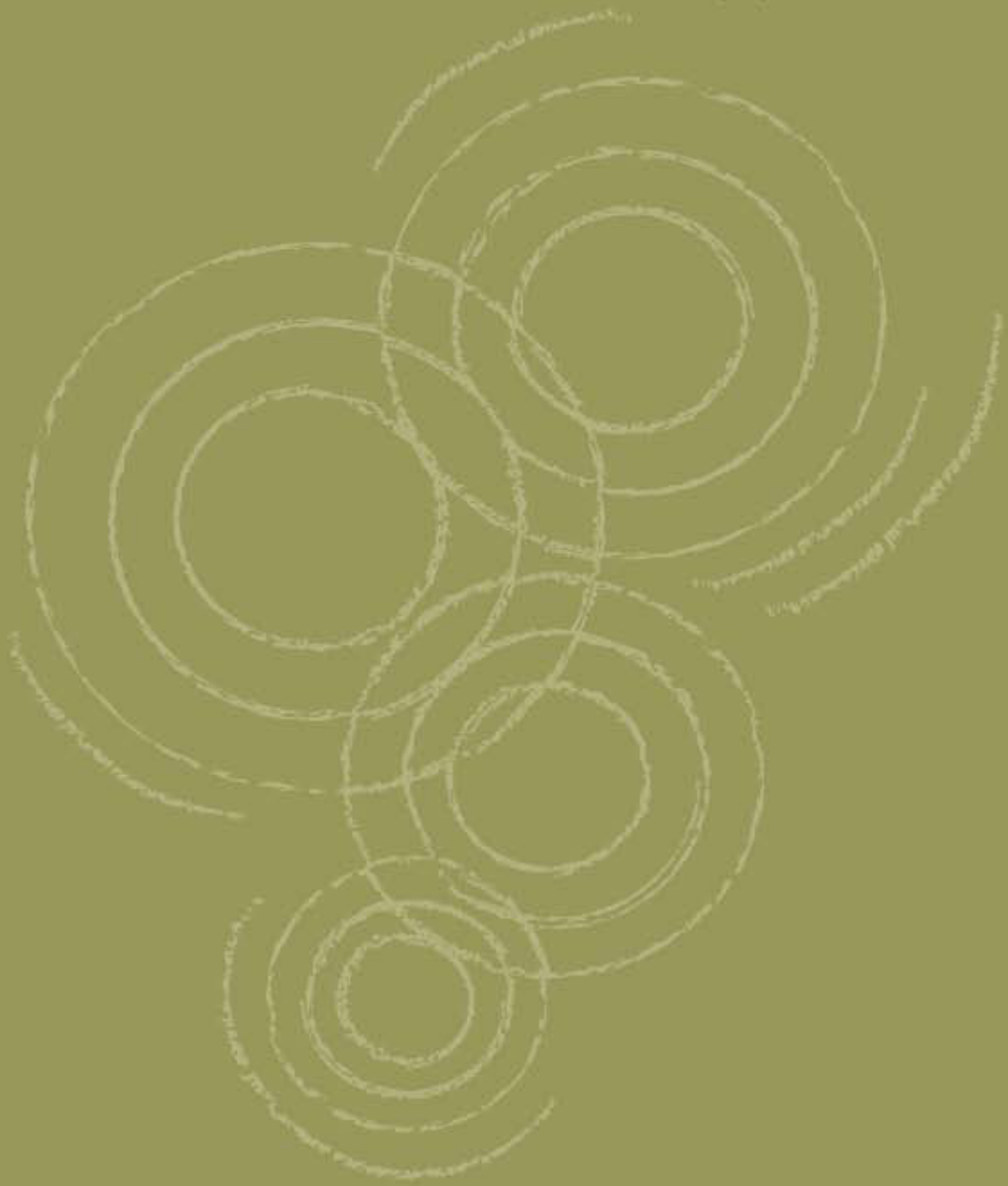
Queensland Wetland Definition and Delineation Guideline

Part B: Delineation and Mapping Guideline



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Queensland wetland definition and delineation guidelines

Part B: Delineation and mapping guidelines

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Introduction

What is the Queensland wetland definition and delineation guideline?

The Queensland wetland definition and delineation guideline is comprised of two parts.

Part A of the guideline is a guide to existing wetland definitions and the application of the Queensland Wetlands Program Wetland Definition (Program Wetland Definition).

Part B is the delineation and mapping guideline.

The intent of Part B is to provide more detailed information on how to apply the definition to delineate and map the boundary of a wetland.

This guideline is intended to assist government agencies, landowners, conservationists, natural resource managers, scientists, surveyors, consultants and others wanting to delineate and map the boundaries of an identified wetland feature for decision-making, dispute resolution and planning purposes. In some cases requirements for development assessment may advise or stipulate the use of this guideline for regulatory purposes.

The purpose of this document is to provide a detailed wetland survey method to delineate and map the boundary of a wetland, defining its position, shape and size, at a property scale using the Program Wetland Definition.

The document is based on the information requirements and indicators of the Program Wetland Definition. It is a companion technical manual/guideline to Part A of the Queensland wetland definition and delineation guideline [1], the wetland soils assessment and methodology [2], the associated soils field guide [3] and the wetland indicator species list. Readers should refer to those documents for a full explanation of the wetland definition and soils indicators and methods.

Skills required for wetland survey and delineation

In some situations where there is good existing information and the wetland boundary is clearly discernable, people with basic plant identification, or other relevant skills, may be able to identify and/or delineate a wetland. However, in many cases the identification and delineation of wetlands will require specialised field, laboratory and desktop investigation skills. This requires people with skills in plant identification and the collection of vegetation structural and abundance data and/or soil survey, and/or the collection of fauna data. An understanding of wetland ecology, particularly their dynamic nature and their response to seasonal conditions and longer term climate variability, is important. In addition, a person with GIS/mapping skills is required to compile the final map, which might result from the delineation process.

The time required will vary with the complexity of the site as well as the experience and knowledge of the people undertaking the survey. Features that cover a small area with good existing information and boundaries that are clearly visible on existing imagery may be confirmed from a brief desk top evaluation. A more complex but still simple identification, such as the one detailed in Eubenangee Swamp, may only require two hours in the field (plus travel time) and half a day in the office (plus time to acquire imagery and data). Larger and more complex sites may take several days work in the field by vegetation, fauna and soils scientists and several days in the office by GIS staff to map and to write up the findings. Field assessments will generally require more than one person to (safely) collect the required data.

Application to previously identified wetlands

This guideline sets out procedures to establish if an area is a wetland or not and if so to describe, to a specified accuracy, where the boundary between the wetland and non-wetland is. In practice an area may have been identified as a wetland from pre-existing mapping, e.g. Queensland Wetlands Program (Program) wetland map, or surveys and this guideline can be used to provide definitive verification and/or to refine the boundary at a larger scale.

