

AN EVALUATION OF THE SOILS OF TILLEY SWAMP AND MORELLA BASIN, SOUTH AUSTRALIA

Richard H Merry and Robert W Fitzpatrick

CRC LEME OPEN FILE REPORT 195

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For South Australian Department of Water, Land and Biodiversity Conservation



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Cover Photograph:

Description: View looking east across Tilley Swamp with *Melaleuca halmaturorum* vegetation on the left and cleared land on the right.

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(Ms Penny Everingham)

CRC LEME/CSIRO Land and Water Client Report

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Executive Summary

This report aims to evaluate the soils of Tilley Swamp and the Morella Basin, north-east of Kingston in the South-east of South Australia in order to:

- determine the baseline physical/chemical condition/characteristics of soils/sediments at the Tilley Swamp watercourse prior to water storage;
- identify the presence of impermeable subsoil barriers;
- predict the possible affects to soil condition as a result of water retention for seasonal and yearly sequential water storage and assess the historical condition of soil materials (eg; watercourse inundated 2 years in 5);
- assess the likely extent and effects of sodicity to the soil as a result of water retention;
- assess the potential for acid sulfate soils;
- advise the appropriate wetting/drying regime for the Tilley Swamp soil type(s) and the subsequent associated risks to native and productive vegetation;
- identify appropriate mitigation strategies for identified risks; and
- advise an appropriate monitoring program to measure impact or change to the Tilley Swamp watercourse as a result of water retention and subsequent changes to soil condition.

Soils were inspected and sampled in some detail at 26 sites and analysed for chemical, mineralogical and some physical properties.

The samples obtained in this survey should provide an adequate baseline for soil condition in the Tilley Swamp watercourse. Recorded locations and long-term storage of the samples will allow for future re-sampling and analysis, if required.

Several kinds of impermeable barriers, or barriers restricting downward movement of water or root development, exist in Tilley Swamp. Massive calcretes occur on the eastern side and around the margins of the potentially inundated area. However they can be discontinuous and undulate over distances of tens to hundreds of metres and are almost certainly cracked and not completely confining. Wet, reduced clays, which will restrict downward water movement, underlie much of Morella Basin and the western side of Tilley Swamp. These features will also restrict root development, as will dense, compacted (dry) subsoils observed in Tilley Swamp.

The soils of the area are already saline and sodic, and have been so for a long period of time. Much of this condition is attributable to the proximity of the water table to the soil surface, and therefore extended inundation is unlikely to have a significant effect on future soil condition. *The effects of accession of fresher water or water of significantly different ionic composition for different periods, potential soil leaching and evaporative concentration will require geochemical modelling.*

If the cation and anion composition of groundwater and drain water remain approximately the same as at present, a change in soil sodicity would not be expected.

Although there is evidence of some acid production near the top of the reduced water table, the acid is likely to be rapidly neutralised in this highly alkaline, calcareous

environment. Monosulfides in drains may be mobilised by increased flows, and its main effect is likely to be rapid de-oxygenation of the drain waters.

In the natural state, the soils and mature plants of this environment are adapted to inundation. However, the pasture plants of the agricultural areas in Tilley Swamp are not adapted and will not survive any prolonged inundation. A wetland plant specialist should be able to advise on this situation.

The main risks of water storage in Tilley Swamp watercourse (Morella Basin and Tilley Swamp) are:

- Increased salinisation of soils if drain water is stored in the southern portion of Tilley Swamp which is less saline than the northern area;
- De-oxygenation of inundated soils that contain a high organic matter content.

Both these risks exist naturally in these environments. To mitigate these risks it is important to manage large areas of standing water during the hotter parts of the year when evaporation rates are high.

A future monitoring program should include:

- Confirming the distribution of inundation waters;
- Occasional re-sampling and analysis of soils;
- Continuous data logging of redox probes during an inundation event if further understanding of the reducing conditions is required;
- Checking the composition of salt efflorescences and monosulfidic oozes as indicators of environmental change.

Table of Contents

1. Introduction.....	1
2. Background and Methodology.....	1
2.1. Background	1
2.2. Brief description of landscape and soils	2
2.3. Field work	2
2.4. Laboratory treatment and analyses.....	6
2.4.1. Soil analysis methods.....	6
2.4.2. X-ray Diffraction analysis.....	7
2.4.3. Geochemical analysis.....	7
2.4.4. Chromium reducible sulfur	7
3. Results and Discussion	8
3.1. Determine the baseline physical/chemical condition/ characteristics of soils/sediments at the Tilley Swamp watercourse prior to water storage	8
3.2. Identify the presence of impermeable subsoil barriers.....	8
3.3. Predict the possible affects to soil condition as a result of water retention for seasonal and yearly sequential water storage and assess the historical condition of soil materials (eg, watercourse inundated 2 years in 5)	11
3.4. Assess the likely extent and effects of sodicity to the soil as a result of water retention	13
3.5. Assess the potential for acid sulfate soils.....	14
3.5.1. Sulfidic materials adjacent to drains.....	14
3.5.2. Monosulfidic black ooze in drains.....	17
3.5.3. Sulfate-containing salt efflorescences.....	19
3.5.4. Elevated metal concentrations	21
3.6. Advise the appropriate wetting/drying regime for the Tilley Swamp soil type(s) and the subsequent associated risks to native and productive vegetation	21
3.7. Identify appropriate mitigation strategies for identified risks	22
3.8. Advise an appropriate monitoring program to measure impact or change to the Tilley Swamp watercourse as a result of water retention and subsequent changes to soil condition.....	22
3.8.1. Recommended actions for soil observations during and following the first period of inundation	23
3.8.2. Recommended actions in long term after several periods of water retention	23
4. References	24
5. Appendices	25

1. Introduction

As a result of the Upper South-East Dryland Salinity and Flood Management Program in South Australia and the restriction on the release of these drainage water to the Coorong at Salt Creek, there is expected to be an occasional need to impound water following periods of excessive flow. The occurrences of impoundment are expected to be irregular and water cover may exist for periods of months to in excess of one year.

