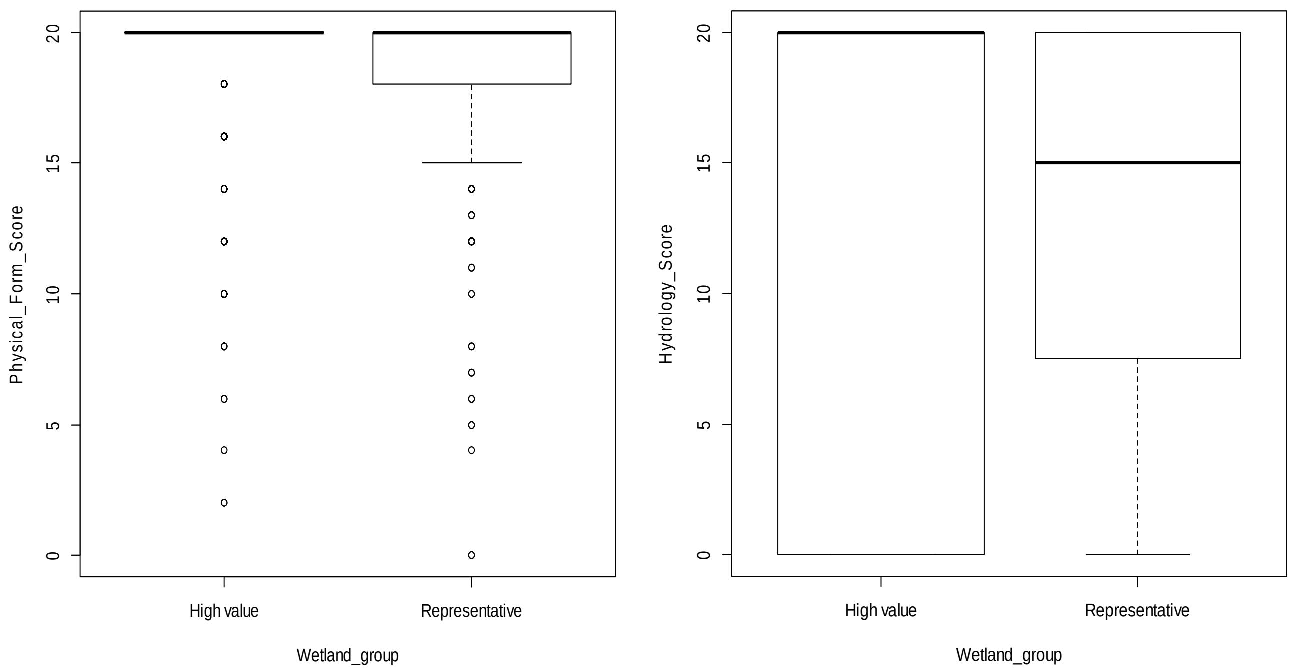

Figure 24. Box plot showing physical form subindex scores [**] (left) and hydrology subindex scores [**] (right) for high-value and representative wetlands.

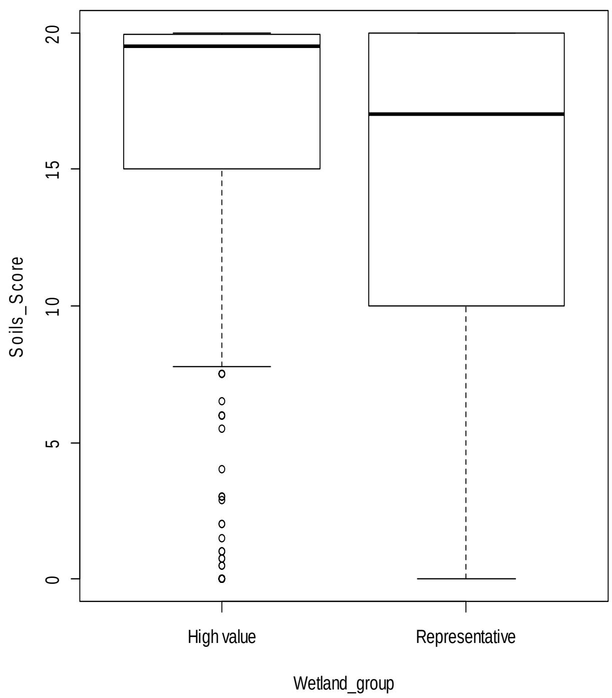

Figure 25. Box plot showing soils subindex scores [***] for high-value and representative wetlands.

3.2.3 Other attributes

Figures 26–30 show the range of condition scores (overall IWC score) for categories of wetland type attributes and several other attributes that were expected to influence wetland condition for the high-value and representative wetlands (Table 18). The range of condition scores among wetland type categories (see Table 7) is also presented. Where there is a significant difference between categories, as determined by tests on their means, the *p*-value is reported in square brackets in the figure caption using the following annotation: < 0.001 = ***, < 0.01 = **, < 0.05 = *, > 0.05 = NS (not significant). Scatter plots are used to show overall condition scores plotted against wetland area for the high-value and representative wetlands.

Table 18. Attributes and their categories presented in Figures 26–30.

Attribute type	Attribute	Categories
Wetland type	Climate	Semi-arid
		Temperate
	Landscape context	Alpine
		Upland
		Lowland
	Water regime	Permanent
		Seasonal
	Salinity	Fresh
		Saline
Other	Water source	River or stream
		Groundwater
		Surface runoff
		Artificial channel
		River/Groundwater
		River/Artificial Channel
		Groundwater/Artificial Channel
		Groundwater/Artificial Channel/River
	Land tenure	Public
		Private
	Wetland phase	Full
		Filling
		Receding
		No water present

High-value wetlands

The mean IWC overall scores for wetlands in the temperate zone were significantly higher than those for wetlands in the semi-arid climate zone, although temperate wetlands exhibited a much greater range. Alpine wetlands were in better condition than lowland and upland wetlands (Figure 26). There was no significant difference in the condition between permanent and seasonal wetlands, nor between fresh and saline wetlands (Figure 27). There was a significant difference in mean wetland condition scores between the wetland phase categories. Wetlands with no water present at the time of the assessment were in poorer condition than wetlands with some water (Figure 28). Mean wetland conditions scores for wetlands on public land were significantly higher than for wetlands on private land.. More wetlands fed by groundwater and local runoff were in better condition than river-fed wetlands, and wetlands fed entirely or in part by an artificial channel were in poorer condition than all other water sources (Figure 29).

Of the 10 wetland types, semi-arid permanent saline wetlands (Type 9) had the lowest condition scores and, as observed with the landscape context attribute, the alpine wetlands (Type 16) had the highest condition scores (Figure 30).

The scatter plot (Figure 31) shows that there is not a simple linear relationship between IWC overall condition and wetland area. This was confirmed by the Pearson's correlation coefficient, which was very low (0.01). However, a pattern is evident whereby only wetlands smaller than approximately 300 ha were in very poor or poor condition (i.e. IWC scores 1-4).

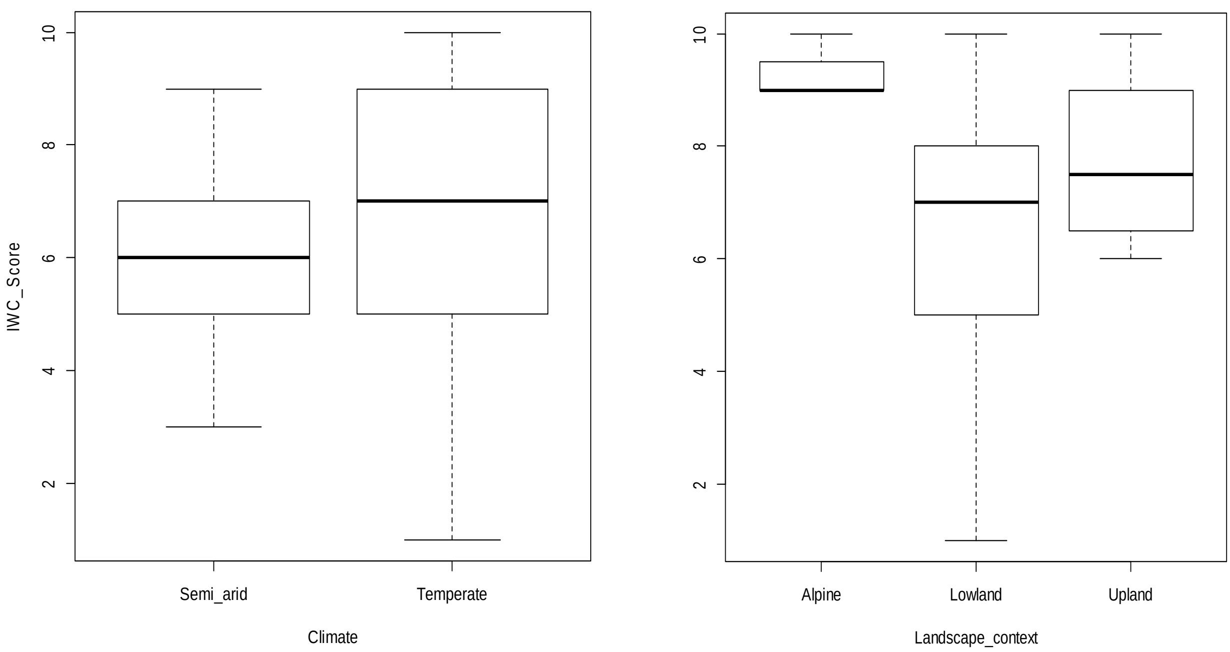

Figure 26. Box plot showing overall IWC scores for climate categories [***] (left) and landscape context categories [***] (right).

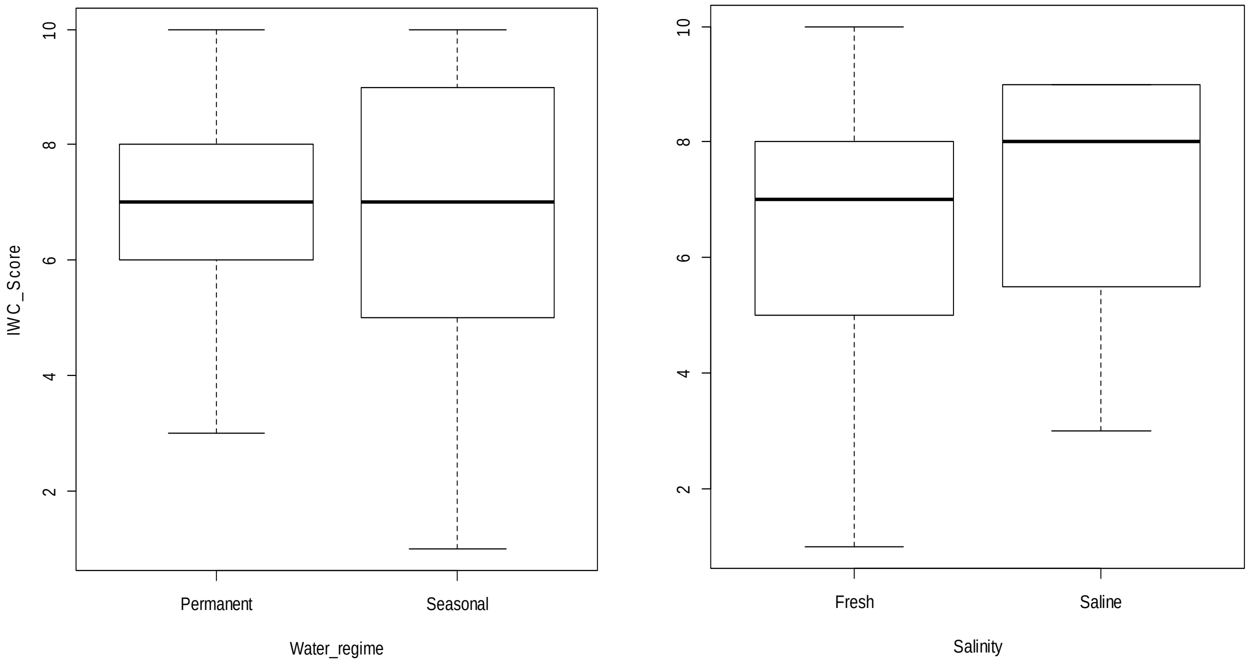

Figure 27. Box plot showing overall IWC scores for water regime categories [NS] (left) and salinity categories [NS] (right).