Applying the definition and establishing the wetland/non-wetland boundary

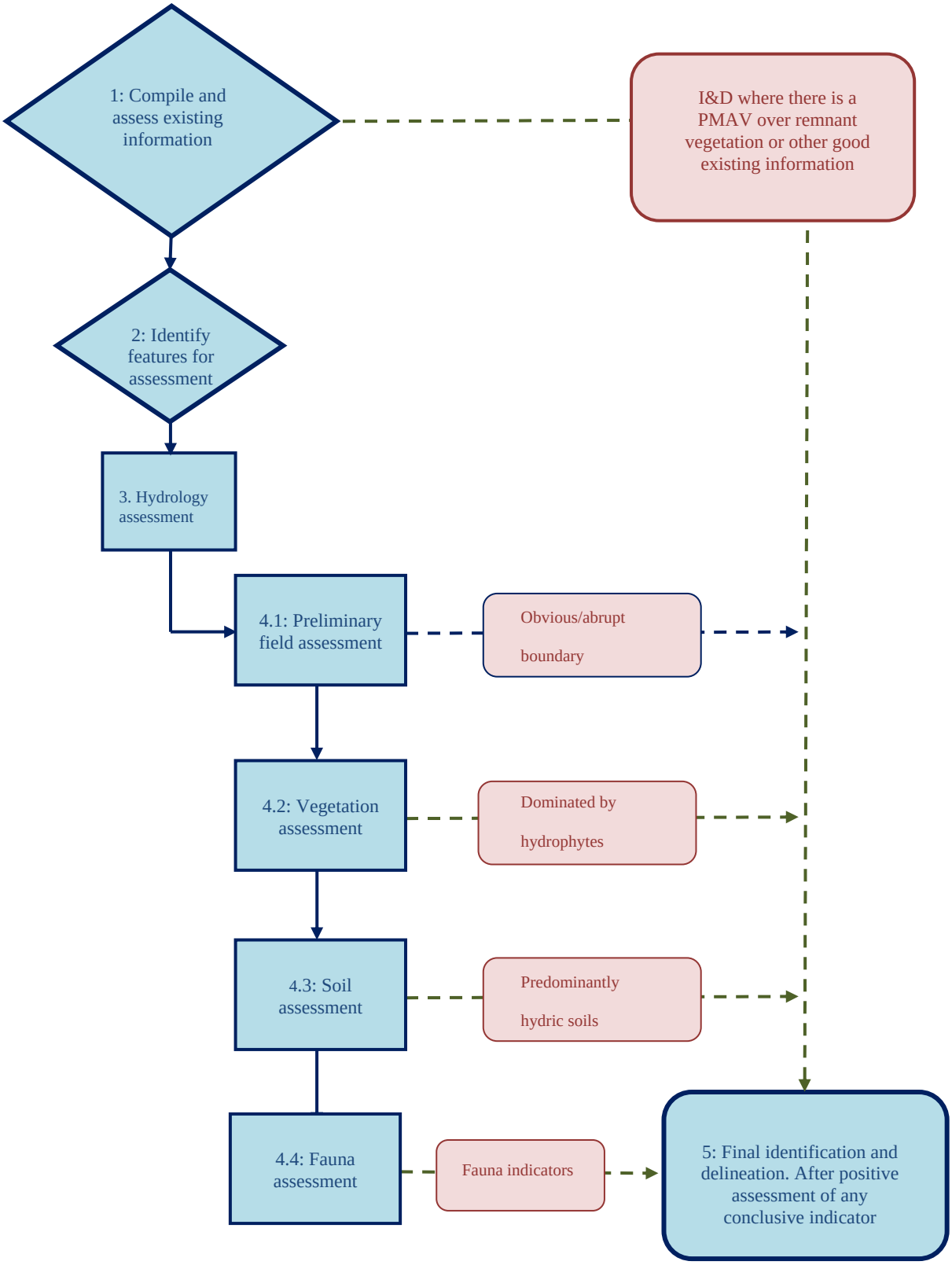
The Program Wetland Definition consists of criteria for hydrology, biota and substrate factors, which are used to test if a feature is a wetland or not. Each criterion is assessed by indicators that can be described by the collection of information or evidence from field survey or other sources. Part A (Table 2) of this guideline provides a list of indicators for each criterion.

Five steps to identify and delineate wetland boundaries are shown in Figure 1 and described below. These steps ensure information is collected to identify wetlands and delineate boundaries in the most efficient and effective manner. While the collection of information for multiple criteria or indicators provides a stronger evidence base, a final positive wetland determination and boundary delineation may be made whenever information for a positive wetland indicator has been collected. Thus, in many cases not all steps will be required to make a wetland determination and boundary delineation.

Where good existing information is available or where an obvious wetland boundary occurs in the field and can be readily identified on imagery, it may be possible to make a determination during the first three steps. For example, where an entire site comprises a rocky ridge with no wetland features present or a flooded swamp that is dominated by spike sedge (*Eleocharis* spp.), it is likely that a final determination may be made with qualitative information and at a much earlier stage than a site comprising a mixture of wetland and non-wetland features and gradational boundaries. The presence of a positive indicator of one of the wetland criteria is required to identify an area as wetland, although information for all criteria may be required to determine if an area is not a wetland, particularly if inconclusive indicators are present.

Figure 1 Steps for wetland survey and delineation

I&D – identification and delineation



Step 1 – Compile and assess existing information

The pre-planning stage, including the range of information that should be assessed, is outlined in Part A of this document. Where a site has been previously surveyed and there is good existing information, or where an interim determination is adequate for the purposes of a particular assessment, a final identification and delineation can be made at this stage. A property map of assessable vegetation (PMAV) [4], which identifies regional ecosystems may be used to delineate wetland boundaries where the site is covered by remnant vegetation. The regional ecosystems identified on the PMAV can be identified as wetlands or non-wetlands using the regional ecosystem description database [5].

Step 2 – Identify features for assessment

For larger and/or more variable sites, the different features present on the site must be identified to ensure subsequent sampling covers the full range of variation present. It may be possible to assess the variability of small (<1 ha) or relatively homogenous sites during a field inspection. However, generally this step will require the assessor to interpret imagery, such as aerial photography, into uniform strata based on discernable vegetation, soils or topographic patterns for subsequent field assessment. Pre-existing wetland, regional ecosystem, soil or other mapping will often be used in conjunction with image interpretation to classify the patterns.

Step 3 – Hydrological assessment

The wetland hydrology assessment sheet lists the indicators and evidence that are used to establish the presence of inundation of a feature. In many cases the inundation will be assessed iteratively in conjunction with flora and soils indicators, which can be used to determine the hydrology criteria has been met (Table 2, part A). Often a desktop assessment of hydrology will be carried out from imagery and other available information before field assessment, with further direct evidence or other indicators.

The hydrology criterion in the wetland definition is met when any indicators listed in the wetland hydrology assessment sheet are present.

Step 4 – Field assessment

Step 4.1 – Preliminary field inspection

The preliminary stratification of the site identified in step 2 should be verified by an initial field inspection. Additional features not apparent in step 2 may be added. The collection and identification of plant species unfamiliar to the ecologist at this stage will facilitate more efficient and effective subsequent collection of site data.

This step may be combined with more detailed assessment (step 4.2, 4.3 and 4.4) and a final conclusion made, where the area is small or uniform, there is adequate existing information or the area is familiar to the person doing the assessment. In other cases this step will guide planning for the subsequent survey of features that require detailed assessment of vegetation and/or soils and fauna.

Step 4.2 – Vegetation assessment

For each feature identified in step 2, the vegetation should be assessed to determine which areas are dominated by wetland plants and, therefore, meet the biotic criterion (i) in the definition. Procedures follow the site survey methods detailed in Appendix 2 of the regional ecosystem mapping methodology for Queensland [6] the above ground vegetation biomass (see Part A, or [6] Appendix 2). A list of wetland indicator plants has been prepared to facilitate the identification of vegetation dominated by wetlands species.

The biotic–plants criterion in the wetland definition is met when the abundance of wetland indicator plants in the ecologically dominant layer (EDL) is >50 per cent of the total.

Qualitative assessment

For areas clearly dominated by wetland plants (e.g. >70 per cent of the dominant layer is composed of wetland species) the ecological dominance can be assessed into broad cover classes and species abundance can be recorded as relative dominance classes (for an example, see the wetland inundation assessment sheet).

Quantitative assessment

Where the EDL is not clear and there is a mixture of wetland and non-wetland plants, quantitative abundance data must be collected. Crown cover should be measured at a plot using the crown intercept method detailed in the regional ecosystem mapping methodology for Queensland ([6], Appendix 2.8.1). For tree layers, basal area can provide a more precise estimate of abundance ([6], Appendix 2.8.2).

Step 4 .3 – Soil assessment

The field guide for assessing wetlands soils in Queensland [3] sets out methods to identify wetland soil indicators. Areas already identified as wetland by the vegetation assessment do not require further soil assessment for positive identification, although soils information for such areas could be required for inventory and evaluation purposes. Thus, soil samples may often only be required on the areas adjacent and to the upland side of the boundary identified by the vegetation assessment.

The soil criterion in the wetland definition is met when there is a predominance of wetland soil indicators as listed on the wetland soil assessment sheet.

Step 4.4 – Fauna assessment

Features already identified as wetland through vegetation or soil assessment do not require further assessment for positive identification, although fauna information for such areas may be required for inventory and evaluation purposes. For sites that have been subjected to hydrological modification, fauna may be a useful indicator of the degree of change (see 'decreased inundation').

The type of fauna information to be collected will depend on the type of animals being surveyed as well as the type of wetland. Often information on the life cycle of fauna is required for the interpretation of wetland fauna indicators. In cases where large numbers of mobile fauna occur, such as colonies of breeding water fowl, the abundance of fauna species associated with a particular vegetation community can identify a feature as a wetland. In other cases individual point locations of each fauna record may be required for interpolation of the wetland boundary. Standard fauna survey methodologies for different groups are widely available although the specific methodology will depend on the specific fauna and site attributes.

