Indicators of Reduction in Soils

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Indicators of Reduction in Soils

July 2011

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Contents

List of figures

List of tables

Glossary

Anaerobic	Pertaining to or caused by the absence of oxygen
ASC	Australian Soil Classification
Biologic zero	The temperature at which biological activity in the soil ceases and reduction does not occur; defined by 5 degrees Celsius measured at 0.5 m below the soil surface (Tiner 1999)
Chroma	Method for describing colour that depicts the purity or strength of the colour
CP	Conservation Park
DERM	Department of Environment and Resource Management
DIWA	Directory of Important Wetlands in Australia
IRIS	Indicator of Reduction in Soils
NP	National Park
QWP	Queensland Wetlands Program (or 'the Program')
Redox features	Wetland soil features that are formed primarily through the oxidation and reduction of iron
TC	Total carbon
USDA	United States Department of Agriculture
Wetland system	There are 6 wetland systems as defined by the Queensland Wetland Mapping and Classification project; Riverine, Lacustrine, Palustrine, Estuarine, Marine and Subterranean wetlands (www.epa.qld.gov.au/wetlandinfo/site/WetlandDefinitionstart/WetlandDefinition/Systemdefinitions.html).
Wetland Types	A method to describe lacustrine and palustrine wetlands based on the Queensland Wetlands Program Habitat Typology (www.epa.qld.gov.au/wetlandinfo/site/Wetland Definitionstart/WetlandDefinitions/Typologyintro/Typology.html).

Executive summary

Wetland legislative regimes rely on the clear identification and demarcation of wetlands to support management policies. A large proportion of Queensland's wetlands are seasonal in appearance and ephemeral in nature, due to the state's highly variable climate. The periodic nature and variable extent of these wetlands makes their accurate mapping difficult, as episodic boundaries can change from season to season or over several years. The problem with identifying these wetlands is that field indicators (such as soil features and wetland vegetation) may only be present at times of saturation and may disappear during drier times.

A wetland soil in Queensland is defined as having 'a substratum which is predominantly undrained soils that are saturated, flooded or ponded long enough to develop anaerobic conditions in the upper layers' (EPA 2005). In order to define a soil as a wetland soil there needs to be anaerobic conditions (or indicators of anaerobic conditions) present. The identification of soils as wetland soils is problematic where soil indicators are not readily identifiable, or where the interpretation of soil indicators requires evidence of a current hydrologic regime. This situation exists commonly within seasonal and ephemeral wetlands in Queensland. Consequently a simple but effective diagnostic test would be very useful.

The Indicator of Reduction in Soils or IRIS method was developed in the USA (Castenson & Rabenhorst 2006, Jenkinson & Franzmeier 2006, Rabenhorst & Burch 2006) and involves the use of synthetic iron oxides to indicate the presence of reducing conditions in soils. The method is used to determine whether a soil is in a reduced state without relying on less definitive visual soil indicators or using expensive equipment which is time consuming. Polyvinyl chloride (PVC) pipes are coated with a paint prepared from a synthetic iron oxide (predominately ferrihydrite) and placed in the soil. Upon removal, the pipes are visually assessed for the loss of the iron oxide paint from the surface which indicates that reduced conditions are present.

This report details and discusses the findings of a trial, conducted by the Department of Environment and Resource Management (DERM) during 2009, to test the applicability of the IRIS method for wetland identification in Queensland. Trials were run at eight palustrine, seasonally inundated wetlands across South East Queensland. From the results of this study it is concluded that the IRIS method can indicate that soils are reducing and that this may assist with wetland identification. It is recommended that the method be utilised as an additional line of evidence to identify a wetland soil at sites where soil features are lacking, or where evidence of a current hydrologic regime is required in order to conclusively determine the presence of a wetland soil.

The IRIS test needs to be undertaken when a wetland is considered to be in a reduced state. Saturation with water, a supply of microbes, a source of organic carbon and suitable soil temperatures are all required in order for this method to accurately reflect reducing condition in soils. The time period for the IRIS test to be conducted should be at least 28 days.

A level of 15 per cent removal of ferrihydrite paint, over the entire surface of the pipe, within 0.3 m of the soil surface is recommended as confirmation of reducing conditions, sufficient to support evidence of a wetland soil. As more trials are conducted in the future it is anticipated that this figure will be revised.

Presently the IRIS method is not recommended to be used in isolation as a tool for wetland identification, rather it should be applied in conjunction with current soil indicators used in identification of wetlands in Queensland.

1 Introduction

1.1 Background

Wetland legislative regimes rely on the clear identification and delineation of wetlands to support management policies. Indicators that reflect hydrology, and are relatively unchanging once formed, are more useful for wetland identification. Direct observation of inundation or water table heights is the most accurate way to identify a wetland. This process, however is not practical because it requires long periods of time to monitor accurate trends in water levels. Wetland vegetation and soil features can reflect current hydrologic regimes and are used for wetland identification in Queensland currently.

A large proportion of Queensland's wetlands are seasonal and ephemeral due to its highly variable climate. Extensive ephemeral wetlands are present in the arid and semi-arid interior regions of Queensland and many wetlands in the tropical and sub-tropical climatic regions are only seasonally saturated. The definition of a wetland in Queensland, developed by the Queensland Wetlands Program (the program), was specifically tailored to capture the episodic nature of these wetlands, using terminology such as 'periodic' and 'intermittent' (EPA 1999). The full definition of a wetland is outlined in the Queensland Wetland Definition and Delineation Guideline <www.epa.qld.gov.au/wetlandinfo/site/WetlandDefinitionstart/WetlandDefnitions/definitionguide.html>.

The periodic nature of these wetlands affects their accurate mapping, because the wetted boundaries can change from season to season or over several years. A problem in identifying these wetlands is that field indicators (such as soil features and wetland vegetation) may only be present at times of saturation and can change during drier times (Federal Interagency Committee for Wetland Delineation 1989).

A wetland soil in Queensland is defined as having 'a substratum which is predominantly undrained soils that are saturated, flooded or ponded long enough to develop anaerobic conditions in the upper layers' (EPA 2005). In order to define whether a soil is a wetland soil there needs to be anaerobic conditions or indicators of anaerobic conditions present. An anaerobic environment can alter the chemistry of soil and this is reflected in soil morphological characteristics. Some characteristics conclusively identify a wetland soil (organic materials, acid sulfate soil material and gleyed soil matrix colours). Other features, like redox features (see glossary), can indicate a wetland soil but are not irrefutable (Bryant et al 2008). Some soil features can form and persist in the environment, which can be problematic because they may be relict features that do not reflect current hydrology. The identification of wetland soils can be difficult where soil indicators are not readily identifiable or where the interpretation of soil indicators requires evidence of a current hydrologic regime. This situation is commonly encountered with seasonal and ephemeral wetlands in Queensland. Hence, an effective diagnostic tool would be useful.

There are some situations where soil features may be lacking or inconclusive when identifying a wetland:

1. Soil features of a wetland are present across an entire landscape, however only specific areas are considered wetlands through vegetation or hydrology. This is commonly the case within seasonal wetlands. For example, entire landscapes of the Cape York region (such as some alluvial plains within Lakefield National Park) are completely mottled throughout the soil profile but are not considered wetlands.
2. Soils may be naturally lacking in minerals or elements (especially iron-rich minerals) that are needed to allow the formation of morphological characteristics that identify a wetland soil. This is not only the case in wetlands that are seasonal or ephemeral but can occur in wetlands that are permanently inundated. Sand-dominated wetlands in the Cape Flattery dune lakes area (North Queensland) are an example of wetlands where redox features do not readily form due to a natural lack of iron in the soil.
3. Wetland soil features may be relict within a landscape and require evidence of a current hydrologic regime in order to be utilised for wetland identification. Soils in arid and semi-arid climatic regions can have features of wetland soils, however, they may not be part of a current hydrologic regime but a relict one.

1.1.1 Redox processes in wetland soils

The major difference between a well-drained soil and a poorly drained, submerged soil, is its oxidation and reduction status. A waterlogged or anaerobic soil is usually greyish or green in colour, has a low redox potential and contains the reduced form of various soil minerals (Ponnamperuma 1972). An anaerobic environment affects the oxidation and reduction reactions in soil that govern the formation of many wetland soil features. The accumulation of organic materials, the formation of redox features and production of hydrogen sulfide (rotten egg) gas are all examples of products of reduction reactions in an anaerobic environment commonly observed in wetlands (Richardson & Vepraskas 2001).

The principal reduction-oxidation reaction in soils involves iron hydroxides (Tiner 1999, SSSA 1989). Microbial activity in the soil is important for the oxidation and reduction of iron. Metabolic oxidation of organic material by microbes produces electrons which need to be transferred to an electron acceptor (SSSA 1989). When a soil is well-drained and aerated, oxygen is the dominant electron acceptor for these reactions. Under anaerobic conditions oxygen is excluded and anaerobic microbes use other soil components as final electron acceptors (Mitsch & Gosslink 2007). There is a sequence of preferred electron acceptors as a soil becomes more reduced (Table 1).

In an aerobic environment iron is present in its oxidised form (Fe^{3+}). Iron oxy-hydroxides coat the outside of silicate minerals and give aerobic soil a characteristic reddish brown colour. The reduced form of iron (Fe^{2+}) is colourless and can be mobile in soils. When iron is in its reduced form the brighter colours disappear and the soil is left with the grey colour of the silicate minerals (Figure 1).

Table 1 Sequence of electron acceptors when a soil is flooded (Brady & Weil 2008).

Sequence of electron acceptors	Element	Oxidised form	Reduced form
1	Oxygen	O^2	H_2O
2	Nitrogen	NO_3^-	N^2
3	Manganese	Mn^{4+}	Mn^{2+}
4	Iron	Fe^{3+}	Fe^{2+}
5	Sulfur	SO_4^{2-}	H_2S
6	Carbon	CO_2	CH_4

(Ferric iron) + (electron from microbial respiration) <---------- > (Ferrous iron)

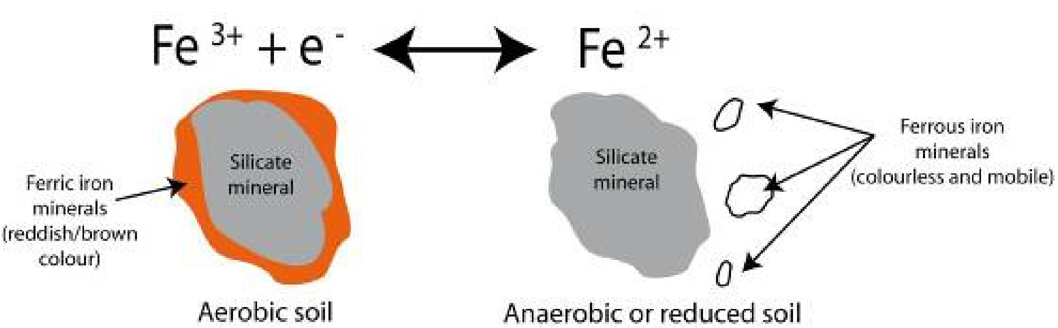


Figure 1 Oxidation and reduction reaction of iron in soils[1].

[1] Most mineral soils are predominantly made up of silicate minerals which are a greyish colour (Vepraskas 1995)

Fe^{2+} may translocate to other horizons or pores in the soil where it can be oxidised at a later time, or can move entirely out of the soil via the soil solution (Jenkinson & Franzmeier 2006). The microbial reduction of iron is a process which forms bleached zones (where all the iron has been removed and leached) and highly coloured zones of iron accumulation in soils, where reduced iron has been redistributed to and re-oxidised (SSSA 1989).

See Appendix A for further information on the process of oxidation and reduction of iron in soil.

1.1.2 Using soil redox status to identify wetlands

The IRIS method

The Indicator of Reduction in Soils or IRIS method was developed in the USA (Castenson & Rabenhorst 2006, Jenkinson & Franzmeier 2006, Rabenhorst & Burch 2006). The method is used to determine whether a soil is in a reduced state without relying on less conclusive visual soil indicators or using equipment which is labour intensive and expensive. This method involves the use of synthetic iron oxides to indicate the presence of reducing conditions in soils.

Briefly, the IRIS method involves PVC pipes which are coated with a paint prepared from a synthetic iron oxide, and placed in the soil. Upon removal, the pipes are visually assessed for the loss of the iron oxide paint from the surface which indicates that reduced conditions are present (Castenson & Rabenhorst 2006, Jenkinson & Franzmeier 2006). The synthetic iron oxide paint (predominantly ferrihydrite) is composed of Fe^{3+} which gives the paint a distinct reddish colour. Under anaerobic conditions Fe^{3+} is quickly reduced to its divalent cation, Fe^{2+}, which is colourless and mobile. The method reveals the natural oxidation and reduction processes that occur across all soil types.

In the USA, to classify a wetland soil using the IRIS method pipes are required to have a certain quantity of paint removed (Vepraskas 2005):

For soils with high water tables:

1. Soil will be considered anaerobic when three out of five tubes have Fe removed from 30 per cent of a zone that is 6 inches [15.24 cm] long.
2. Top of the zone of Fe removal must be within 6 inches [15.24 cm] of soil surface for all textures.

For ponded or flooded soils:

1. Soil will be considered anaerobic when three out of five tubes have Fe removed from 30 per cent of a zone that is 2 inches [5.08 cm] long.
2. Top of the zone of Fe removal must be within 4 inches [10.16 cm] of soil surface for all textures.

The IRIS technique is now incorporated in the Hydric Soil Technical Standard notes (USDA 2007), which are an update of the publication *Field Indicators of Hydric Soils in the United States* (USDA 2006).

1.2 Objectives

The aim of the Program is to support the management and conservation of Queensland's wetlands. Within the program, soils projects were undertaken to support the mapping and management of wetlands.

This study had two objectives:

1. Test the IRIS method and its interpretation procedures under Queensland conditions.

In Queensland, the periodic nature of many wetlands can lead to a lack of morphological indicators that characterise a wetland soil. Many wetlands can also have visual wetland soil features which are inconclusive.

The IRIS method is to be tested on a number of differing wetlands across Queensland to assess whether it can accurately reflect anaerobic or reducing conditions in soils. Information is specifically required on:

- the time necessary for this test to be conducted in periodically inundated wetlands to provide an accurate representation of reducing conditions
- the effect of different soils and soil conditions on the amount and pattern of reduction that occurs
- the degree of reducing conditions required to determine the presence of a wetland soil in Queensland
- the applicability of the method across differing climatic regions and landscapes.

2. To document variations to the IRIS method.

Climatic conditions and wetlands in Queensland are different to those where the IRIS method was developed (North America). Queensland's wetlands and landscapes are much drier and variations to the method may be required for its use in Queensland or nationally.

2 Methodology

2.1 Wetland selection

Wetland selection for the IRIS trials was based on the following criteria; available data, wetland system, soil types and access constraints. Because of the short-term nature of the project (6 months), coastal wetlands of South East Queensland were targeted. South East Queensland (SEQ) was considered an area (being in the sub-tropical climatic region) in which wetlands may be saturated and exhibit reducing conditions, even though these trials were being conducted from winter to spring, in a region dominated by summer rainfall (Figure 2).

The focus was on natural systems or where natural processes dominated therefore, national parks or conservation parks which contained appropriate wetlands were identified and included in the site selection process.

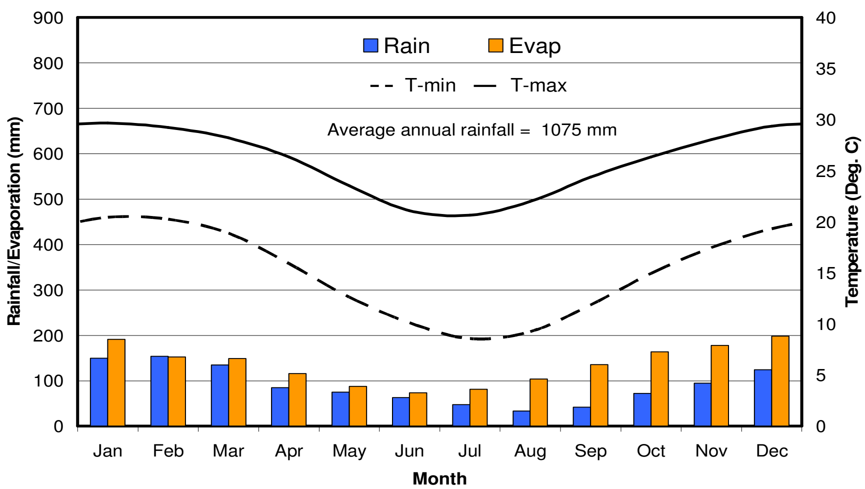


Figure 2 Average rainfall, evaporation and temperature maximum and minimum for Brisbane, South East Queensland (DERM 2009a).

2.1.1 Available data

Information regarding Queensland's wetlands is available through Queensland Wetland Mapping <www.epa.qld.gov.au/wetlandinfo/site/MappingFandD.html>.

2.1.2 Wetland system

It was decided to focus on palustrine wetland systems (see glossary for list of other wetland systems) as they were considered the most likely to be influenced by seasonal changes and the most likely to require information to assist in identifying wetland boundaries. Estuarine and marine systems are more regularly influenced by tidal inundation and riverine and lacustrine systems can have fairly well defined boundaries.

Palustrine wetland systems are defined as (DERM 2009c):

"Primarily vegetated non-channel environments of less than 8 ha, which include billabongs, swamps, bogs, springs, soaks etc, and have more than 30 per cent emergent vegetation."

2.1.3 Soil types

It was important to sample across a wide range of soil types in order to determine the effect that this variable might have on the IRIS method. The wetlands selected for the study encompassed a range of soils types from sands to clays to organic matter dominated soils.

Eight wetlands were selected for the IRIS trials (Figure 3). Table 2 provides a summary of these wetlands with a full list of site locations in Appendix B.

Figure 3 Location of the eight wetlands selected for IRIS trails.

Table 2 Descriptions of wetlands selection for IRIS trails (*DERM (2009c), **DERM (2009a)).

Wetland name	Wetland type*	Dominant Soil types	In DIWA (criteria for inclusion)	Description	Average annual rainfall (mm)**
Bribie Island—Trial 1	Coastal and sub coastal non-floodplain tree swamp—melaleuca and eucalypt spp	Clays and sands	Yes (1,2,3,4,5)	The major land uses of Bribie Island are national park, forest reserve and private plantations. It is a low sand island with a wide variety of wetland aggregations such as creeks, lagoons, swamps and tidal flats (DEWHA 2009).	1400
Bribie Island—Trial 2	Coastal and sub coastal non-floodplain grass/sedge/herb swamp	Organic and clay			
Bribie Island—Trial 3	Coastal and sub coastal non-floodplain tree swamp—melaleuca and eucalypt spp	Organic and clay			
Carbrook Conservation Park—Trial 4	Coastal and sub coastal floodplain tree swamp—melaleuca and eucalypt spp	Clays	Yes (1, 2)	Carbrook CP covers 103 ha of *Melaleuca quinquenervia* (paperbark teatree), *Casuarina glauca* (swamp oak) and mixed Eucalypt forest which runs along the tidally influenced Native Dog Creek (QPWS 1999a).	1200
Carbrook Conservation Park—Trial 5	Coastal and sub coastal floodplain tree swamp—melaleuca and eucalypt spp	Clays			
Mooloolah River National Park—Trial 6	Coastal and sub coastal floodplain tree swamp—melaleuca and eucalypt spp	Organic and clay	Yes (1,3,5)	Mooloolah River NP contains segments of open heath, eucalypt woodlands, teetree swamps and mangrove forests near the Mooloolah River (QPWS 1999b)	1700
Mooloolah River National Park—Trial 7	Coastal and sub coastal floodplain wet heath swamp	Clays and sands			
Noosa National Park—Trial 8	Coastal and sub coastal floodplain wet heath swamp	Organic and sands	Yes (1,2,3,5)	Closed heath and sedge lands which are part of poorly drained quaternary coastal dune systems. Water has collected due to run off and infiltration from adjacent dunes (DERM 2009b).	1650

2.2 Sample locations and descriptions

A transect sampling procedure was used to assess the changes in paint removal from sites within the saturated zone of the wetland to sites considered external to the wetland (Figure 4). This method is the same employed by Bryant et al (2008) when developing the methodology for wetland soil indicator use in Queensland. The three zones within the transect were categorised as:

1. Saturated zone: The wettest lowest-lying area. For wetlands that were dry when sampled, this was the lowest part of the wetland that could be accessed. For wetlands that were inundated when sampled, this is the area at the water's edge.
2. Transition zone: This area appeared to be inundated intermittently or seasonally. There is evidence of saturation through vegetation or landform features.
3. Outer zone: Above the high-water mark. No evidence of inundation at any time. This constitutes non-wetland areas.

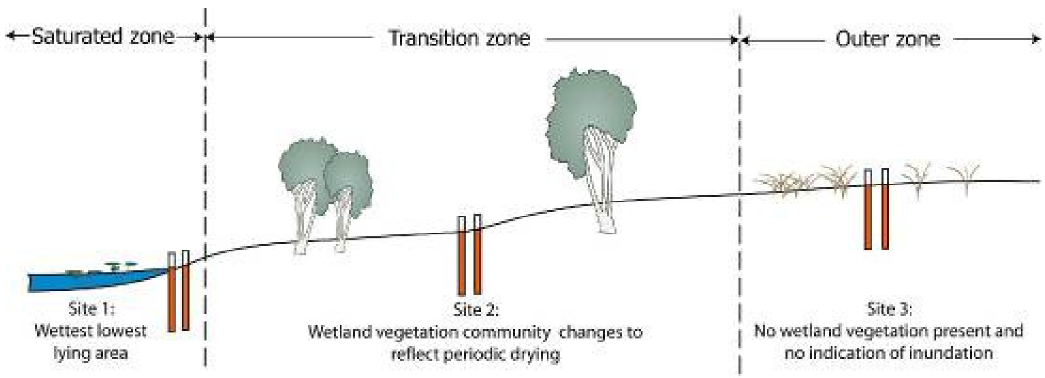


Figure 4 Diagram of transect sampling and installed IRIS tubes.