Since there is no specific information available that relates to the effect of impounding saline drainage water on the soils of the area, this report aims:

- to determine the baseline physical/chemical condition/characteristics of soils/sediments at the Tilley Swamp watercourse prior to water storage;
- to identify the presence of impermeable subsoil barriers;
- to predict the possible affects to soil condition as a result of water retention for seasonal and yearly sequential water storage and assess the historical condition of soil materials (eg; watercourse inundated 2 years in 5);
- to assess the likely extent and effects of sodicity to the soil as a result of water retention;
- to assess the potential for acid sulfate soils;
- to advise the appropriate wetting/drying regime for the Tilley Swamp soil type(s) and the subsequent associated risks to native and productive vegetation;
- to identify appropriate mitigation strategies for identified risks; and
- to advise an appropriate monitoring program to measure impact or change to the Tilley Swamp watercourse as a result of water retention and subsequent changes to soil condition.

2. Background and Methodology

2.1. Background

There has been very little published soil information relevant to the Tilley Swamp region covered in this report. Blackburn (1952) of CSIRO Division of Soils completed a survey of the Kingston-Avenue drainage area, part of which abuts the study area immediately to the south of Petherick Road. His report is relevant to the Tilley Swamp area because he describes the interdune soils, lunettes and land 'islands' (ie, land that is not flooded with the rest of the interdune and are usually remnants of a smaller calcareous dune line running parallel to and between the main dune ranges, all of which trend north-north-west). There are limited soil analytical data available with this report, archived by CSIRO in Canberra, but they use different methods of chemical analysis from those used today.

The DWLBC Land Resource Information Group has mapped the area of interest in some detail. Soils and attribute maps of the study area were made available by DWLBC Land Resource Information. These maps are based on 1:40,000 aerial

photography ground truthed with field observation in the study area, but the original field observation data were not available for this report. The area is described wholly by the Tilley Swamp (TIS) Land System. Soil profiles described and characterised by DWLBC and which may relate to this area, but are not within it, are SE032 to SE036 and SE075. Profiles SE075 (calcareous loam over calcrete and reduced materials) and SE034 (wet saline soil) were the profile types most similar to those encountered in this study.

2.2. Brief description of landscape and soils

The study area was defined from the digital elevation model provided by DWLBC (Figure 1). The area that could potentially be flooded was indicated by using GIS to “flood” the area from a base level of 2 metres to 5.7 metres AHD in 30 cm intervals (Figure 2). Although Morella basin began to “fill” from the 2 metre height, flooding of Tilley Swamp did not occur until flood heights greater than 4.2 metres were reached, though this assumes progressive filling from the northern end.

Drains have been constructed through both Morella Basin and on the eastern margin of Tilley Swamp. In Morella the drain is a little to the east of the centre line while in Tilley Swamp, the main drain is mostly to the extreme eastern side of the interdune flat although there are natural and (shallow) constructed drainage lines closer to the western side of the interdune flat.

Marginal to the “swamp” and on the above-mentioned “islands”, soils are formed on relict coastal dunes, usually (shallow) sandy on calcrete with some deep sand and sandy loam over clay texture contrast soils. The low-lying, interdune flat soils are usually saline, especially so in the Morella Basin to the north of the land system with little vegetation except samphire. These soils contain smectitic clay at depth (Appendix Table A6). A much larger area to the south in Tilley Swamp proper is less saline and supports (often very dense) *Melaleuca halmaturorum*, cutting grass (*Gahnia* sp.) and some native grasses, or is cleared grazing land. *Melaleuca halmaturorum* can use ground water saltier than seawater (52 dS m⁻¹) (Denton & Ganf, 1994). All soils in the areas surveyed are calcareous and many are highly calcareous (> 50% CaCO₃).

DWLBC attribute maps, based on field observation, indicate that the western part of the Tilley Swamp interdune (ie, west of the small “range” that almost bisects the interdune for much of its length) differs in several respects from the interdune to the east of this range. Soils to the west are generally more loamy (less sandy) have less hard calcrete and have water tables standing above the soil surface for longer periods (3 to 10 months) of the year.

The whole area has soil salinity related to the saline groundwater table, though we also found evidence of water perched on calcrete and some clayey layers immediately above the calcrete. Many calcrete layers had laminations on the upper surface suggesting perching, dissolution and precipitation of carbonate. Surface drainage of the interdune flats is poor for both of these reasons resulting in high susceptibility to seasonal and permanent waterlogging (especially in Morella Basin) and flooding.

2.3. Field work

The selection of sampling and inspection sites for this study planned to cover at least five cross sections of the interdune flat at Morella in the north to north of Petherick Rd in the south, though this would depend on field access. Field activities took place

during the week beginning 30th May 2005 following a prolonged dry spell, although some surface soil layers were damp from rain showers. Access to some areas was restricted by the inability to cross the drain, which was full, and surface water in Morella Basin and by the dense *Melaleuca* scrub in much of Tilley Swamp. Access to the latter was restricted to tracks and walking into the scrub.