Step 5 – Final identification and delineation

The final wetland identification and delineation of its boundary may be made at any step where there are conclusive indicator(s) that can be used to verify that the hydrology and one of the other criteria have been met (Figure 1 and Figure 9 in Part A). The wetland delineation is determined by a single line representative of the landward wetland extent relative to the site surveyed.

The wetland boundary may initially be marked with stakes, tape or by obvious describing features on the ground, such as the extent of a dominant vegetation types. In some instances, the wetland extent may not be easily defined on the ground and may need to be produced by interpolation from sample sites/transects that span the wetland boundary. In these cases it may be necessary to locate soil or vegetation sample sites and transects so that the interpolated or estimated boundary can be spatially referenced to a geographic co-ordinate system.

Mapping of the boundary

Wetlands boundaries may be located on the ground using prominent features, marking tape or survey stakes. However, generally mapping of the boundary onto a coordinate system is the most effective and preferred way of communicating the extent of the wetland. General steps for mapping are outlined in the regional ecosystem mapping methodology for Queensland ([6], Appendix 1). Below are specific details relevant to the mapping of wetlands.

Format, datum and projection

Mapping may be created in a variety of formats. Preferably, digital mapping data should be captured for use in a geographic information system (GIS). The data may be formatted in any standard datum and projection, although the preferred data is the GDA94. Digital mapping is also the most suitable way of supplying mapping information that is part of the supporting information, such as location of flora, fauna and soil assessment sites.

Boundary location by field survey

The coordinates of boundaries that have been identified on the ground may be established using a global positioning system (GPS) to provide a track or list of waypoints that sit on the identified wetland boundaries.

Handheld GPS generally have an accuracy of ±10 metres, although this accuracy can be improved if using a differential GPS. Generally, a GPS will be used to record the location of a boundary defined by features, such as the abrupt change in vegetation or soils that have been identified in the vegetation or soils assessment.

If a greater accuracy is required, a surveyor may be required to locate a wetland boundary (or sample sites, transects and so on) marked in the field by an ecological or soil scientist. Standard surveying practices generally describe features in relation to the cadastral boundary and/or man-made landmarks (e.g. old fence posts). The allotment and wetland boundaries need to be referenced to a geographic coordinate system.

Delineation of mapping from imagery

There is a variety of remotely sensed imagery available that are suitable for large scale wetland assessment and delineation. Table 1 lists some major image sources and associated advantages and disadvantages for each type. Imagery can be used as a base on which to map the boundary. This linework can then be transferred to a GIS using a number of standard cartographic techniques. If the imagery is scanned and rectified then linework can be captured by direct delineation within a GIS.

Table 1 Examples of imagery that can be used for large scale wetland mapping and delineation

Imagery	Scale	Advantages	Limitations
Colour aerial photography			
Stereo pairs	1:5, 000	Individual photos of specific areas readily available. Use stereoscopic assessment to assess topography and vegetation pattern, which are particularly relevant to wetlands.	Choice of season might be limited, which may not be optimal for wetland assessment unless flown specifically. Difficult to accurately transfer boundaries to a geo-referenced map. Difficult to obtain time series that can be used to quantify hydrological regime.
(Ortho)-rectified	1:5, 000	Can digitise straight onto GIS or overlay with other spatial data.	Can't use in stereo pairs without sophisticated software.
High resolution Satellite data e.g.			
IKONOS or QUICKBIRD	1:10,000	Can choose one or time series to highlight particular inundation event or other wetland conditions. <1 m pixel size suited to large scale (1:10,000) assessments.	Cost can be expensive (includes balancing ortho-rectification, etc).
SPOT 5–10 metre pixels	1:25, 000	Widely available	While 5–10 metre pixels are freely available, use is limited to about 1:25,000 scale. Smaller pixels sizes are available (but expensive).
Lidar imagery to develop large scale digital elevation model (DEM)	Up to 1:10,000	Gives very good delineation of topography and vegetation height.	Expensive to purchase and process.

Rectification of imagery

Geo-referenced digital imagery can be used as a backdrop layer, in conjunction with other spatial information as well as for delineating features onto a geo-referenced map. This type of imagery has recently become more widely available through applications such as Google Earth or using GIS software to create it. However, if geo-referenced imagery is used to map and delineate wetland boundaries, the accuracy of the geo-referencing, i.e. how close a point on the image is to that point on the ground, must be known and specified.

Generally geo-referenced imagery can be purchased with a known level of spatial accuracy that will be listed in the meta-data accompanying the imagery. In some cases the purchaser can request a level of accuracy appropriate to the use. For example, if a wetland boundary is required to be located with an accuracy of ±10 metres then imagery with a spatial error less than this is required.

Software programs can be used to carry out simple geo-referencing, or in some cases ortho-rectification of scanned imagery. Simple geo-referencing allows the user to allocate coordinates to a scanned image but does not correct for changes in elevation or the complex geometry of the image. The accuracy of such simple geo-referencing is lower in more hilly terrain but more importantly difficult often to quantify without comparison with independent known points such as ground control points. Similarly while the imagery in Google Earth often appears to be very good (B. Wilson personal observation) the accuracy of individual areas varies and more

importantly is not stated. The collection of control points outlined under the 'Application kit for property maps of assessable vegetation under the *Vegetation Management Act 1999*' [4], is an example of information required to assess the accuracy of image rectification.

Ortho-rectification of aerial photographs is based on a digital terrain model or digital elevation model and undergoes a process that aims to remove the effects of aerial camera lens tip and tilt, image scale variations and object displacements due to ground relief. This is accomplished by reprocessing the photograph to conform to the orthographic projection, hence the name, ortho-photo. This type of rectification can produce very accurate geo-referencing, for example, 1:25, 000 ortho-photos often have a spatial accuracy about ±2 metres.

Scale and accuracy

The scale and accuracy of wetland boundary delineation are discussed in 'Scale' of Part A of this guideline. The main points to consider are:

- generally, for statewide assessment purposes or consistency an assessment or mapping scale of 1:25,000 that identifies areas to a minimum size of 0.25 ha is appropriate
- the scale of delineation with respect to minimum size and level of detail in the boundary should be in accordance with the scale of definition used to define wetlands (usually 1:25,000–1:35,000) rather than the scale required to obtain an adequate level of accuracy for the location of the boundary
- a mosaic area of wetland and non-wetland features is considered a wetland if the features having wetland attributes occupy greater than 50 per cent of the area with a minimum scale of delineation 0.25 ha
- the method used to delineate the boundary must be described and include an error estimate for the accuracy of the boundary. To ensure a wetland is included in a defined boundary it must be assumed that the boundary delineated is buffered by the stated level of accuracy.

Positional accuracy of mapped boundary

The (horizontal[1]) positional accuracy of any point on a map is a measure of the distance between the location of the point on the map and the true location of that point. A formal estimate of position accuracy requires analysis of sample data to estimate the mean value for the fit of the map being assessed to a reference layer, which is assumed to be correct often to some specified level of confidence measured by the standard error of the mean [7, 8].

The positional accuracy of the spatial location of points or boundaries should be expressed as confidence limit in (ground) metres. For example, a boundary that has an accuracy of ±10 metres means the actual boundary can be 10 metres either side of where the line is described and located. This means that to be sure of including the wetland within the area delineated then it must be assumed that the boundary is 10 metres towards to upland area (Figure 13, Part A).

Formal accuracy assessments are often reported as the root-mean-square error (RMSE), which is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source, of higher accuracy, for identical points. In addition, the RMSE is usually reported at a specified confidence interval, often 95 per cent. This confidence level means that 95 per cent of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value [9].

The accuracy of the map will vary with the method used to describe it and is the sum of the errors from all sources. For example, where a boundary is delineated from rectified imagery, the final accuracy of the boundary is the accuracy of the image rectification to the ground plus the cartographic standards that determine how accurate features are delineated with respect to the image. The latter will vary with a number of factors including

[1] Vertical positional accuracy can be measured but for wetlands horizontal positional accuracy only is required because they are generally flat features.

the scale of compilation, the degree that the feature can be seen on the image and the care with which the lines are drawn.

An estimate of accuracy can be derived by comparing the mapping data with known ground locations. Ground locations can be located using a GPS, although in this case the error in GPS must be taken into account and added to the resulting error estimate, which in the case of non-differential GPS is about 10 metres.