To ascertain the length of time needed for the IRIS method to give an accurate representation of the redox status of a wetland, trials were run over two different periods (14 days and 28 days). This allowed a comparison to assess whether there was a significant difference in paint removal between shorter and longer timeframes.

Soils were described to a depth of 1.0 m where possible and laboratory analysis was conducted for each soil profile with samples taken at 0.0-0.1 m and 0.2-0.3 m depth intervals. Descriptions of micro-relief and other surface characteristics were recorded. Water table heights were recorded when IRIS pipes were installed and removed.

Each soil sample was analysed for pH, electrical conductivity (EC), nitrate (NO_3^-), chloride (Cl^-), total carbon (TC) and total nitrogen (TN). All analyses were consistent with national standards of field sampling and laboratory analysis (McDonald et al 2001, Rayment & Higgenson 1992).

Where a water table was present (within 0.3 m of the soil surface) a test for Fe^{2+} was undertaken using Merck Fe^{2+} indicator strips. This gave an indication of the concentration of Fe^{2+} present in water (in mg/L).

2.3 IRIS methodology

A method for the synthesis of ferrihydrite paint by Rabenhorst (2006) is described in Appendix C.

2.3.1 Mineralogical composition of paint

There are many iron oxides found in soils, one being ferrihydrite. Various iron oxides are reduced at different redox potentials with ferrihydrite reduced at a higher redox potential, compared to other iron oxides in the soil (SSSA 1989). In order to reflect when iron first becomes reduced in soils it is therefore practical to use ferrihydrite as the indicator mineral for the IRIS method.

For ferrihydrite to be a suitable mineral it needs to be able to adhere to PVC piping. Ferrihydrite has a poorly crystalline structure which in a pure solution (100 per cent) is easily wiped off the surface of PVC piping (Rabenhorst & Burch 2006).

Goethite is an iron oxide which, at the same pH, is reduced at a lower redox potential than ferrihydrite. Goethite has a mineral structure more like thin strips or lath shapes. Studies which have analysed paint with differing ratios of ferrihydrite and goethite minerals suggest that goethite adds structural support to the mixture which makes the paint more durable on PVC piping (Rabenhorst n.d). Having a paint solution which contains goethite for durability and ferrihydrite as an indicator is recommended.

Ferrihydrite also has a redder colour compared to goethite (5YR compared with 7.5YR and 10YR respectively) (USDA 2009). As goethite is reduced at a lower redox potential a residual yellowish painted area may be observed on the pipe. This needs to be taken into consideration when examining pipes as it still indicates that the ferrihydrite minerals have been reduced and removed.

2.3.2 Pipe preparation

Pipes were cleaned first with acetone to remove any ink and then sanded with medium sandpaper (100 grit). Pipes were then cut to 600 mm lengths with the lower 500 mm painted with ferrihydrite paint.

Test pipes were painted with two coats with the first coat left to dry overnight. The paint was then tested for durability by trying to wipe the paint off with a finger (Jenkinson & Franzmeir 2006).

After the start of trial 1, some of the paint was being removed during the installation process. A second set of pipes was then prepared using coarse sandpaper (40 grit). This appeared to help the paint adhere better to the PVC pipe. Both types of tubes were installed at each wetland for comparison (results outlined in section 3.2.3). In the results the pipes are differentiated as to whether they were sanded with medium or coarse sandpaper.

2.3.3 Installation and removal methods

A method was devised to minimise paint loss from the surface of the pipes upon installation and removal. An unpainted pipe of the same length and width was first placed in the soil, removed, and replaced by a painted pipe, in one movement attempting not to rotate the pipe. This method had worked successfully in a previous study (Bryant et al 2008), however it appeared at the first trial site a significant amount of paint was being removed. A new method was therefore devised to minimise paint loss.

The second method involved using an unpainted PVC pipe of slightly larger diameter (internal diameter 19 mm compared to 17 mm for painted pipes) which was placed in soil and removed. The painted pipe was then inserted inside the larger pipe and placed back in the soil. The outside (larger) pipe was removed leaving the painted pipe in the soil (Figure 5). This method allows the PVC pipe to be placed in the ground without any paint being removed. The method however may not allow sufficient contact with the soil to provide an accurate representation of reduced conditions. Both installation methods were used at five of the wetlands in the current study (trials 1, 2, 3, 4 and 5) in order to make a comparison between the two methods and the effect on removal of paint. This comparison is discussed in section 3.2.1.

Pipes were installed to 0.5 m deep (where possible) in a random layout across an area approximately 1.0 m^2 at each site (Figure 5). Upon removal each pipe was washed down with water to remove any loose soil and then allowed to dry.

Figure 5 Installation method involving the use of a larger diameter pipe (left), random layout of pipes (right).

2.3.4 Analysis of paint removal

Pipes were photographed by rotating 120 degrees to obtain three images which covered the entire surface. Photographs of the pipes were stitched together in Adobe Photoshop CS2 to form a single image. A visual estimate of the percentage of paint removed was undertaken using standard charts (Figure 6). Two people independently assessed the percentage of paint removed and these figures were averaged for each pipe.

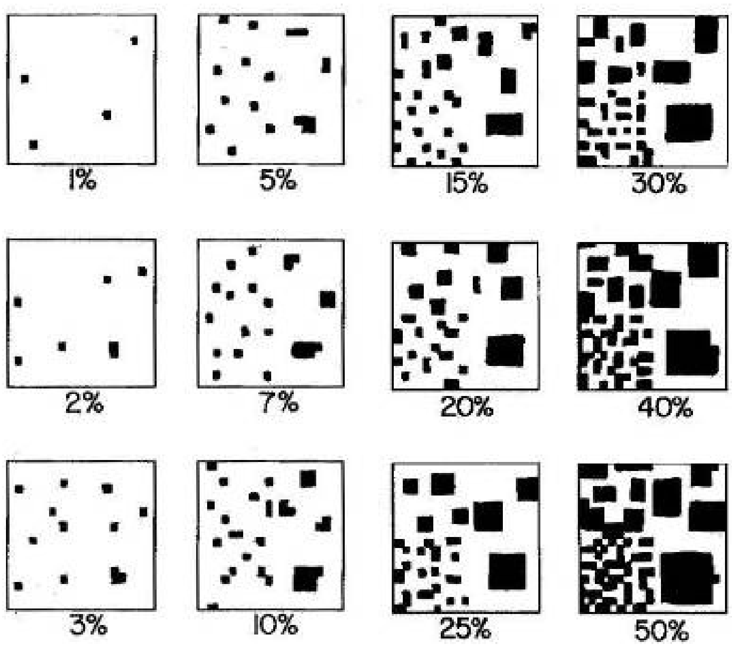
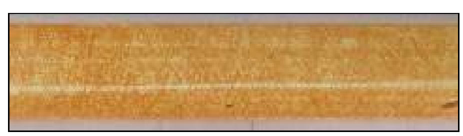
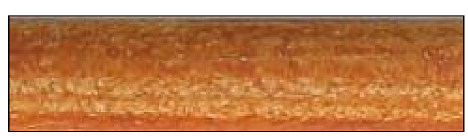


Figure 6 Chart for estimating the percentage of paint removed (Munsell 2000).

Criteria for assessment

Several criteria for the visual assessment were applied in order to accurately analyse paint removal, especially in cases where there appeared to be discrepancies. The following types of marks (outline in Table 3) were discarded from the visual analysis.

Table 3 Types of marks discarded from analysis.

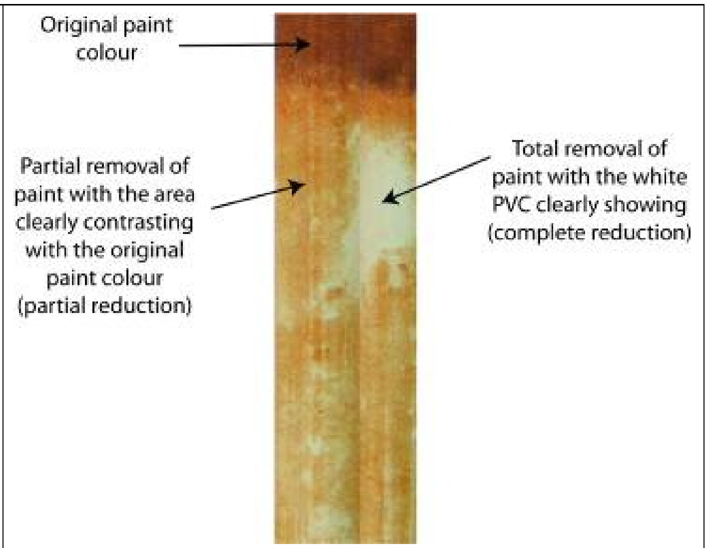
Installation marks: long linear marks caused by paint being scratched off upon installation and removal.	
Differences in layers of paint application: marks which appeared to be due to a thin layer of paint compared to the rest of the pipe, rather than areas which have been reduced.	

Anomalies or spots which were not consistent with the rest of the pipe were also discarded (Jenkinson & Franzmeier 2006).

Marks considered evidence of reduction

Two different types of paint removal (outlined in Table 4) were considered to be evidence of paint having been reduced:

Table 4 Contrasting reduced areas included in the analysis.

Paint was completely removed from the pipe with the white of the PVC clearly showing. A thin layer of paint had been removed which clearly contrasted from other sections of the pipe.	

3 Results and discussions

According to the Program's definition, soils must exhibit evidence of anaerobic conditions in the upper layers to be considered a wetland soil. This upper layer thickness is recommended to be 0.3 m (Bryant et al 2008). To be consistent with the depth required to be classified as a wetland soil in Queensland the results from the IRIS trials focus on the percentage removal of paint within the surface 0.3 m.

Trial results are presented for individual wetlands followed by some general interpretations. This is followed by discussions of the effect of various factors on the IRIS trial results: soil type, patterns of paint removal, and visual versus quantitative assessment of paint removal and conditions necessary for the reduction of iron.

3.1 Individual trails

The following section describes the results of the IRIS trials at individual wetlands. The number of pipes installed at each wetland varied according to the nature of the wetland and whether it was appropriate to install pipes (i.e. several of the sites outside the wetland were too dry to install pipes properly). The number of pipes installed at each wetland is given in Table 5.

Table 5 Number of pipes installed at each trial.

Location and trial number	Number of pipes installed at each wetland
Bribie Island - 1	19
Bribie Island - 2	21
Bribie Island - 3	21
Carbrook CP - 4	21
Carbrook CP - 5	14
Mooloolah River NP - 6	16
Mooloolah River NP - 7	20
Noosa NP - 8	25
TOTAL	**157**

Bribie Island — Trial 1

Study area

Bribie Island is located approximately 60 km north of Brisbane, South East Queensland. The major land uses of Bribie Island are National Park, forest reserve and private plantations (trees). It is a low sand island with a wide variety of wetland aggregations such as creeks, lagoons, swamps and tidal flats (DEWHA 2009). The study area is situated at the southern end of the central swamp (which spans approximately 15 km in a north-south direction in the middle of the island). It is an example of a coastal and sub-coastal non-floodplain tree swamp (Melaleuca and Eucalyptus spp.) in the South East Queensland bioregion (Figure 7).

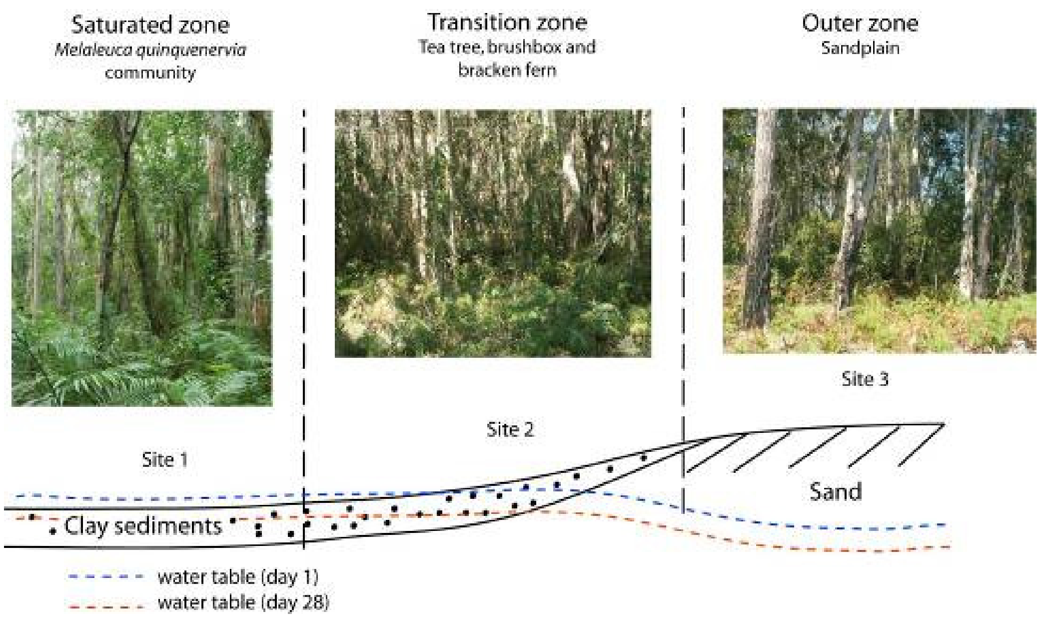


Figure 7 Cross section of wetland (trial 1).

Table 6 Wetland soil indicators (within 0.3 m) for trial 1.

Indicator	Site 1	Site 2	Site 3
Organic materials and total carbon (TC) %*	Organic materials to 0.3 m TC: 28.8%	Organic materials to 0.3 m TC: 11.3%	Organic materials layer 0.15 m thick TC: 3.17% (sample taken at 0.3 m)
Matrix colour	Dark brown to dark grey	Black to dark grey	Grey
Chroma values are less than or equal to 2	Yes	Yes	Yes
Mottles and segregations	Very few <5 mm faint grey mottles	Absent	Absent
Ferruginous root channel and pore linings	Absent	Absent	Absent
pH*	Very strongly acid	Very strongly acidic	Very strongly acidic
Texture	Loam	Loam to clay loam	Sand to loamy sand
Acid sulfate materials	Absent	Absent	Absent
Electrical conductivity (EC)	Non saline	Non saline	Non saline
Fe^{2+} test	Positive – 10 mg/L Fe^{2+}	Positive – 10 mg/L Fe^{2+}	No test performed

** Total carbon % (Dumas method) and pH taken from surface 0.1 m. See Appendix D for explanation of pH codes.*

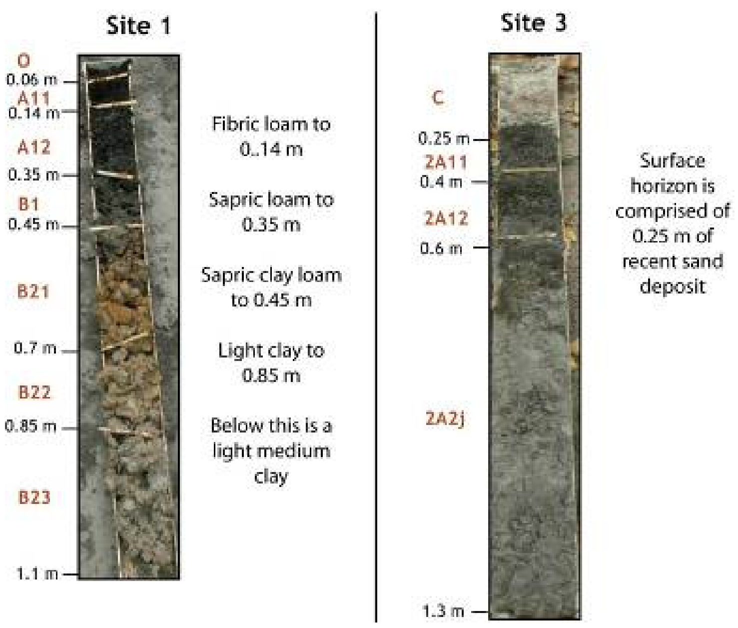
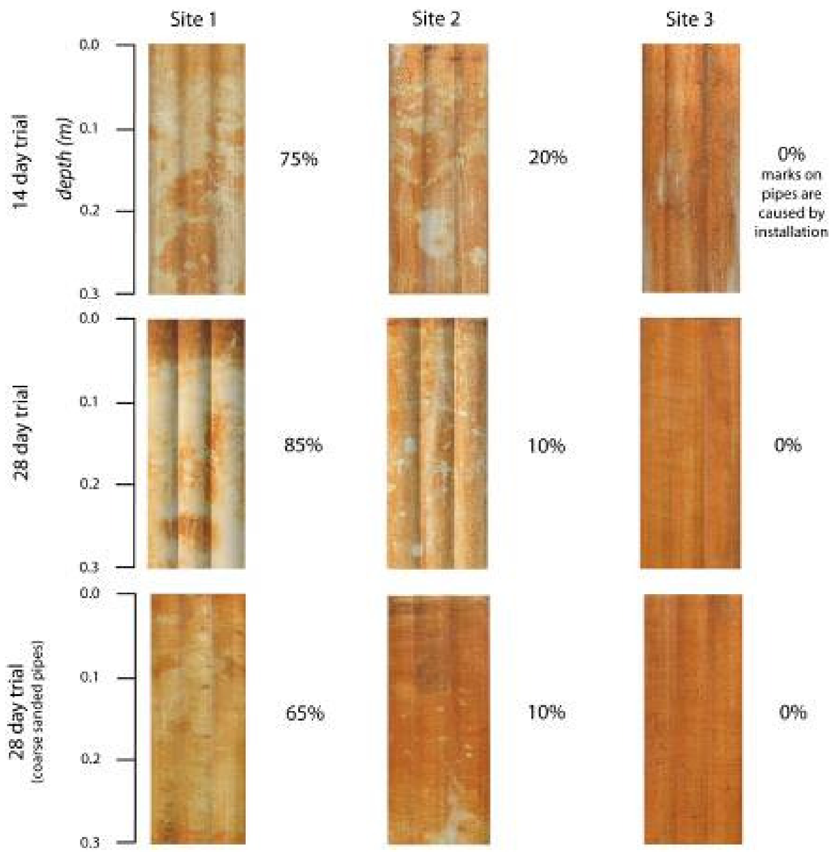


Figure 8 Soil profiles at Bribie Island (trial 1).



Note: Pipes are representative of the average of all pipes in the analysis.

Figure 9 IRIS results for Bribie Island (trial 1) — average percentage of paint removed.

Summary of IRIS observations — trial 1

Site 1: A highly reduced soil is present. Removal of paint is patchy and inconsistent across soil horizons. The site was inundated throughout the trials.

Site 2: A reduced soil is evident from the patchy removal of paint observed. The water table was at the soil surface for the majority of the trial.

Site 3: There is no evidence to say that the soil at this site is in a reduced state. The site was not inundated and there was no presence of a water table throughout the trial (within 0.5 m). No ferrihydrite paint was removed from any pipes.

The reducing conditions evident from the removal of paint are consistent with the boundary of the wetland (figures 9 and 11). There is no paint removed in the area considered outside the wetland and the level of paint removed decreased moving into areas which were less saturated.

The soil profiles in the saturated and transition zone appeared to be in a highly reduced state. These sites were saturated throughout the trial with stagnant water; there are high carbon levels in the surface 0.3 m (greater than 10 per cent TC) and the soil temperatures (at 0.7 m below ground surface) were suitable for microbial activity (temps remained above 10°C). This suggests that the removal of ferrihydrite paint is an accurate reflection of the reduced conditions at this wetland.

The pattern of the paint removed differed between the two pipes (coarse and medium sanded). The same trend of decreasing amount of paint removed, moving out of the wetland, was observed from both sets of pipes. The ferrihydrite paint appears to adhere more firmly to the coarse sanded pipes and only one layer of paint has been removed. This compared with two layers of paint being removed from the medium sanded pipe where the white of the PVC is clearly visible (Figure 10). This may be caused by:

1. ferrihydrite paint adhering more firmly to the coarse sanded pipe which has only allowed one layer of paint to be reduced and removed
2. ferrihydrite minerals having been reduced and removed and the residual yellow layer which has been left on the coarse sanded pipe is goethite which is reduced at a lower redox potential.

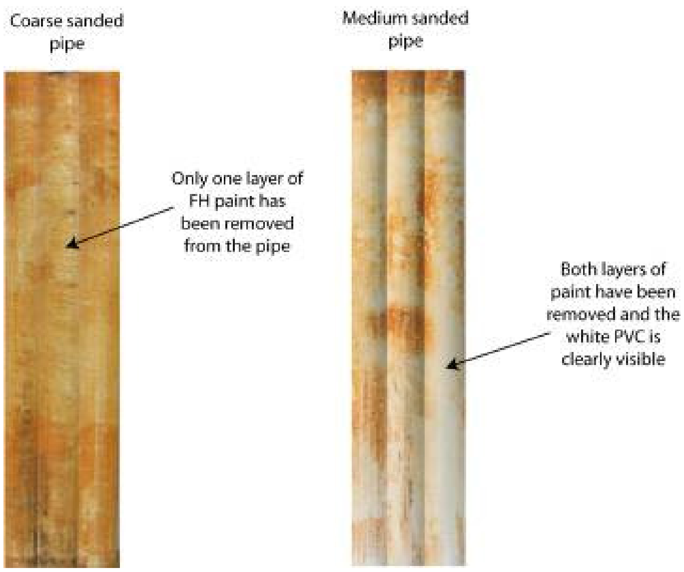


Figure 10 Patterns of paint removal between coarse and medium sanded pipes at site 1 (28 days).

Figure 11 Trial 1 sites and current wetlands mapping (DERM 2009c).