Twenty-six sites were inspected in detail (Figure 1; GPS locations Appendix Table A1) though soil samples were not taken from all. Many other locations were inspected and where available, drains, cuttings and eroded areas were used. Soil pits were hand dug, where possible, and augered to obtain deeper samples. The depth of sampling was often restricted by calcrete or hard carbonate or in a few instances by the watertable. Soil materials were sampled in bulk or small samples retained in chip trays. Detailed sampling was made of salt efflorescences, iron oxyhydroxides, hard carbonates, black monosulfides and reduced subsoil materials for mineralogical analysis.

Brief morphological descriptions of materials collected (Appendix Table A2) were conducted according to the Australian Soil and Land Survey Field Handbook (McDonald *et al.*, 1990). Soil morphological descriptors such as colour, mottling, consistency, cementation, texture, structure, concentrations/segregations of materials or fragments (e.g. carbonates and ironstone), abundance of roots/pores and reaction (or fizz) to 1 N HCl are useful properties for soil identification. Soil colour was determined on either moist (m) or dry (d) samples using Munsell Soil colour notation (Munsell Soil Color Charts, 1994) (Appendix Table A2). Soil colour is usually the first property recorded in a morphological description of soils (and may be the only feature of significance to a layperson) and provides an indicator of redox status because soil colour relates to soil aeration and organic matter content (Fitzpatrick *et al.* 1999).

A few measurements were made in the field. At site TS24, drain water had a pH of 8.4 and EC of 13.7 dS/m. Black mottles in the soil at the water's edge (~ 195 cm from soil surface) had a redox potential (redox or Eh, corrected to standard hydrogen electrode) of – 60 millivolts (mV). This low value (oxidised environments have Eh values of +400 to +600 mV) indicates that sulfate will be reduced to sulfide. At 30 cm from the water's edge, this increased to +135 mV. Both Eh measurements would be regarded as normal for these reduced soil materials.

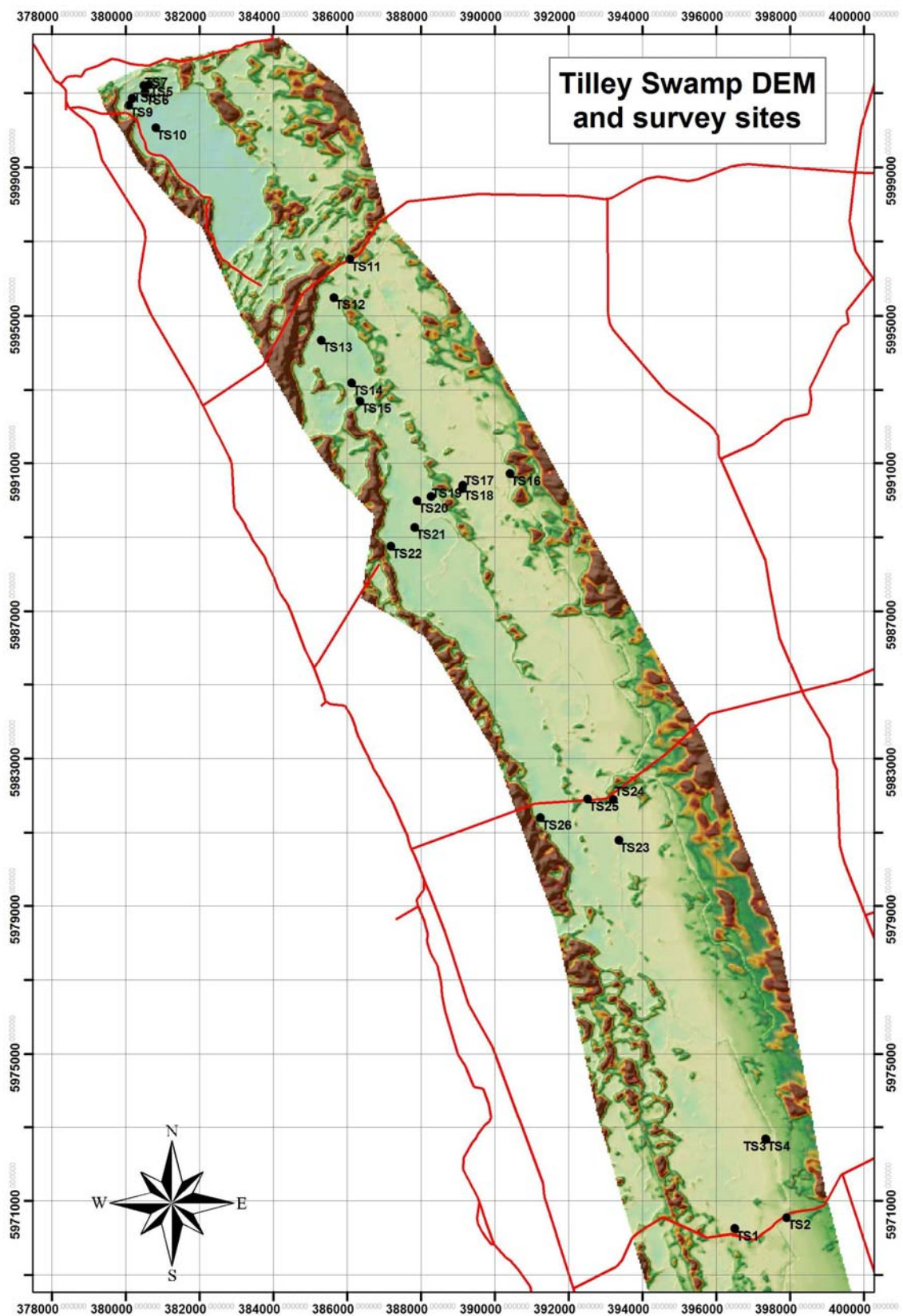


Figure 1. Tilley Swamp and Morella Basin (northernmost part of interdune) showing the topography and soil sampling sites.