For small areas, an alternative to providing a formal estimate of accuracy is to provide an estimate based on the information and cartographic standards used to capture the mapping data. For example, a map could be given an error of 15 metres with the following justification:

Digital ortho-rectified imagery with a stated accuracy of 5 m was used as a base. The wetland boundary was associated with clearly visible features on the imagery and was digitised at a scale of 1:5,000 to within 2 mm of its actual location on the image. This equates to 10 m on the ground. The final accuracy is therefore estimated as the error from the digitising (10 m) plus the error in the imagery that the mapping was digitised to (5 m).

The above claim would be difficult to verify if the mapped boundary was not associated with features that were clearly visible on the imagery.

The method used to delineate the boundary must be described and include an error estimate for the accuracy of the boundary. To ensure a wetland is included in a defined boundary it must be assumed that the boundary delineated is buffered by the stated level of accuracy.

The final accuracy level required will depend on the purpose for which the survey is being made. For example, if a wetland is 300 metres away from a proposed development, an accuracy of 50 metres may be adequate to verify that the development will not impinge directly on the wetland, while wetland boundaries that cross or adjoin small lots may need to be delineated with greater accuracy.

Limits to precision of wetland boundary

In some instances the level of precision at which the wetland boundary can be delineated may limit the spatial accuracy at which the boundary can be defined. Wetlands are communities, or ecosystems, that are defined by spatially connected groups of plants (and animals) and associated environmental factors. This limits the precision at which a boundary can be defined. For example, in the case of a palustrine wetland defined by the dominance of a tree species with crowns 5–10 metres wide and separated from adjacent trees by at least the same distance (Figure 2), it is difficult to define the extent of the wetland community with a precision greater than about 10 metres (Figure 3). Wetlands dominated by water or ground layer species may be defined at a greater level of precision but in all cases the accuracy of the wetland boundary must be commensurate with the precision that the boundary of the particular wetland can be described.

Figure 2 River red gum (*E. camaldulensis*) fringing the Barcoo River, Welford NP (B. Wilson)

The red line indicates the top of the river bank while the blue line indicates to edge of the red gum crowns, which are part of the fringing riverine wetland. Thus, in this case, the precision at which the wooded wetland vegetation can be delineated from the adjacent floodplain community is about 10 metres.

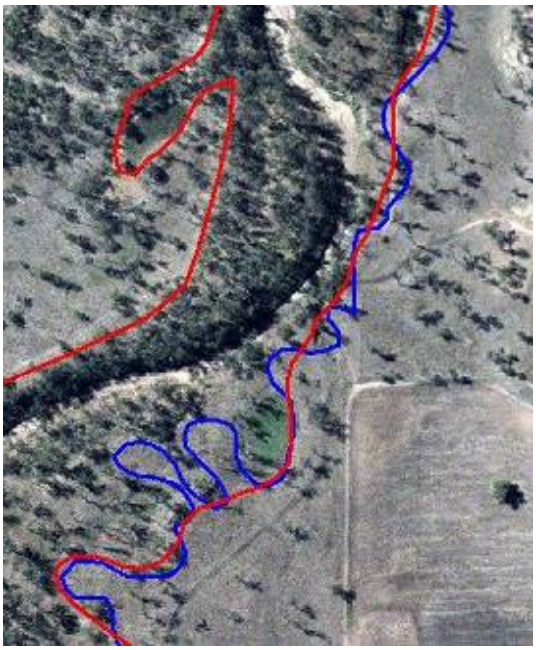


Figure 3 Wetland boundary on the Condamine River (scale 1:5,000)

Both lines have been drawn at 1:5,000 scale to get the required accuracy for location of line (±10 m). The red line has maintained an appropriate scale (1:25,000) for delineation of a wooded wetland ecosystem boundary while the blue line has traced wetland/non-wetland features at a larger scale than is appropriate.

Sampling intensity for verification of feature attributes

The number of sites required to verify the vegetation or soil attributes of an identified feature will vary with the area of the feature, the scale at which the assessment is being conducted and the heterogeneity of the vegetation and/or soils associated with the feature.

The minimum number of ground observations per hectare that should be used for land surveys at different scales is taken from the Australian standard for land surveys [10] and are listed in the regional ecosystem mapping methodology for Queensland [6]. Wetland determinations at a property level are generally carried out to delineate features with a minimum size of about 0.25 ha–0.5 ha (see above) and, therefore, require a sampling intensity of about one site every 1–4 ha with a minimum of one site per feature. These specifications should not be confused with the marking out of an actual wetland boundary. There needs to be adequate sampling or marking of an identified feature to meet the specified accuracy requirement or confidence interval. Thus, for delineation purposes the density of sites will often be higher in the vicinity of the wetland boundary, than required in the general specifications listed above.

Sample location

The location of sample sites should follow standard resources survey practices such as those outlined in the survey methodology for Queensland [6] and Australia [10]. These include sampling representative sites of each feature identified in Step 2 and orientating (vegetation) sample plots to minimise environmental gradients (i.e. usually along the contour). In cases where the features on the ground cannot be accurately identified on imagery or there are gradational boundaries, samples need to be located along multiple transects that cross the site perpendicular to the wetland boundary (generally 90 degrees to the contours) with a greater density of sites around the actual boundary.

Problem wetlands

This section identifies procedures for situations where the assessment of indicators and criteria may give inconsistent or misleading information on the identification and delineation of wetlands.

Intermittent/episodic wetlands

Many wetlands in Queensland, particularly in more arid parts of the state, are only intermittently or episodically inundated. While such areas may be vegetated or support wetland-dependent fauna when wet, in between inundation events biota may be lacking or may change in composition to non-wetland species. These changes may be seasonal or, in some cases, can last for many years in association with longer term climatic cycles.

In such cases soils may provide indicators of wetland extent. However, where soil indicators are absent or inconclusive, an assessment of biota that is normally present during the wet periods must be made, because this is the period that determines the wetland characteristics of a site.

The following list outlines procedures that can be used to assess vegetation of sites during dry periods:

- assess only perennial long-lived species for positive wetland determination
- look for perennial, subterranean regenerating parts, such as tubers
- assess aerial photography for land form and landscape position to compare with similar areas of known floristic composition in wet times
- use the above to equate to a regional ecosystem description that is listed as a wetland
- make a preliminary assessment that can only be confirmed when the area is wet again.

Modified hydrology

Increased inundation

Wetland plants and soils may be absent from newly created or modified wetlands because the hydrological regime may not have been operating long enough. Soils will not generally be a useful indicator in such cases because hydric soils characteristics take many years to develop. Non-wetland plants can die very quickly (in a matter of weeks) when subjected to even minor water logging so the predominance of such plants can be used to indicate non-wetlands. When vegetated, the boundary of artificial or modified wetlands may be established by observing where non-wetlands plants have died or wetlands plants have colonised. Otherwise the hydrology of similar natural wetlands can be used as a reference to assess the artificial wetland.

The following is a list of steps that can be used to determine wetland areas that have been newly created. This list has, in part, been adapted from Part IV, subsection 4 of the US Army Corp wetland delineation manual [11].

Step	Indicator
Has hydrology changed	Presence of levees, dams etc that increase area and/or duration of inundation or water-logging
Document when changes occurred	Aerial photo record or any other appropriate documentation of when changes were made
Assess vegetation and if required fauna	Vegetation qualitative assessment and fauna assessment
Quantify hydrological regime from image history or other appropriate source	Compare with other known wetlands

Decreased inundation

Where modifications are associated with reduced inundation, the vegetation and soils indicators could be relictual. Common types of hydrological modifications that occur in Queensland include:

1. dam construction; may make an area drier if occurs down stream of a dam but may make an area wetter if it occurs:
    a. upstream of the dam wall within the dams lake
    b. downstream of the dam but in a channel that the impoundment regularly supplies water to
2. levees, dykes, bunds and similar structures
3. direct infilling or levelling of wetlands
4. drainage ditch construction. Constructed to drain water from a wetland
5. ground water extraction.

While in some cases the alteration may have completely eliminated inundation from an area, such as springs that are now extinct due to water extraction from the Great Artesian Basin, in many cases the alterations may have only partially changed the water regime. These cases require an assessment of the degree of alteration in hydrology.

Ideally this assessment would be from quantified hydrological records but generally the assessments will be of indirect indicators of change such as those listed in Table 2.