Bribie Island — Trial 2

Study area

This wetland is an example of a coastal and sub-coastal non-floodplain grass, sedge, herb swamp with organic soils within the South East Queensland bioregion (Figure 12).

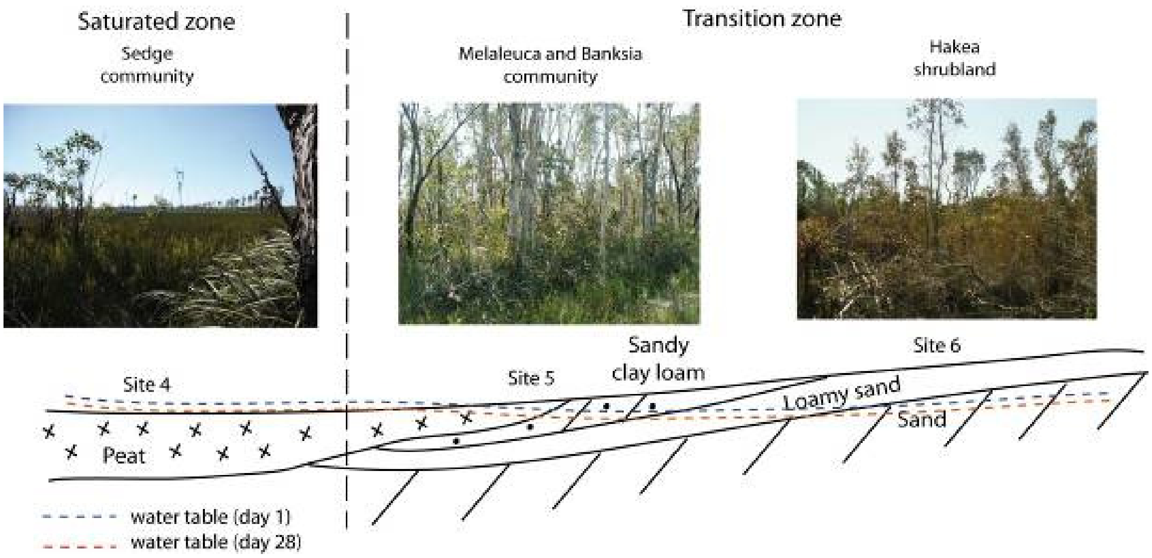


Figure 12 Cross section of wetland (trial 2).

Table 7 Wetland soil indicators (within 0.3 m) for trial 2.

Indicator	Site 4	Site 5	Site 6
Organic materials and total carbon (TC) %*	Organic materials to 0.3 m TC: 30.6%	Organic materials to 0.3 m TC: 7.4%	Organic materials layer 0.2 m think starting within 0.3 m, TC: 3.64%
Matrix colour	Dark brown	Dark grey	Dark brown
Chroma value is less than or equal to 2	Yes	Yes	No
Mottles and segregations	Absent	Very few <5 mm distinct orange mottles	Few <5 mm distinct orange mottles, Few <5mm faint orange mottles
Ferruginous root channel and pore linings	Absent	Present	Present
pH*	Very strongly acidic	Very strongly acidic	Very strongly acidic
Texture	Loam	Loam to clay loam	Loamy sand to sandy loam
Acid sulfate materials	Absent	Absent	Absent
Electrical conductivity (EC)	Non saline	Non saline	Non saline
Fe^{2+} test	Positive - 3 mg/L Fe^{2+}	Positive - 3 mg/L Fe^{2+}	Positive - 3 mg/L Fe^{2+}

** Total carbon % (Dumas method) and pH taken from surface 0.1 m. See Appendix D for explanation of pH codes.*

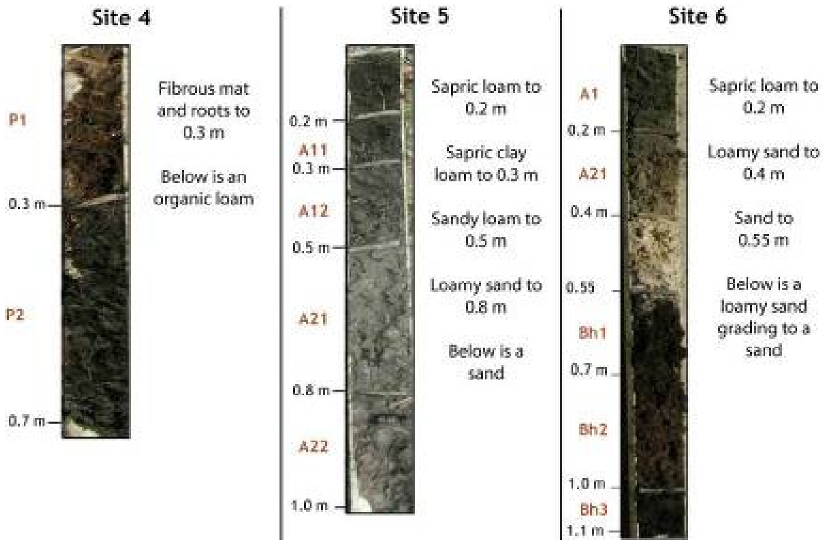
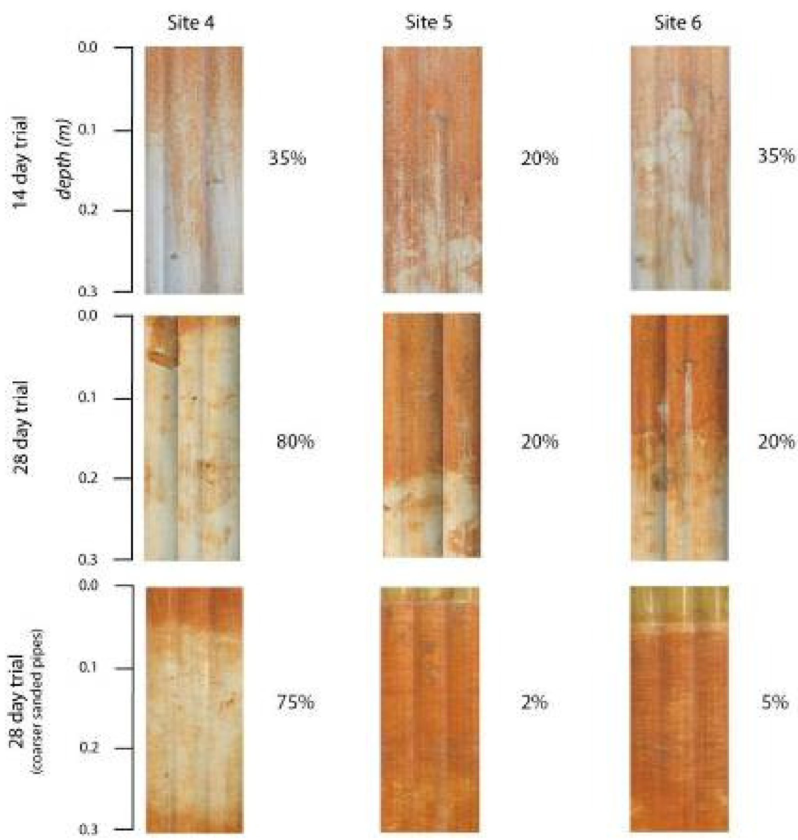


Figure 13 Soil profiles at Bribie Island (trial 2).



Note: Pipes are representative of the average of all pipes in the analysis.

Figure 14 IRIS results for Bribie Island (trial 2) — average percentage of paint removed.

Summary of IRIS observations — trial 2

Site 4: A highly reduced soil is present. The removal of paint is uniform below a section of aerated soil (from which there was no removal of ferrihydrite paint). The site was inundated throughout the trial. There is a large difference in the percentage of paint removed between the 14 day and 28 day trials (35 per cent and 80 per cent respectively).

Site 5: A moderately reduced area is evident from the uniform removal of paint below 0.2 m. The site was not inundated but a water table was present within 0.3 m for a period of time throughout the trial. There is a large difference in the percentage of paint removed between coarse and medium sanded pipes (two per cent and 20 per cent respectively).

Site 6: A moderately reduced area is evident from the uniform removal of paint. The site was not inundated but a water table was present within 0.5 m for a period of time throughout the trial. There is a large difference in paint removed between coarse and medium sanded pipes (five per cent and 20 per cent respectively).

The reducing conditions present, as indicated by the removal of paint, suggest that all of the sites along the transect are still considered to be within the wetland boundary. There is very little difference between the percentage of paint removed from pipes at sites five and six which would indicate these are within the transition zone. This is consistent with soil observations and current wetlands mapping (Figure 15). The percentage of paint removed decreases along the transect as pipe locations move out of the saturated zone; this is consistent with sites becoming less saturated.

Figure 15 Trial 2 sites and current wetland mapping (DERM 2009c).

Throughout the trial the wetland was inundated in the saturated zone. There appears to be an oxidised layer of soil at the surface of the profile where no ferrihyrite paint was removed. The wetland is very open (no trees) and is dominated by sedge species. This may allow oxygen to penetrate the water via mixing caused by wind action across the surface of the wetland. Below this aerated layer however the soil appears highly reduced with uniform removal of paint from the entire pipe.

In the 14 day trial there was no great difference between the percentage of paint removed in the saturated zone and transition zone. A study by Jenkinson & Framzmeir (2006) found that in a trial using IRIS pipes there was a greater amount of paint removed after 15 days which was due to microbial activity increasing. This may be the case at this wetland with a greater level of paint removed in the more anoxic environment of the saturated zone past 14 days.

Bribie Island — Trial 3

Study area

This wetland is an example of a coastal and sub-coastal non-floodplain tree (Melaleuca and Eucalypt spp.) swamp with organic and sandy soils within the South East Queensland bioregion (Figure 16).

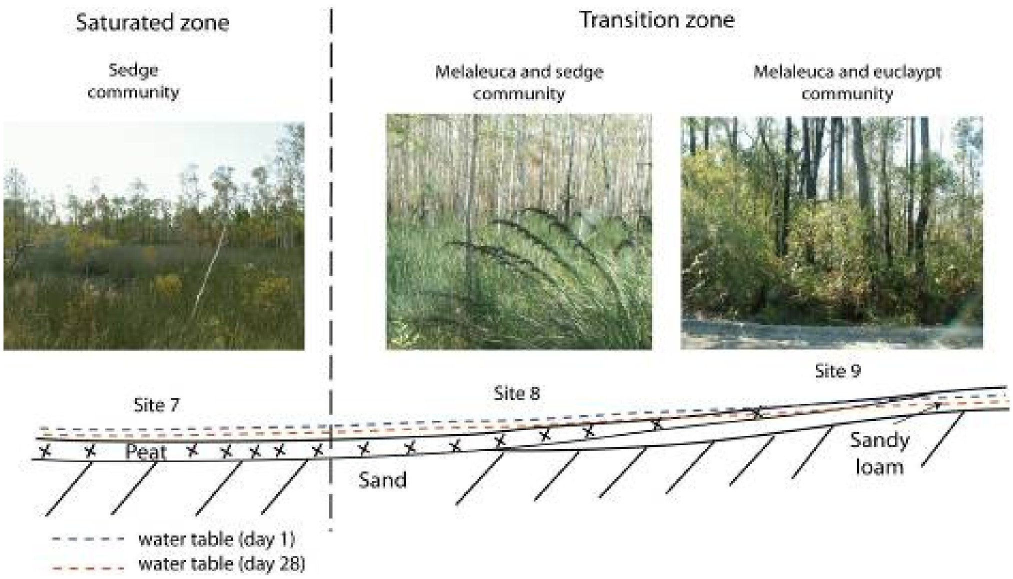


Figure 16 Cross section of wetland (trial 3).

Table 8 Wetland soil indicators (within 0.3 m) for trial 3.

Indicator	Site 7	Site 8 (Profile to 0.2 m)	Site 9
Organic materials and total carbon (TC) %*	Organic materials to 0.3 m TC: 13.4%	Organic materials to 0.2 m TC: 17.7%	Organic materials to 0.3 m TC: 9.54%
Matrix colour	Black	Black	Black
Chroma values are less than or equal to 2	Yes	Yes	Yes
Mottles and segregations	Absent	Absent	Absent
Ferruginous root channel and pore linings	Absent	Absent	Absent
pH*	Very strongly acidic	Very strongly acidic	Very strongly acidic
Texture	Loam to sand	Loam to sandy loam	Loam to sand
Acid sulfate materials	Absent	Absent	Absent
Electrical conductivity (EC)	Non saline	Non saline	Non saline
Fe^{2+} test	Positive - 10 mg/L Fe^{2+}	Positive - 3 mg/L Fe^{2+}	Positive - 3 mg/L Fe^{2+}

**Total carbon % (Dumas method) and pH taken from surface 0.1 m. See Appendix D for explanation of pH codes.*

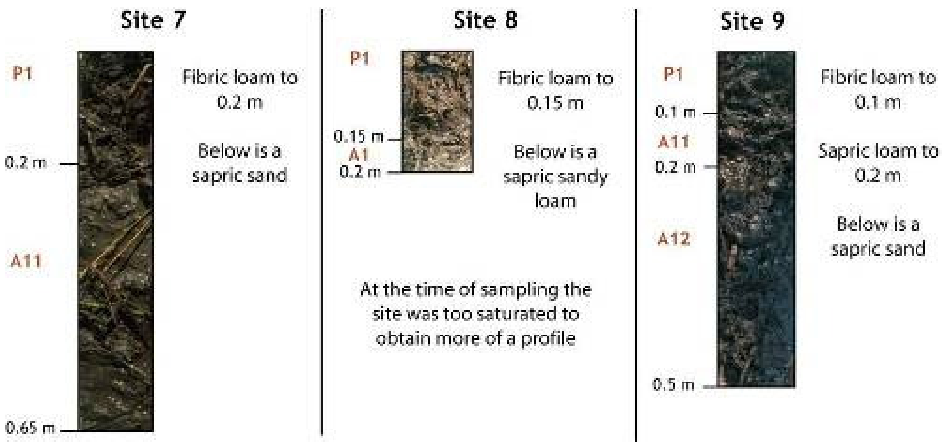
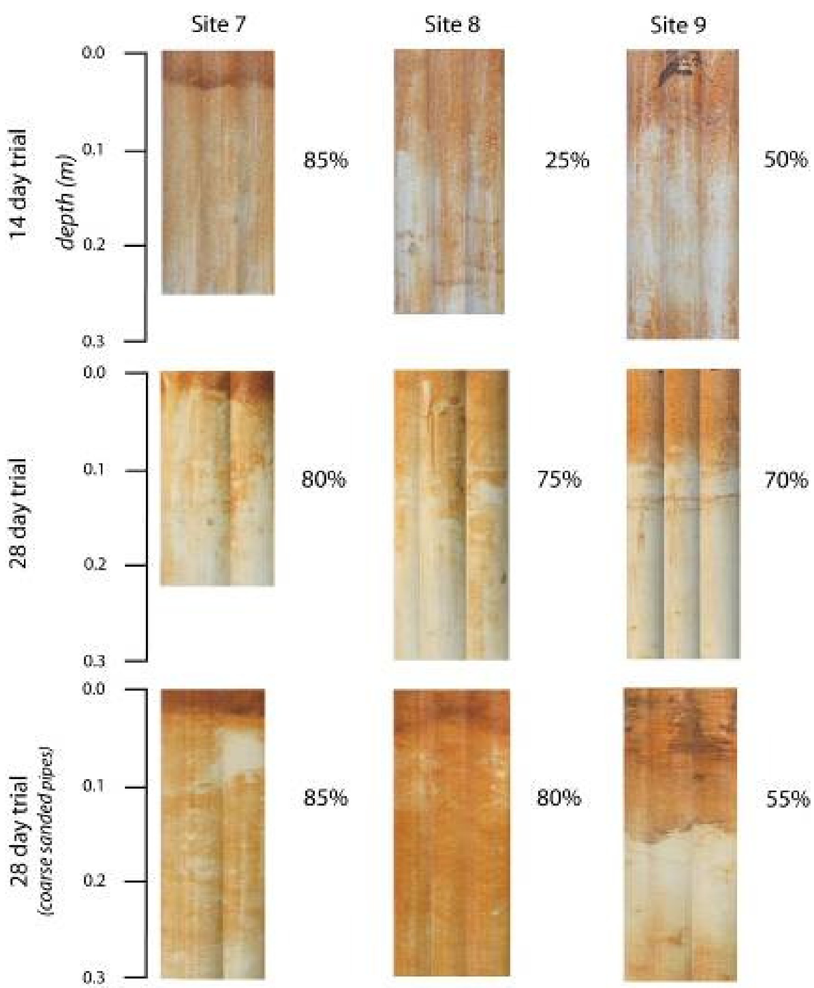


Figure 17 Soil profiles at Bribie Island (trial 3).



Note: Pipes are representative of the average of all pipes in the analysis.

Figure 18 IRIS results for Bribie Island (trial 3)—average percentage of paint removed.

Summary of IRIS observations — trial 3

Site 7: A highly reduced area is evident from the large removal of paint. Removal is uniform and very distinct below 0.05 m. The site was inundated throughout the trial.

Site 8: A highly reduced area is evident from the large removal of paint. Removal is patchy in the 14 day trial with a more uniform removal of paint in the 28 day trial. There is a large difference in the percentage of paint removed between the 14 day and 28 day trial (25 per cent to 75 per cent respectively). The site was inundated throughout the trial.

Site 9: A highly reduced area is evident from the large amount of paint removed. Removal of paint is uniform (more significantly within the 28 day trial). The water table was at the soil surface for the majority of the trial.

This wetland appears to be in a highly reduced state as evidenced by the large quantity of paint removed across all sites along the transect. Conditions at this wetland appear to be conducive to the reduction of iron; there are high carbon levels (>9 per cent TC in the surface 0.1 m) and the area is inundated with water which is not flowing. This suggests that the removal of paint is an accurate reflection of reduced conditions at this wetland.

There is an oxidised layer of soil at the surface of the profile in the saturated zone where no ferrihydrite paint was removed. This is attributed to a layer of aerated water similar to that found at trial 2. Below this layer however the soil appears highly reduced with uniform removal of paint from the entire pipe.

The site on the very edge of the wetland appears to be in a highly reduced state with a sharp boundary between the wetland and non-wetland areas at this location (Figure 19).

There is a large difference between the percentages of paint removed from the 14 day trial to the 28 day trial (medium sanded pipes) in the transition zone. This again can be attributed to the increase in microbial activity beyond 14 days in an area which was consistently saturated throughout the trial.

At sites that were inundated (sites 7 and 8) there is a dark band of paint at the surface of the pipes which is significant darker than the original applied paint. This may be due to ferrihydrite paint being reduced from the lower sections of the pipe and re-oxidised on the pipes above the soil surface, at the top of the water table, where there is oxygen available in the water, forming this darker band (for more information see section 3.1.3).

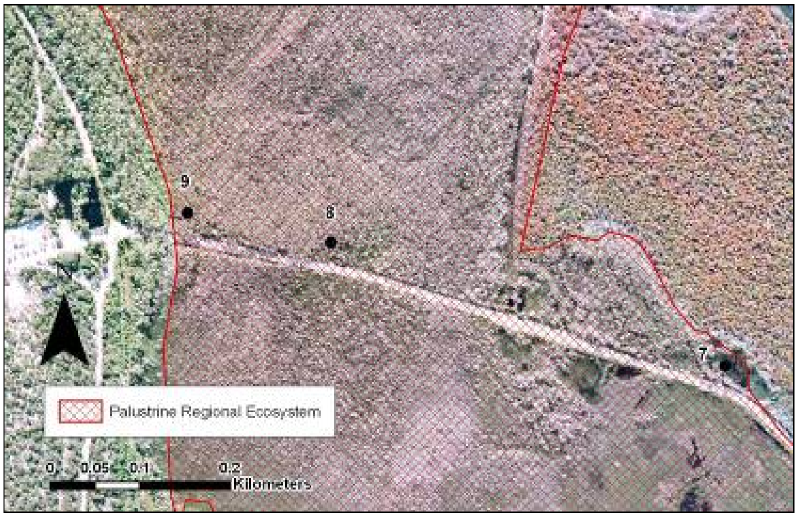


Figure 19 Trial 3 sites and current wetland mapping (DERM 2009c).

Carbrook Conservation Park — Trial 4

Study area

Carbrook Conservation Park is located approximately 35 km south-east of Brisbane, South East Queensland. The 103 ha park includes *Melaleuca quinquenervia* (paperbark teatree), *Casuarina glauca* (swamp oak) and mixed Eucalypt forest which runs along tidally influenced Native Dog Creek (QPWS 1999a). This study area is a typical example of a coastal and sub-coastal floodplain tree swamp (Melaleuca and Eucalyptus spp.) in the South East Queensland bioregion (Figure 20).