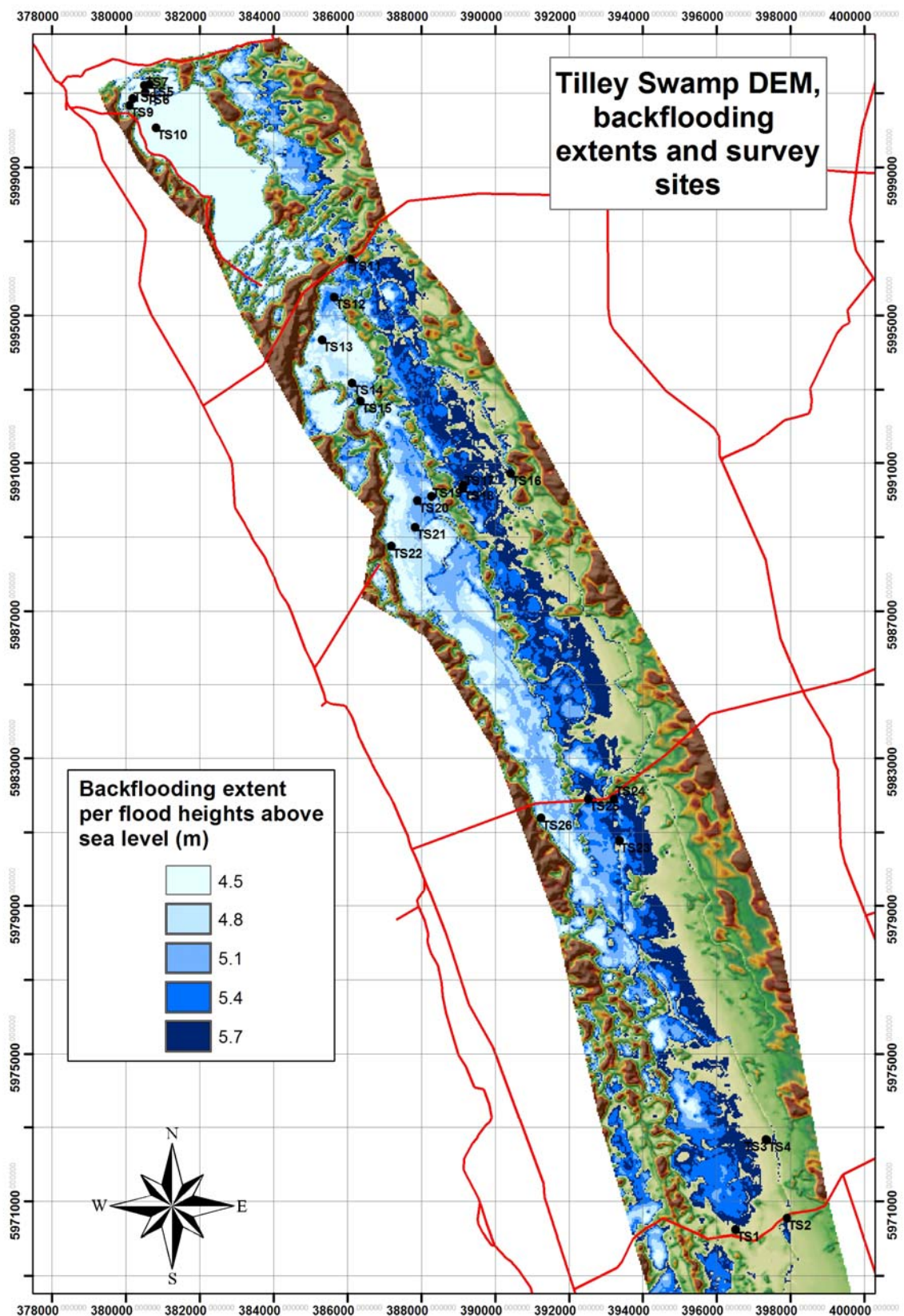


Figure 2. Flood level extents (the base level is 2 m). Soil sampling sites are also shown.

2.4. Laboratory treatment and analyses

Upon return to the laboratory, soil colours were recorded for the sampled state and the bulk materials briefly described (following McDonald *et al.*, 1990; Appendix Table A2) then air-dried in a forced draught oven at 40°C, crushed and passed through a 2 mm sieve. Material greater than 2 mm was inspected (mostly coarse shell fragments, complete shell or coarse organic matter), and proportions recorded. Reduced, sulfidic materials were sub-sampled and frozen for chromium-reducible sulfur (S_{cr}) analysis.

The following analyses were performed using the standard methods of the Analytical Chemistry Unit, CSIRO Land and Water, Urrbrae, from which division details of the analytical methods can be obtained.

1:5 soil water extracts: pH, EC, Cl^- , soluble cations and anions by ICPAES; all bulk samples (83).

Saturation extracts: analyses as for 1:5 extracts; 26 samples.

Calcium carbonate equivalent: 26 samples.

Total carbon and sulfur: 22 samples.

Chromium reducible sulfur (S_{cr}): 8 samples.

X-ray diffraction mineralogical analysis: 13 samples.

X-ray fluorescence elemental analysis: 10 samples.

The methods used are summarised below and results of these analyses are presented in the Appendix Tables 3 to 7.

2.4.1. Soil analysis methods

Sample preparation and moisture: A sub-sample was dried at 40°C, then crushed and sieved through a 2 mm sieve to prepare an air-dry, <2 mm sample for further analysis. Where needed, the moisture content was calculated from the measured weight loss on drying a weighed, representative sub-sample of the as-received soil sample at 105°C.