Table 2 Steps for assessing hydrological modification

	Assessment	Conclusions that may be drawn
1	Examine current satellite imagery for signs of current inundation.	Hydrology has been modified and needs further investigation.
2	Compare vegetation on altered site to a similar neighbouring wetland which has not undergone hydrological modification.	If the vegetation is similar particular in under-storey non-woody species then area is assessed as still a wetland.
3	Compare fauna on altered site with similar neighbouring wetland.	Fauna will react to changes in hydrology and, therefore, if the composition is not or little different to the reference site then hydrology modification can be assessed as not changing the site from a wetland.
4	Direct assessment of impact of modification.	Is the impact localised (e.g. drainage channel) or widespread (e.g. diversion of all flooding into a wetland area).
5	Detailed groundwater studies, if available.	These can be used to quantify hydrological regime before and after alterations were made and to compare with other wetland areas.

Adapted from the Federal Interagency Committee for Wetland Delineation Manual [12].

Modified vegetation

Vegetation indicators need to be assessed under normal conditions. Therefore, in areas where vegetation is absent due to clearing or long term climatic cycles, and soils indicators are lacking or inconclusive, the vegetation that would grow at the site under normal wet conditions needs to be determined. In cases where there has been no hydrological modification it can be generally assumed that cleared vegetation would regrow. Areas where there has been hydrological modification require an assessment of the degree of modification and an interpretation of whether this impact would prevent wetlands species regrowing.

Pre-clearing vegetation can be determined using the Queensland survey and mapping methodology for pre-clearing vegetation [6]. Historical aerial photographs can be used to determine vegetation present before clearing by comparing the vegetation at uncleared sites that have a similar photo-pattern to the cleared area. Survey records and soils and other mapping can also assist in determining pre-clearing vegetation. Wetland areas that have been cleared of vegetation will often have a ground layer of regrowth species that can be used to indicate the type of vegetation that was originally at a site or is likely to regrow.

Fauna as a delineation criterion

The existence of some fauna species can not only identify a feature as a wetland but also delineate the wetland's extent. The Queensland Wetlands Program's wetland indicator fauna species list is a list of species whose presence can help define or delineate the extent of a wetland.

When collecting fauna data and noting presence or absence, it is important to remember that some wetland indicator fauna species might not be present at all times. It is also important to understand how a species depends on a wetland.

In some wetland situations, the absence of flora or soils means fauna can be the only criterion that can provide a delineation tool, for example:

- rock pools with only algae and algae eating frogs and/or fish
- superhaline water bodies, which are too salty for plants, but support algae-eating brine shrimp
- tidal sand flats, which are free of plants, but when covered by the tide are feeding grounds for fish and crustaceans.

Case studies

The following case studies are examples of the information and format required to verify and delineate a wetland/non-wetland boundary at a specified accuracy. The first case shows where a previously identified wetland is adjusted to larger scale imagery. The second case shows how a simple obvious boundary at Eubenangee swamp is verified with qualitative vegetation information, while the third case details a larger more heterogeneous area requiring vegetation and soil survey.

Brigalow Creek, Goondiwindi

Wetland existing information and context summary

Existing information and context
The wetland has been identified on the QWP wetland mapping version 1.2 (Figure 4) at a scale of 1:100,000.

Wetland methodology and survey summary

Assessment methodology and survey
The existing boundary has been largely unchanged but located onto an ortho-rectified image at a greater level of accuracy.

Final wetland determination and boundary delineation

Final wetland determination and boundary delineation
The boundary of the wetland has been redrawn onto 2003 ortho-rectified imagery that has an accuracy of ±2.2 metres to give a final boundary accuracy of ±7.2 metres.

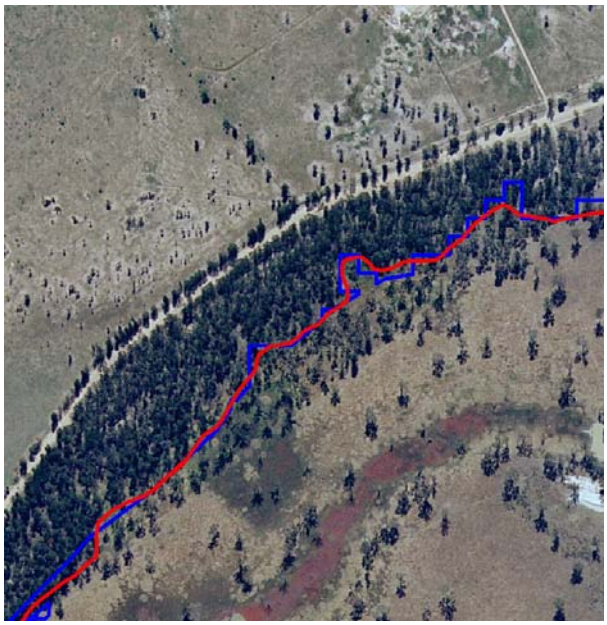


Figure 4 Simple wetland delineation at Goondiwindi showing original boundary delineation from Queensland wetlands mapping version 1.2 in blue and updated boundary in red, which has been drawn onto ortho-rectified imagery.

Eubenangee swamp

Wetland existing information and context summary

Existing information and context
The site is located at Eubenangee swamp in north Queensland. The area surveyed was approximately 45 ha on the southern boundary of the swamp (Figure 5) and is shown on the Queensland Wetlands Program wetland map (version 1.3) as palustrine wetland 7.3.5a – Melaleuca quinquenervia open-forest on poorly drained peaty humic gley soils where the water table is near or above the ground for most of the year. Areas to the south are mapped as non-wetland on the wetland map and on the regional ecosystem map (version 5.0) as cleared with the pre-clearing vegetation 7.8.1b – Mesophyll vine forest on basalt. The wetland boundary on the existing mapping is associated with an abrupt change on topographic and geological mapping for the areas from the flat alluvial soils to the gently sloping basalt soils.

Wetland methodology and survey summary

Assessment methodology and survey
A preliminary boundary was delineated on 1:25,000 scale ortho-rectified aerial photography and then finalised after field inspection. The field survey collected qualitative vegetation sites along a transect across the boundary (Figure 6) and verification sites along the boundary. Field assessment verified that the wetland boundary delineated is associated with an abrupt change from the flat alluvial soils to the gently sloping basalt soils. Four sites on a transect across the boundary were located and their vegetation described using the wetland vegetation proforma. This verified the change in wetland (hydrophyte) dominated vegetation between sites three and four. The occurrence of similar vegetation along the boundary was verified by field traverse at observational sites. Thus, the survey confirmed the existing regional ecosystem mapping and wetland mapping for the site with minor shifts in the boundary location required.

Wetland hydrology summary

Inundation: summarise the assessment and results of the wetland hydrology assessment sheet
The site is situated on a depression on a floodplain. Landsat imagery from 1999 shows most of the floodplain to be inundated with water.

Wetland vegetation summary

Vegetation: summarise the assessment and results of the wetland vegetation assessment sheet
Quantified vegetation sites (see wetland hydrology assessment sheet) were established across the preliminary boundary identified on the imagery (red points on Figure 6). Additional quantitative vegetation sites were also assessed at other locations (blue points on Figure 6). Sites 1–3 were dominated by hydrophytes vegetation and, therefore, confirmed as wetlands.

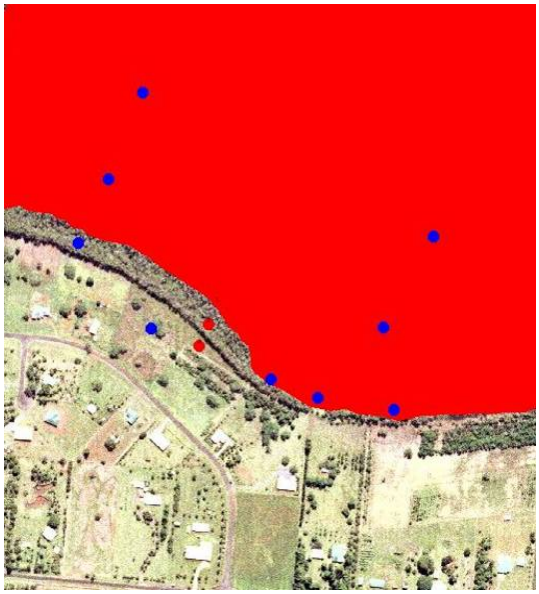


Figure 5 Existing wetland mapping for the areas showing palustrine swamp in red bordered by non wetlands areas to south (source Queensland Wetland Mapping version 1.3).