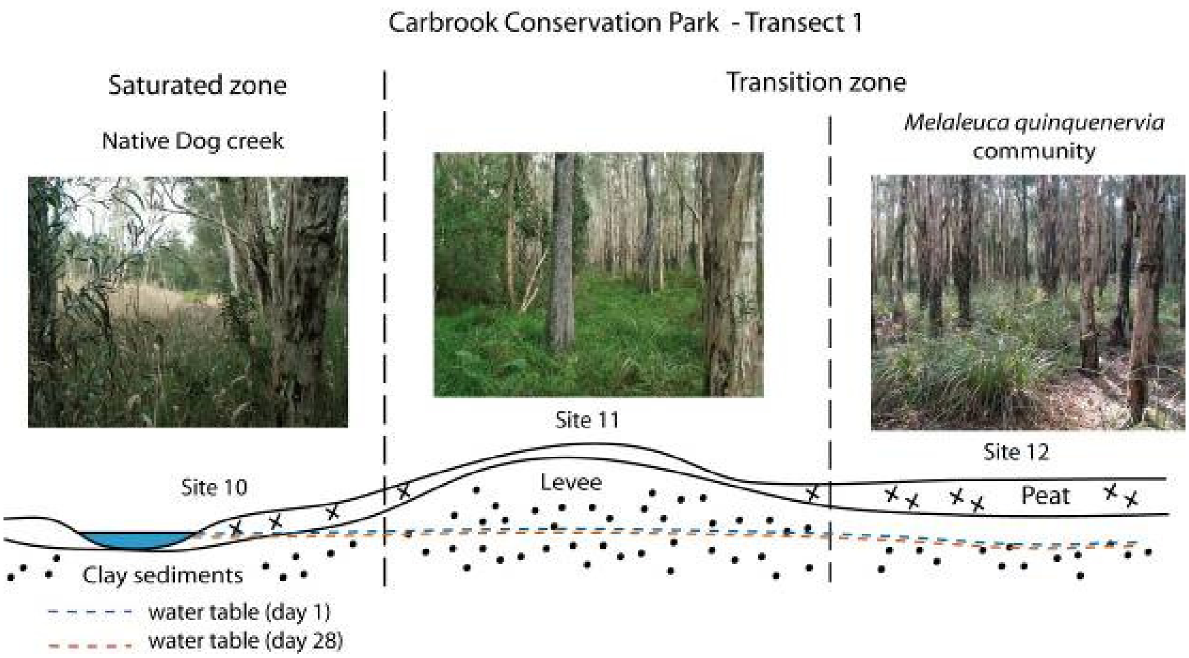


Figure 20 Cross section of wetland (trial 4).

Table 9 Wetland soil indicators (within 0.3 m) for trial 4.

Indicator	Site 10	Site 11	Site 12
Organic materials and total carbon (TC) %*	Organic materials to 0.3 m TC: 28.2%	Organic materials to 0.1 m TC: 16.3%	Organic materials to 0.3 m TC: 19.2%
Matrix colour	Dark brown to black	Black	Black
Chroma values are less than or equal to 2	Yes	Yes	Yes
Mottles and segregations	Absent	Absent	Few <5 mm distinct dark mottles
Ferruginous root channel and pore linings	Absent	Absent	Absent
pH*	Very strongly acidic	Very strongly acidic	Very strongly acidic
Texture	Loam to light clay	Loam to light clay	Loam
Acid sulfate materials	Present	Absent	Absent
Electrical conductivity (EC)	Moderately saline	Non saline	Moderately saline
Fe^{2+} test	Negative - 0 mg/L Fe^{2+}	No test performed	No test performed

**Total carbon % (Dumas method) and pH taken from surface 0.1 m. See Appendix D for explanation of pH codes.*

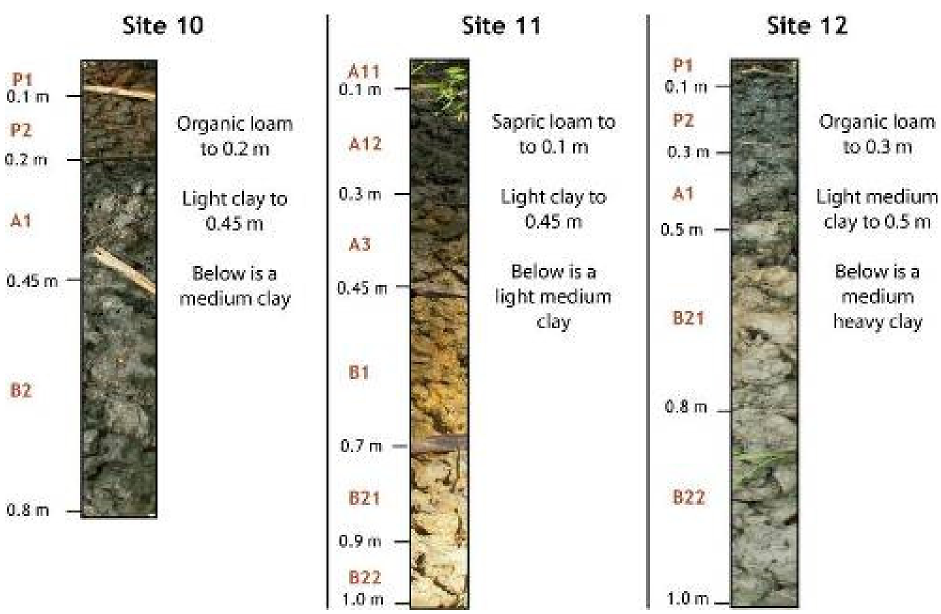
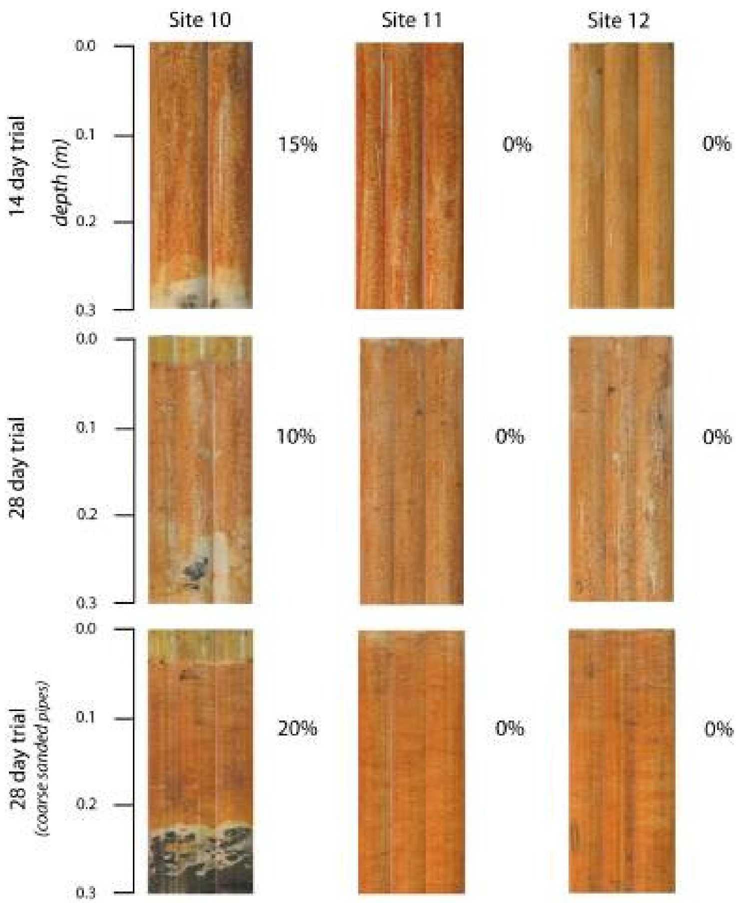


Figure 21 Soil profiles for Carbrook CP (trial 4).



Note: Pipes are representative of the average of all pipes in the analysis.

Figure 22 IRIS results for Carbrook CP (trial 4) — average percentage of paint removed.

Summary of IRIS observations — trial 4

Site 10: A highly reduced area is evident from the uniform removal of paint. Removal of paint and a dark staining of the pipe occur consistently below 0.2-0.25 m. The water table at this site remained constant at around 0.25-0.3 m.

Site 11: No evidence of reduced soil profile, no water table present within 0.5 m.

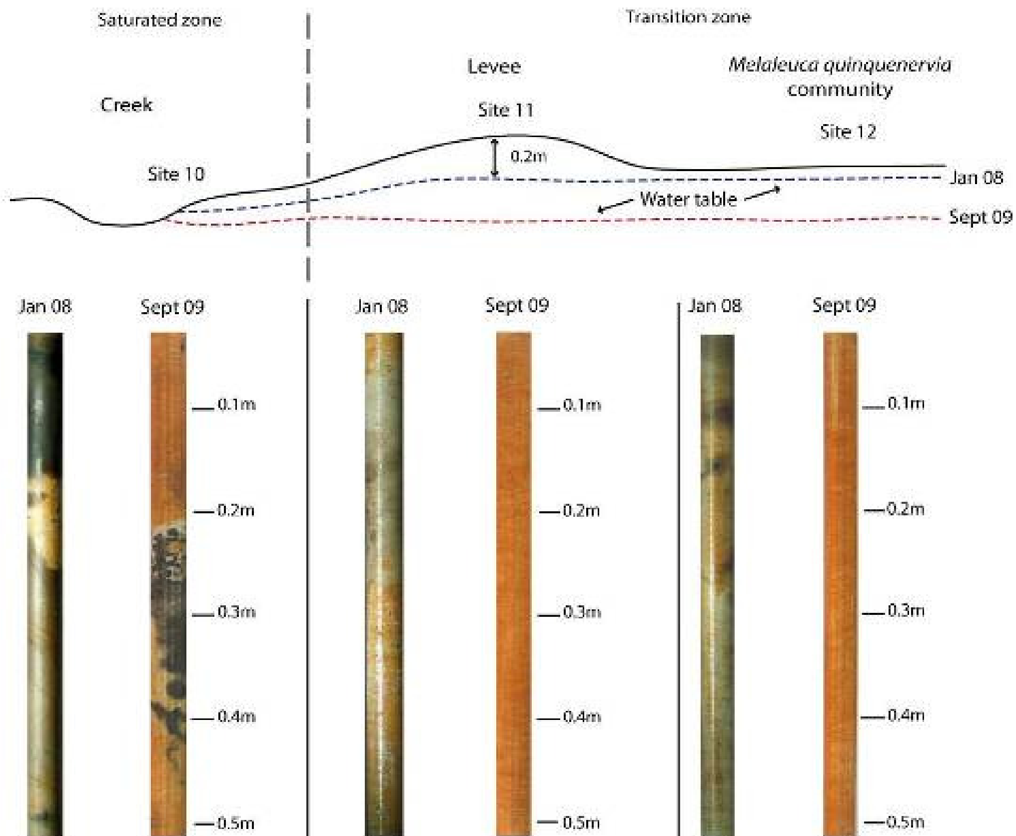
Site 12: No evidence of reduced soil profile, no water table present within 0.5 m.

The majority of this wetland appeared dry and in an oxidised state with no water table detected within the transition zone and soils only being moist, not saturated. The only evidence of a reduced area (from the removal of ferrihyrite paint) is in the saturated zone, at approximately 0.25 m below the surface, where there was a constant water table throughout the trial allowing the soil profile to remain saturated. The different trial durations (14 day to 28 days) had no effect on the amount of paint removed. This was consistent across all sites and all pipes (coarse and medium sanded for this trial).

The prominent dark/black staining pattern on pipes in the saturated zone of site 10 is a result of the reaction of the ferrihydrite paint with soluble sulfides in the soil to form iron monosulfides (see section 3.1.3). The wetland is in an area which contains acid sulfate soils within 5 m of the soil surface (QASSIT 2002).

An IRIS trial was conducted at the same wetland in January 2008 (Bryant et al 2008). This study observed that soils at the wetland were highly reduced as there was a large quantity of paint removed from IRIS pipes (Figure 23). The 2008 study was conducted at a time when the water tables were high (at or near the surface across all sites along the transect) and the wetland was visibly inundated in areas.

It is clear that the lack of saturation during the current IRIS trial was the limiting factor in preventing the removal of paint.



In January 2008 at the time of installation the water table was at 0.02 m and the pipe was inundated completely on removal. Reduction is uniform over majority of pipe with nearly all of the paint removed.

In September 2009 the water table remained constant at approximately 0.25 m below ground level. Reduced areas are evident from the uniform removal of paint past 0.2 m.

The soil is a Hydrosol with fibric and sapric loam to light clay textures to 0.5 m.

Both pipes are stained a prominant dark/black colour. This is caused by the reaction of the ferrihydrite paint with sulfides in the soil to form iron monosulfides. Acid sulfate materials were detected at this site (hydrogen sulfide gas).

In January 2008 at the time of installation the water table was at 0.2 m below ground level. Reduction is uniform in a section between 0.05 m and 0.25 m. Below 0.25m removal of paint is patchy and circular.

In September 2009 there was no water table present within 0.5 m. There is no evidence of a reduced area with no removal of paint from any of the IRIS tubes installed.

The soil is a Hydrosol with sapric loam to heavy light clay textures to 0.5 m.

There is no evidence of dark stains as seen at site 10 on either set of pipes.

In January 2008 at the time of installation the water table was at 0.05 m below ground level and there was visible surface water present on removal of pipes. Reduction is uniform over majority of pipe with nearly all of the paint removed below 0.25 m.

In September 2009 there was no water table present within 0.5 m. There is no evidence of a reduced area with no removal of paint from any of the IRIS tubes installed.

The soil is a Hydrosol with fibric and sapric loam to light medium clay textures to 0.5 m.

In January 2008 iron staining of the surrounding environment was visible when the pipes were removed. A similar dark staining is present in patches on the pipe as seen at site 10.

Figure 23 Carbrook Conservation Park (trial 4): comparison between January 2008 and September 2009 trials.

Carbrook Conservation Park — Trial 5

Study area

This study area is a typical example of a coastal and sub-coastal floodplain tree swamp (Melaleuca and Eucalyptus spp.) in the South East Queensland bioregion (Figure 24).

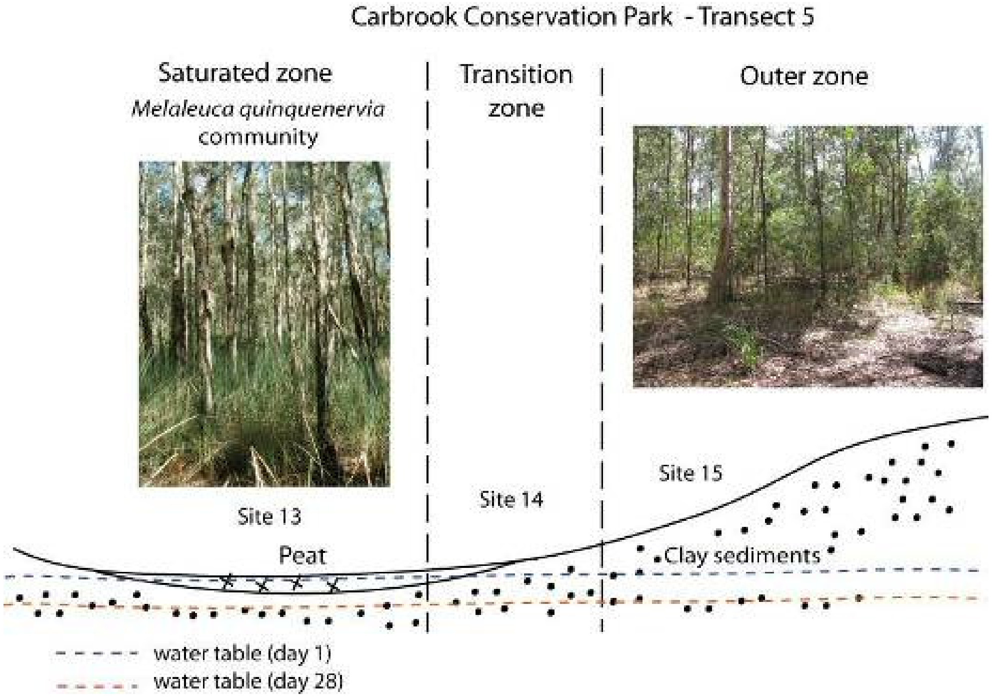


Figure 24 Cross section of wetland (trial 5).

Table 10 Wetland soil indicators (within 0.3 m) for trial 5.

Indicator	Site 13	Site 14	Site 15
Organic materials and total carbon (TC) %*	Organic materials to 0.3 m TC: 13.2%	Organic materials to 0.3 m TC: 20.6%	Not present TC: 8.55%
Matrix colour	Black	Black	Brownish black
Chroma values are less than or equal to 2	Yes	Yes	Yes
Mottles and segregations	Absent	Absent	Few fine <5 mm distinct yellow mottles Very few < 5 mm distinct red mottles
Ferruginous root channel and pore linings	Absent	Absent	Absent
pH*	Very strongly acidic	Very strongly acidic	Strongly acidic
Texture	Loam to clay loam	Loam to clay loam	Loam to light medium clay
Acid sulfate materials	Absent	Absent	Absent
Electrical conductivity (EC)	Moderately saline	Moderately saline	Non saline
Fe^{2+} test	Positive - 500 mg/L Fe^{2+}	Positive - 500 mg/L Fe^{2+}	No test performed

**Total carbon % (Dumas method and pH taken from surface 0.1 m. See Appendix D for explanation of pH codes.*

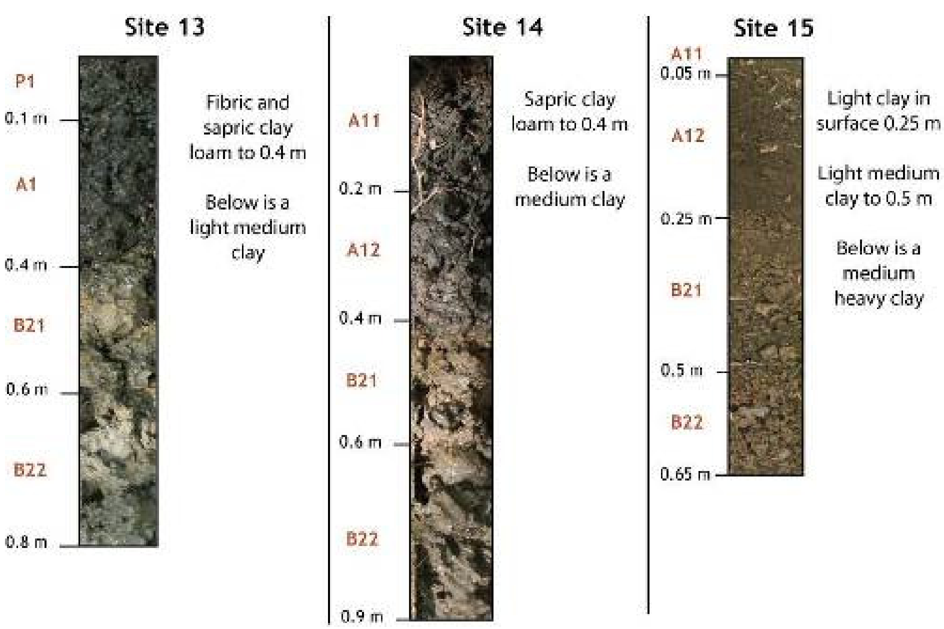
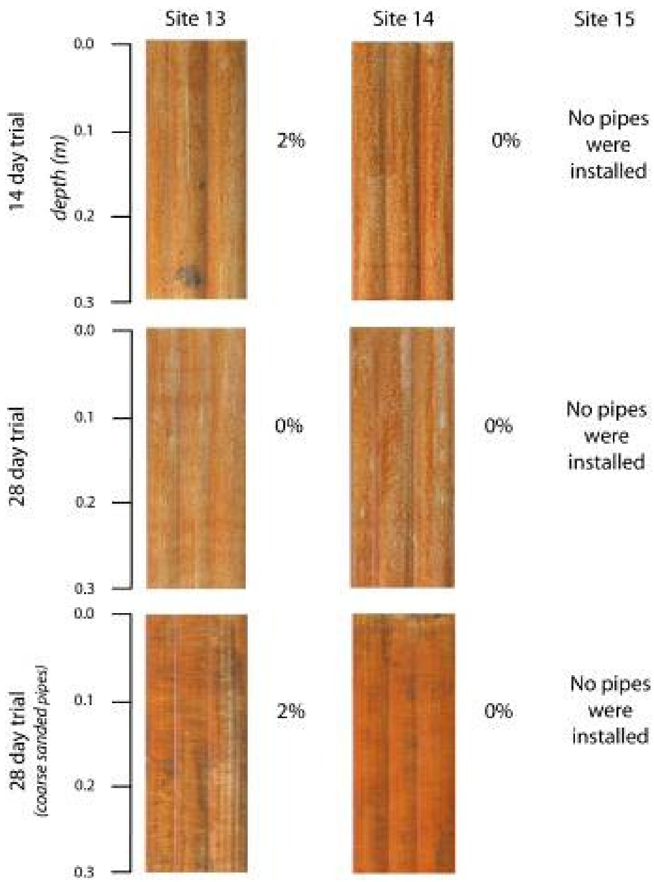


Figure 25 Soil profiles at Carbrook CP (trial 5).



Note: Pipes are representative of the average of all pipes in the analysis

Figure 26 IRIS results for Carbrook CP (trial 5) — average percentage of paint removed.

Summary of IRIS observations – trial 5

Site 13: Very small dark coloured patches of pipe are the only evidence of removal of paint. The water table dropped from 0.05 m to 0.45 m throughout the trial.

Site 14: No evidence of a reduced area, the water table dropped from 0.35 m to below 0.5 m throughout the trial.

Site 15: No pipes installed.

The wetland appears to be in a dry oxidised state with little (two per cent) or no removal of paint across all sites at this trial. The water table dropped significantly (to below 0.5 m deep) during the duration of the trial which did not allow the upper 0.3 m of soil to become and remain saturated for a sufficient period of time to remove the ferrihydrite paint.

The small areas of paint removed from pipes in the saturated zone have a dark/black stain similar to that present at trial 4, although not as prominent. This again can be attributed to the formation of iron monosulfides through the reaction with soluble sulfides in the soil (see section 3.1.3).

A large amount of Fe^{2+} was measured in the water table (>500 mg/L) (Figure 27). This area is influenced by saline water from a creek flowing from the tidally influenced Logan River. This large level of Fe^{2+}

measured in the water may be a result the oxidation of pyrite within the soil as the wetland is mapped within an area that contains acid sulfate soils within 5 m of the soil surface (Figure 27).