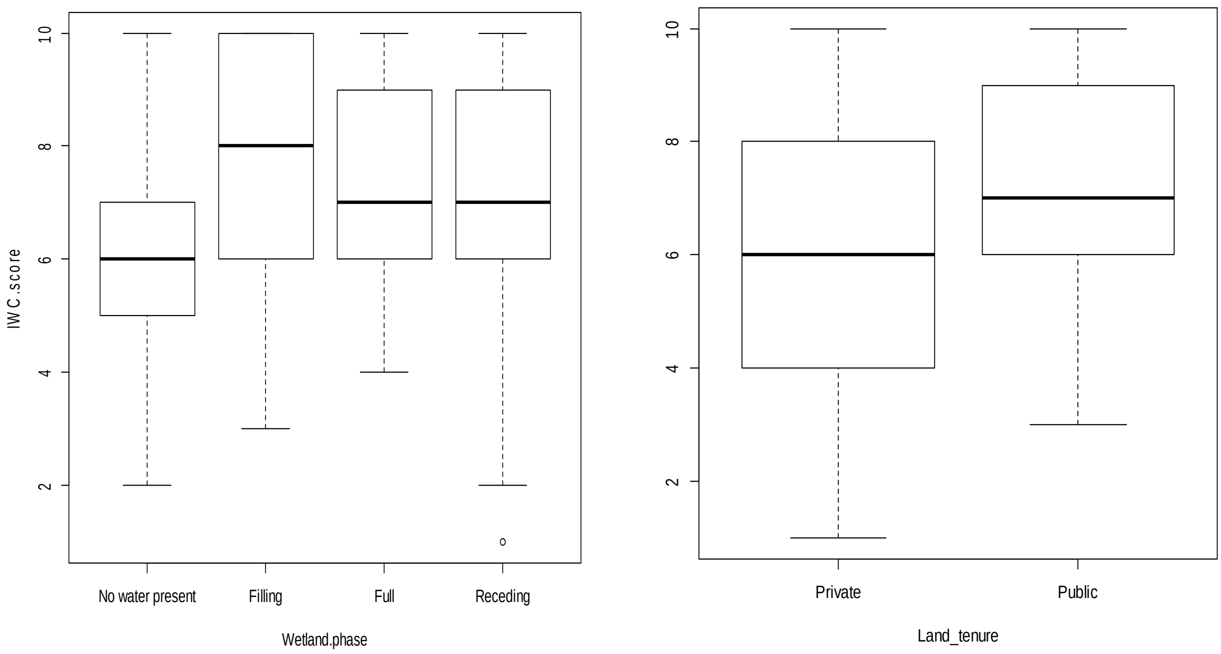

Figure 28. Box plot showing IWC overall scores for wetland phase categories [***] (left) and land tenure [***] (right).

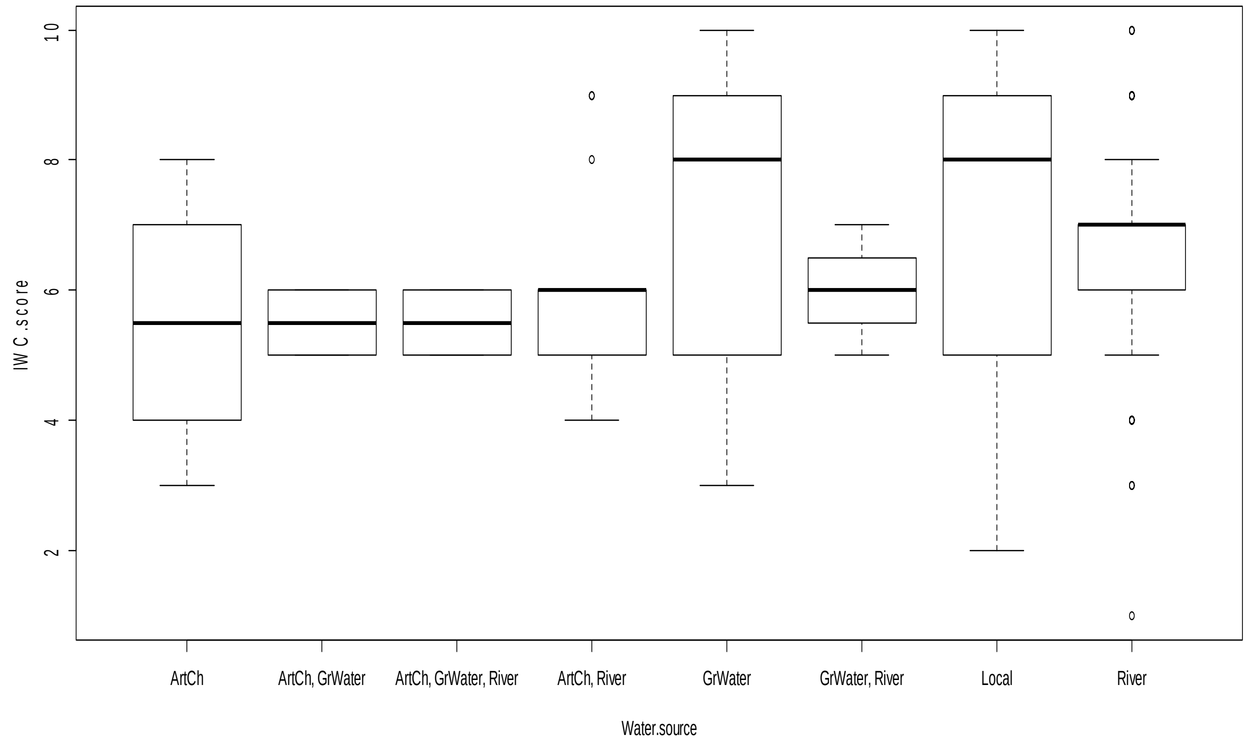

Figure 29. Box plot showing IWC overall score for water source categories [***]. ArtCh = artificial channel, GrWater = groundwater.

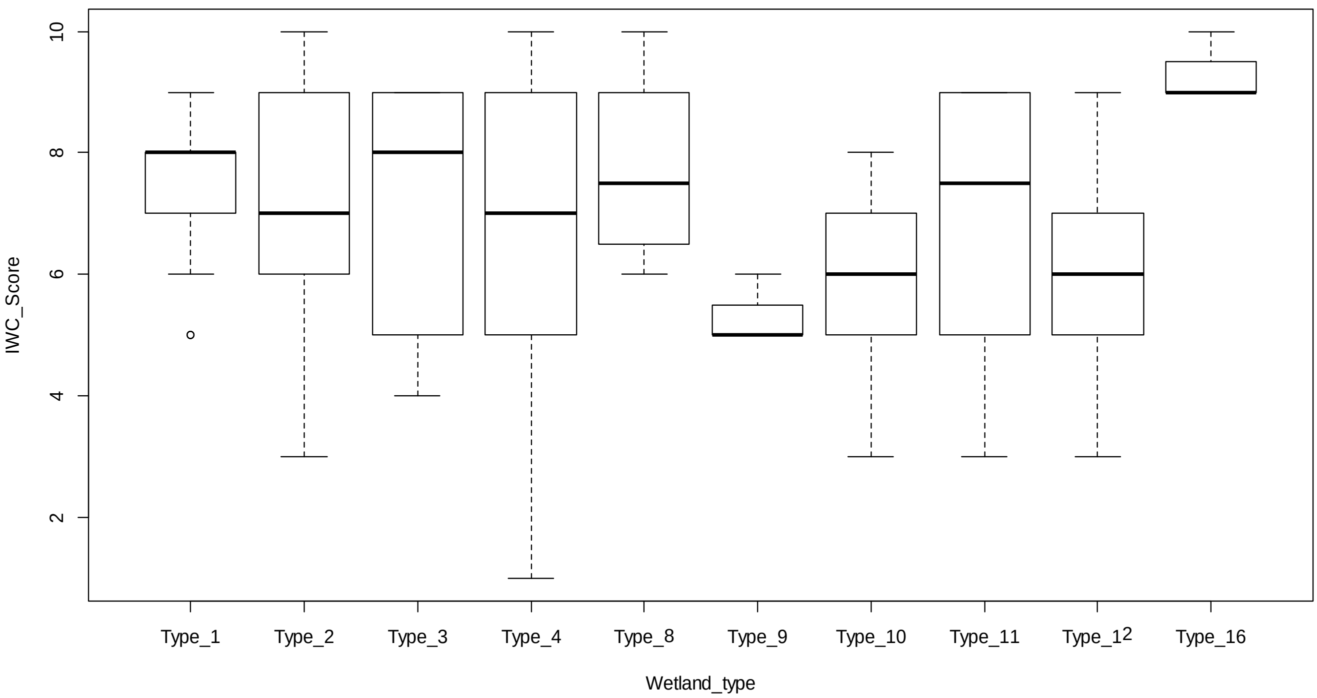

Figure 30. Box plot showing IWC overall score for wetland types [***]. Wetland types are shown in Table 11. Note: no wetlands of types 13-15 were assessed.

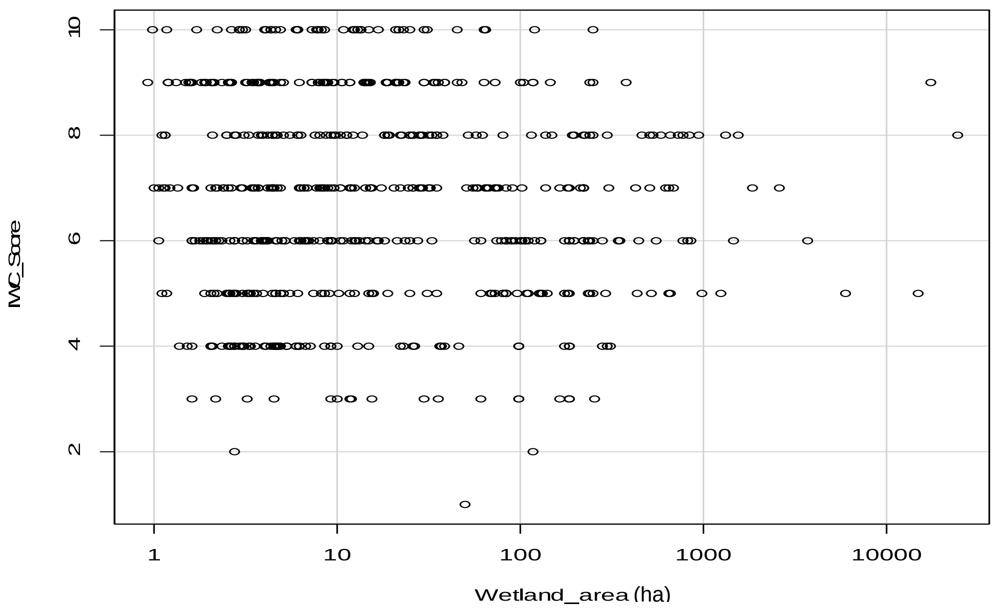

Figure 31. Scatter plot of IWC overall score against wetland area for the high-value wetlands.

Representative wetlands

Unlike the high-value wetlands, the mean IWC overall scores for representative wetlands in the temperate zone were not significantly different to those of wetlands in the semi arid climate zone (Figure 32). However, as with the high-value wetlands, representative upland and alpine wetlands were in better condition than most lowland wetlands (Figure 32). The condition of permanent wetlands was significantly better than seasonal wetlands but the condition of fresh and saline wetlands were not significantly different to each other (Figure 33). As with high-value wetlands, the condition of wetlands with no water present were significantly lower than for other wetland phases and the condition of wetlands on public land was significantly higher than those on private land (Figure 34). Wetlands fed by an artificial channel have much lower condition scores that wetlands with other water sources. Groundwater fed wetlands had the highest condition scores (Figure 35).