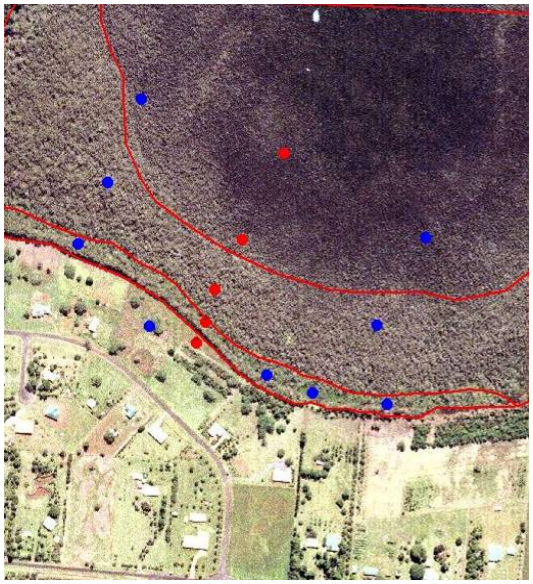


Figure 6 Simple wetland delineation at Eubanagee swamp in northern Queensland. Red lines show stratification used for sampling. Red dots are the location of quantitative vegetation sites. Blue dots are the location of vegetation verification observational sites.

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Application of wetland definition to survey sites

Site no	Inundation criteria	Vegetation criteria	Soil criteria	Wetland assessment
1	yes	yes	Not assessed	Wetland
2	yes	yes	Not assessed	Wetland
3	yes	yes	Not assessed	Wetland
4	no	no	Not assessed	Non-wetland
5	no	no	Not assessed	Non-wetland
6	yes	yes	Not assessed	Wetland
7	yes	yes	Not assessed	Wetland
8	no	no	Not assessed	Non-wetland
9	yes	yes	Not assessed	Wetland
10	yes	yes	Not assessed	Wetland
11	No	No	Not assessed	Non-wetland
12	No	No	Not assessed	Non-wetland
13	No	No	Not assessed	Non-wetland
14	no	no	Not assessed	Non-wetland

Final wetland determination and boundary delineation

Final wetland determination and boundary delineation
The final boundary was digitised directly onto 1:25,000 scale ortho-rectified aerial photography with an accuracy of ±1.2 m at a scale of 1:5,000 with a cartographic positional accuracy of ±5 m. Therefore, the final boundary has an positional accuracy of ±6.7 m.

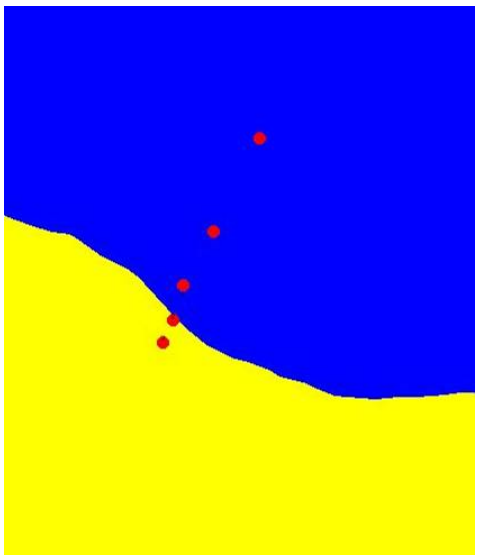

Figure 7 Area showing final wetland boundary delineation with wetland shaded blue and non-wetland yellow

Wetland hydrology assessment sheet

Imagery			
Type	Landsat TM	Dates inundation observed	1992 September
		Dates inundation not observed	

Landscape features

Microrelief	Present	Not present	Other features	Present	Not present
Debil Debil			Aerial roots		
Swamp hummock			Iron staining		
Flood carried debris			Flood staining		
Wetland drainage patterns			Mud cracks,		
Surface staining			Algal flakes		
Salt crusts			Wetland soils (Part 1 of wetland key in soils field guide),		
Wetland landform pattern	Floodplain		Wetland landform element	Swamp	

Wetland vegetation assessment sheet – quantitative

Site No.	1	Recorder:	F. Smith, E. Brown, J. Green	Day/Date:	4/5/07
Locality					
MGA	Zone	55	E 0391029	N 8077180	:
GDA94	Longitude	___ . ____		Latitude	__ . ____

Vegetation structure

Median height of EDL is to be measured

Stratum	Median height	Height interval	Crown cover*
T1	9.5		55
G	2.3		70
Structural formation:			
Ecologically dominant layer			**T1**
Proportion of EDL wetland indicators:			**100%**

Plant species

Layer.	Cover*	Wetland indicator	Scientific Name
T1	50	Y	Melaleuca quinquenervia
T1	5	Y	Lophostemon suaveolens
G	25	Y	Lepironia articularis
G	40	Y	Scleria polycarpa

Site No.	2	Recorder:	F. Smith, E. Brown, J. Green	Day/Date:	4/5/07
Locality					
MGA	Zone	55	E 0391016	N 8070675	:
GDA94	Longitude		.	Latitude	.

Vegetation structure

Median height of EDL is to be measured

Stratum	Median height	Height interval	Crown cover*
T1	9.5		30
G	2.3		50
Structural formation:			
Ecologically dominant layer		**T1**	
Proportion of EDL wetland indicators:		**100%**	

Plant species

Layer.	Cover*	Wetland indicator	Scientific Name
T1	25	Y	Melaleuca quinquenervia
T1	5	Y	Lophostemon suaveolens
G	35	Y	Lepironia articularis
G	9	Y	Scleria polycarpa

Site No.	4	Recorder:	F. Smith, E. Brown, J. Green	Day/Date:	4/5/07

Zone 55 E 0391016 N 8070675 :

Zone 55 E 0 N :

Vegetation structure

Median height of EDL is to be measured

Stratum	Median height	Height interval	Crown cover*
		-	
S1	1.8	-	1
G	0.7	-	65
Structural formation: Tussock grassland			
Ecologically dominant layer			**G1**
Proportion of EDL wetland indicators:			**<10%**

Plant species

Layer.	Cover*	Wetland indicator	Scientific Name
S1	0.1	N	Glochidion sp.
G	5	Y	Ischaemum australe
G	58	N	Imperata cylindrica

Wetland vegetation assessment sheet – qualitative

Site No	easting	Northing	Dominant species	Wetland/non wetland vegetation
6			Melaleuca quinquenervia, Lepironia articularis	Wetland vegetation
7			Melaleuca quinquenervia, Lepironia articularis	Wetland vegetation
8			Imperata cylindrica	Non-wetland vegetation
9			Melaleuca quinquenervia, Lepironia articularis	Wetland vegetation
10			Melaleuca quinquenervia, Lepironia articularis	Wetland vegetation
11			Imperata cylindrica	Non-wetland vegetation
12			Imperata cylindrica	Non-wetland vegetation
13			Imperata cylindrica	Non-wetland vegetation
14			Imperata cylindrica	Non-wetland vegetation

Goorganga Plain

Wetland existing information and context summary

Existing information and context
The site is located at Goorganga Plains in north Queensland, which occurs on a seasonally inundated floodplain. The area surveyed was approximately 7 ha on the southern boundary of the swamp and is shown on the QWP wetland map (version 1.3) as palustrine wetland grading from a Melaleuca open-forest (8.3.13b or 8.3.11). The whole site is mapped as non-remnant vegetation indicating the vegetation at the site has been disturbed.

Wetland methodology and survey summary

Assessment methodology and survey
The site was stratified using coloured 2005 ortho-rectified aerial photography with reference to version 6b regional ecosystem mapping and stereoscopic examination of aerial photographs (Figure 10). The preliminary strata identified were verified in the field and surveyed. Sites were located along a transect running across the gradient from wetter low lying areas to higher less-inundated areas (Figure 10). Sites one and two were verified as wetland from vegetation sites alone, while the third site was dominated by non-wetland exotic species. Soil sampling at this site identified wetland indicators including high organic carbon content, mottling and ferruginous root channel linings.

Wetland hydrology summary

Inundation: summarise the assessment and results of the wetland inundation assessment sheet
The site is situated on a floodplain. Landsat imagery from 1999 shows the area to be inundated with floodwaters, which was confirmed by anecdotal information from the land holder.