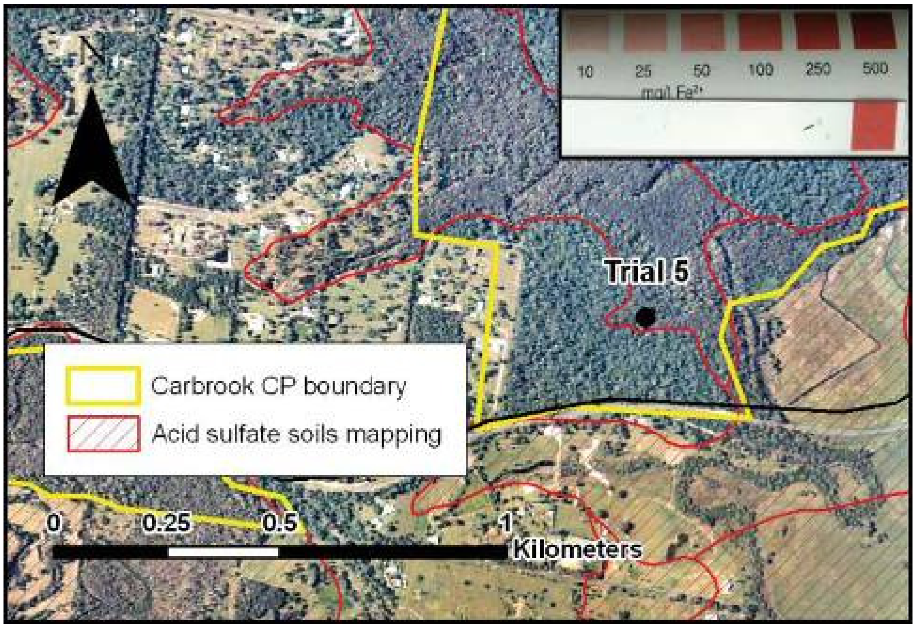


Figure 27 Trial 5: Acid sulfate soils mapping and level of Fe2+ in water (top right corner).

Mooloolah River National Park — Trial 6

Study area

Mooloolah River National Park is located approximately 85 km north of Brisbane, South East Queensland. The geology of the area is mostly quaternary estuarine, floodplain and tidal delta deposits with areas of Landsborough Sandstone. The park is situated on a low-lying floodplain and encompasses a number regionally significant vegetation communities including *Melaleuca quinquenervia* open forest and substantial areas of mainland heath (QPWS 1999b). This study area is a typical example of a coastal and sub-coastal floodplain tree swamp (Melaleuca and Eucalyptus spp.) in the South East Queensland bioregion (Figure 28).

Due to time and access constraints the trials for Mooloolah River NP ran over 16 and 27 days.

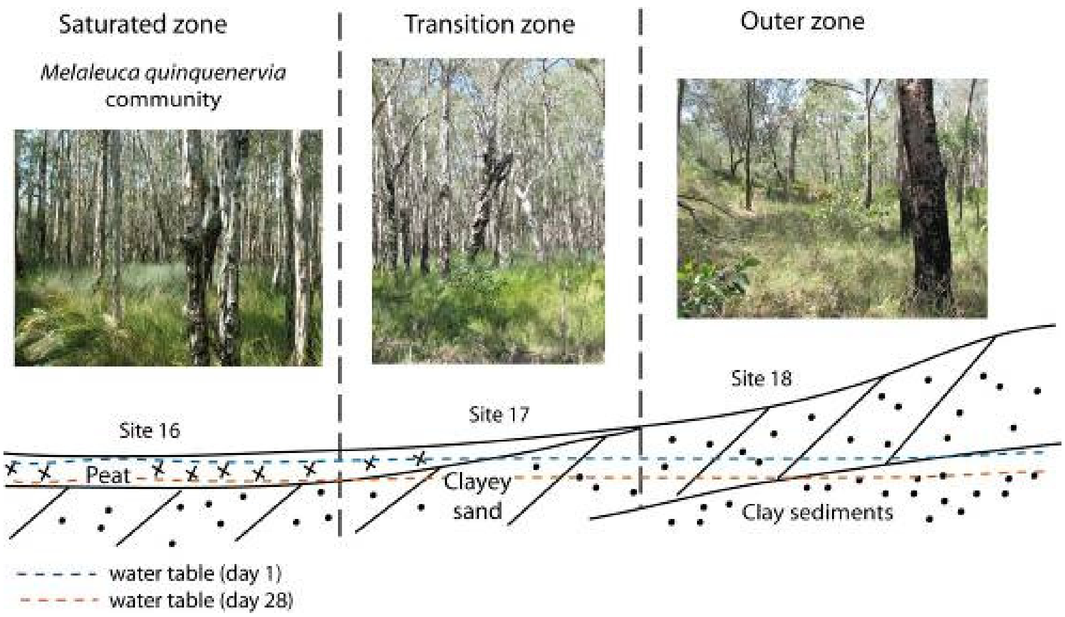


Figure 28 Cross section of wetland (trial 6).

Table 11 Wetland soil indicators (within 0.3 m) for trial 6.

Indicator	Site 16	Site 17	Site 18
Organic materials and total carbon (TC) %*	Organic materials to 0.3 m TC: 11.5%	Organic materials to 0.3 m TC: 7.74%	Not present TC: 3.81%
Matrix colour	Black to brownish black	Brownish black	Brownish black
Chroma values are less than or equal to 2	Yes	Yes	Yes
Mottles and segregations	Absent	Absent	Absent
Ferruginous root channel and pore linings	Absent	Absent	Absent
pH*	Very strongly acidic	Very strongly acidic	Very strongly acidic
Texture	Loam to sandy loam	Clay loam	Clay loam
Acid sulfate materials	Absent	Absent	Absent
Electrical conductivity (EC)	Non saline	Non saline	Non saline
Fe^{2+} test	Positive – 3 mg/L Fe^{2+}	Positive 3 mg/L Fe^{2+}	No test performed

**Total carbon % (Dumas method) and pH taken from surface 0.1m. See Appendix D for explanation of pH codes.*

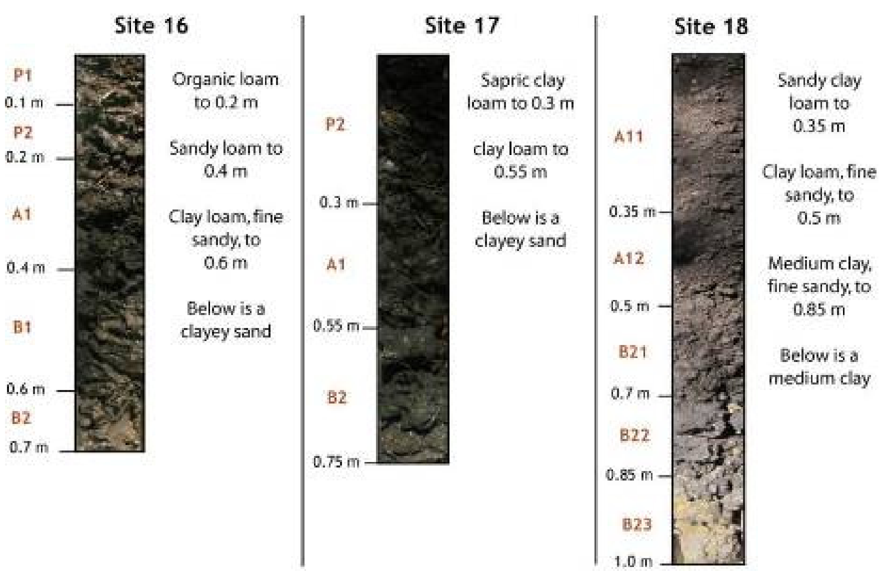
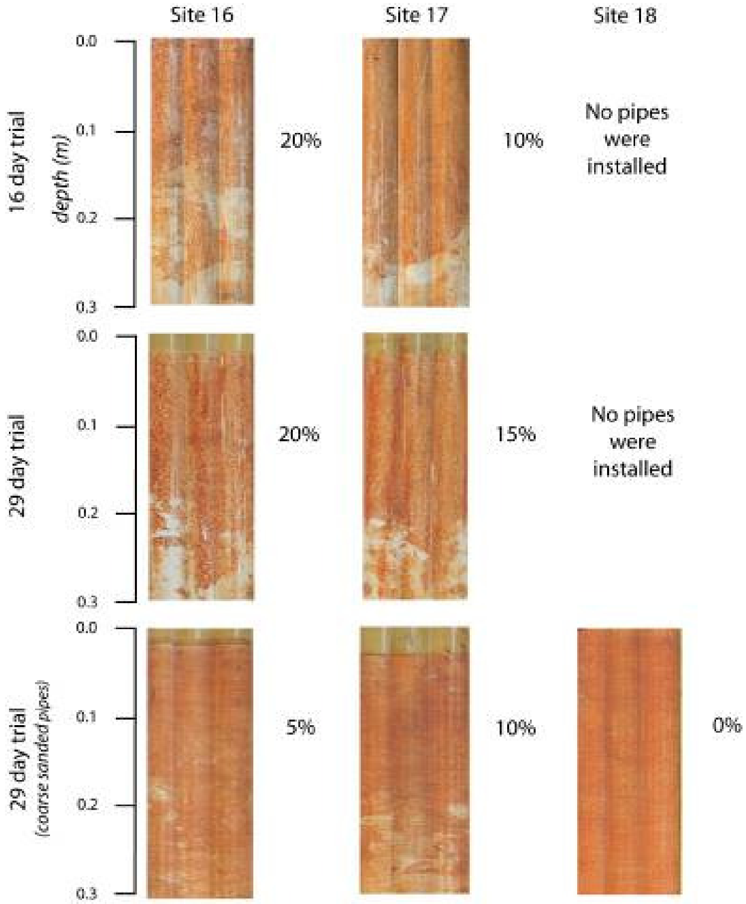


Figure 29 Soil profiles at Mooloolah River NP (trial 6).



Note: Pipes are representative of the average of all pipes in the analysis.

Figure 30 IRIS results for Mooloolah River NP (trial 6) — average percentage of paint removed.

Summary of IRIS observations – trial 6

Site 16: A moderately reduced soil profile is evident from the patchy removal of paint. There is a large difference in the percentage of paint removed between the coarse and medium sanded pipes (5 per cent to 20 per cent respectively). The water table remained between 0.1 and 0.25 m throughout the trial.

Site 17: A moderately reduced soil profile is evident from the patchy removal of paint. The water table dropped from 0.15 to 0.45 m throughout the trial.

Site 18: There is no evidence of a reduced soil present. There was no water table present within 0.5 m throughout the trial.

During the IRIS trial at Mooloolah River National Park the area was subject to a wildfire (Figure 31) which burned through the surface layer of organic material at this wetland. The fire does not appear to have had an effect on the trial.

Figure 31 Trial 6 before the fire (left) and after (right).

The entire wetland appears to be in a moderately reduced state with very shallow water tables and high carbon contents (>7 per cent TC in the surface 0.1 m), within the saturated and transition zones. The removal of ferrihydrite paint is correlated to the boundary of the wetland (Figure 32) with a larger amount of paint removed from pipes in the saturated zone compared to less saturated areas (transition zone). No paint was removed in the area considered outside the wetland.

There was very little difference in paint removal between the 16 day and 27 day trials (medium sanded pipes).This suggests that the wetland is only moderately reduced and microbial activity is remaining constant. Microbial activity was most likely limited by the zone of saturation within the soil profile as the water table dropped by 0.15 m and 0.3 m in the saturated and transition zones respectively over the course of the trials.

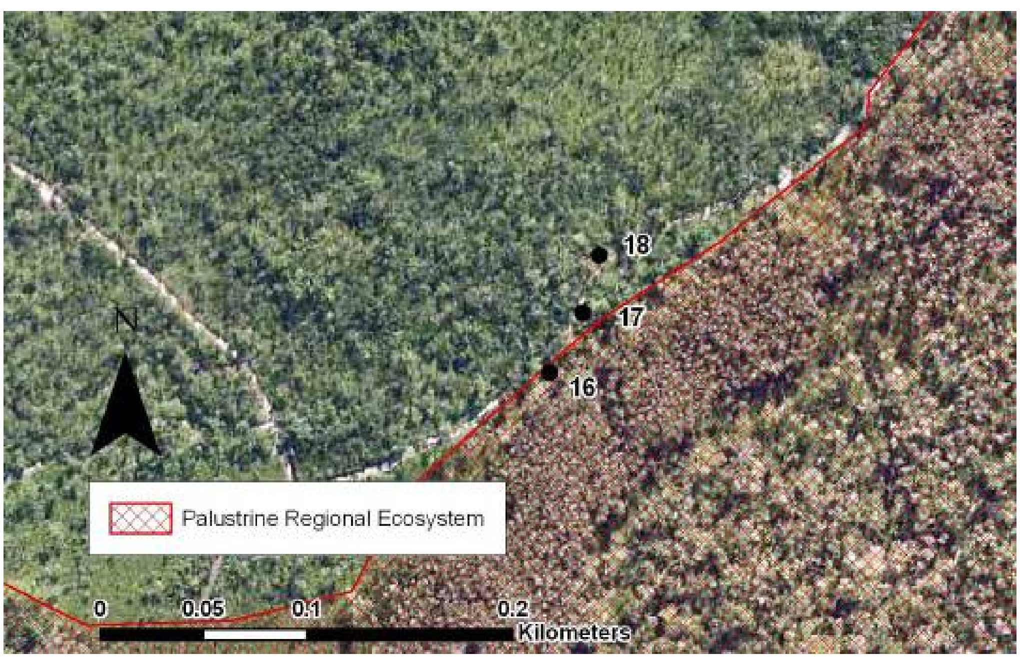


Figure 32 Trial 6 sites and current wetland mapping (DERM 2009c).

Mooloolah River NP — Trial 7

Study area

This study area is a typical example of a coastal and sub-coastal floodplain tree swamp (Melaleuca and Eucalyptus spp.) in the South East Queensland bioregion (Figure 33).

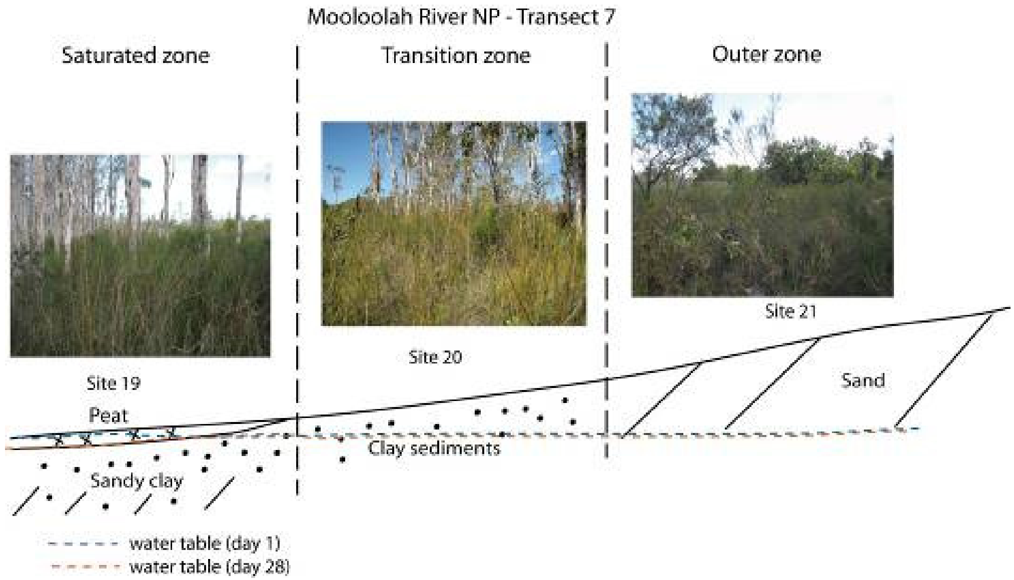


Figure 33 Cross section of wetland (trial 7).

Table 12 Wetland soil indicators (within 0.3 m) for trial 7.

Indicator	Site 19	Site 20	Site 21
Organic materials and total carbon (TC) %*	Organic materials to 0.3 m TC: 8.7%	Organic materials to 0.1 m TC: 5.53%	Organic materials to 0.3 m TC: 3.93%
Matrix colour	Black	Black to greyish yellow- brown	Brownish black
Chroma values are less than or equal to 2	Yes	Yes	Yes
Mottles and segregations	Absent	Absent	Absent
Ferruginous root channel and pore linings	Absent	Absent	Absent
pH*	Very strongly acidic	Very strongly acidic	Very strongly acidic
Texture	Loam to clay loam	Loam to clay loam	Loamy sand
Acid sulfate materials	Absent	Absent	Absent
Electrical conductivity (EC)	Non saline	Non saline	Non saline
Fe^{2+} test	Positive – 3 mg/L Fe^{2+}	No test performed	No test performed

** Total carbon % (Dumas method) and pH taken from surface 0.1 m. See Appendix D for explanation of pH codes.*

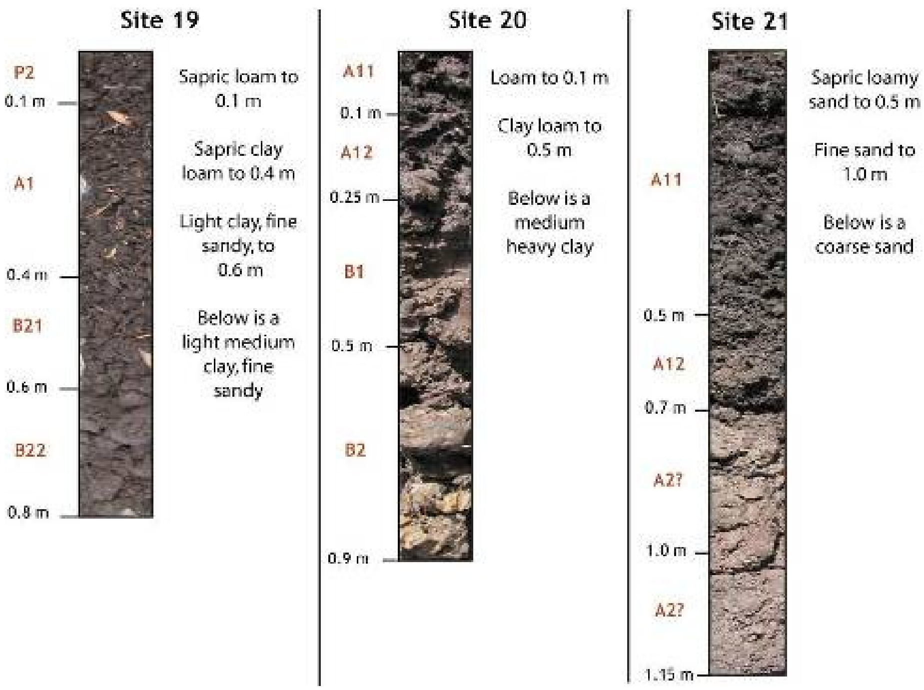
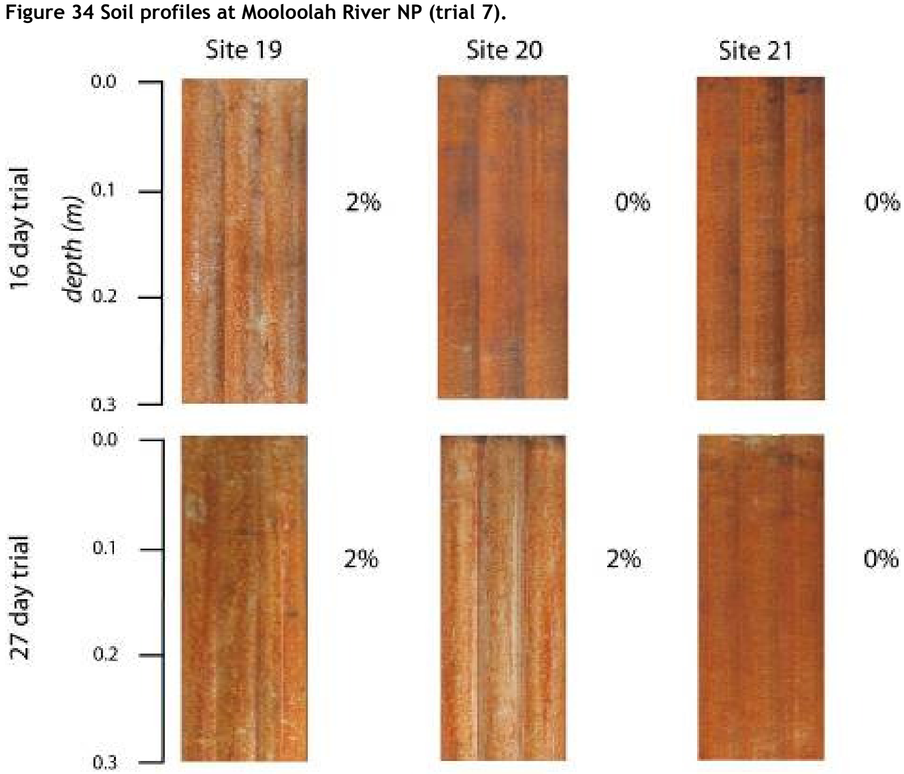


Figure 34 Soil profiles at Mooloolah River NP (trial 7).



Note: Pipes are representative of the average of all pipes in the analysis.

Figure 35 IRIS results for Mooloolah River NP (trial 7) — average percentage of paint removed.

Summary of IRIS observations — trial 7

Site 19: At this site the soil does not appear to be in a reduced state due to the small percentage of paint removed (two per cent). The water table dropped from 0.1 m to 0.45 m during the trial.

Site 20: The soil at this site does not appear to be in a reduced state due to the small percentage of paint removed (two per cent). The water table dropped from 0.45 m to below 0.5 m throughout the trial.

Site 21: There is no evidence of a reduced soil profile. There was no water table present within 0.5 m throughout the trial.

During the IRIS trial at Mooloolah River National Park the area was subjected to a wildfire (Figure 36) which burned through the surface layer of organic material. The fire was much hotter at this wetland than at trial 6 and the area was significantly more burned. The swamp dried significantly after the wildfire with the surface layer of organic material in the saturated zone burnt off and the water table dropping by 0.35 m.

Figure 36 Trial 7 before the fire (left) and after (right).

Very little paint was removed at all sites along the transect, the greatest quantity was two per cent, with no significant difference between the 16 day and 27 day trials. This suggests that the soils were not in a reduced state.