As with the high-value wetlands, the semi arid permanent saline wetlands (Type 9) had the lowest condition scores. In contrast, the lowland permanent saline wetlands in the semi arid zone had a high condition score (Type 1). As observed with the landscape context attribute, alpine wetlands (Type 16) had the highest condition scores (Figure 36).

The scatter plot (Figure 37) shows that it is not a simple linear relationship between IWC overall condition and wetland area. This was confirmed by the Pearson's correlation coefficient which was very low (0.02). However, a pattern is evident whereby only wetlands smaller than approximately 50 ha were in very poor or poor condition (i.e. IWC scores 1-4).

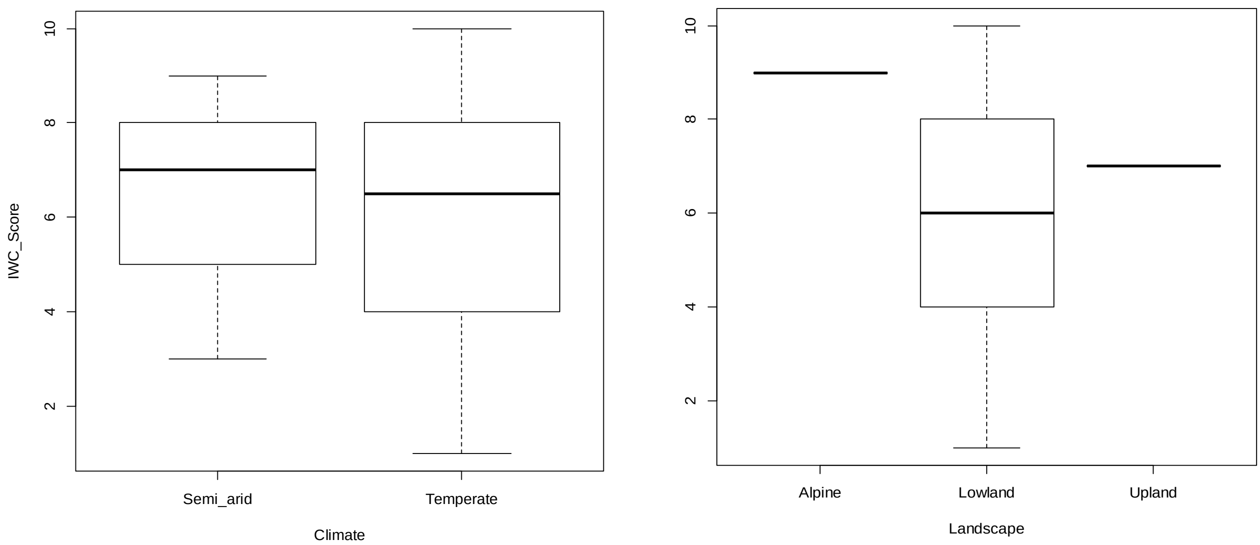

Figure 32. Box plot showing overall IWC scores for climate categories [NS] (left) and landscape context categories [**] (right).

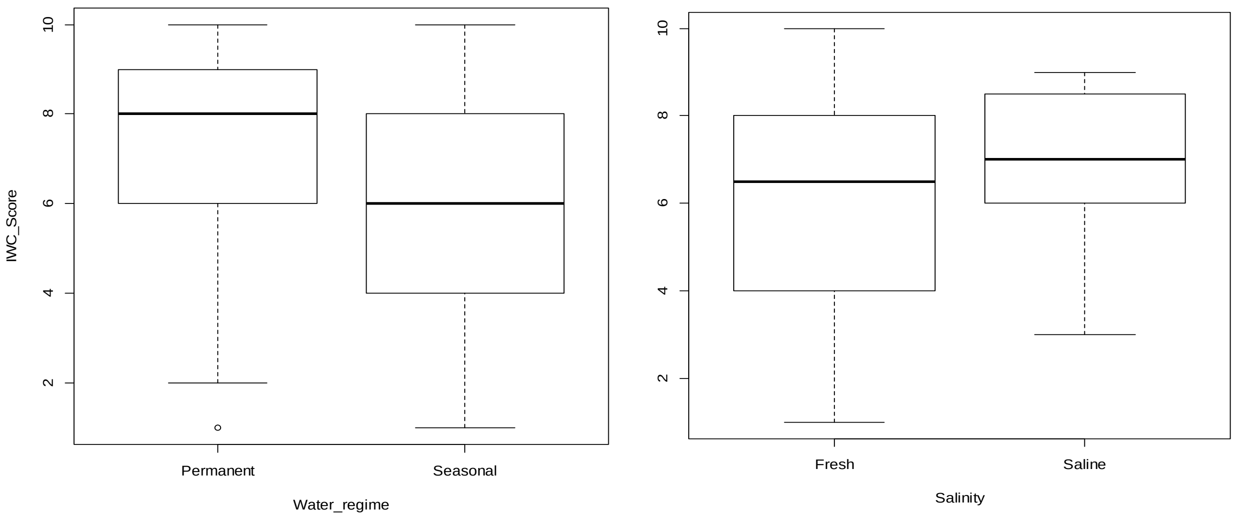

Figure 33. Box plot showing overall IWC scores for water regime categories [***] (left) and salinity categories [NS] (right).

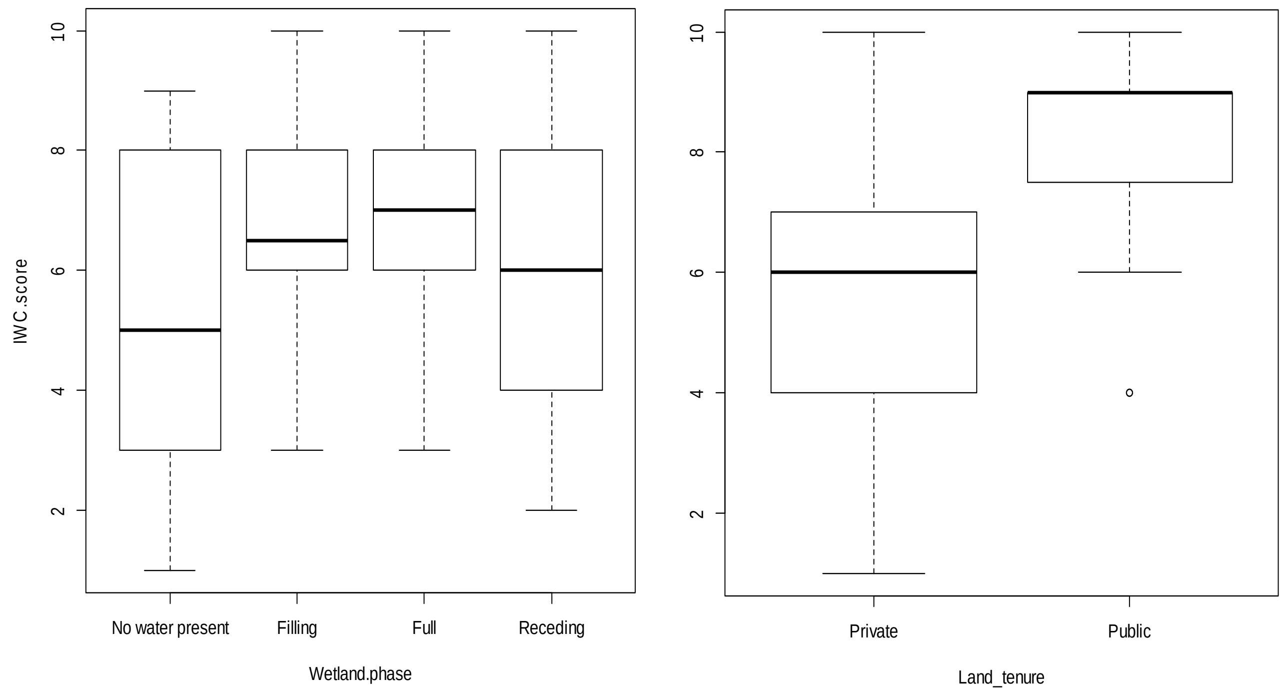

Figure 34. Box plot showing IWC overall scores for wetland phase categories [*] (left) and land tenure [***] (right).

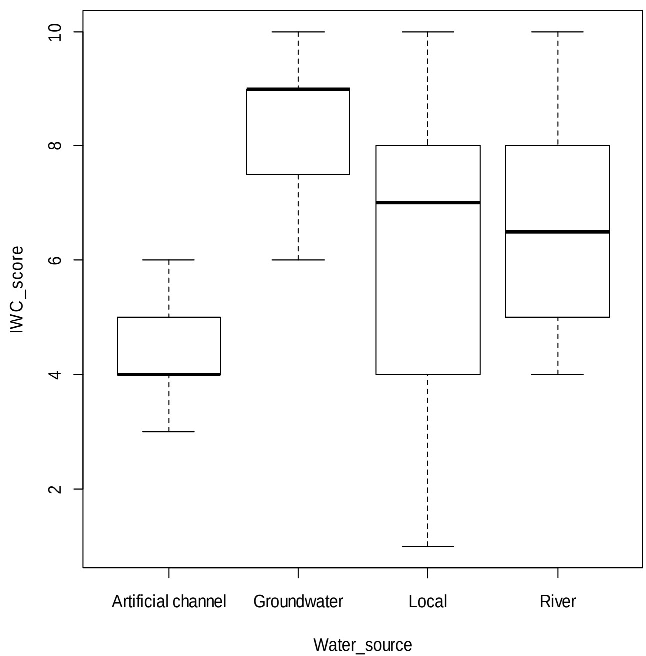

Figure 35. Box plot showing IWC overall score for water source categories [*]. ArtCh=artificial channel, GrWater=groundwater.

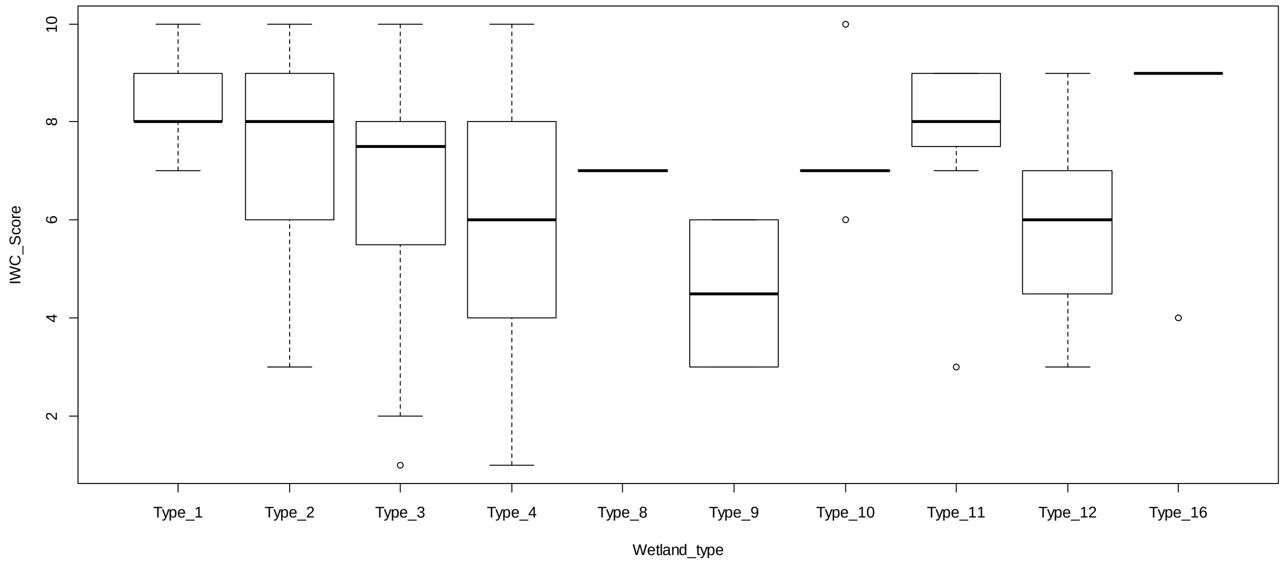

Figure 36. Box plot showing IWC overall score for wetland types [***]. Wetland types are shown in Table 11. Note: no wetlands of types 13-15 were assessed.