Wetland vegetation summary

Vegetation: summarise the assessment and results of the wetland vegetation assessment sheet
Sites one and two are dominated by wetland vegetation Melaleuca viridiflora var. viridiflora. The vegetation on site three but has been cleared and is dominated by non-wetland exotic species.

Wetland soils summary

Soils: summarise the methods and results of the soils inundation assessment sheet
The soils on site three show mottles in the upper layer (<0.3 m) and wetland indicator, ferruginous root channel and low chroma values. These are positive wetland soil indicators as the site is seasonally inundated.

Application of wetland definition to survey sites

Site no	Inundation criteria	Plant criteria	Soil criteria	Wetland assessment
1	yes	yes	Not assessed	Wetland
2	yes	yes	Not assessed	Wetland
3	yes	no	Yes	Wetland

Final wetland determination and boundary delineation

Final wetland determination and boundary delineation
The final boundary (Figure 11) was digitised directly onto 1:25,000 scale ortho-rectified aerial photography with an accuracy of ±2.2 m at a scale of 1:10,000 with a cartographic positional accuracy of ±10 m. Therefore, the final boundary has an positional accuracy of ±12.2 m.

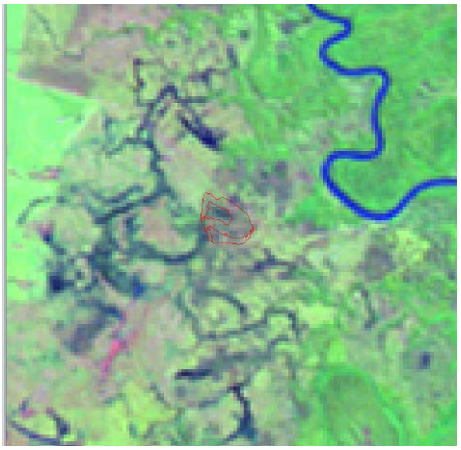

Figure 8 Landsat scene from 1990 wet season showing inundation across the area

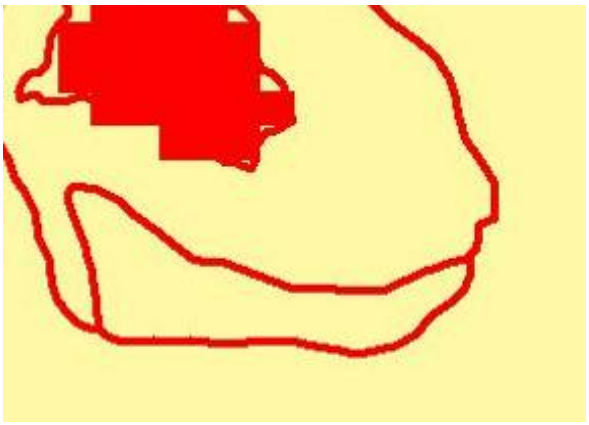

Figure 9 Existing wetland mapping for the areas showing palustrine swamp bordered by non-wetlands areas to south (source Queensland Wetland Mapping version 1.3)

Figure 10 Preliminary feature stratification and location of vegetation sample sites

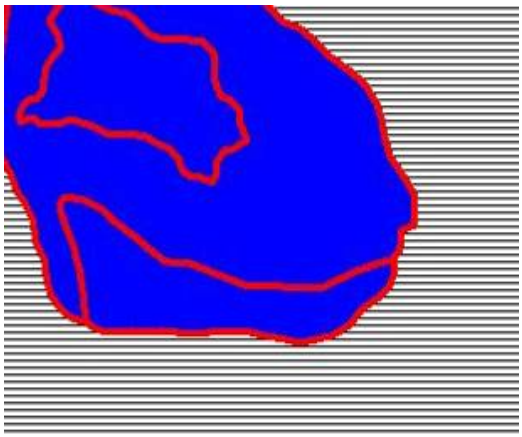

Figure 11 Area showing final wetland boundary delineation with wetland shaded blue and area not surveyed hatched

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Wetland hydrology assessment sheet

Site No.	1,2, 3	Recorder:	F. Smith, E. Brown, J. Green	Day/Date:	4/6/07
Locality					
MGA	Zone		E		N	:
GDA94	Longitude		.	Latitude		.

Imagery			
Type	Landsat TM	Dates inundation observed	March 1990
		Dates inundation not observed	

Landscape features

Microrelief	Present	Not present	Other features	Present	Not present
Debil Debil		X	Aerial roots		X
Swamp hummock		X	Iron staining		X
Flood carried debris		X	Flood staining		X
Wetland drainage patterns		X	Mud cracks		
Surface staining		X	Algal flakes		X
Salt crusts		X	Wetland soils (Part 1 of wetland key in soils field guide)		
Wetland landform pattern			Wetland landform element		
Depth to water table		cm			
Notes: e.g. anecdotal evidence, direct observation, hydrological modelling					
Anecdotal evidence of inundation at site from landholder					

Wetland vegetation assessment sheet – quantitative

Site No.	1	Recorder:	F. Smith, E. Brown, J. Green	Day/Date:	4/6/07
Locality					

MGA Zone 55 E 0391029 N 8070718 :

GDA94 Longitude ___ . ____ Latitude ___ . ____

Vegetation structure

Median height of EDL is to be measured

Stratum	Median height	Height interval	Crown cover*
T1	9.5		55
G	2.3		70
Structural formation:			
Ecologically dominant layer			**T1**
Proportion of EDL wetland indicators:			**90%**

Plant species

Layer.	Cover*	Wetland indicator	Scientific Name
T1	50	Y	Melaleuca viridiflora var. viridiflora
T1	5	Y	Lophostemon suaveolens
G	25	Y	Cyperus gunnii subsp. novae-hollandiae
G	40	Y	Leersia hexandra
G		Y	Cyperus dactylotes
G		Y	Cyperus lucidus

Site No.	2	Recorder:	F. Smith, E. Brown, J. Green	Day/Date:	4/6/07
Locality					
MGA	Zone	55	E 0391029	N 8070718	:
GDA94	Longitude		.	Latitude	.

Vegetation structure

Median height of EDL is to be measured

Stratum	Median height	Height interval	Crown cover*
T1	9.5		55
G	2.3		70
Structural formation:			
Ecologically dominant layer			**T1**
Proportion of EDL wetland indicators:			**90%**

Plant species

Layer.	Cover*	Wetland indicator	Scientific Name
T1	50	Y	Melaleuca viridiflora var. viridiflora
T1	5	Y	Lophostemon suaveolens
G	25	Y	Cyperus gunnii subsp. novae-hollandiae
G	40	Y	Leersia hexandra
G		Y	Cyperus dactylotes
G		Y	Cyperus lucidus

Site No.	3	Recorder:	F. Smith, E. Brown, J. Green	Day/Date:	4/6/07
Locality					
MGA	Zone	55	E 0391029	N 8070718	:
GDA94	Longitude		.	Latitude	.

Vegetation structure

Median height of EDL is to be measured

Stratum	Median height	Height interval	Crown cover*
T1	9.5		2
G	0.5		55
Structural formation:			
Ecologically dominant layer			**G**
Proportion of EDL wetland indicators:			**<10%**

Plant species

Layer.	Cover*	Wetland indicator	Scientific Name
T1	50	Y	Melaleuca viridiflora var. viridiflora
G	40	N	Digitaria eriantha
G	1	N	Cyperus gunnii

Wetland soils field record sheet

Site No.	3	Recorder:	F. Smith, E. Brown, J. Green	Day/Date:	1/5/07
Locality	Goorgandra Plain				
MGA	Zone		E 6 7 1 0 1 0	N 7 7 4 0 9 9 3	:
GDA94	Longitude		.	Latitude	.
Climatic region:		Subtropical X	Semiarid	Arid	

Wetland soils

Organic material (within 0.3 m of soil surface)	ACIDIC	KANDOSOLIC	REDOXIC	Hydrosol
P horizon	Present		Not present	X
Thickness of P horizon	_____cm			

Wetland soil indicators

Organic material (within 0.3 m of soil surface)	Present		Not present	X	
Thickness of organic materials layer	__0___cm				
Texture qualifier Fibric	Yes/No	Sapric	Yes/No	Hemic	Yes/No

Acid sulfate materials (within 0.3 m of soil surface)

Hydrogen sulfide gas (rotten egg gas)	No	Monosulfidic black ooze	No	Sulfurous segregations	No

Gley colours Present		Not present	X		
Thickness of gley layer	_____cm	Depth to gley layer	_____cm		
Soil water interface	Present		Not present	X	
Depth to soils water interface	_____cm				
Mottles (<0.3 m of surface)	Present	X	Not present		
Segregations (<0.3 m of surface)	Present		Not present	X	
Ferruginous root channel and pore linings (<0.3 m of surface)	Present	X	Not present		

Soil matrix chroma (within 0.3 m of the soil surface)

Are chroma values less than or equal to two (2) in the wettest lowest lying area?	Yes	X	No	
Do chroma values decrease moving into the wetland from sites considered outside?	Yes		No	X

Figure 12 High organic carbon content, mottling and ferruginous root channel linings all positive indicators of periodic inundation

Templates and formats

Recommended field equipment

Vegetation: GPS, camera, 50 m tape, compass, clinometer and/or hypsometer, Bitterlich stick, specimen collecting bag, plant press, tags, 3 m × 1 m lengths of PVC pipe with two elbows for sub-quadrant, clipboard, proforma, pencils and eraser.