It appears that the depth of the saturated zone in the soil profile was the limiting factor for reducing conditions at this wetland. There were suitable conditions to promote a reduced environment with sufficient levels of carbon present (>3.5 per cent TC in the surface 0.1 m). As all three sites appear to be included within the boundary of current wetlands mapping (Figure 37), it is likely that this wetland would become reduced when it remains saturated for a prolonged period.

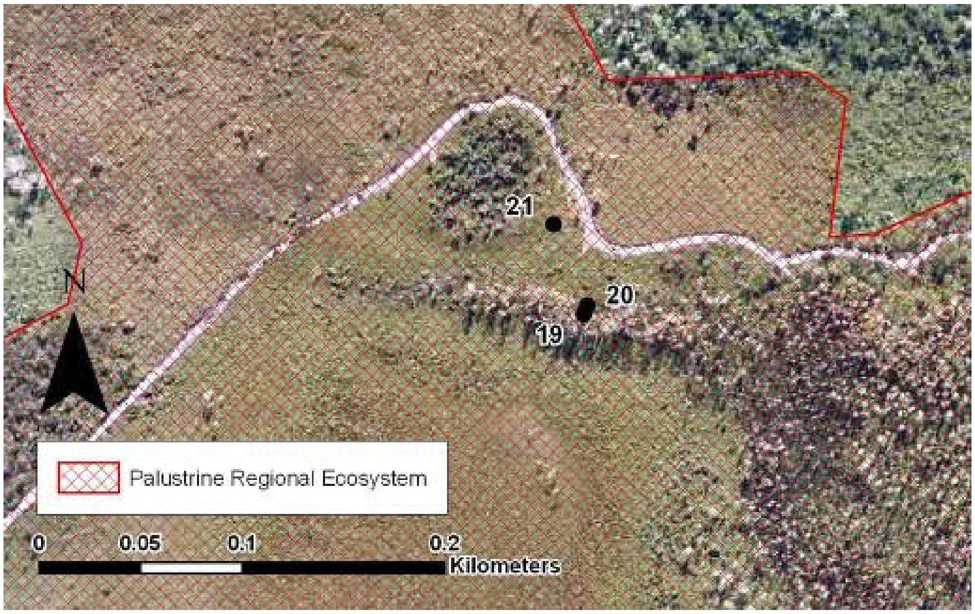


Figure 37 Trial 7 sites and current wetland mapping (DERM 2009c).

Noosa National Park — Trial 8

Study area

Noosa National Park is situated approximately 150 km north of Brisbane. The geology of the study area is predominantly quaternary estuarine, floodplain and tidal delta deposits and holecene beach ridge systems. The area is comprised of heath and sedgelands on a poorly drained sand plain which borders the residential area of Peregian Beach. This wetland is a good example of a coastal and sub-coastal floodplain wet heath swamp in the South East Queensland bioregion (Figure 38).

Due to time and access constraints the trial for Noosa NP ran over 14 and 27 days.

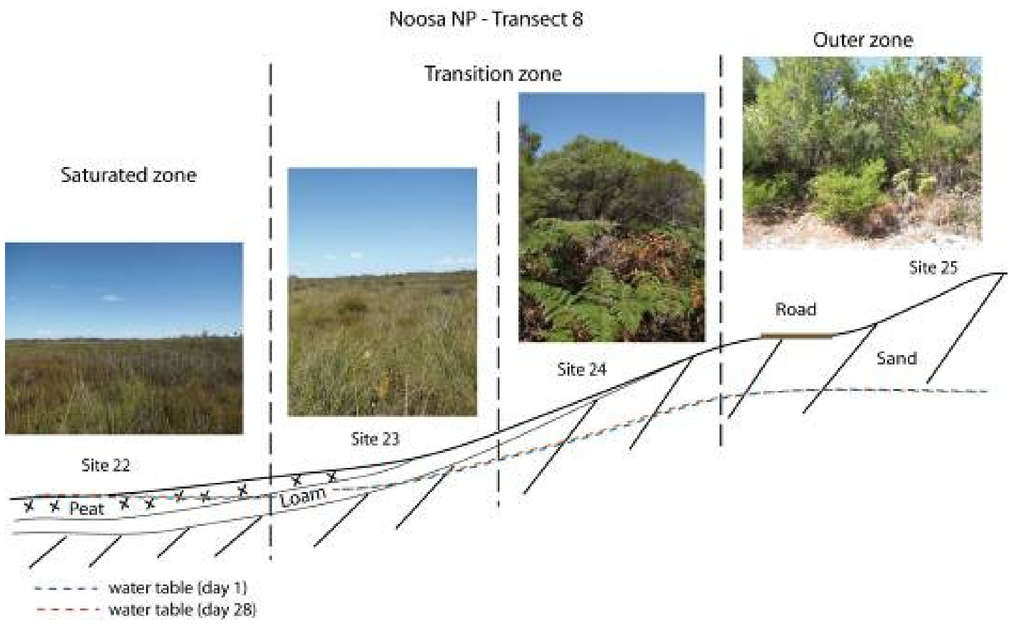


Figure 38 Cross section of wetland (trial 8).

Table 13 Wetland soil indicators (within 0.3 m) for trial 8.

Indicator	Site 22	Site 23	Site 24	Site 25
Organic materials and total carbon (TC) %*	Organic materials to 0.3 m TC: 9.35%	Organic materials to 0.3 m TC: 17.1%	Organic materials to 0.3 m TC: 10.5%	No organic materials TC: 0.83%
Matrix colour	Black	Brownish black to black	Brownish black to black	Brownish black to brownish grey
Chroma values are less than or equal to 2	Yes	Yes	Yes	Yes
Mottles and segregations	Absent	Absent	Absent	Absent
Ferruginous root channel and pore linings	Absent	Absent	Absent	Absent
pH*	Very strongly acidic	Very strongly acidic	Very strongly acidic	Very strongly acidic
Texture	Loam to sandy loam	Loam	Loam	Sand
Acid sulfate materials	Absent	Absent	Present	Absent
Electrical conductivity (EC)	Non saline	Non saline	Non saline	Non saline
Fe^{2+} test	Positive -3 mg/L	No test performed	No test performed	No test performed

** Total carbon % (Dumas method) and pH taken from surface 0.1 m. See Appendix D for explanation of pH codes.*

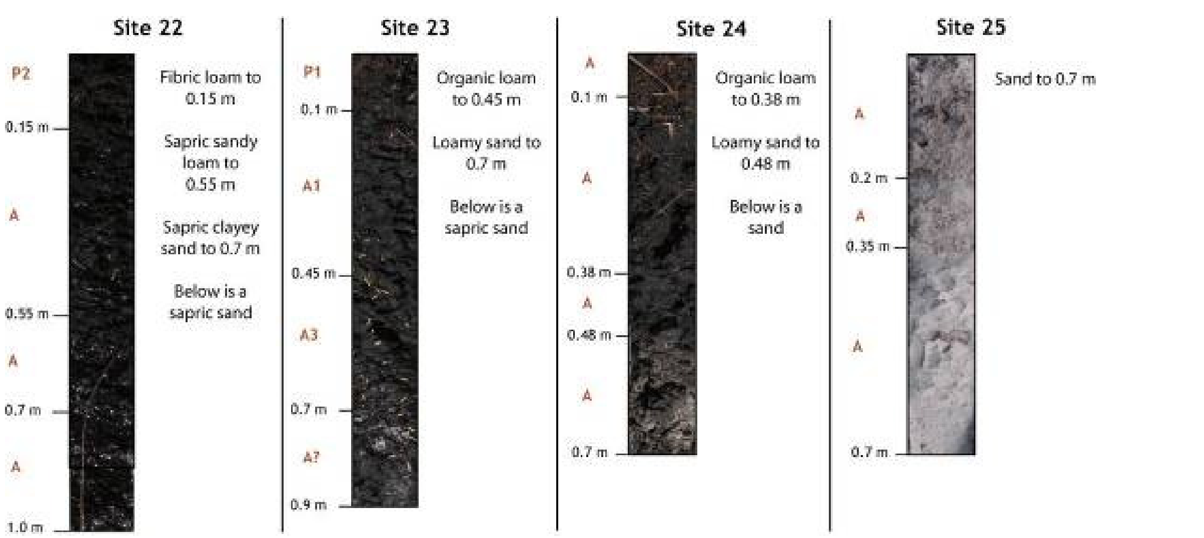
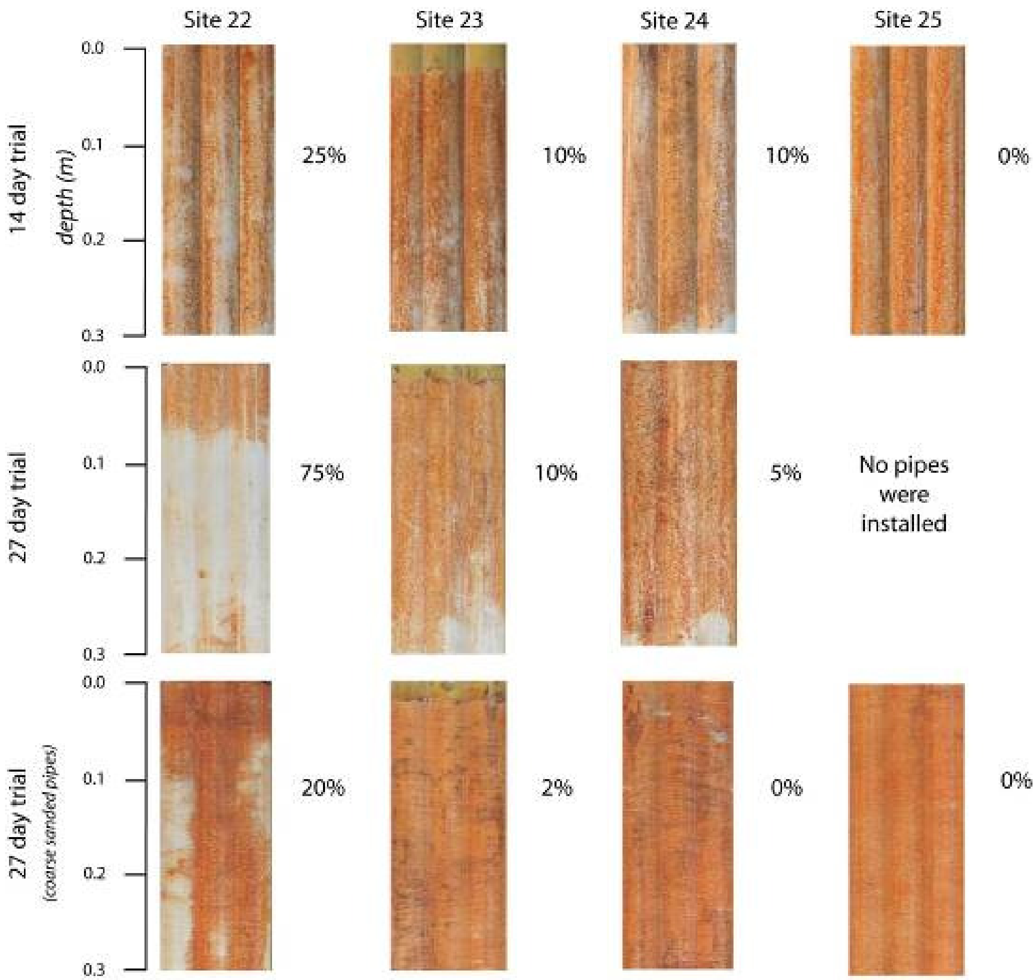


Figure 39 Soil profiles at Noosa NP (trial 8).



Note: Pipes are representative of the average of all pipes in the analysis.

Figure 40 IRIS results for Noosa NP (trial 8) — average percentage of paint removed.

Summary of IRIS observations - trial 8

Site 22: A highly reduced soil is evident from the large removal of paint. Paint removal is smaller and patchy in the 14 day trial compared to the 27 day trial, which had uniform removal of paint below 0.05 m. There is a large difference in the percentage of paint removed between the coarse and medium sanded pipes (20 per cent to 75 per cent respectively). The water table remained constant at the soil surface throughout the trial.

Sites 23 and 24: A slightly reduced soil is evident through the small amount of paint removed. The water table remained at 0.45-0.5 m throughout the trial.

Site 25: There is no evidence of a reduced soil. No water table was observed within 0.5 m of the soil profile throughout the trials.

There is a larger percentage of paint removed from pipes in the saturated zone which decreases into the transition zone. There is no removal of paint from pipes in the outer zone (site 25) which is consistent with the boundary of the wetland (Figure 41).

The wetland appears to be in a highly reduced state in the saturated zone with high water table levels, allowing complete saturation of the soil profile, and sufficient soil carbon levels (>9 per cent TC in the surface 0.1 m). This suggests that the removal of paint is an accurate reflection of reducing conditions at this site.

There is a large difference in paint removed from the medium sanded pipes between the 14 day and 27 day trial (in the saturated zone only). This may be attributed again to the rate of microbial activity increasing after 14 days at a site which appears to be anoxic and with high water tables throughout the trial.

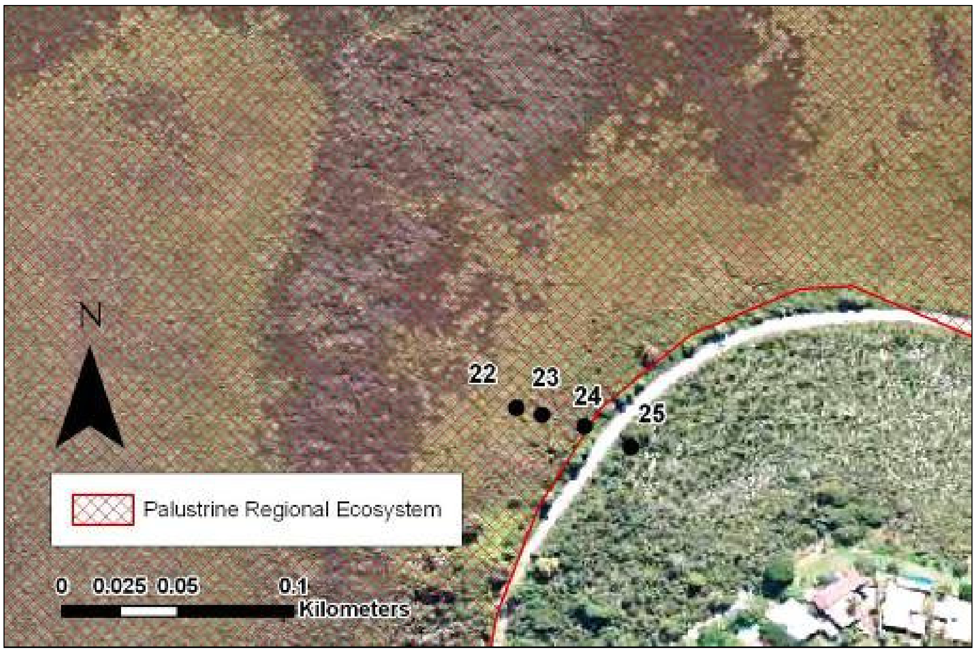


Figure 41 Trial 8 sites and current wetland mapping (DERM 2009c).

3.1.1 General interpretation of IRIS trials

A comparison of the average percentage of paint removed was made across all the wetlands in the current study (tables 14 and 15). Not all sites had the same number of replicates counted in the analysis. This was because some pipes were covered with soil which could not be removed without also removing paint. Consequently these pipes were not of sufficient quality to be measured.

A greater percentage of paint was removed from sites in the saturated zone compared with sites in the transition or outer zone across all wetlands as one might expect. Sites that had a considerable amount of paint removed (>60 per cent) were in areas which were inundated at some stage during the trials.

The water table, at all of the wetlands, dropped during the trials (Figure 42). For several wetlands this had an effect on the zone of saturation within 0.3 m of the soil surface. Wetlands that were inundated, or had water tables remain at, or within 0.3 m of the surface, had the largest amount of paint removed.

The sites where more than 98 per cent of paint remained was where the water table had dropped below 0.3 m after 28 days (trials 4, 5 and 7). This occurred in both the saturated and transition zones of the wetlands.

A comparison was also made between the paint removed from the medium sanded pipes between trial durations (14 days and 28 days).There were some sites at which a large increase in the amount of paint had been removed between 14 days and 28 days (sites 4, 8, 9 and 22). These sites were in areas that had been inundated or had water tables at the soil surface during the trials. However the increase in paint removed between 14 and 28 days was not consistent across all sites that had been inundated or had high water tables.

There was no clear trend in the percentage of paint removed between the 14 day and 28 day trials across the remaining sites:

- six sites had an increase in the average percentage of paint removed (with the largest increase being 10 per cent at site 1)
- eight sites had a decrease in average percentage paint removed (the largest difference being 15 per cent at site 6)
- five sites had no change in average percentage of paint removed.

A comparison between coarse and medium sanded pipes was undertaken (for the 28 day trial only). At sites that had been inundated there was little difference between the quantity of paint removed between the two sets of pipes (trials 1, 2 and 3). Where there were high water tables but no inundation (trial 6 and 8), a larger percentage of paint was removed from the medium sanded pipes. There was little to no difference in paint removal at sites which appeared to be in aerated or oxidised states. At these sites all pipes had a low percentage of paint removed (trials 4, 5 and 7).

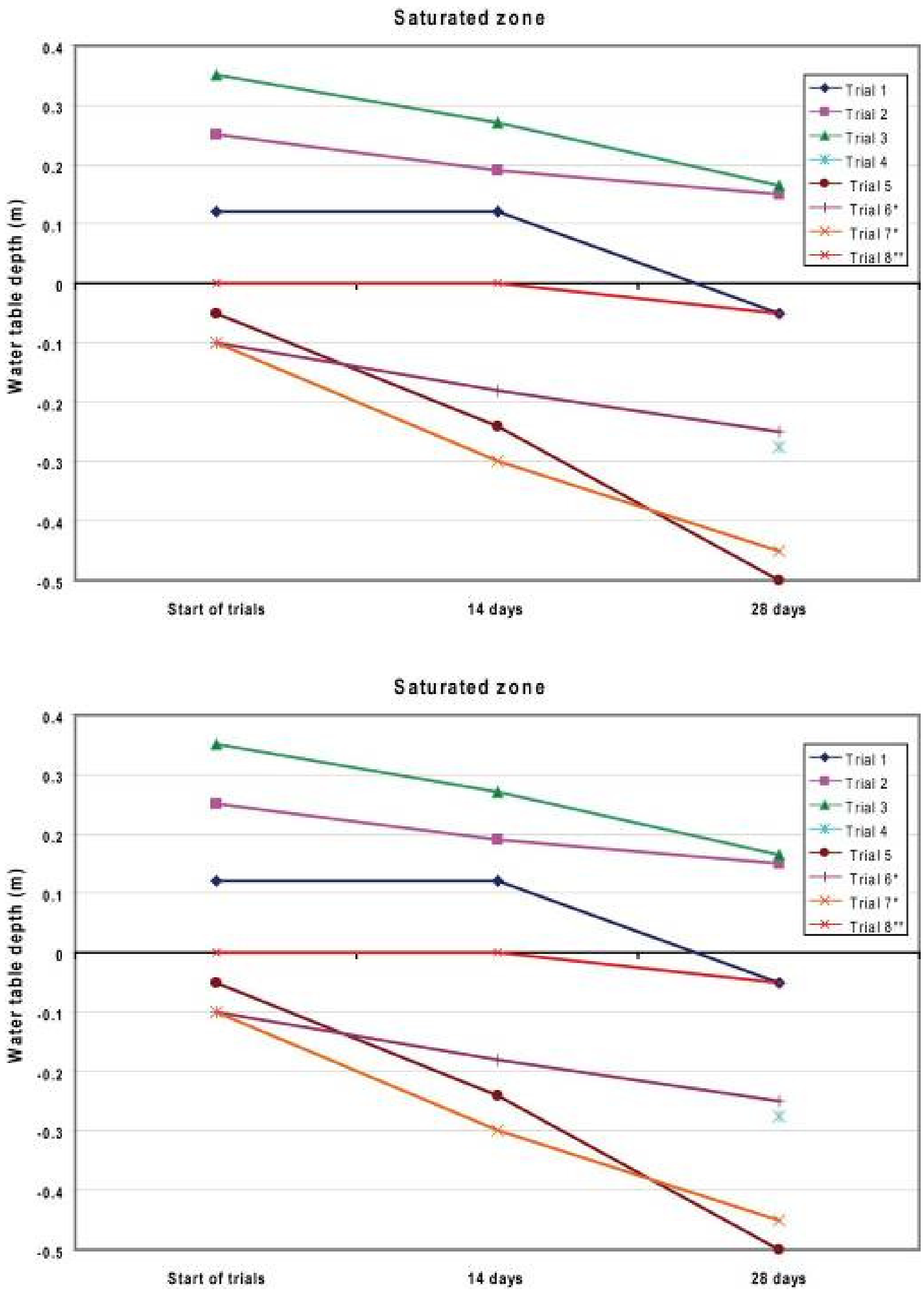


Figure 42 Average water table heights: saturated zone (above), transition zone (below).

Table 14 The average percentage removal of paint (from the surface 0.3 m) across all wetlands in the study (medium sanded pipes).