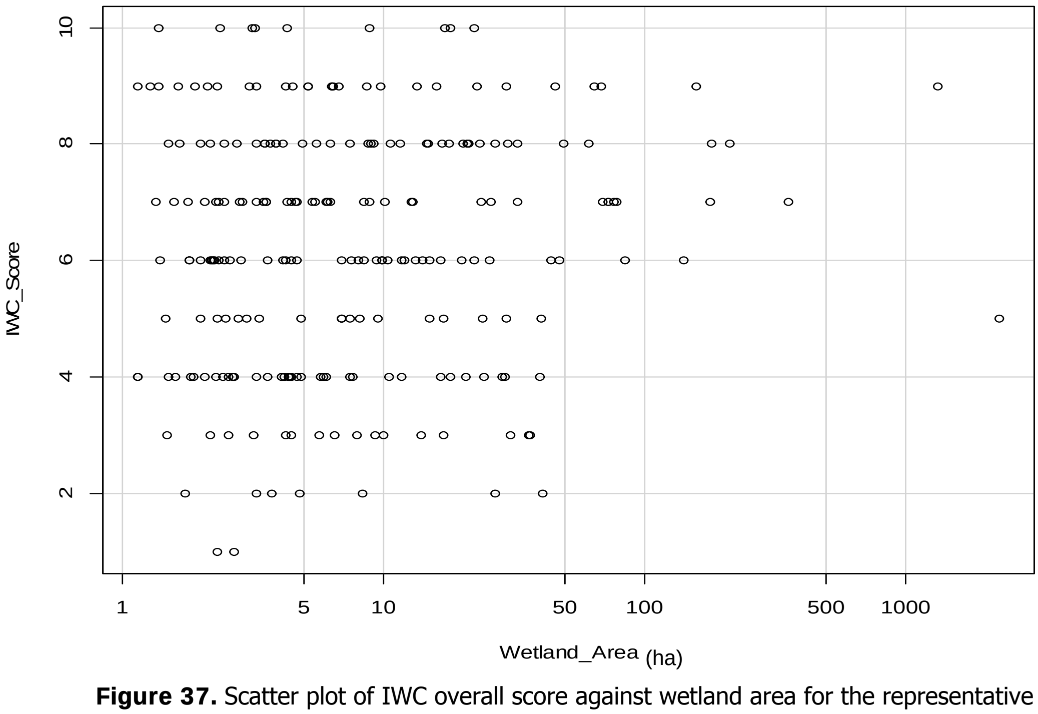

Figure 37. Scatter plot of IWC overall score against wetland area for the representative wetlands.

3.3 Threats and sources of threat for high-value and representative wetlands

For the purpose of this analysis, a threat was considered to be operating at a wetland if its corresponding IWC measure or subindex condition category was very poor, poor or moderate. This was used to determine the proportion of high-value and representative wetlands subject to threats and the proportion with sources of threats. See Section 2.3.2 and Table 12 for a list of threats and threat sources. For some threats, e.g. altered hydrology, there are many threat sources. Because of this is possible to have a high proportion of wetlands with a particular threat source but a low proportion of wetlands with the corresponding threat.

Almost half of the high-value wetlands had altered hydrology. Soil disturbance was the next most common threat at these wetlands (19% of wetlands), followed by degraded water quality (15%), reduced wetland area (14%) and altered wetland form (6%) (Table 19). The most prevalent threat sources at the high-value wetlands were pugging by livestock and feral animals (56% of wetlands), grazing leading to nutrient enrichment (54%), a change to the flow regime of the water source (36%), disturbance of wetland soils by vehicles (35%) and excavation of the wetland bed (25%). Threat sources were present at wetlands on public and private land, and in some cases more prevalent at wetlands on public land (e.g. change to the flow regime of the water source and obstruction of inlets) (Table 19).

At the representative wetlands, soil disturbance was the most prevalent threat (38% of wetlands), followed by altered hydrology (32%), degraded water quality (28%), reduced wetland area (26%) and altered wetland form (12%) (Table 20). The most prevalent threat sources were non-point source runoff and grazing leading to nutrient enrichment (both occurring at 59% of all wetlands), pugging by livestock and feral animals (55%), excavation of the wetland bed (45%), a change to the flow regime of the water source (35%) and landforming (e.g. levelling) (30%). All threat sources (except two that were uncommon) were 2–10 times more prevalent on private land than on public land.

At the high-value wetlands, local runoff and rivers were the most common water sources (Table 21). Altered hydrology was more prevalent at river-fed wetlands (69%) than at wetlands with other water sources .Sources of threat for river-fed wetlands included a changed flow regime of the water source (66%), obstructed of wetland inlets (28%) and obstruction of wetland outlets (18%). Over 20% of wetlands with an artificial channel as a water source had all but two altered hydrology threat sources (Table 20). None of the sources of threat for wetlands fed by local runoff were dominant.

The majority of representative wetlands were fed by local runoff. Of these wetlands, 28% were threatened by altered water regimes. Half of the river-fed wetlands were threatened by altered hydrology (Table 21). The most common sources of threat for wetlands fed by local runoff were a change to wetland water source flow regime (27%) and obstruction of wetland inlets (21%). For the river-fed wetlands, the most common sources of threat were change to wetland water source flow regime (68%) obstruction of wetland inlets (33%) and obstruction of wetland outlets (23%). A quarter of wetlands which were groundwater fed had a changed wetland water source flow regime (Table 20).

Table 19. Percentage of all high-value wetlands with threats operating on them, and their corresponding threat sources.

Threat	**IWC measure that corresponds to the threat**	**% All wetlands** (*n* = 586)	**% Public wetlands** (*n* = 381)	**% Private wetlands** (*n* = 205)	**IWC activity that corresponds to the threat source**	**% All wetlands** (*n* = 586)	**% Public wetlands** (*n* = 381)	**% Private wetlands** (*n* = 205)
Reduced wetland area	Reduction in wetland area	14	8	24	not documented in the IWC assessment			
Altered wetland form	Severity of change to wetland bathymetry	6	4	11	Excavation (e.g. dams)	25	16	41
					Landforming (e.g. levelling)	16	9	27
Altered hydrology	Hydrology subindex score (severity of change to wetland water regime)	46	51	39	Change to wetland water source flow regime	36	40	29
					Obstruction of wetland inlets	18	21	14
					Obstruction of wetland outlets	15	14	16
					Drainage of water from the wetland	7	2	14
					Water disposal into wetland	7	6	11
					Extraction of water from the wetland	3	3	3
					Activities that raise the water level	9	9	9
					Activities that increase groundwater height	9	11	4
					Activities that decrease groundwater height	6	2	14
Degraded water quality	Water properties subindex score (eutrophication and change in salinity)	15	10	25	Discharge of nutrients into wetland (point source)	11	9	15
					Urban drainage	3	3	2
					Nutrient runoff (non-point source)	3	4	1
					Grazing	54	48	65
					Aquaculture	0	0	0
					Increase salinity	5	6	3
Soil disturbance	Soils subindex score (extent and severity of soil disturbance)	19	11	35	Pugging by livestock and feral animals	56	53	63
					Cultivation	8	2	21
					Carp mumbling	2	3	0
					Trampling by humans	6	6	6
					Vehicle disturbance	35	36	33
Any threat		60						

Table 20. Percentage of all representative wetlands, and representative wetlands on public and private land with threats operating on them, and their corresponding threat sources.

Threat	IWC measure that corresponds to the threat	% All wetlands (*n* = 240)	% Public wetlands (*n* = 53)	% Private wetlands (*n* = 187)	IWC activity that corresponds to the threat source	% All wetlands (*n* = 240)	% Public wetlands (*n* = 53)	% Private wetlands (*n* = 187)
Reduced wetland area	Reduction in wetland area	26	11	28	not documented in the IWC assessment			
Altered wetland form	Severity of change to wetland bathymetry	12	4	14	Excavation (e.g. dams)	45	23	52
					Landforming (e.g. levelling)	30	17	34
Altered hydrology	Hydrology subindex score (severity of change to wetland water regime	32	23	34	Change to wetland water source flow regime	35	28	37
					Obstruction of wetland inlets	23	26	22
					Obstruction of wetland outlets	16	7	19
					Drainage of water from the wetland	11	0	14
					Water disposal into wetland	5	11	3
					Extraction of water from the wetland	3	6	3
					Activities that raise the water level	11	7	12
					Activities that increase groundwater height	3	6	3
					Activities that decrease groundwater height	3	0	4
Degraded water quality	Water properties subindex score (eutrophication and change in salinity)	28	6	35	Discharge of nutrients into wetland (point source)	4	2	4
					Urban drainage	2	4	2
					Nutrient runoff (non-point source)	59	24	68
					Grazing	59	24	69
					Aquaculture	2	0	2
					Increase salinity	5	0	6
Soil disturbance	Soils subindex score (extent and severity of soil disturbance)	38	7	46	Pugging by livestock and feral animals	55	24	64
					Cultivation	16	0	20
					Carp mumbling	<1	2	0
					Trampling by humans	5	4	6
					Vehicle disturbance	23	21	23
Any threat		62						

* Activities that reduce the wetland area were not documented in the IWC assessment.

Table 21. Percentage of wetlands in each water source category with an altered water regime and corresponding threat sources for high-value and representative wetlands.

	Threat and IWC activity that correspond to the threat source	Local (%) (*n* = 256)	River (%) (*n* = 220)	Groundwater (%) (*n* = 66)	Artificial channel (%) (*n* = 18)	Artificial channel/ River (%) (*n* = 17)	Ground water/ River (%) (*n* = 3)
High-value wetlands	**Threat**						
	Altered hydrology	37	69	8	50	53	0
	Threat sources						
	Change to wetland water source flow regime	12	66	12	39	76	67
	Obstruction of wetland inlets	9	28	5	33	59	100
	Obstruction of wetland outlets	10	18	6	22	59	0
	Drainage of water from the wetland	7	5	3	28	18	0
	Water disposal into wetland	4	5	5	56	35	0
	Extraction of water from the wetland	1	4	2	0	24	0
	Activities that raise the water level	6	12	2	33	24	0
	Activities that increase groundwater height	0	9	18	28	47	33
	Activities that decrease groundwater height	6	1	27	0	6	0
		Local (%) (*n* = 183)	**River (%)** (*n* = 40)	**Groundwater (%)** (*n* = 12)	**Artificial channel (%)** (*n* = 5)	**Artificial channel/ River (%)** (*n* = 0)	**Ground water/ River (%)** (*n* = 0)
Representative wetlands	**Threat**						
	Altered hydrology	28	50	0	100		
	Threat sources						
	Change to wetland water source flow regime	27	68	25	80		
	Obstruction of wetland inlets	21	33	8	40		
	Obstruction of wetland outlets	15	23	8	40		
	Drainage of water from the wetland	10	13	8	20		
	Water disposal into wetland	4	8	0	20		
	Extraction of water from the wetland	3	8	0	0		
	Activities that raise the water level	10	15	0	20		
	Activities that increase groundwater height	3	5	0	0		
	Activities that decrease groundwater height	4	0	0	0		

3.4 Wetland condition modelling

Model development was based on IWC scores and categories for 860 wetlands from the first (high-value wetlands) and second (representative wetlands) statewide assessments.

Results for all modelling approaches are presented below (see Section 2.3. for modelling methods). Where appropriate, model averaging was also explored, but as the averaged models were no better than the individual models they were not included. We also explored *ad hoc* methods such as running all methods and using the most frequent prediction as the final prediction. None of these methods improved the likelihood of a correct prediction.