Soils: the requirements for soils survey are set out in the wetlands soils field guide [3]. These include an auger/shovel, Australian Soil and Land Survey Field Handbook, tape measure, pH kit, soil colour chart, field record sheets, camera, GPS and water.

Fauna: GPS, camera, proformas, pencils and eraser, various additional equipment depending on fauna group being surveyed.

Office: GIS software, imagery for the site, other relevant resource information.

Mapping information formats

Mapping information should be in a digital format with the following specifications:

- the data must be projected to a standard datum preferable GDA94
- file formats for line-work, polygons and points (vector data sets) must be:
    - ESRI shapefile or coverage
    - Mapinfo; or
- file formats for graphics (e.g. aerial photographs, satellite imagery, other raster data sets like DEM's) must be:
    - tiff or GeoTiff
    - jpg or GeoJpg
    - Erdas Imagine IMG format (noBMP); or
    - Arc Grid.
- attributes: the mapping must have a minimum of one attribute called 'wetland'. The values in this attribute indicate if an area is 'wetland' or 'non-wetland.'

Assessment proformas

Wetland existing information and context summary

Existing information and context

Wetland methodology and survey summary

Assessment methodology and survey

Wetland hydrology summary

Inundation: summarise the assessment and results of the wetland inundation assessment sheet

Wetland vegetation summary

Vegetation: summarise the assessment and results of the wetland vegetation assessment sheet

Wetland soils summary

Soils: summarise the methods and results of the soils inundation assessment sheet

Wetland fauna summary

Fauna: summarise the methods and results of the fauna assessments conducted

Application of wetland definition to survey sites

Site no	Inundation criteria	Plant criteria	Soil criteria	Wetland assessment
1	Yes/No or not assessed	Yes/No or not assessed	Yes/No or not assessed	Wetland or non-wetland
2	Yes/No or not assessed	Yes/No or not assessed	Yes/No or not assessed	Wetland or non-wetland
3…	Yes/No or not assessed	Yes/No or not assessed	Yes/No or not assessed	Wetland or non-wetland

Final wetland determination and boundary delineation

Final wetland determination and boundary delineation

Wetland hydrology assessment sheet

Site No.		Recorder:		Day/Date:	
Locality					
MGA	Zone		E	N	:
GDA94	Longitude		.	Latitude	.

Imagery			
Type		Dates inundation observed	
		Dates inundation not observed	

Landscape features

Microrelief	Present	Not present	Other features	Present	Not present
Debil Debil			Aerial roots		
Swamp Hummock			Iron staining		
Flood carried debris			Flood staining		
Wetland drainage patterns			Mud cracks,		
Surface staining			Algal flakes		
Salt crusts			Wetland soils (Part 1 of wetland key in soils field guide)		
Wetland landform pattern			Wetland landform element		
Depth to water table		cm			
Notes: e.g. anecdotal evidence, direct observation, hydrological modelling					

Wetland vegetation assessment sheet – quantitative

Site No.		Recorder:		Day/Date:	
Locality					
MGA	Zone		E	N	:
GDA94	Longitude	.		Latitude	.

Vegetation structure

Median height of EDL is to be measured

Stratum	Median height	Height interval	Crown cover*
Structural formation:			
Ecologically dominant layer			
Proportion of EDL wetland indicators:			

Plant species

Layer.	Cover*	Wetland indicator	Scientific Name

Wetland vegetation assessment sheet – qualitative

Site no	easting	Northing	Dominant species	Wetland/non-wetland vegetation
6				
7				
8				
9				
10				
11				
12				
13				
14				

Wetland soils assessment sheet

Site No.		Recorder:		Day/Date:	
Locality					
MGA Zone		E		N	:
GDA94	Longitude		.	Latitude	.
Climatic region:		Subtropical	Semiarid	Arid	

Wetland soils

Organic material (within 0.3 m of soil surface)	ACIDIC	KANDOSOLIC	REDOXIC	Hydrosol
P horizon	Present		Not present	
Thickness of P horizon	_____cm			

Wetland soil indicators

Organic material (within 0.3 m of soil surface)	Present		Not present		
Thickness of organic materials layer	__0___cm				
Texture qualifier Fibric	Yes/No	Sapric	Yes/No	Hemic	Yes/No

Acid sulfate materials (within 0.3 m of soil surface)

Hydrogen sulfide gas (rotten egg gas)	Yes/No	Monosulfidic black ooze	Yes/No	Sulfurous segregations	Yes/No

Gley colours Present		Not present			
Thickness of gley layer	_____cm	Depth to gley layer	_____cm		
Soil water interface	Present		Not present		
Depth to soils water interface	_____cm				
Mottles (<0.3 m of surface)	Present		Not present		
Segregations (<0.3 m of surface)	Present		Not present		
Ferruginous root channel and pore linings (<0.3 m of surface)	Present		Not present		

Soil matrix chroma (within 0.3 m of the soil surface)

Are chroma values less than or equal to two (2) in the wettest lowest lying area?	Yes		No	
Do chroma values decrease moving into the wetland from sites considered outside?	Yes		No	

References

1. Department of Environment and Resource Management, Queensland Wetland Definitions Guideline: A guide to existing wetland definitions and the application of the Queensland Wetlands Program Definition. 2009, Department of Environmental and Resource Management, Brisbane. p. 89.
2. Bryant, K.L., et al., Soil Indicators of Queensland Wetlands: State-wide Assessment and Methodology. 2009, Department of Environmental and Resource Management, Brisbane.
3. Bryant, K.L., et al., Soil Indicators of Queensland Wetlands: Field Guide. 2008, Department of Natural Resources and Water: Brisbane.
4. Department of Natural Resources Mines and Energy, Application Kit for a Property Map of Assessable Vegetation. Vegetation Management Act 1999. 2004, Department of Natural Resources, Mines and Energy, Brisbane.
5. Environmental Protection Agency, Regional Ecosystem Description Database (REDD). Version 5.0. 2005, Environmental Protection Agency.
6. Neldner, V.J., et al., Methodology for Survey and Mapping of Regional Ecosystems and Vegetation Communities in Queensland. Version 3.1. 2005, Queensland Herbarium, Environmental Protection Agency: Brisbane. p. 128.
7. Congalton, R.G. and K. Green, Assessing the accuracy of remotely sensed data: principles and practices. 2nd edition. 2009, Boca Raton, Florida: CRC Press.
8. Greenwalt, C.R. and M.E. Schultz, Principles and Error Theory and Cartographic Applications, ACIC Technical Report No. 96. 1968, Aeronautical Chart and Information Center, U.S. Air Force, St. Louis, MO. p. 89.
9. Federal Geographic Data Committee, Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy 1998, U.S. Geological Survey, <www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/index_html>
10. Gunn, R.H., et al., Mapping, in Australian Soil and Land Survey Handbook: Guidelines for Conducting Surveys., R.H. Gunn, et al., Editors. 1988, Inkata Press, Melbourne. p. 90–112.
11. US Army Corps of Engineers, Wetland Delineation Manual. 1987, Environmental Laboratory, Vicksburg, MS.
12. Federal Interagency Committee for Wetland Delineation, An Unofficial Copy of the Federal Manual for Identifying and Delineating Jurisdictional Wetlands. 1989, U.S. Army Corps of Engineers, EPA, FWS, USDA Soil Conservation Service: Washington, D.C.