Wetland	Position along transect	Water table heights (m): start of trial	14 day period		28 day period	
			Average removal of paint (%)	Water table heights (m): end of trial	Average removal of paint (%)	Water table heights (m): end of trial
Bribie Island: Trial1	Saturated zone (site 1)	+ 0.12	75	+ 0.12	85	0.0
	Transition zone (site 2)	0.0	20	0.0	10	- 0.15
	Outer zone (site 3)	absent	0	absent	0	absent
Bribie Island: Trial 2	Saturated zone (site 4)	+ 0.25	35	+ 0.19	80	+ 0.17
	Transition zone (site 5)	not recorded	20	- 0.25	20	- 0.3
	Outer zone (site 6)	not recorded	35	- 0.3	20	- 0.4
Bribie Island: Trial 3	Saturated zone (site 7)	+ 0.35	85	+ 0.27	80	+ 0.18
	Transition zone (site 8)	+ 0.25	25	+ 0.17	75	+ 0.1
	Outer zone (site 9)	0.0	50	0.0	70	- 0.22
Carbrook Conservation Park: Trial 4	Saturated zone (site 10)	- 0.25	15	- 0.25	10	- 0.3
	Transition zone (site 11)	absent	0	absent	0	absent
	Outer zone (site 12)	absent	0	absent	0	absent
Carbrook Conservation Park: Trial 5	Saturated zone (site 13)	- 0.05	2	not recorded	0	- 0.45
	Transition zone (site 14)	- 0.35	0	absent	0	absent
	Outer zone (site 15)	NA	NA	NA	NA	NA
Mooloolah River National Park: Trial 6*	Saturated zone (site 16)	- 0.1	20	- 0.18	20	- 0.25
	Transition zone (site 17)	- 0.15	10	- 0.27	15	- 0.45
	Outer zone (site18)	absent				absent
Mooloolah River National Park: Trial 7*	Saturated zone (site 19)	- 0.1	2	- 0.3	2	- 0.45
	Transition zone (site 20)	- 0.45	0	- 0.4	2	absent
	Outer zone (site 21)	absent	0	absent	0	absent
Noosa National Park: Trial 8**	Saturated zone (site 22)	0.0	25	0.0	75	0.05
	Transition zone (site 23)	- 0.5	10	- 0.5	10	- 0.45
	Transition zone (site 24)	- 0.5	10	- 0.5	5	- 0.5
	Outer zone (site 25)	absent	0	absent	NA	absent

** Mooloolah River NP trial durations were 16 days and 29 days respectively.*

*** Noosa NP trials durations were 14 days and 27 days respectively.*

NOTE: For water table heights: (+) = above the soil surface; (-) = below the soil surface; (absent) = no water table observed within 0.5 m.

Table 15 The average percentage removal of paint (from the surface 0.3 m) across all wetlands in the study (coarse sanded pipes).

Wetland	Position along transect	Water table heights (m): start of trial	Water table heights (m): end of trial (28 days)	Average paint removed (%)
Bribie Island: Trial 1	Saturated zone (site1)	+ 0.12	- 0.1	65
	Transition zone (site 2)	0.0	0.25	10
	Outer zone (site 3)	absent	absent	0
Bribie Island: Trial 2	Saturated zone (site 4)	+ 0.19	+ 0.17	75
	Transition zone (site 5)	- 0.25	- 0.38	2
	Outer zone (site 6)	- 0.3	- 0.4	5
Bribie Island: Trial 3	Saturated zone (site 7)	+ 0.27	- 0.15	85
	Transition zone (site 8)	+ 0.17	- 0.1	80
	Outer zone (site 9)	0.0	0.14	55
Carbrook CP: Trial 4	Saturated zone (site 10)	- 0.25	- 0.25	20
	Transition zone (site 11)	absent	absent	0
	Outer zone (site 12)	absent	absent	0
Carbrook CP: Trial 5	Saturated zone (site 13)	not recorded	absent	2
	Transition zone (site 14)	absent	absent	0
	Outer zone (site 15)	NA	NA	NA
Mooloolah River NP: Trial 6*	Saturated zone (site 16)	- 0.1	- 0.18	5
	Transition zone (site 17)	- 0.15	- 0.27	10
	Outer zone (site 18)	absent		0
Mooloolah River NP: Trial 7*	Saturated zone (site 19)	- 0.1	- 0.3	NA
	Transition zone (site 20)	- 0.45	- 0.4	NA
	Outer zone (site 21)	absent	absent	NA
Noosa NP: Trial 8**	Saturated zone (site 22)	0.0	0.0	20
	Transition zone (site 23)	- 0.5	- 0.5	2
	Transition zone (site 24)	- 0.5	- 0.5	0
	Outer zone (site 25)	absent	absent	0

** Mooloolah River NP trial duration was 29 days.*

*** Noosa NP trial duration was 27 days.*

NOTE: For water table heights: (+) = above the soil surface; (-) = below the soil surface; (absent) = no water table observed within 0.5 m.

3.1.2 Soil types

Different soils types (sands, clays and organic dominated soils) do not appear to directly influence the removal of paint from the IRIS pipes. There were similar percentages of paint removed across differing soil types, and also differing patterns of paint removed within similar soil types.

Soil types have an effect on the rate at which water flows through the soil profile. A clay soil generally has a slower transmission rate than sands and peats due to smaller pore sizes. This can prevent water from draining away quickly and can contribute to the formation of a wetland. Some clay soils do however contain large macro-pores which allow the transmission of water rapidly. A sandy soil can transmit water rapidly and wetlands that have sandy soils are often largely influenced by groundwater systems.

While not directly influencing the reduced areas at a wetland, soil type more significantly influences the zone of saturation in a soil profile.

3.1.3 Patterns of paint removal

There were different patterns of paint removal from sites across the study. These patterns represent differing soil properties or processes that occur in the profile. The following are examples of the different patterns of paint removed which was observed in the current study.

Circular or donut shaped patches

These were very distinct round marks (Figure 43A). In a study conducted by Jenkinson & Franzmeir (2006) this pattern occurred on IRIS tubes and its morphology was compared to the way that bacterial cultures form in petrie dishes. In the current study these marks were found in soils that were likely to be reduced in different areas in the soil profile, rather than across the entire profile. This could be an effect of macro-pores and roots creating preferred pathways for water and allowing sections of the soil profile to become saturated while allowing others to remain in an oxidised state.

Dark/black colouration

At one site in the current study (Site 10, trial 4) there was evidence of significant dark colourations of the IRIS tubes (Figure 43B). This was caused by the reaction of soluble sulfides in the soil with the ferrihydrite paint to form iron monosulfides. Iron oxides can react with sulfides very quickly and without the need for microbes (Fanning et al 2009). At this site evidence of acid sulfate materials were present (hydrogen sulfide gas was detected upon auguring).

Uniform removal of paint

At several areas there was complete removal of paint from the entire surface of the pipe. This occurred in highly reduced areas, at sites that were inundated or had a water table at or near the surface throughout the trials. The entire soil profile, below a certain depth, appeared to be completely saturated and in an anoxic state (Figure 43C).

Patchy removal of paint

At the majority of sites where a reduced area was evident by the removal of paint, the pattern was patchy or not uniform across the pipe (Figure 43D). This may be the result of microbes consuming organic material which is not uniform across a horizon (Vepraskas 1998). This pattern of removal can also occur when the Fe^{2+} moves into other parts of the soil (i.e. soil pores) where the redox potential may be higher and Fe^{2+} is able to re-oxidise (SSSA 1989).

This type of pattern was observed in wetlands that appeared only moderately reduced, or at sites which had reduced zones within the soil profile but not a completely reduced soil profile.

Re-oxidised ferrihydrite paint

At several sites there was a band of ferrihydrite paint, at the top of the pipe, which was darker than the original applied paint (Figure 43E). This may be where ferrihydrite paint is reduced and removed from the lower parts of the IRIS pipe and transported to the top of the pipe, which was at the top of the water table where oxygen is available. The Fe^{2+} has then re-oxidised, forming this darker band (Jenkinson & Franzmeir 2006).

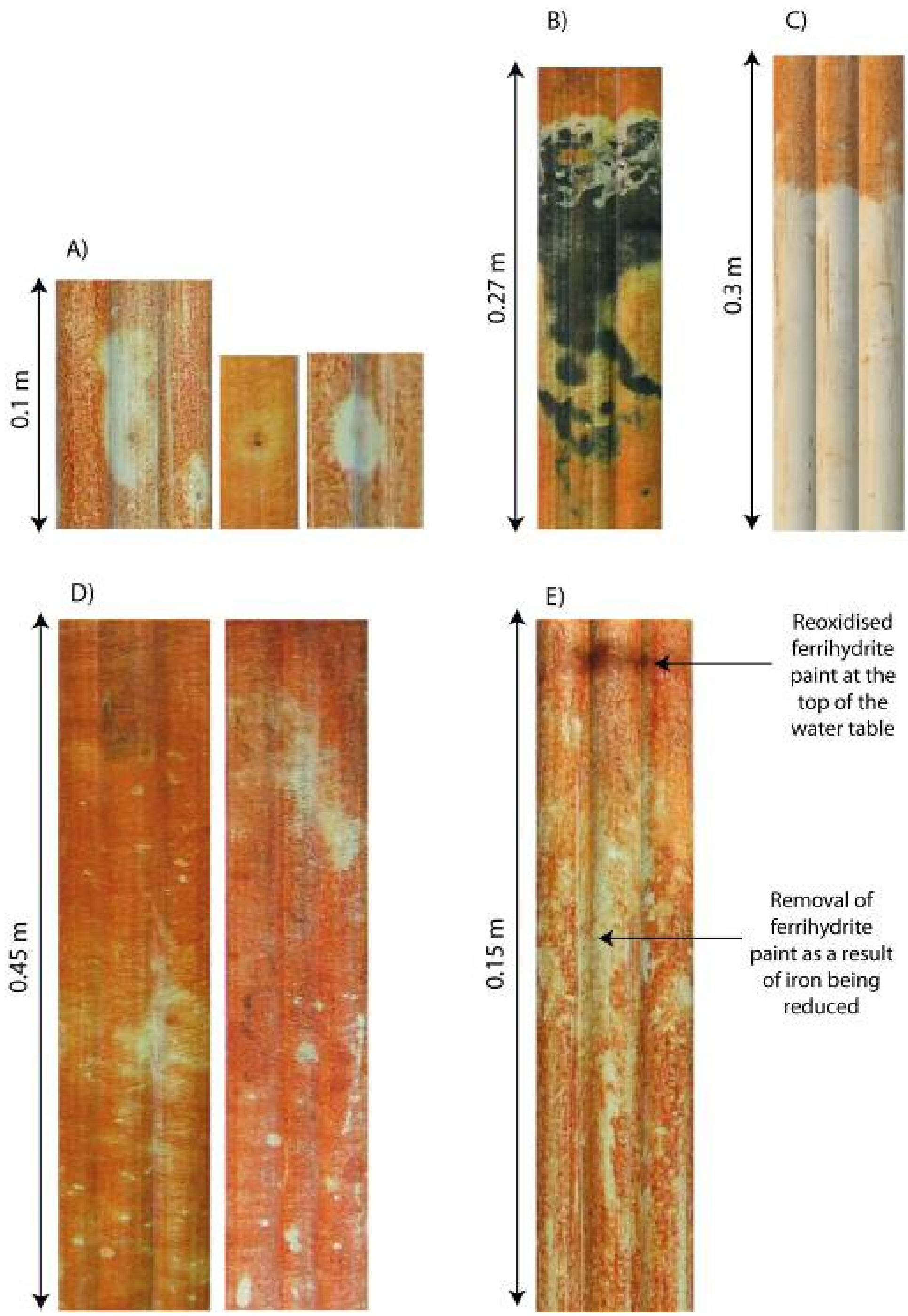


Figure 43 Patterns of paint removed from pipes in the current study A) circular or donut shaped, B) dark/black colouration, C) uniform, D) patchy and E) re-oxidised band of ferrihydrite paint.

3.1.4 Visual *versus* quantitive assessment of paint removal

A visual estimate of the percentage removal of paint is considered to be as adequate as a statistical analysis from imaging software (Rabenhorst n.d). As irregularities are always present across sites (e.g. paint being removed from installation, anomalies in applications of paint and so on) a visual estimate allows these marks to be discarded.

The inconsistent layering when applying paint to the PVC pipes causes difficulties in standardising colour limits (i.e. what has and has not been reduced) for imaging software to be accurately consistent across several pipes. A quantitative assessment using imaging software may be better standardised over time. However from the current study it is considered that the visual estimate of the percentage of paint removed is sufficient.

3.1.5 Conditions necessary for the reduction of iron

For the IRIS method to yield a positive result in the wetland, the test must be carried out in areas or at times when it is anticipated that the wetland soil will be reducing. This requires several conditions:

Saturation with water

Soil needs to be saturated with water for iron to be reduced. If water is flowing through a wetland, then the oxygen within the water will continue to act as the electron acceptor (Vepraskas 1998). Studies by Jenkinson & Franzmeir (2006) have found that little or no paint is removed when wetlands are moist and not saturated. This was apparent in the current study, most significantly at Carbrook Conservation Park (trials 4 and 5). At these sites the wetlands were not inundated at any time. The water table at trial 5 was high to begin with (0.05 m from the surface), however over the duration of the trial this dropped to below 0.5 m. As these wetlands appear to have appropriate conditions for iron to become reduced e.g. >8.5 per cent TC in the surface 0.1 m and suitable soil temperatures, it appears that the only limiting factor was the absence of saturation with stagnant water.

Organic carbon

A source of organic matter is required for iron to become reduced. Anaerobic microbes require organic carbon as an energy source. The lower the levels of organic carbon the longer it takes for a soil to become reduced (Jenkinson & Franzmeir 2006). A review by Dear & Svensson (2007) found that at least three per cent carbon is required in order for soils to become reduced after three days of saturation. Another study using the IRIS technique showed that there were greater rates of removal of ferrihydrite paint in soils which had 1.7 to 2.6 per cent of organic carbon than in soils with 0.5 to 0.7 per cent organic carbon (Jenkinson & Franzmeir 2006). Carbon levels in the current trials ranged 0.83 to 20.6 per cent TC (in the surface 0.1 m) and 0.5 to 8.4 per cent (in the subsurface 0.2-0.3 m). Where paint was removed from pipes, carbon levels were above 3.5 per cent TC. However, this was only at sites where there were also sufficient saturation levels for reducing conditions to occur.

A soil may be waterlogged for a long period of time but not become reduced if there is too little organic material (Vepraskas 1998). A study by Vepraskas & Wilding (1983) found that a soil (on a Texas coastal plain) which had <1 per cent organic matter was saturated from mid-February to early May before the reduction of iron occurred. This has implications for the effectiveness of the IRIS method in areas with low levels of organic material, particularly the wetlands in the arid and semi-arid environments in Queensland. A study by Bryant et al (2008) found that in the semi-arid and arid environments of Queensland, the average level of total carbon percentage (in the surface 0.1 m) in the saturated zone of 23 wetlands was 0.5. The IRIS method may be ineffective in Queensland wetlands with low levels of organic carbon because the soils would not become reduced even though the soil may be saturated or waterlogged long enough for wetland vegetation to establish.

Soil temperatures

Soil temperatures have a significant effect on the rate of microbial activity in soils. At biological zero (see glossary) (i.e. 5°C) microbial activity in the soil ceases (Tiner 1999). At lower temperatures longer periods of saturation are required in order for soils to become reduced. Reducing conditions have been know to occur in soils after two days, at soil temperatures of above 9°C, provided that the right conditions are present i.e. there is a source of organic carbon and the soil is saturated (Vaughan, Rabenhorst & Needleman 2009).

The greater study area for this trial is South East Queensland, a sub-tropical environment. Soil temperatures at Bribie Island (trials 1 and 2) have been monitored for the last two years, with temperatures not falling below 10°C (at a depth of approximately 0.7 m) at either site during the winter months. During the current IRIS trials the temperature of these soils did not fall below 13°C (Figure 44). It is therefore expected that temperature limitations to all the current IRIS trials were minimal. In areas where soil temperatures may drop below 5°C (temperate regions and areas with cold winter (e.g. southern inland Queensland) it is possible that soils would not become reduced (or only reduced after a long period of saturation) and that use of the IRIS method may be ineffective.

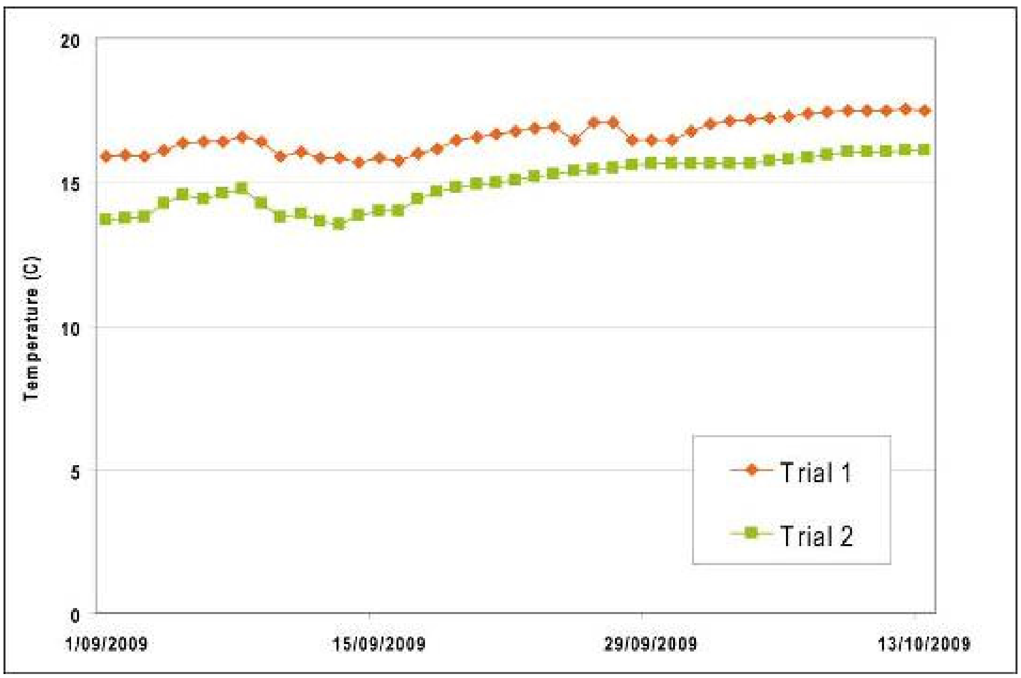


Figure 44 Soil temperatures at trials 1 and 2 (at approximately 0.7 m).

3.2 IRIS method enhancement for Queensland wetland soils

3.2.1 Installation methods

A comparison of two installation methods was completed across five trials (Table 16). The two methods were:

- Installation Method 1: An unpainted pipe of the same diameter as the painted pipe was placed in the soil, removed, and then replaced by a painted pipe (attempting to insert in one movement without rotating the pipe).

- Installation Method 2: An unpainted pipe of slightly larger diameter (internal diameter 19 mm compared with 17 mm for painted pipes) was placed in the soil and removed. The painted pipe was then inserted inside the larger pipe and pushed back in the soil. The outer (larger) pipe was removed leaving the painted pipe within the ground.

Bribie Island – Trials 1, 2 and 3

At Bribie Island, the sites with pipes installed using Method 2 were the coarse sanded pipes. The majority of these pipes had less paint removed compared to the pipes that were medium sanded. This however was a result of paint adhering more firmly to the coarse sanded pipes rather than a lack of contact with the soil.

The largest difference in paint removed between the two methods was at trial 2 (transition zone) (Table 16). Pipes which were installed using Method 2 were installed at a different time to ones using the first method. The water table had dropped significantly between these two trial times which caused the soil to remain moist but not saturated and hence the pipes had different quantities of paint removed.

Carbrook CP – Trials 4 and 5

There was no large difference in paint removal between the two installation methods at both trials. There was a similar percentage removal of paint across all trial durations/installation methods and pipes.

Table 16 The average percentage of paint removed from pipes (from the surface 0.3 m) between the two installation methods trailled.

	Average amount of paint removed (%)									
	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
Installation method	1	2	1	2	1	2	1	2	1	2
Saturated zone	85	65	80	75	80	85	10	20	0	2
Transition zone	10	10	20	2	75	80	0	0	0	0
Outer/transition zone	0	0	20	5	70	55	0	0	NA	NA

The use of Method 2 appears more effective in limiting the amount of paint that is removed upon installation, and is considered the preferred method from this study.

3.2.2 Duration of IRIS trails

The greatest difference in paint removal between the two trial periods (14 days and 28 days) were at sites which were either inundated or had water tables that remained at the soil surface throughout the trials. These were areas which were expected to be highly anoxic and in a reduced state. The difference in paint removed may be explained through the rates of microbial activity in soils over time and the level of saturation within a soil profile. Jenkinson & Franzmeir (2006) found that the rates of removal of paint from IRIS tubes increased significantly between days 15 and 24 and that this was due to microbial activity taking a number of days to gain momentum. An increased rate of microbial activity would be in response to anoxic conditions and complete saturation of soil profile.

There was no trend in removal of paint between the different trial periods at sites which were not inundated and where the water tables did not remain consistently high. These sites did not have large, uniform quantities of paint removed but still had evidence of reduced areas (patchy removal of paint).

The limiting factor of using a trial duration for fewer than 14 days is that the wetland does not have adequate time for microbial populations to multiply and the oxidation of organic matter to increase sufficiently. A longer time period of 14 days is required in order to gain a more accurate representation of the status of the wetland. Duration of trials should therefore be a minimum of 14 days.

3.2.3 Coarse *versus* medium sanded pipes

In the wetlands that were inundated (trials 1, 2 and 3) paint was substantially removed from both sets of pipes (medium and coarse sanded) to a similar degree.

The largest difference between the two sets of pipes was in environments that appeared to be only moderately reduced, had reduced areas occurring in sections throughout the soil profile or at sites that had high water table, but were not inundated. In trials 8 and 6 there is a large difference in the level of paint removed between coarse and medium texture pipes within the saturated zone (20 per cent and 75 per cent respectively for trial 8 and; five per cent and 20 per cent for trial 6). These wetlands were not inundated throughout the trial but had high water tables (at surface or within 0.3 m).

4 Conclusions and recommendations

4.1 Current methodology for identifying wetland soils in Queensland

From the current trials the IRIS method is able to indicate reduced conditions in soils. This test would be effective in providing an additional line of evidence to support the identification of wetland soils, particularly in situations where soil features are lacking or inconclusive.