The expected relationships between the model variable and wetland condition are as follows:

- Increased public land ownership and/or nature conservation in the wetland catchment would lead to better condition due to fewer threats and sources of threat on public land.
- Increased Landscape Development Intensity Index score would lead to worse condition due to the increased risk of threats and threat sources associated with more intensive land uses.
- Increased wetland size would lead to better condition due to lower exposure of larger wetlands to threats and sources of threat.
- Saline wetlands likely to be in better condition. Threat levels may differ among fresh and saline wetlands for several reasons, e.g. freshwater wetlands are more attractiveness for livestock grazing and saline aquifers feeding saline groundwater wetlands are unlikely to be exploited for consumptive purposes

3.4.1 Ordinal response classification tree

The result of the ordinal response classification tree using an impurity function is presented in Figure 38. All predictors were considered for the classification tree, but only six improved the model enough to be included in the final classification. It can be seen that the proportion of public land in the wetland catchment is important in determining the IWC condition score. A larger proportion of public ownership would seem to imply better wetland condition. Wetlands fed by groundwater also seem to have better condition. Generally the larger the VicgridNorth reference (i.e. farther north of the wetland), the higher the condition score. Other predictors used by the ordinal classification tree are the rainfall index, VicgridEast reference, and whether the wetland is fresh or saline. However, as the model is a poor predictor of wetland condition, there is no indication that these associations are valid.

A summary of the model results is as follows:

- Good condition was over-predicted. For example, 28 wetlands of Moderate condition were predicted as Good (see highlighted cell in Table 22).
- Half of the testing data was misclassified (see Table 32).
- Good and Excellent condition were correctly predicted over 60% of the time (see Table 33).
- In testing, the observed and predicted wetland conditions were moderately correlated ($\rho = 0.539$).

Table 22. The summarised observed versus predicted IWC categories for the testing data using the ordinal classification tree method. Highlighted cell shows over-prediction of the Good category.

Classification Tree		**Predicted category**			
		Poor	**Moderate**	**Good**	**Excellent**
Observed (actual IWC category)	**Poor**	11	6	8	1
	Moderate	8	16	28	0
	Good	3	13	38	8
	Excellent	1	2	8	21

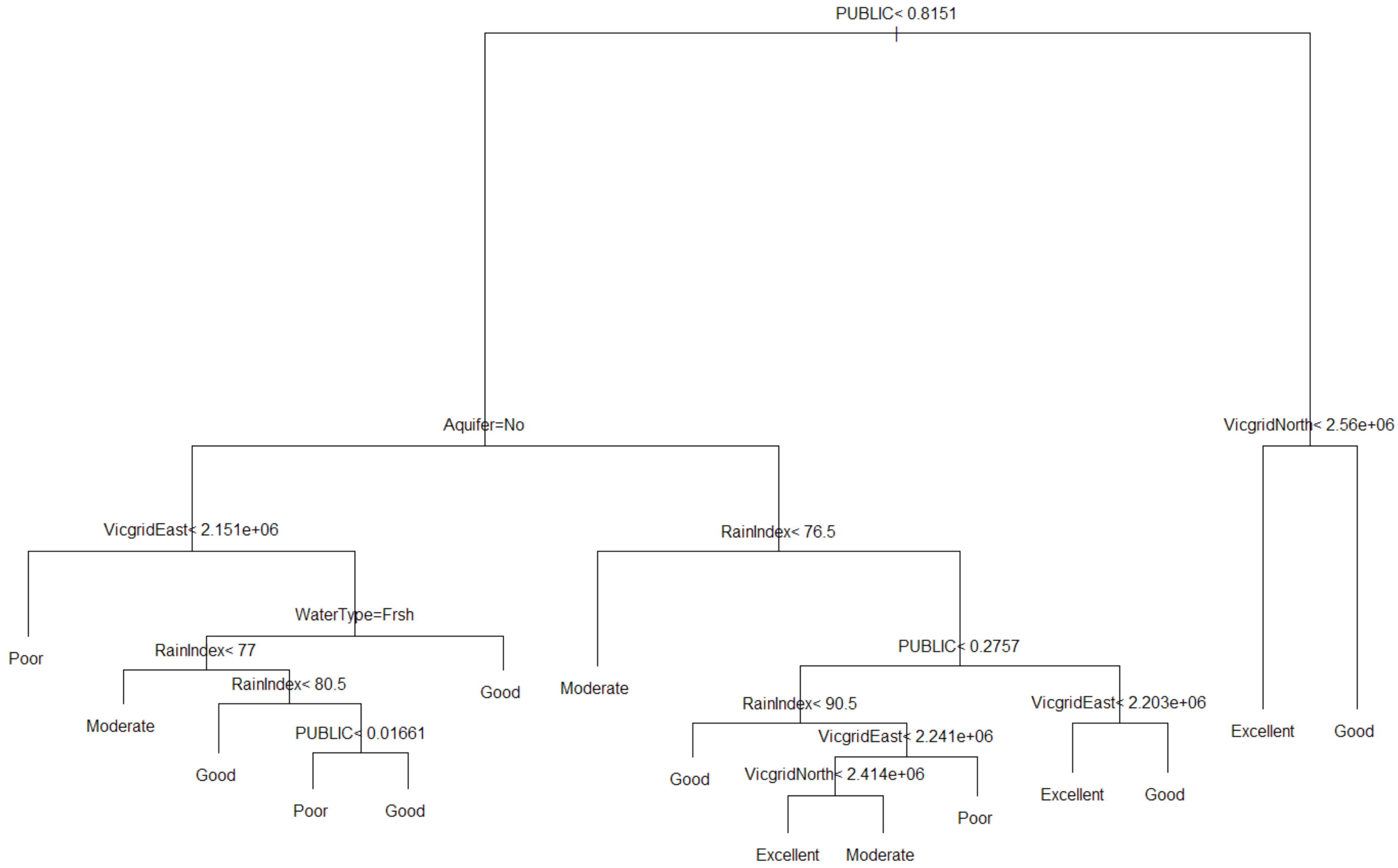

Figure 38. The classification tree using the training data for the IWC categories. If the statement is true, branch to the left; if false, branch to the right.

3.4.2 Continuation ratio ordinal regression

The continuation ratio ordinal regression resulted in two models, one using ascending conditions, the other descending. The reason is that the models will not be symmetrical and therefore will not give the same results or necessarily use the same variables.

Ascending model

The ascending model uses the data in three groups: (1) all the observations (to distinguish between Poor and not Poor IWC categories), (2) the not Poor observations (to distinguish between Moderate and Good or better IWC categories), and (3) Good or better (to distinguish between Good and Excellent IWC categories). The best model (as determined by the smallest BIC) for the ascending regression (see Equations 1–3 in Appendix 2) resulted in the predictions in Table 23. From the equations it can be seen which variables are important in distinguishing between IWC categories.

The proportion of public land in the buffer is important in distinguishing between Poor or not Poor and Good and Excellent IWC categories. Higher public ownership of land in the wetland catchment increases the likelihood of being in the higher category, and groundwater increases the likelihood of not Poor and Excellent. Similarly, higher proportions of residential, commercial and community (ResComEct) or livestock grazing (LU52) land use decreases the odds of being not Poor. A higher proportion of mixed farming and grazing (LU53) decreases the odds of being not Poor and Excellent (as opposed to Good) but, surprisingly, increases the odds of being Good or better (as opposed to Moderate). The model however performed poorly as indicated by several categories being under or over predicted, low sensitivity for some categories and low specificity. A higher proportion of natural land use (Nature) increases the odds of being Good or better, while floodplains decrease its odds. The farther north the wetland, the more likely it is to be classified as not Poor. The more northerly the site the less likely the wetland is in Excellent condition. However, as the model is a poor predictor of wetland condition, there is no indication that these associations are valid.

A summary of other model results is as follows:

- Good condition was highly over-predicted, with 17 wetlands in the Poor category and 33 in the Moderate category incorrectly predicted as Good (see highlighted cells in Table 23).
- The sensitivity, which is a measure of the proportion of a category correctly predicted, of the Poor (15.4%) and Moderate (26.9%) categories were both very low (see Table 33).
- The specificity, which is a measure of the proportion of samples correctly rejected from a category, was low (see Table 34).
- This model does not consistently correctly predict the lower condition score.

Table 23. The summarised observed versus predicted IWC categories for the testing data using continuation ratio ordinal regression (ascending). Highlighted cells show over-prediction of the Good category.

Continuation ratio (ascending)		Predicted category			
		Poor	Moderate	Good	Excellent
Observed (actual IWC category)	Poor	4	4	17	1
	Moderate	4	14	33	1
	Good	0	15	39	8
	Excellent	0	1	9	22

Descending model

This model uses the data in three groups: (1) all the observations (to distinguish between Excellent and not Excellent IWC categories), (2) the not Excellent observations (to distinguish between Good and Moderate or worse IWC categories, and (3) Moderate or worse (to distinguish between Moderate and Poor IWC categories). The best model (as determined by the smallest BIC) for the descending regression (see Equations 4–6 in Appendix 2) resulted in the prediction in Table 24. From the equations it can be seen which variables are important in distinguishing between IWC categories. A wetland catchment with a larger proportion of public ownership decrease the odds of being classified in the lower group for each equation. Groundwater influence reduces the odds of being classified not Excellent and Poor. Wetlands with above-average rainfall over the three years prior to the survey significantly affected the odds of being classified as not Excellent and Moderate or worse, but there were several interactions with other terms, and whether the odds increased or decreased could not be generalised. The longitude of the wetland significantly affected the odds for Moderate or worse and Poor classifications, but again there were several interactions with other terms, and whether the odds increased or decreased towards east or west could not be generalised. However, as the model is a poor predictor of wetland condition, there is no indication that these associations are valid.

A summary of other model results is as follows:

- Moderate IWC condition was over-predicted, with 30 wetlands in the Good category predicted as Moderate (see highlighted cell in Table 24).
- The specificity, which is a measure of the proportion of samples correctly rejected from a category, was low (see Table 34).
- This model did not consistently predict the lower condition categories correctly.

Table 24. The summarised observed versus predicted IWC categories for the testing data using continuation ratio ordinal regression (descending). Highlighted cell shows over-prediction of the Moderate category.

Continuation ratio (descending)		**Prediction**			
		Poor	**Moderate**	**Good**	**Excellent**
Observed	**Poor**	9	11	5	1
	Moderate	8	28	16	0
	Good	5	30	23	4
	Excellent	0	5	7	20

3.4.3 Frequentist ordered probit regression with flexible thresholds

This method produces a single equation to give a score and a series of cut-offs. The prediction then depends on where the score lies within the cut-offs. The thresholds are ordered, so the lower scores tend to be classified in the lower categories. Model selection was completed using the smallest BIC. The resulting model is summarised in Equation 7 in Appendix 2.

Public ownership and natural land use were key factors in determining the category to which the wetland belongs; wetlands with higher proportions of either have an increased score and therefore are more likely to be in the higher condition categories. Generally wetlands with groundwater influence also have a higher score, while the farther east the wetland is, the lower the score. Additionally the higher the LDII the higher the score, the better the condition which is contrary to that expected. However, as the model is a poor predictor of wetland condition, there is no indication that these associations are valid.

A summary of other model results is as follows:

- Many moderate wetlands were misclassified as Good, and Poor wetlands as Moderate (highlighted cells in Table 25).
- The Goodman and Kruskal's γ shows a moderate association (0.668; see Table 32).
- The sensitivity, which is a measure of the proportion of a category correctly predicted, of the Poor (8%) and Moderate (39%) categories were low (see Table 33).

Table 25. The summarised observed versus predicted IWC categories for the testing data using Frequentist ordinal probit regression with variable thresholds. The highlighted cells show misclassification of the Poor and Moderate categories.