Electrical conductivity ($EC_{1:5}$): A 10 g sub-sample was placed in a screw cap container, 50 ml water added and the suspension shaken for one hour (1:5 soil:water ratio). The electrical conductivity was measured after calibrating the conductivity meter using 0.1M KCl (12.9 dSm⁻¹; Method 2B1; Rayment and Higginson (1992)).

pH_{1:5}: The pH meter was calibrated using pH 7.00 and pH 9.00 buffers. The pH was measured on the same suspension as used for EC (Method 4A1; Rayment and Higginson, 1992).

Soluble cations and anions: 10 mL of solution was extracted from the 1:5 soil solution extracts following the EC measurements, filtered through an 0.45 µm filter and ions measured using ICPOES and the chloride method indicated below.

Chloride: Cl was measured colorimetrically on soil and saturation extracts using Method 5A2 (Rayment and Higginson, 1992)

Calcium carbonate equivalent: Sub-samples (1 to 2 g) of soil and pure calcium carbonate were analysed by adding HCl and measuring CO₂ gas pressure in a glass vessel using a pressure transducer following a slightly modified method after Sherrod *et al.* (2002). Results for inorganic carbon are expressed as calcium carbonate equivalent.

Total carbon and sulfur: Total C and S were measured using a Leco CS analyser.

Organic carbon: The organic carbon content was calculated by subtracting the inorganic (carbonate) carbon from the total carbon.

Saturation extracts of whole soil were obtained and EC, Na, K, Mg, Ca, Sr, Cl and S were determined by ICPOES (Rayment and Higginson, 1992) and the chloride method mentioned above. Sodium adsorption ratios (SAR) were calculated according to Rayment and Higginson (1992, p.192).

2.4.2. X-ray Diffraction analysis

Samples were ground in an agate mortar and pestle and lightly pressed into shallow aluminium sample mounts for X ray diffraction (XRD) analysis (Appendix Table A4).

XRD patterns were recorded with a Philips PW1800 microprocessor-controlled diffractometer using Co K α radiation, variable divergence slit, and graphite monochromator diffraction patterns were recorded in steps of 0.05° 2 θ with a 1.0 second counting time per step, and logged to data files on an IBM-compatible PC for analysis. Mineralogical compositions for all soil samples are summarised in Appendix Table A6.

2.4.3. Geochemical analysis

The samples were analysed by X-ray fluorescence spectrometry (XRF) at CSIRO for: (i) major elements and some trace elements (SiO₂, Al₂O₃, Fe₂O₃, MnO, MgO, CaO, Na₂O, K₂O, TiO₂, P₂O₅, Cl and Zr) on fused borate glass discs and (ii) trace elements using pressed powder samples. These results are presented in Appendix Table A7.

2.4.4. Chromium reducible sulfur

Methods for analysing soil samples to assess acid sulfate generation potential are given in Ahern, McElnea and Sullivan (2004), which includes the chromium reducible sulfur (SCR or Scr) (Method Code 22B).

3. Results and Discussion

Results and Discussion are presented here in terms of the aims of this report as shown in the Introduction.

3.1. Determine the baseline physical/chemical condition/ characteristics of soils/sediments at the Tilley Swamp watercourse prior to water storage

The soil sampling carried out in this project should be sufficient to provide some idea of a baseline condition for soil. GPS locations of sampling sites (Datum AGD66, Zone 54, UTM projection) are shown in Appendix Table A1. Analytical technologies change over time. As the condition of Tilley Swamp may also change over time, it is important that the soil samples relating to this study are archived and made available should matching samples be taken at some future date. The samples will be stored in the CSIRO Land and Water soil store in the Plant Sciences building at Urrbrae.

The recorded chemical and mineralogical condition is outlined below and in the Appendix Tables A2 to A7.

Key Finding:

- The samples obtained in this survey provide an adequate baseline for soil condition in the Tilley Swamp watercourse.
- Recorded locations and long-term storage of the samples will allow for future re-sampling and analysis, if required.

3.2. Identify the presence of impermeable subsoil barriers

There are potential barriers to vertical (upwards *and* downwards) penetration of water and plant roots. Calcretes were frequently encountered, though inspection of exposures in drains indicates that they are not continuous and can be expected to have cracking. In many cases there appears to be an increase in clay content of soil, sometimes 30 cm thick and reduced above the calcrete, and soils are usually saturated and more clayey below the calcretes, though there will be some variability. Saturated, saline clays restrict the downward movement of overlying water. If overlying water becomes fresh, the sodic clays, which are present at the high salinities and sodium adsorption ratios (SARs) observed, will disperse and clog existing pores, further restricting water movement. The presence of bleached soil above calcretes indicates that water commonly perches on the existing calcretes and clays.

Calcretes appear to be common in the eastern side and at the margins of Tilley Swamp, and at the margins of Morella Basin. They are usually encountered at depths from about 30 and 120 cm and occur where the soil profile is drier, or usually dries out seasonally. In situations where water stands for long periods or the surface is within capillary reach of groundwater, as in Morella Basin and the western side of Tilley Swamp, no hard calcretes were encountered within the top 120 or so centimetres. These wet soils may have coarser textures with much calcium carbonate in their upper layers, overlying heavy, smectitic clay. The heavy subsoil clays are usually wet and reduced and likely to have low rates of transmission of water.