Currently, wetland soils in Queensland are determined by assessment using a key against a various soil indicators (Figure 45). The IRIS method may be used as a surrogate indicator for hydrology, or water table heights, as it requires a saturated profile in order to reflect reducing conditions. The IRIS method would therefore be most effective in being able to provide evidence of a current hydrologic regime, particularly, to support the use of redox features (i.e. presence of mottles, segregations (iron and manganese), ferruginous root channel and pore linings, and decreasing matrix chroma) in identifying wetland soils.

Key to wetland identification using soil indicators

Part 1: Wetland soils

1) Is the soil an Organosol in the Australian Soil Classification*?

Yes .... Within wetland
No .... Go to 2

2) Does a P horizon occur within 0.3 m of the soil surface**?

Yes .... Within wetland
No .... Go to 3

Part 2: Wetland soil indicators

3) Which climatic region is the site in?

Tropical/Equatorial .... Go to 4
Subtropical .... Go to 4
Semiarid .... Go to 5
Arid .... Go to 5

4) Are organic materials present within 0.3 m of the soil surface and is the thickness of the organic materials layer at least 0.2 m?

Yes .... Within wetland
No .... Go to 5

5) Is there evidence of acid sulfate soils within 0.3 m of the soil surface?

Yes .... Within wetland
No .... Go to 6

6) Is there evidence of gleyed soil matrix colours in a horizon starting within 0.3 m of the soil surface?

Yes .... Within wetland
No .... Go to 7

7) Are redox features present within the 0.3 m of the soil surface?

Yes .... Go to 8
No .... Not a wetland soil

Part 3: Landscape features

8) Do the surrounding landscape features provide supporting evidence of a current hydrologic regime?

Yes .... Within wetland
No .... Insufficient evidence to identify a wetland soil

* Isbell (2002)
** P horizon as defined by Mcdonald *et al* (1990)

Figure 45 Key to wetland soil identification in Queensland (Bryant et al 2008).

4.2 Using IRIS to identify wetland soils in Queensland

4.2.1 Level of paint removal to demonstrate reducing conditions

In the majority of wetlands within the current study where there was evidence of reducing conditions (moderately or highly reduced) the average proportion of paint removed was between 10–15 per cent (within the surface 0.3 m). This was the average of all pipes installed at sites for the same duration. These areas were considered to be within the boundary of the wetland according to current Queensland Wetlands Program wetlands mapping (DERM 2009c) and from analysing other soil indicators found at each site. This was consistent across areas which were inundated and in areas where there were high water tables.

This figure is lower than what is currently utilised in the USA however this is not unexpected in an environment which is significantly drier and where organic matter levels are generally lower.

The season in which the trials were conducted (late winter to spring) was not the most likely time for wetland soils to display reducing conditions in SEQ. This may be reflected in an underestimate of the amount of paint that is required to be removed to provide evidence of a hydrologic regime. Taking a precautionary approach, it is recommended currently that the minimum average level of paint removed across all pipes installed at a site be 15 per cent (within 0.3 m of the soil surface) to support evidence of a wetland soil.

4.2.2 Guide to IRIS use in Queensland wetlands

A consistent guide to IRIS use is necessary if this is to be incorporated into management policies to assist in the identification of wetlands.

Transect sampling

To identify the boundary of a wetland and to capture the changes across the ecotone, it is recommended that transect sampling be used. Transects should traverse the margin of the wetland, travelling from the saturated zone (wettest or lowest lying area) to areas outside of the wetland. IRIS tubes should be installed at sites which have been previously described, using the *Soil Indicators of Queensland Wetlands: Field Guide* (Bryant 2008), so that the results can be assessed against the wetland soil indicators present at each site.

Pipe preparation

Paint should be prepared in order to have a mineralogical ratio of at least 30–40 per cent goethite for durability. The use of medium sand paper is recommended as this appeared to display the saturation level in the profile and hence reduced conditions at individual sites.

A method for preparing ferrihydrite paint and constructing IRIS tubes is outlined in Appendix C.

Installation and layout of pipes

A minimum of four pipes are required to be installed at each site. Pipes can be installed using one of two methods:

1. An unpainted pipe of the same diameter as the painted pipe is placed in the soil, removed, and then replaced by a painted pipe (attempt to insert in one movement without rotating the pipe).
2. An unpainted pipe of slightly larger diameter (internal diameter 19 mm compared with 17 mm for painted pipes) is placed in the soil and removed. The painted pipe is then inserted inside the larger pipe and pushed back in the soil. The outer (larger) pipe is then removed leaving the painted pipe within the ground.

Depending on the conditions at each site either of these methods may be adequate methods of installation. Installation Method 2 however effectively limits the amount of paint removed on installation.

Pipes needs to be evenly spaced across an area no more than 1–2 m^2 and installed on level ground (Figure 46). Where possible install pipes with the painted section completely underground. If this is not possible (e.g. impeded due to a rocky subsurface) install to the greatest depth possible and mark on the pipe the level of the soil surface for reference.

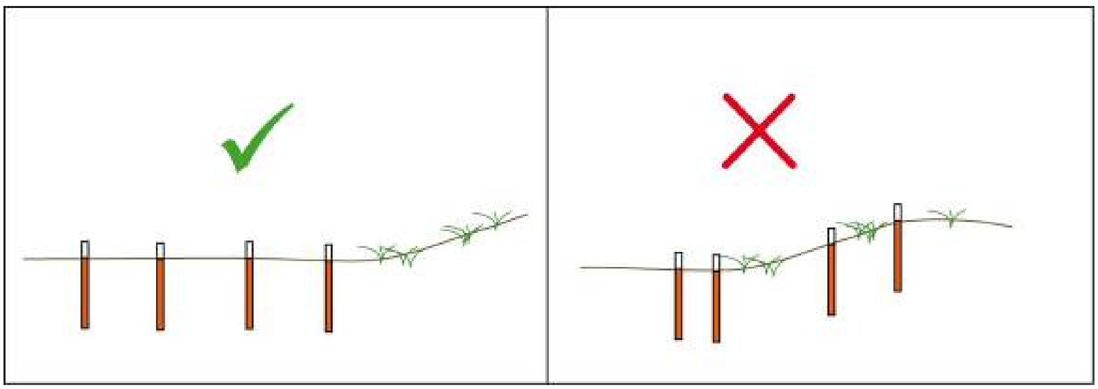


Figure 46 Correct installation of pipes (left), incorrect installation of pipes (right).

Duration

A test period of at least 28 days is recommended. This needs to be at a time when the wetland is likely to be in a reduced state and when the wetland is likely to be saturated for the longest continuous period of time. For wetlands that are seasonal this is during the wet season for that region. For ephemeral wetlands this cannot be predicted however this would be at a time when the wetland is saturated.

Analysis of paint removal

A visual estimate of paint removal using standard charts is recommended. At least two people are required to independently assess the pipes with the results averaged for each site.

An area over the entire surface of PVC pipe which has 15 per cent removal of ferrihydrite paint within 0.3 m of the soil surface is recommended as confirmation of reducing conditions, sufficient to support evidence of a wetland soil.

Proposed incorporation of IRIS method in wetland identification procedures in Queensland

This method can be utilised as an additional line of evidence to assist in interpreting soil features for wetland identification. It is proposed that the IRIS method, based on the research from the current study, be incorporated into the Part 2 of the *Key to Wetland Identification Using Soil Indicators* (Figure 47). At this stage it is not recommended that the IRIS method be utilised on its own to identify a wetland soil but in conjunction with other soil features at a site.

Key to wetland identification using soil indicators

Part 1: Wetland soils

1) Is the soil an Organosol in the Australian Soil Classification*?

Yes .... Within wetland
No .... Go to 2

2) Does a P horizon occur within 0.3 m of the soil surface**?

Yes .... Within wetland
No .... Go to 3

Part 2: Wetland soil indicators

3) Which climatic region is the site in?

Tropical/Equatorial .... Go to 4
Subtropical .... Go to 4
Semiarid .... Go to 5
Arid .... Go to 5

4) Are organic materials present within 0.3 m of the soil surface and is the thickness of the organic materials layer at least 0.2 m?

Yes .... Within wetland
No .... Go to 5

5) Is there evidence of acid sulfate soils within 0.3 m of the soil surface?

Yes .... Within wetland
No .... Go to 6

6) Is there evidence of gleyed soil matrix colours in a horizon starting within 0.3 m of the soil surface?

Yes .... Within wetland
No .... Go to 7

7) Are redox features present within the 0.3 m of the soil surface?

Yes .... Go to 8
No .... Not a wetland soil

8) Does the IRIS*** method indicate reduced conditions within 0.3 m of the soil surface?

Yes .... Within wetland
No .... Go to 9

Part 3: Landscape features

9) Do the surrounding landscape features provide supporting evidence of a current hydrologic regime?

Yes .... Within wetland
No .... Insufficient evidence to identify a wetland soil

* Isbell (2002)
** P horizon as defined by Mcdonald *et al* (1990)
*** Indicator of reduction in soil

Proposed incorporation of IRIS method

Figure 47 Proposed incorporation of IRIS method into key to wetland identification using soil indicators.

5 Summary

The IRIS method trialled in this project was adapted from the technique developed in the USA. The study has demonstrated that the IRIS method can indicate that soils are reducing and that this may assist with wetland identification.

Presently the IRIS method is not recommended to be used in isolation as a tool for wetland identification, but in conjunction with the *Key for Wetland Identification Using Soil Indicators* (Figure 47). It is recommended that the method be utilised in the following situations as an additional line of evidence to identify a wetland soil.

1. Sites where wetland soil features are lacking. This may occur:
   a. In transitional areas where soil indicators start to drop out of the soil profile.
   b. In areas where soils are naturally lacking in minerals (particularly iron–rich minerals) which form wetland soil features.
2. Sites where soil indicators described still require evidence of a current hydrologic regime in order to conclusively determine the presence of a wetland soil.

The IRIS test needs to be undertaken when a wetland is considered to be in a reduced state. Saturation with water, a supply of microbes, a source of organic carbon and suitable soil temperatures are required in order for the reduction of iron to occur. There are some situations in Queensland where these conditions will influence the application of the method. These are described below.

- There are implications to applying the IRIS method in wetlands in the semi-arid and arid regions of Queensland. These wetlands have a lower soil carbon levels than others in Queensland, and require longer periods of time to become reduced. Using the IRIS method in wetlands with a total carbon level of less than 1 per cent may not provide definitive results. The soils in these wetlands may never become reduced, regardless of whether they are saturated sufficiently for wetland vegetation to establish.
- The most important factor influencing the extent of reduction is the degree of saturation through the soil profile. Soils that were completely saturated or were saturated in parts of the profile had the largest removal of paint. Soils which were moist but not saturated had very little or no removal of paint. It is important to conduct the test in the season in which the wetland is the most likely to be saturated (e.g. in SEQ it would be appropriate to conduct the test at the end of the wet season in February). Conducting this test at a time in which the wetland is not saturated will not reflect the degree of reduced conditions.
- Microbial activity is lower in colder climates and ceases at biological zero (5°C). Soil temperatures in temperate regions or during winter seasons when the soil is likely drop below 5°C may impede the method being able to accurately reflect reduced conditions.

The time period for the IRIS test to be undertaken is at least 28 days in order to determine an assessment of reducing conditions. Microbial activity can increase over time and a shorter time period may not reflect the extent of this activity.

Soil types appear to have minimal direct effect on the IRIS method. They do however influence the rate of transmission of water through a soil. In clay-dominated soils water is transmitted slower and may allow water to pool and stagnate. In organic and sand-dominated wetlands water movement is faster which may influence the level of aerated water that flows through a wetland. Although not directly affecting the IRIS method, soil textures should be taken into consideration when interpreting results. The amount of paint removed and patterns of removal are more significantly influenced by the zone of saturation within a soil profile and not the soil type.

The variation in mineralogical composition of ferrihydrite paint may present issues when trying to standardise this method. In a reduced soil with a constant redox potential, using paint predominantly made up of ferrihydrite will show larger areas reduced compared to a paint mixture with higher goethite content. A standard composition is therefore necessary in order for this method to be used. According to

Rabenhorst, Bourgault & James (2008) and Rabenhorst & Burch (2006) a 40:60 ratio of goethite to ferrihydrite is optimal for durability and in indicating reduced conditions.

An area of 15 per cent over the entire surface of PVC pipe which has had ferrihydrite paint removed, within 0.3 m of the soil surface is recommended as confirmation of reducing conditions, sufficient to support evidence of a wetland soil. This value must be the average of at least four pipes installed at any one site. This maximum value of percentage paint removed in the current study that reflected reduced conditions. As more trials are conducted in the future it is expected that this figure will be revised and updated.

It is recommended that the IRIS method be incorporated into the *Key to Wetland Identification Using Soil Indicators* as a surrogate for demonstrating a current hydrologic regime, particularly to support the use of redox features (presence of mottles, segregations (iron and manganese), ferruginous root channel and pore linings, and decreasing matrix chroma) in identifying wetland soils.

Given the limited timeframe of this study and the variation that is commonly observed in wetlands, further testing of the method is required to develop this into a tool which can be utilised exclusively to identify Queensland wetlands. A more robust method requires further testing across differing climatic regions, wetland systems and types, to determine its robustness for Queensland conditions.

Appendix A Eh and pH

The oxidation and reduction of iron is dependent on the redox potential (Eh) and pH. Redox potential is measured in volts or millivolts and is an indication of the tendency of a chemical to acquire electrons. The higher a chemical's redox potential the more likely that it will accept electrons and become reduced. In the case of soils the chemical is the composite of minerals, water and organic material present at a particular point in time.

Fe^{2+} activity generally increases with decreasing Eh and pH. However at a certain Eh and pH of the soil, the solubility of Fe^{3+} decreases, which slows down Fe^{2+} activity. Anaerobic conditions can start to occur when the redox potential of the soil is approximately 300 mV (Reddy & DeLaurne 2008) (Figure 48). Soils are considered anaerobic if the redox potential at pH 7 is 175 mV or less (Figure 49).This line was developed for use in soils with a pH value between three and nine,across all soil textures and is currently used as one of the means to classify a soil as anaerobic in the Hydric Soil Technical Notes in the USA (USDA 2007).

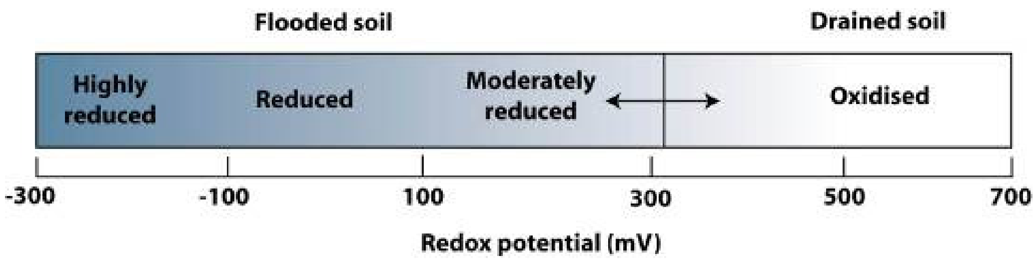


Figure 48 Redox potentials a drained and flooded soil (Adapated from Reddy & DeLaurne 2008).

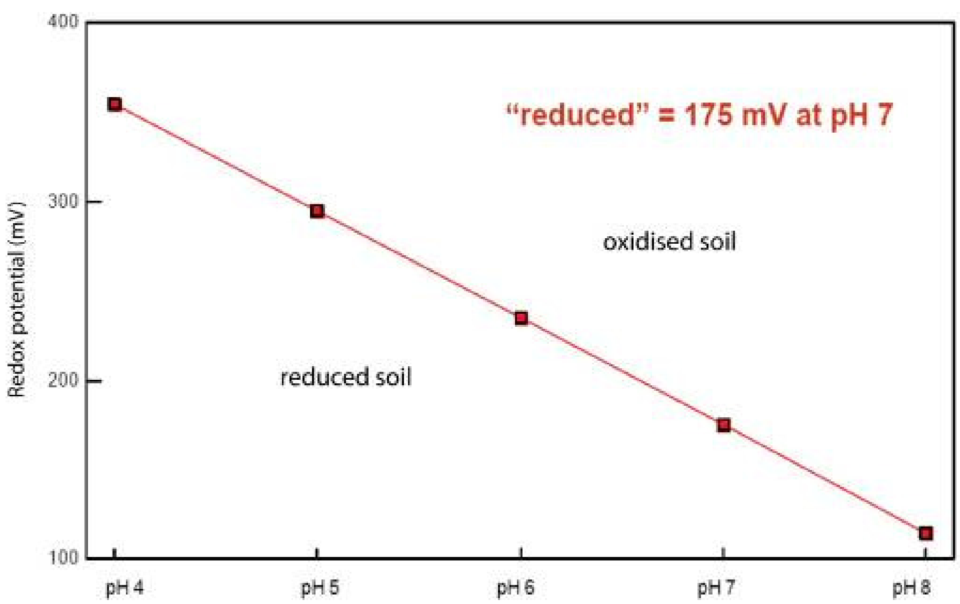


Figure 49 Eh/pH line for reduced soils (adapted from USDA 2007).

Appendix B Wetland sites list

Wetland	Trial number	Site number	Location			SALI ID*
			Zone	Easting	Northing	
Bribie Island	1	1	56	512707	7011849	WET15
		2	56	512716	7011837	WET16
		3	56	512437	7011912	WET18
Bribie Island	2	4	56	512520	7017727	WET22
		5	56	512329	7017738	WET23
		6	56	512021	7017686	WET24
Bribie Island	3	7	56	512019	7021561	IRIS1
		8	56	511579	7021699	IRIS2
		9	56	511419	7021732	IRIS3
Carbrook CP	4	10	56	526726	6937382	WET215
		11	56	526703	6937422	WET216
		12	56	526671	6937425	WET217
Carbrook CP	5	13	56	528235	6937656	IRIS4
		14	56	528245	6937671	IRIS5
		15	56	528233	6937687	IRIS6
Mooloolah River NP	6	16	56	510888	7044841	IRIS7
		17	56	510904	7044870	IRIS8
		18	56	510912	7044898	IRIS9
Mooloolah River NP	7	19	56	510062	7044645	IRIS12
		20	56	510064	7044649	IRIS11
		21	56	510047	7044689	IRIS10
Noosa NP	8	22	56	508991	7071743	IRIS13
		23	56	509002	7071740	IRIS14
		24	56	509020	7071735	IRIS15
		25	56	509040	7071726	IRIS16

** Soil and Land Information database.*

Appendix C Synthesis of ferrihydrite paint

Martin C Rabenhorst (2006)

Dissolve 16 g of anhydrous $FeCl_3$ in 0.5 L of distilled water (approximately 0.2 M) in a 2 L beaker. Add a magnetic stir bar and place on a magnetic stirrer. The initial pH of this solution will be approximately 1.6. While stirring, monitor the pH as you add approximately 370 mL of 1M KOH until you reach a pH of 12 (use pH buffers of 7 and 10 (or higher) to standardise the pH meter rather than 4 and 7). At around pH 4, the Fe oxides will begin to precipitate rapidly and the suspension will become very thick. You will need to speed up the stir bar and continue to adjust it in order to maintain a stirred suspension. Continue adding the KOH until the pH reaches 12.0, adding it more slowly and carefully as you approach the final pH. Allow the suspension to stand for approximately 30 minutes, then restart the stirring and check the pH. If it has dropped below 12.0, add additional KOH drop-wise to bring it back to the target pH. The total volume of suspension should be approximately 900 mL.

Transfer the suspension equally into four 250 mL nalgene bottles and centrifuge at approximately 1000 rpm for five minutes to concentrate the Fe oxides. Discard the supernatant. Transfer the contents of the four tubes into two 250 mL tubes and centrifuge wash the precipitated Fe oxide two times with distilled water, discarding the supernatant each time.

After the third centrifugation, re-suspend the Fe oxides with distilled water and transfer to dialysis tubing. Place the dialysis tubing into basins filled with distilled water and replace the water at approximately 6 hr intervals during the first day and then at approximately 12 hr intervals for a total of three days. Transfer the Fe oxides from the dialysis tubing to a nalgene storage bottle and keep in the dark. The suspension should be suitable for painting IRIS tubes approximately one week (seven days) after the initial synthesis of the Fe oxides (this will vary based upon a number of factors including laboratory and storage temperature).

To get the paint to the right consistency, place the paint in a 250 mL centrifuge bottle and centrifuge at approximately 1000–1500 rpm for approximately five minutes. After centrifugation, decant the supernatant so that there is approximately the same volume of supernatant as the volume of the Fe oxide cake at the bottom of the bottle. Then thoroughly re-suspend the Fe oxide and the paint should be at approximately the correct consistency for painting tubes.

Paint is applied to the tubes (half inch schedule 40 PVC that has been cleaned with acetone to remove ink and lightly sanded with very fine sandpaper) using a two inch foam brush while the tube is spun using a cordless drill (typically we use 60 cm tubes and paint the lower 50 cm). Before painting a large number of tubes, be sure to test the paint by painting one or two prepared PVC IRIS tubes and allowing the paint to dry overnight. If the paint on the tubes is resistant to abrasion (does not rub off easily on your fingers) then proceed to paint and prepare IRIS tubes.

Once the paint has been tested, it should be stored in the refrigerator to minimise mineralogical alteration over time (Rabenhorst & Burch, 2006). Approximate shelf life when stored cold (refrigerated) is a couple of months. Tubes that have been painted have a long shelf life (a year or perhaps even up to several years) as long as they are kept dry.

Appendix D pH codes

(Hazelton & Murphy 2007)

pH	Ratings
>9.0	Very strongly alkaline
9.0-8.5	Strongly alkaline
8.4-7.9	Moderately alkaline
7.8-7.4	Mildly alkaline
7.3-6.6	Neutral
6.5-6.1	Slightly acid
6.0-5.6	Moderately acid
5.5-5.1	Strongly acid
5.0-4.5	Very strongly acid

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