Ordinal Probit (Frequentist)		**Prediction**			
		Poor	**Moderate**	**Good**	**Excellent**
Observed	**Poor**	2	13	10	1
	Moderate	3	18	31	0
	Good	1	14	41	6
	Excellent	0	0	11	21

3.4.4 Support vector machine using ν classification

The Support Vector Machine (SVM), once trained, predicted the IWC categories as summarised in Table 26. While these predictions are not generally as good as those of most other methods (as seen from the association scores in Table 33), they could be improved with a larger training data set and the inclusion of the ordinal nature of the data, as SVMs are most useful with very large data sets. If the predicted classifications are compared within the training data (Table 26) they are much more accurate, more so than any of the other methods. The results for the training groups for the other models were not included as they were far less accurate.

With a larger data set to train with, it may be possible to get significantly improved predictions for the data not used for learning. Also, this method does not use the knowledge that the categories are ordinal, treating them as nominal. To attempt to use the ordinal nature of the responses, the SVM was used to predict a series of groups, similar to the method used for the continuation ratio ordinal regression. This meant training the SVM on classifying three responses for each of the ascending and descending models.

The summary of the predictions for the testing data of these methods are shown in Table 28 (ascending), and Table 29 (descending). They both performed better in terms of the measures used to estimate model performance (Table 32) than the straight SVM, with ascending being the better of the two. Again, none of the SVM methods were able to predict the IWC categories for the testing data particularly well, close to 60% misclassification for each method and the best association being 0.502 (Table 33).

Table 26. The summarised observed versus predicted IWC categories for the testing data using a support vector machine.

SVM (Testing)		**Prediction**			
		Poor	**Moderate**	**Good**	**Excellent**
Observed	**Poor**	10	6	9	1
	Moderate	6	16	27	3
	Good	7	23	26	6
	Excellent	1	5	5	21

Table 27. The summarised observed versus predicted IWC categories for the training data using a support vector machine.

SVM (Training)		**Prediction**			
		Poor	**Moderate**	**Good**	**Excellent**
Observed	**Poor**	101	1	8	0
	Moderate	8	173	11	3
	Good	7	5	213	9
	Excellent	3	2	10	134

Table 28. The summarised observed versus predicted IWC categories for the testing data using a support vector machine for three ordinal decisions (ascending).

SVM (ascending)		**Prediction**			
		Poor	**Moderate**	**Good**	**Excellent**
Observed	**Poor**	9	9	5	3
	Moderate	5	20	24	3
	Good	3	25	23	11
	Excellent	1	2	10	19

Table 29. The summarised observed versus predicted IWC categories for the testing data using a support vector machine for three ordinal decisions (descending).

SVM (descending)		**Prediction**			
		Poor	**Moderate**	**Good**	**Excellent**
Observed	**Poor**	8	9	7	2
	Moderate	14	16	21	1
	Good	8	24	23	7
	Excellent	4	2	3	23

3.4.5 Bayesian ordinal probit regression

For Bayesian ordinal probit regression, each individual predictor was included in the model as well as interactions highlighted in previous models as being important, namely: the interaction between public and aquifer, public and rain index, residential commercial and VicgridNorth, rainfall and VicgridEast, rain index and land use 53, and the wetland catchment area and aquifers (log index). The approach actually gives a posterior distribution for each coefficient rather than just an estimate. However, to illustrate the model, the mean values of each parameter and the thresholds are given in Equation 8 in Appendix 2 for the standardised data.

Using the 95% high density interval (Table 30), it is possible to see which variables are influential in determining the IWC category. If the interval from 2.5% to 97.5% includes zero, then we could not reject the assumption that the variable had 'zero' effect. By that standard it would seem that higher proportion of public ownership, natural state, mixed farming and grazing, rain index (paired with public ownership), and combined rainfall and VicgridEast increase the scores and therefore IWC categories. Temperate climate and the availability of groundwater also increase the scores. Conversely, the higher the VicgridEast, the combined proportion of residential, commercial, and community and VicgridNorth, the combined rain index and land use category 53, and larger wetland catchment area where ground water is present decrease the scores, resulting in lower IWC categories. These were then used to give the predictions shown in Table 31. However, as the model is a poor predictor of wetland condition, there is no indication that these associations are valid.

A summary of other model results is as follows:

- The Poor category was under-predicted and Moderate and Good categories were difficult to distinguish (Table 32).
- The associations were the second best for each statistic in the methods used, but these are not strong (Table 33).

Table 30. Quantiles for each parameter from the Bayesian ordinal probit regression using a Markov chain Monte Carlo analysis. The dark grey cells indicate a variable with a positive influence, and the light grey cells indicate a negative influence. All unshaded cells could be considered to have zero influence.

	2.50%	25%	50%	75%	97.50%
(Intercept)	0.64291	0.89395	1.0191	1.1516605	1.38852
LDII	0.262872	-0.0333	0.0901	0.2162941	0.46361
Public	0.399986	0.57959	0.67272	0.7623394	0.93513
lnWetHect	-0.071101	0.12275	0.22873	0.3315854	0.5328
lnBufferArea	-0.497522	-0.27653	-0.15696	-0.03851	0.17491
ClimateTemperate	0.035791	0.28479	0.42481	0.5567037	0.81284
FloodplainYes	-0.342175	-0.17284	-0.08582	0.0003908	0.16121
AquiferYes	0.249744	0.39035	0.46452	0.5398562	0.68267
PropBuffWet	-0.163225	-0.07628	-0.02779	0.0257603	0.13792
RainIndex	-0.010642	0.08593	0.13364	0.1834449	0.27411
Rainfall	-0.268075	-0.13653	-0.06897	-0.0049791	0.12544
WaterTypeSaline	-0.121479	0.08968	0.19744	0.308945	0.52143
ResComEtc	-0.10577	0.02042	0.088	0.1571398	0.29023
MinInd	-0.02208	0.06223	0.10887	0.1611377	0.26798
Nature	0.051228	0.39818	0.60454	0.8286318	1.29112
VicgridEast	-0.26091	-0.17954	-0.13743	-0.0962728	-0.0173
VicgridNorth	-0.355293	-0.22112	-0.15178	-0.0841063	0.03729
LU51	0.061508	0.20071	0.2789	0.3580073	0.50387
LU52	-0.162045	0.07463	0.20308	0.3375026	0.60483
LU53	-0.121225	0.25422	0.45692	0.6742504	1.08901
LU57	-0.003858	0.16788	0.26358	0.3661994	0.58662
PUBLIC:AquiferYes	-0.33455	-0.19624	-0.12248	-0.0476841	0.0922
PUBLIC:RainIndex	0.195416	0.27677	0.31949	0.3608298	0.44217
ResComEtc:VicgridNorth	-0.243826	-0.16803	-0.13018	-0.0925881	-0.02304
Rainfall:VicgridEast	0.079652	0.15891	0.19894	0.2405926	0.3205
RainIndex:LU53	-0.309386	-0.2232	-0.17802	-0.133322	-0.04746
lnBufferArea:AquiferYes	-0.431544	-0.29665	-0.22568	-0.1557569	-0.02897
gamma2	0.948671	1.03874	1.08621	1.1347916	1.2264
gamma3	2.262386	2.39339	2.46682	2.538042	2.66093

Table 31. The summarised observed versus predicted IWC categories for the testing data using a Bayesian ordinal probit regression.

Ordinal Probit (Bayesian)		Prediction			
		Poor	Moderate	Good	Excellent
Observed	Poor	2	17	6	1
	Moderate	1	25	26	0
	Good	0	22	36	4
	Excellent	0	1	12	19

Table 32. The measures used to estimate model performance for each method used in the prediction of the IWC categories. These were all calculated on the data withheld for testing. The highlighted cells show the best model for that statistic.

Model	Statistic				
	MER	Goodman & Kruskal's γ	Somer's D	Spearman's ρ	Kendall's τ
Classification Tree	0.500	0.649	0.509	0.539	0.481
Continuation ratio (ascending)	0.541	0.579	0.452	0.456	0.401
Continuation ratio (descending)	0.535	0.588	0.457	0.493	0.435
Ordinal probit regression (Frequentist)	0.523	0.689	0.543	0.526	0.487
Support vector machine	0.576	0.427	0.330	0.371	0.319
SVM cont. ratio ascending	0.587	0.502	0.386	0.426	0.372
SVM cont. ratio descending	0.593	0.443	0.341	0.390	0.337
Ordinal probit regression (Bayesian)	0.523	0.681	0.536	0.535	0.484

Table 33. The sensitivity of each of the models when compared with the testing data. Sensitivity is a measure of the proportion of that category correctly predicted. The highlighted cells show the best model for that statistic.

Model	IWC Category			
	Poor	Moderate	Good	Excellent
Classification Tree	0.423	0.308	0.613	0.656
Continuation ratio ascending	0.154	0.269	0.629	0.688
Continuation ratio descending	0.333	0.538	0.371	0.625
Ordinal probit regression (Frequentist)	0.077	0.385	0.661	0.625
Support vector machine	0.385	0.308	0.419	0.656
SVM cont. ratio ascending	0.346	0.385	0.371	0.594
SVM cont. ratio descending	0.308	0.308	0.371	0.719
Ordinal probit regression (Bayesian)	0.077	0.481	0.581	0.581

Table 34. The specificity of each of the models when compared with the testing data. Specificity is a measure of the proportion of a category correctly rejected from that category.

Model	IWC Category			
	Poor	Moderate	Good	Excellent
Classification Tree	0.918	0.825	0.600	0.936
Continuation ratio ascending	0.973	0.833	0.464	0.929
Continuation ratio descending	0.910	0.617	0.736	0.964
Ordinal probit regression (Frequentist)	0.973	0.767	0.545	0.950
Support vector machine	0.904	0.717	0.627	0.929
SVM cont. ratio ascending	0.938	0.700	0.645	0.879
SVM cont. ratio descending	0.822	0.708	0.718	0.929
Ordinal probit regression (Bayesian)	0.993	0.667	0.600	0.964

The models originally included the Corrick classification of the wetland, and showed that it was a useful predictor of the IWC score. However, as it is being replaced with a classification that is yet to be determined, the methods were repeated without it. The wetland types used in the other analyses were not included as model variables because of time constraints.

4 Discussion

The two statewide IWC assessments performed between 2009 and 2011 provide for the first time condition assessments of 827 wetlands, which is about 6% of Victoria's wetlands. Data from these assessments will be valuable for informing policy development, assessing risks to wetland values, determining management priorities, setting targets and monitoring longer-term trends in condition.

4.1 Condition of the high-value and representative wetlands

Although the assessment of the high-value wetlands was made during a period of protracted drought, over half (56%) were in good or excellent condition overall and only 1% in very poor condition. These results may indicate the resilience of these wetlands to drought and the effectiveness of their management (DSE 2012a). At the subindex level, however, the condition of the wetland catchment (land use intensity and wetland buffer), biota (vegetation) and hydrology (water regime) was very poor for 24–33% of high-value wetlands. The low proportion in very poor condition overall however indicates that wetlands were very unlikely to be in very poor condition for more than one of these subindices.

There was a significant difference in the condition of the three high-value wetland categories Figure 18 indicates that of the three wetland groups (Ramsar, DIWA and Edenhope wetlands), the overall condition was poorest for the Ramsar group. This was largely due to the low hydrology subindex scores of many river-fed Ramsar wetlands (Figure 19).

The proportions of representative wetlands and high-value wetlands in excellent or good condition were similar, but a much larger proportion of representative wetlands (25%) were in either poor or very poor condition compared to high-value wetlands (14%). At the subindex level, almost three times the proportion of representative wetlands soils and twice the proportion of catchments than the high-value wetlands were in very poor condition. Proportionally fewer representative wetlands than high-value wetlands had very poor hydrology, however. This was probably because many river-fed high-value wetlands had an altered hydrology and one or more related threat sources.

Mean overall condition and subindex scores, except for biota, were significantly higher for the high-value wetlands than for the representative wetlands. This is most likely because threats and sources of threat at the high-value wetlands were either less prevalent or more effectively managed at the high-value wetlands.