Observation of soils supporting cutting grass and melaleuca showed some differences in rooting patterns. The cutting grass typically explored the upper soil layers to calcrete (Figure 3). Melaleuca root distributions show distinct restrictions over much of Tilley Swamp with a concentration in the top 10 to 15 centimetres. Since this plant is tolerant of high soil salinities, which are frequently highest at the soil surface and the distributions are not explainable by sodicity or soil chemistry, it is probable that restriction in rooting depth in this plant is due to very hard (high bulk density) subsoil or seasonal waterlogging that results in anoxic conditions. Bulk density measurements were not made, but physical resistance to augering and crow bar indicates that a high density soil restriction is likely and may be the result of



Figure 3. Root system of *Gahnia* sp. over calcrete at Site TS23. The roots appear to show little restriction and leave dark areas of organic matter accumulation.

carbonate cementing – the calcium carbonate content is greater than 80% by 20 cm at Site TS 18 (Figure 4).

If the iron-rich layer observed in profile TS2 (see Figure 8) forms more extensively and hardens more with drying, it is likely to become a barrier to both water and roots,

though some small roots were observed in it. This layer forms as a result of oxidation of reduced iron at the upper surface of the groundwater table and is not believed to be extensive at present.

Much of the lower-lying soil surface of Morella Basin is covered by a layer of soil 1 to 3 cm thick (Figure 5), which appears to be of slightly coarser texture than that underlying, have organic matter layers and probably some more clayey sub-layers. It is likely to have been more recently deposited. This layer is moist or wet and may prevent surface water infiltration or cause shedding of rain and entrained salts to lower-lying soil surfaces.



Figure 4. Melaleuca roots form a near-surface mass with few deeper than 20 cm (Site TS18).

Key Findings:

- Several kinds of impermeable barriers, or barriers restricting downward movement of water or root development, exist in Tilley Swamp.
- Massive calcretes occur on the eastern side and around the margins of the potentially inundated area. However they are discontinuous and undulate over distances of tens to hundreds of metres and are almost certainly cracked.
- Wet, reduced clays, which will restrict downward water movement, underlie much of Morella Basin and the western side of Tilley Swamp. These features will also restrict root development, as will dense, compacted (dry) subsoils observed in Tilley Swamp.



Figure 5. The surface soil layers 2 to 5 cm thick common on Morella Basin. The surface is covered by an organic filament (algal?) and small shells. (Site TS10.)

3.3. Predict the possible affects to soil condition as a result of water retention for seasonal and yearly sequential water storage and assess the historical condition of soil materials (eg, watercourse inundated 2 years in 5)

There are likely to be several consequences of water retention, but in the long-term, these effects may not differ greatly from natural processes that have existed historically in the interdune area, though it is probable that inundation waters may have been fresher in the past. See also the sections below on sodicity and potential acid sulfate soils.

The current drain water analyses (DWLBC data) indicate a Langelier Index of 1.2, and high magnesium (Mg), sodium (Na) and sulfate (SO_4^-) concentrations (Appendix Table A3; Morella Basin and Water Valley drains). A positive Langelier Index indicates that carbonate minerals (of calcium (Ca) and Mg) will precipitate from the impounded water. As well as cementing of soil materials with carbonate, there will be an increase in the already high (26) value for sodium adsorption ratio (SAR: related to exchangeable sodium percentage (ESP) in soils).

The cation and anion concentrations of 1:5 soil:water extracts was determined for 83 soil samples (Appendix Table A4) and of saturation extracts, total C and S, and inorganic C as calcium carbonate in a subset of soil samples (Appendix Table A5). The 1:5 and saturation extracts provided consistent results. If the concentration of these elements in drain waters (Morella Basin and Water Valley at Petherick Rd were used) are indicative of flood waters, these characteristics can be compared with the data from the 1:5 water extracts. Comparisons were made of soil extract cation and anion ratios, using Mg as an indicator (divisor) element. It is not known for certain

whether the characteristics of the drain waters are indicative of historical surface waters that may have flooded the area, but should be representative of ground waters. Changes in both concentration and relative amounts are to be expected, the former through evaporative concentration or rainwater dilution and the latter through the precipitation and formation of less soluble minerals, such as calcite.

Although there is some variability, the 1:5 water extracts suggest that:

- a) The southern end of the area, around Petherick Rd, is less saline than further north,
- b) Most soils show evaporative concentration of salts at or near the surface and (less so) near the watertable surface,
- c) Surface soils in and near drains often reflect the anion and cation ratios of drain water as do deeper subsoils (about 1 metre or more). Monovalent cations (Na, K) and anions (SO_4^- , Cl^-) are often more concentrated relative to Mg in other soil layers, and
- d) SAR values indicate that sodicity tends to be similar to that of the drain waters (20 to 25) and where sampled soils were moist from the proximity to groundwater. Sodicity usually increases in soil layers not moist from drain and groundwater.

These results confirm the expectation that soil condition with respect to the kind and concentration of salts should follow that of future inundation water. If these waters are not significantly different in composition from current drain waters, it is probable that the soil environment will remain similar to its current state. *The effects of accession of fresher water or water of significantly different ionic composition for different periods, potential soil leaching and evaporative concentration will require geochemical modelling.*

As discussed below, the high organic matter content of many of the soils under melaleuca is likely to result in rapid development of anoxic soil condition and reduction. This is a natural process.

Soil analysis by XRF (Appendix Table A7) indicates high concentrations of strontium (average 3091 ppm; sd 2097 ppm). This element is potentially toxic to plants, but water extracts indicate a very low solubility. The water extracts of soil show extractable boron, which can also be toxic to plants, to be higher in the moist soils of drains and drainage ways with evaporative concentration in the immediate surface layers. It is probable that wetland plants are adapted to elevated boron and other potentially toxic ions.

Extended periods of inundation may result in degraded condition of the existing excavated drains.

Key Findings:

- The soils of the area are historically saline and sodic.
- The sodic condition is attributable to the proximity of the water table to the soil surface, extended inundation is unlikely to have a significant effect on future soil condition.
- *The effects of accession of water of significantly different ionic composition, potential soil leaching and evaporative concentration will change over time and require geochemical modelling to predict the effect on sodicity.*

3.4. Assess the likely extent and effects of sodicity to the soil as a result of water retention

Sodium Adsorption Ratios (SAR) were measured on the 1:5 soil:water extracts and also on the saturation extracts from soil pastes. SAR is calculated using the formula (concentrations in meq/L):

$$\text{SAR} = \text{Na}^+ / \sqrt{[\frac{1}{2}(\text{Ca}^{2+} + \text{Mg}^{2+})]}$$

and usually correlates well a soil's exchangeable sodium percentage (ESP). The SAR data for the 1:5 extracts and saturated pastes are numerically different, but correlate highly (Figure 6). The outlying point is from a footslope seepage at TS15. As outlined above, the high Langelier Index suggests that the measured SAR of the drain water, if comparable to the flood water for Tilley Swamp, will underestimate the effect of the water on sodicity. Most of the soils have high to very high SAR_{1:5} (average of 83 samples is 25.8, sd 17.9; highest value 76), and SAR_{se} values (Appendix Tables A4 and A5), though as pointed out above, sodicity is lower at the southern end of the area and soils that were moist when sampled tended to have SAR values closer to that of the drain water (20 to 25). Other soils usually had greater SAR values. This is likely to result from the removal of divalent cations (Ca and Mg) from the waters by precipitation of calcites, causing an increase in SAR.

If this observation is generally correct, it is likely that sodicity in soils will remain about the same following inundation. Sodicity is a condition of the cation exchange complex (usually clay and organic matter surfaces) of the soil and is unlikely to change significantly unless there are also significant changes in sodium, potassium, calcium and magnesium ratios in the pore water of the soil. Therefore, soils in contact with groundwater are likely to reflect the SAR of the groundwater, but increase under conditions where calcium and magnesium precipitate out as carbonate minerals

As mentioned in Section 3.3, the impounding of fresher water is expected to have several possible effects: there will be an increase in salinity with evaporative concentration or may be some leaching of salts from the soil profile. These effects should not alter soil sodicity unless there is an accompanying change in the relative concentrations of sodium to calcium and magnesium.

Key Finding:

- If the cation and anion composition of groundwater and drain water remain approximately the same as has been experienced historically, a change in sodicity would not be expected.

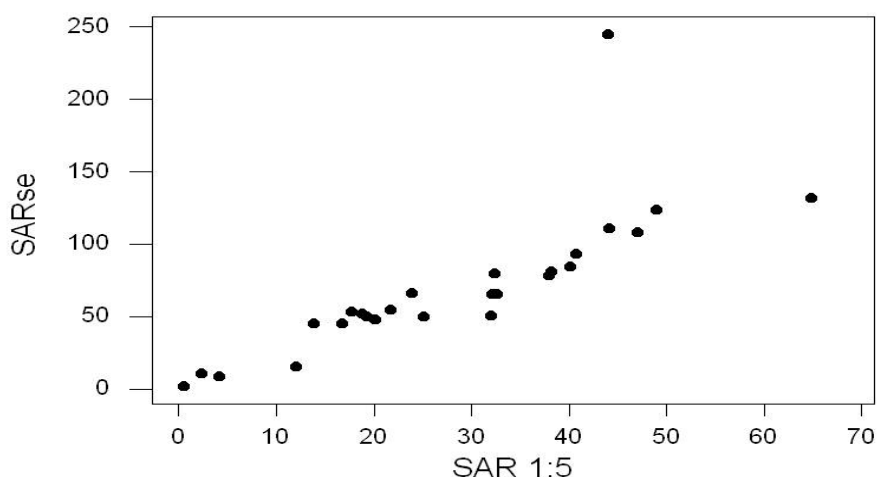


Figure 6. The relationship between sodium adsorption ratio calculated from 1:5 soil water extracts ($SAR_{1:5}$) and saturation extracts (SAR_{se}).

3.5. Assess the potential for acid sulfate soils

3.5.1. Sulfidic materials adjacent to drains

Impoundment of water for extended periods of time (weeks to months) will have a large effect on the oxidation-reduction (redox) status of the soils. This results from biological activity in the inundated soils which uses up oxygen and produces a highly reduced state. As the system becomes more reduced or anoxic, redox potential (Eh in millivolts) becomes more negative with values as low as – 50 mV being measured. As oxygen is removed, sequentially nitrogen is lost, manganese and iron are reduced, sulfate is reduced to sulfide and methane may be produced. The concentration of sulfate in the drain water ranges from 350 to 450 mg/L (Appendix Table A3). Soil analyses (Appendix Table A7) show that soils contain between 200 and 4,600 mg/kg of sulfur. Surface soils, particularly among the melaleuca stands, contain high amounts of organic matter - up to about 6% or more where there is heavy litter accumulation. This high sulfur and carbon environment has all the ingredients for rapid oxygen removal and reduction with inundation.