4.2 Condition of wetlands among attributes

High-value wetlands in the temperate zone (southern and eastern Victoria; see Figure 4) were, on average, in better overall condition than those in the semi-arid zone. However, this difference was not apparent in the representative wetlands. Many of the high-value semi-arid wetlands were fed by rivers with altered hydrology, which may have contributed to this result. It is also possible that drought may have impacted semi-arid wetlands more than temperature wetlands.

At the representative wetlands, a higher proportion of seasonal wetlands than permanent wetlands were in poor condition. Seasonal wetlands are more likely than permanent wetlands to be exposed and vulnerable to threats, because they are more accessible and amenable to activities such as grazing and cultivation. Seasonal and permanent high-value wetlands did not differ significantly in condition. These wetlands were, however, much less exposed to several threats (e.g. degraded water quality and soil disturbance) and threat sources (e.g. grazing) than the representative wetlands.

The condition of wetlands on public land (including alpine wetlands) was better than wetlands on private land for both high-value and representative wetlands. This is again a likely response to exposure of wetlands to threats. Most threats and threat sources were less prevalent on wetlands on public land.

For both high-value and representative wetlands, the condition of wetlands with no water was significantly poorer than those which contained some water (i.e. water receding, wetland filling or wetland full phases). A *post hoc* examination of subindex condition showed that, of all subindices, biota was the most responsible for the lower overall condition scores for the wetlands that held no water. Not surprisingly, it appears that the condition of wetland vegetation was affected by dry conditions. Possible effects of dry (or recently moist) conditions are increased cover of terrestrial species (including weeds), reduced number of critical life forms and poor vegetation structure and health. Although wetland assessors were advised not to assess wetland biota when conditions were so dry that an assessment of the vegetation would not be possible, these results show that it may be necessary to preclude condition assessments from the dry phase. Euliss and Mushet (2011) found that metric scores and condition ratings from an Index of Plant Community Integrity varied annually in response to environmental variation driven primarily by natural climate variation. There were also other indications that less water resulted in poorer condition, for example, semi-arid wetlands had lower scores and wetlands with no water with lower scores. There were also some effects from antecedent rainfall.

The water source of the wetland seemed to influence its condition. Wetlands fed by groundwater and local runoff were more likely to be in better condition than those fed by rivers. This is probably linked with the high exposure of river-fed wetlands to altered hydrology from several sources of threat. Of the wetlands with other sources, those fed entirely or in part by an artificial channel were in the poorest condition, but there were few of these.

While there was no simple linear relationship evident between wetland size and condition, smaller wetlands were more likely to be in poor condition than larger wetlands. This trend was evident for high-value wetlands smaller than 300 ha, and for the representative wetlands smaller than about 50 ha. The reason for these thresholds is unclear.

4.3 Threats

For this study a threat was considered to be operating at a wetland if its corresponding IWC measure or subindex condition category was very poor, poor or moderate. The IWC assessments provided information on five types of threats to wetlands (reduced wetland area, altered wetland form, altered hydrology, degraded water quality and soil disturbance) and 23 sources of threats. One or more threats were operating at over half (about 60%) of the high-value and representative wetlands assessed. Fewer high-value wetlands were affected by most threats than the representative wetlands however. The exception was altered hydrology where more high-value than representative wetlands were proportionally affected (46% compared to 32%).

4.3.1 Threats operating at high-value wetlands

Considering their high-value and that many are on public land, a considerable proportion of high-value wetlands were affected by threats and threat sources. Almost half (46%) were threatened by altered hydrology. Grazing by livestock occurred at more than half the wetlands, and driving vehicles on the wetland at more than one-third. Because these activities did not impact the whole wetland, these contributed to a soil disturbance threat at 19% of wetlands. Grazing was the principal threat source contributing to a degraded water quality threat at 15% of wetlands. Excavation of the wetland bed occurred at a quarter of the wetlands assessed, but this was a threat to altered physical form at only 6% of the wetlands. A considerable proportion of wetlands (14%) were also threatened by reduced wetland area.

Threats to high-value wetlands were slightly more prevalent on private land than on public land, with the notable exception of altered hydrology, which affected a larger proportion of wetlands on public land. Sources of threat to altered hydrology at wetlands on public land were a change to the flow regime of the water source, obstruction of inlets and obstruction of outlets. The majority of wetlands affected by these threat sources were fed by rivers with a changed flow regime. The lower overall condition scores observed for river-fed wetlands than local runoff and groundwater-fed wetlands were probably a consequence of this threat, as were the lower hydrology and overall condition scores observed for the Ramsar wetlands.

Grazing and pugging by livestock and feral animals were also more prevalent at wetlands on private land. This is an important consideration for the management of these wetlands.

4.3.2 Threats at representative wetlands

Soil disturbance was the most prevalent threat operating on the representative wetlands (38% of wetlands), followed by altered hydrology (32%), degraded water quality (28%), reduced wetland area (26%) and altered wetland form (12%). The prevalence of the soils and degraded water quality threat contributed to poorer water properties and soil condition for these wetlands in comparison to the high-value wetlands. All threats were much more prevalent at wetlands on private land.

For the representative wetlands, the most prevalent threat sources (those occurring at more than 25% of wetlands) were non-point source runoff and grazing leading to nutrient enrichment (both occurring at 59% of all wetlands), pugging by livestock and feral animals causing soil disturbance (55%), excavation of the wetland bed (45%), a change to the flow regime of the water source leading to altered hydrology (35%) and landforming (e.g. levelling) (30%). All except two (uncommon) threat sources were 2–10 times more prevalent at wetlands on private land than wetlands on public land.

4.4 Wetland condition modelling

With 860 wetlands assessed with formal IWC categories and over 12 800 to be predicted it was clear that the modelling would have to be robust. Data mining methods can provide that robustness, with techniques of quarantining sections of the data for different purposes (Larose 2006). This means the data used to parameterise the model is independent of the data used to test and validate the models. In data mining it is important that as much predictive information as possible is used in the analysis (Agarwal 2008, Piccarreta 2008, Pinto Da Costa et al. 2010). The information is limited to that which is already known or can be remotely sensed at all wetland sites across Victoria.

The rationale for including as many variables as possible is that they may indicate some important latent variables (Larose 2006, Piccarreta 2008). Latent variables are variables that are not directly observed but may be inferred from the variables that are directly measured. If the models had predicted wetland condition well this could inform the nature of these latent variables.

Variables were chosen by (i) assessing the influence of IWC measures on overall wetland condition through a PCA analysis and selecting appropriate surrogate remote sensed variables and (ii) including other variables which may influence wetland condition. The PCA analysis indicated that wetland buffer, land use intensity, nutrients, wetland area and wetland bathymetry were most influential. Surrogates for these variables, available at a statewide scale, were collated along with many other variables that were expected to influence condition (see Table 15). Biota, wetland buffer and water regime were excluded because there were no available surrogates.

Different modelling approaches were explored in an attempt to find the model(s) with the highest predictive capability. These techniques included: ordinal response classification trees; continuation ratio ordinal regression; Frequentist ordered probit regression; support vector machine learning; and Bayesian ordered probit regression.

None of the models and analyses that were trained and tested performed particularly well and were able to reliably predict wetland condition. As far as correctly predicting the IWC categories for the test data, none of the models predicted better than 50% of the condition categories. The smallest misclassification error rate was from the ordinal classification tree. Given that the response is ordinal, this is not necessarily the best measure, although it does highlight the uncertainty in the predictions. A more appropriate statistical measure is the association (Goodman and Kruskal's γ) which measures the strength of association of the cross-tabulated data. Several methods (classification tree and both ordinal probit regressions) showed a moderate degree of association. In fact, these methods had stronger correlations than the other methods across all the measures of association and correlation. While they are better than the other methods, they are not reliable enough to use for predicting the IWC category for unsurveyed wetlands. Even when using a combination of the best three methods using a majority rule decision, there is a slight increase in the measures of association. However, the misclassification error rate also increases, meaning more wetlands were misclassified.

There were several factors that may have contributed to the poor modelling results and the potential for spurious relationships between wetland condition and the predictor variables.

Not all wetlands were randomly selected. The wetlands sampled for the first statewide assessment were high-value wetlands and therefore did not represent a random sample. Wetlands chosen for the second statewide assessment were randomly selected, but made up only 29% of the 826 wetlands used in the modelling.

There were relatively few wetlands sampled that were in poor and very poor condition (see Tables 16 and 17). Therefore there were less data available to characterise the relationship between predictor variables and wetland condition for the poor and very poor end of the condition gradient. This issue was exacerbated by the fact that the majority of the data has come from high-value wetlands, most of which (86%) were in moderate to excellent condition, while only 13% were poor and 1% very poor (Table 16).

Some of wetland classification attributes may have been incorrectly assigned in the source data sets for the predictor variables (in Table 15). For example there is considerable uncertainty in the attribution of water source data in the floodplain wetlands and groundwater dependent ecosystems spatial data layers that were used in the modelling (Table 15).

The relationships between environmental variables and wetland condition is complex. There are many variables likely to affect wetland condition, such as catchment topography, elevation, geology, climate, and water source, quality and regime. In addition, broad scale trends in variables that influence condition can be overridden by the effects of local factors such as changes to water inlets or outlets.

4.5 Recommendations for further work

The following recommendations may improve the prediction outcomes:

- Base the modelling on a coarser classification (i.e. poor and not poor). Ensure there are additional wetlands in poor condition included to increase the sample size of this category. These additional wetlands may be obtained from quality-controlled IWC assessments from other programs such as Wetland Tender.
- Use updated spatial data as it becomes available to attribute wetlands.
- Construct models to predict individual subindex scores instead of overall condition. If successful it may be possible to construct an overall condition model from these subindex models.
- Include a variable for wetland type derived from the new Victorian wetland classification system when it has been completed.

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Acronyms and glossary

CMA: catchment management authority

Corrick system: the Victorian wetland classification system described in Corrick and Norman (1976, 1980) and Corrick (1981, 1982). The Corrick system classifies wetlands based on naturalness, water permanency, water depth and salinity. Wetlands are further classified into subcategories based on dominant vegetation types, salinity and water depth. The Corrick classification has been applied to wetlands delineated in two geospatial layers: (1) the 1788 spatial layer that represents wetland extent at the time of European settlement in Victoria, and (2) the 1994 spatial layer that represents wetland extent in the period 1978–1994.

DSE: Department of Sustainability and Environment.

EVC: Ecological Vegetation Class. The concept of an EVC was introduced in the Old Growth Study of East Gippsland (Woodgate et al. 1994). EVCs are a type of native vegetation classification described through a combination of floristics, life forms and ecological characteristics, and through an inferred fidelity to particular environmental attributes. Each EVC includes a collection of floristic communities that occur across a biogeographic range, and although differing in species, have similar habitat and ecological processes operating.

Floodplain: a surface adjacent to a stream that is inundated by overbank flows (usually flows with a recurrence interval greater than 2–3 years)

Fresh: a category of the water Framework attribute defined in the classification by a salinity concentration of less than 3000 mg/L when the wetland is greater than 75% full.

GDE: groundwater-dependent ecosystem.

HEV: high ecological value.

Index of Wetland Condition (IWC): a rapid method for determining wetland condition in Victoria. The IWC is a hierarchical index with six sub-indices based on the characteristics that define wetlands: wetland catchment, physical form, hydrology, soils, water properties and biota (Department of Sustainability and Environment 2005).

Indicator: An expression of the environment that estimates the condition of ecological resources, magnitude of stress, exposure of a biological component to stress, or the amount of change in a condition (Breckenridge et al. 1995).

IWC DMS: Index of Wetland Condition Data Management System.

LDII: Land use Development Intensity Index.

Peatland: a permanently wet system with peat soils more than 30 cm deep with more than 20% organic matter (Whinam and Hope 2005). These systems are also termed bogs, fens or mires (Lawrence et al. 2009).

Saline: a category of the water type attribute defined in the Framework by a salinity concentration of greater than 3000 mg/L when the wetland is greater than 75% full.

Strahler classification: a widely used stream order hierarchy developed by Strahler (1952).

Wetland: areas whether natural, modified or artificial, subject to permanent, periodic or intermittent inundation, that hold static or very slow moving water, and develop, or have the potential to develop, biota adapted to inundation and the aquatic environment . This is narrower in scope than the Ramsar definition which includes additional habitats such as shallow marine waters, estuaries, and rivers (Ramsar Secretariat 2012).

Wetland 1994 inventory: the current database of attributes of wetlands in Victoria that links to the wetland 1788 and 1994 spatial layers.

Appendix 1 Landscape Development Intensity Index

Table A1. Land use categories and coefficients used in the Landscape Development Intensity Index (LDII) (Brown and Vivas 2005).

Landscape category	LDII coefficient
Natural System	1.00
Natural Open water	1.00
Pine Plantation	1.58
Recreational / Open Space (low intensity)	1.83
Woodland Pasture (with livestock)	2.02
Pasture (without livestock)	2.77
Low Intensity Pasture (with livestock)	3.41
Citrus	3.68
High Intensity Pasture (with livestock)	3.74
Row crops	4.54
Single Family Residential (low-density)	6.79
Recreational / Open Space (high-intensity)	6.92
High Intensity Agriculture (dairy farm)	7.00
Single Family Residential (medium-density)	7.47
Single Family Residential (high-density)	7.55
Mobile Home (medium density)	7.70
Highway (two-lane)	7.81
Low Intensity Commercial	8.00
Institutional	8.07
Highway (four-lane)	8.28
Mobile Home (high-density)	8.29
Industrial	8.32
Multi-family Residential (low rise)	8.66
High Intensity Commercial	9.18
Multi-family Residential (high rise)	9.19
Central Business District (average 2 stories)	9.42
Central Business District (average 4 stories)	10.00

Table A2. VLUIS land use categories, equivalent LDII landscape categories and their coefficients (see Brown and Vivas 2005).

VLUIS Level 2 category	LDII landscape	LDII coefficient
Unclassified (but often tracks and minor roads)	Recreational / Open Space (high-intensity)	6.92
Residential Use Development Land	Recreational / Open Space (low-intensity)	1.83
Single Residential Accommodation	Single Family Residential (low-density)	6.79
Multiple Occupation	Single Family Residential (high-density)	7.55
Investment Residential	Single Family Residential (low-density)	6.79
Retirement/Aged Care Accommodation	Multi-family Residential (low-rise)	8.66
Ancillary structures (not capable of occupation)	Single Family Residential (low-density)	6.79
Commercial Use Development Land	Recreational / Open Space (low-intensity)	1.83
Retail	Low Intensity Commercial	8
Office	Low Intensity Commercial	8
Short Term Business and Tourist Accommodation	High Intensity Commercial	9.18
Hospitality	High Intensity Commercial	9.18
Entertainment (non-sporting)	High Intensity Commercial	9.18
Tourism Facilities/Infrastructure	High Intensity Commercial	9.18
Personal Services	N.A.	N.A.
Vehicle Car Parking, Washing and Sales	N.A.	N.A.
Advertising or Public Information Screens	N.A.	N.A.
Industrial Use Development Land	Recreational / Open Space (low-intensity)	1.83
Manufacturing	Industrial	8.32
Warehouse/Distribution/Storage	Low Intensity Commercial	8
Noxious/Offensive/Dangerous Industry	Industrial	8.32
Extractive industry site with permit or reserve not in use	Industrial	8.32
Quarry (in use)	Industrial	8.32
Mine (open cut)	Industrial	8.32
Mine (deep shaft)	Industrial	8.32
Tailings Dumps	Industrial	8.32
Well/Bore	Industrial	8.32
Salt Pan (evaporative)	Industrial	8.32
Dredging Operations	Industrial	8.32
Other Unspecified	Industrial	8.32
Native Vegetation	Natural System	1
Agricultural Cropping	Row crops	4.54
Livestock Grazing	Low Intensity Pasture (with livestock)	3.41
Mixed Farming and Grazing	Low Intensity Pasture (with livestock)	3.41
Livestock — special purpose fencing, pens, cages, yards or stables (poultry 2008 conversion)	High Intensity Agriculture (dairy farm)	7
Horticulture Fruit and Vegetable Crops	Citrus	3.68
Horticulture — Special Purpose Structural Improvements	Citrus	3.68
Forestry — Commercial Timber Production	Pine Plantation	1.58
Aquaculture	N.A.	N.A.
Vacant and unspecified	Recreational / Open Space (low-intensity)	1.83
Gas	N.A.	N.A.

Table A2. (continued)

VLUIS Level 2 category	LDII landscape	LDII coefficient
Electricity	N.A.	N.A.
Waste Disposal, Treatment and Recycling	Industrial	8.32
Water Supply	Recreational / Open Space (low intensity)	1.83
Transport — Road Systems	Highway (two-lane)	7.81
Transport — Rail and Tramway Systems	N.A.	N.A.
Transport — Air	N.A.	N.A.
Transport — Marine	N.A.	N.A.
Communications, including Print, Post, Telecommunications and Airwave Facilities	Low Intensity Commercial	8
Vacant or Disused Community Service Site	N.A.	N.A.
Health	High Intensity Commercial	9.18
Education & Research	High Intensity Commercial	9.18
Justice and Community Protection	Low Intensity Commercial	8
Religious	Low Intensity Commercial	8
Community Service and Sporting Club Rooms and Halls	Low Intensity Commercial	8
Government Administration	High Intensity Commercial	9.18
Defence Services/Military Base	High Intensity Commercial	9.18
Community service facilities or other	High Intensity Commercial	9.18
Vacant Land	Low Intensity Commercial	8
State/Regional Sorts Complex	Low Intensity Commercial	8
Local Sports Facilities	Low Intensity Commercial	8
National/State/Regional Cultural Heritage Centres	Low Intensity Commercial	8
Local Cultural Heritage Sites, Memorials and Monuments	Low Intensity Commercial	8
Reserved Land	Natural System	1
Nature Reserve	Natural System	1
Wilderness Area	Natural System	1
National Park	Natural System	1
Natural Monument/Feature	Natural System	1
Natural Forests and Forest Reserves	Natural System	1
Conservation Area	Natural System	1
Protected Landscape/Seascape	Natural System	1
Wetlands	Natural Open water	1
Game/Fauna Reserves	Natural Open water	1

Appendix 2 Model equations

Equations for the continuation ratio ordinal regression (ascending)

Equation 1. Distinguishes between "Poor" and not "Poor" IWCs.

$$\begin{aligned}\text{logit}(\Pr(IWC > \text{"Poor"})) = {} & 168.4 + 2.9 Public + 0.87 I_{Aquifer} - 0.06 PropBuffWet \\ & - 1.3 RainIndex - 0.06 Rainfall - 4.6 ResComEtc - 1.7 VicgridEast \\ & - 4.9 VicgridNorth - 1.7 LU52 - 1.4 LU53 + 0.003 Rainfall \times VicgridEast \\ & + 0.05 RainIndex \times VicgridNorth\end{aligned}$$

Equation 2. Distinguishes between "Moderate" and better than "Moderate" IWC given "Poor" wetlands are excluded.

$$\begin{aligned}\text{logit}(\Pr(IWC > \text{"Moderate"} \mid IWC \geq \text{"Moderate"})) = {} & -6.09 - 0.40 I_{Floodplain} \\ & + 0.07 RainIndex + 3.22 Nature + 8.21 LU53 - 1.80 Nature \times I_{Floodplain} \\ & - 0.09 RainIndex \times LU53\end{aligned}$$

Equation 3. Distinguishes between "Good" and "Excellent" IWC given "Poor" and "Moderate" wetlands are excluded.

$$\begin{aligned}\text{logit}(\Pr(IWC = \text{"Excellent"} \mid IWC \geq \text{"Good"})) = {} & 48.0 + 2.83 Public + 0.95 lnWetHect \\ & - 3.62 lnBufferArea + 0.95 I_{Aquifer} - 38.6 I_{WaterType} - 404.8 MinInd \\ & - 1.52 VicgridNorth - 64.1 LU53 + 1.62 I_{WaterType} \times VicgridNorth \\ & + 15.5 MinInd \times VicgridNorth + 2.57 LU53 \times VicgridNorth\end{aligned}$$

Equations for the continuation ratio ordinal regression (descending)

Equation 4. Distinguishes between "Excellent" and not "Excellent" IWCs.

$$\begin{aligned}\text{logit}(\Pr(IWC < \text{"Excellent"})) = {} & -2.27 - 3.81 Public - 0.59 lnWetHect + 2.14 lnBufferArea \\ & - 3.35 I_{Temperate} - 0.89 I_{Aquifer} - 0.10 RainIndex + 39.9 I_{Saline} \\ & - 0.39 VicgridNorth - 1.23 LU51 - 18.5 LU53 + 0.21 RainIndex \times LU53 \\ & - 1.66 I_{Saline} \times VicgridNorth - 26.9 LU51 \times LU53\end{aligned}$$

Equation 5. Distinguishes between "Good" and "Moderate" or worse IWC given "Excellent" wetlands are excluded.

$$\begin{aligned}\text{logit}(\Pr(IWC < \text{"Good"} \mid IWC \leq \text{"Good"})) = {} & -45.6 + 9.27 Public - 1.06 I_{Temperate} \\ & + 0.07 PropBuffWet + 0.52 RainIndex - 0.06 Nature + 1.92 VicgridEast \\ & - 0.13 Public \times RainIndex - 0.02 RainIndex \times VicgridEast \\ & - 0.19 PropBuffWet \times Nature\end{aligned}$$

Equation 6. Distinguishes between "Moderate" and "Poor" IWC given "Excellent" and "Good" wetlands are excluded.

$$\begin{aligned}\text{logit}(\Pr(IWC = \text{"Poor"} \mid IWC \le \text{"Moderate"})) = &-32.0 - 2.95 Public + 0.05 Rainfall \\ &- 1.19 ResComEtc - 0.89 I_{Aquifer} + 1.31 VicgridEast \\ &- 0.002 Rainfall \times VicgridEast + 17.6 Public \times ResComEtc\end{aligned}$$

Equation for the cumulative link ordinal regression model with flexible thresholds

Equation 7. Equation for the Score function for the cumulative link ordinal regression with flexible thresholds.

$$\begin{aligned}Score = &\ 0.37 LDI + 0.54 Public + 0.15 lnBufferArea + 0.47 I_{Aquifer} + 0.11 RainIndex \\ &+ 014 Rainfall + 0.49 Nature - 0.27 VicgridEast + 0.20 LU57 \\ &+ 0.37 Public \times RainIndex + 0.23 Rainfall \times VicgridEast \\ &- 0.32 lnBufferArea \times I_{Aquifer} - 0.26 RainIndex \times Rainfall\end{aligned}$$

Equation and thresholds for the ordinal probit model using the expected parameter values from a Bayesian regression

Equation 8. The estimated score equation for the ordinal probit model using the coefficient means.

$$\begin{aligned}Score = &\ 1.02 + 0.09 LDI + 0.67 Public + 0.23 lnWetHect - 0.15 lnBufferArea + 0.42 I_{Temperate} \\ &- 0.09 I_{Floodplain} + 0.47 I_{Aquifer} - 0.02 PropBuffWet + 0.13 RainIndex \\ &- 0.07 Rainfall + 0.20 I_{Saline} + 0.09 ResComEtc + 0.11 MinInd + 0.62 Nature \\ &- 0.14 VicgridEast - 0.15 VicgridNorth + 0.28 LU51 + 0.21 LU52 + 0.47 LU53 \\ &+ 0.27 LU57 - 0.12 Public \times I_{Aquifer} + 0.32 Public \times RainIndex \\ &- 0.13 ResComEtc \times VicgridNorth + 0.20 Rainfall \times VicgridEast \\ &- 0.18 RainIndex \times LU53 - 0.23 lnBufferArea \times I_{Aquifer}\end{aligned}$$

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