Reduction in soils already happens in the Tilley Swamp environment in two ways. Firstly, wet and moist subsoils affected by the groundwater table are already reduced and the soils exhibit olive, green, blue and grey colours (eg, Figure 7). Reduced sulfur (sulfide, S^{2-}) is present as the dissolved anion or as the iron mineral, pyrite (FeS_2). This is a natural process that produces potential acid sulfate soil (PASS) materials. Natural (and man-induced) fluctuations in water table heights allow oxygen to periodically enter reduced soil systems at the water-air interface above the watertable. This process, also mediated by micro-organisms, results in the formation of sulfuric acid, which attacks minerals in the near vicinity and precipitates orange-coloured iron oxyhydroxide minerals. This process can be seen in parts of the



Figure 7. The Soil profile in the drain at site TS11. Organic, shelly sandy loam overlies greenish-grey to olive, reduced clayey soil below 70 cm. The hard carbonate layer is between 120 and 150 cm. Below the carbonate layer, the presence of black, sulfidic mottles increases.



Figure 8. Iron minerals formed below hard calcrete at site TS2. This layer contains 15% iron (goethite and ankerite minerals are present, Appendix Table A4), and has “scavenged” high concentrations of arsenic (Appendix Table A5) which is thought to be natural.

excavated drain near Petherick Rd (Site TS2, Figure 8; also see section 3.5.4 below), where a layer of iron oxides several centimetres thick can be observed. *It is probable that this has occurred naturally over many years, but is locally strengthened with the lowered water table in the vicinity of the drain.* The effect of this process over a very long period of time is that during periods when oxygen enters the system and acid is produced, neutralisation is effected by the large amounts of calcium and magnesium carbonate in the soils of the area. Two of the profiles analysed show a marked decrease in carbonate content at around the depth of the water table (Figure 9) and where oxygen is likely to react with reduced sediments. This decrease may be the result of local acid production and dissolution of carbonate minerals.

Chromium reducible sulfur analyses indicate concentrations of about 0.3% in reduced (MBO) materials in the drains and lower values between 0.03 and 0.05% in the reduced soils affected by ground waters. It is the oxidation of these materials that produces acid. Most of the soils analysed had such large concentrations of carbonate minerals that any acid produced in the soils will be quickly neutralised.

There is evidence for development of sulfidic materials (potential acid sulfate soils) during inundation and for acid generation as water levels are lowered. However, the highly calcareous soils that exist in the drains and neutralising capacity in the drain water should mitigate against environmental damage. These processes are similar to natural historical processes. Analyses (Appendix Table A5) show all soil layers to contain carbonate (expressed as CaCO_3 equivalent) with values as high as about 90%, and 40 to 60% being common.

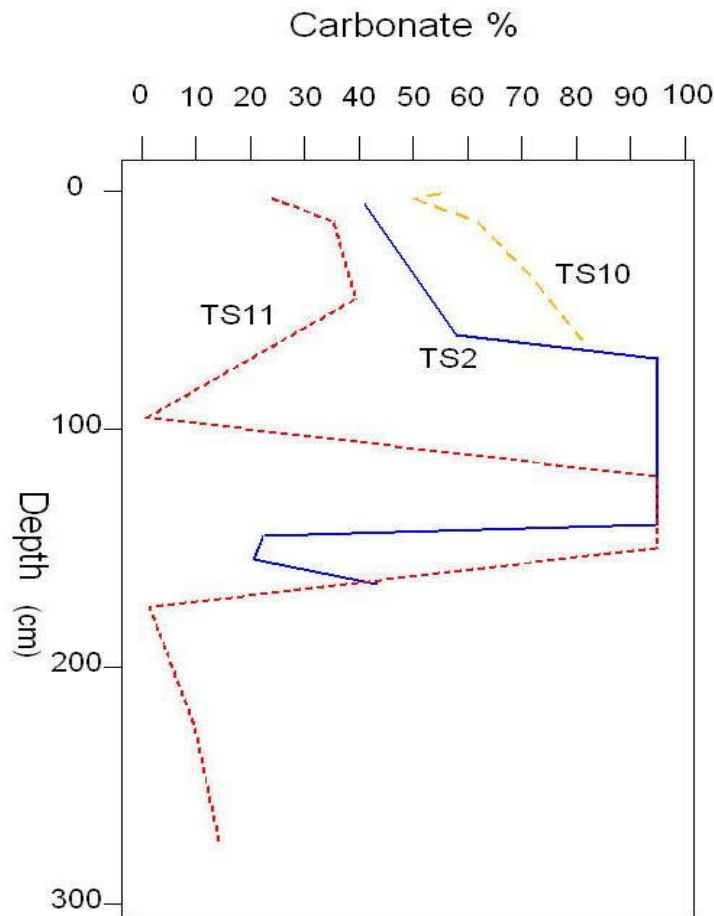


Figure 9. Soil profile distribution of carbonate (as calcium carbonate) from three sites. Sites TS2 and TS11 have hard calcrete, assumed to be 95% CaCO_3 and were sampled from drains. TS10 is from near the middle of Morella basin.

3.5.2. Monosulfidic black ooze in drains

The second occurrence of potential acid sulfate soil material occurs in the constructed drains (and would also occur in natural wetlands). This is manifested in the black oozes (monosulfidic black ooze, MBO) readily observed mainly in the drains and to a lesser extent in soils alongside. The high nutrient environment and the activity of algae and micro-organisms causes reduction and the formation of the black, smelly iron and other sulfides (Figure 10). These substances are very reactive if exposed to oxygen, producing acid. However, provided the materials remain anoxic they are benign. Also if flushed down stream as floodwaters scour the drain channel they may oxidise and become acidic, but the ubiquitous carbonates of calcium, magnesium and sodium in the drain water will neutralise the acid. MBO is also common in the sediments of the Coorong.



Figure 10. Black monosulfides (MBO) near the water level in the drain at site TS11.

However, in these drains deoxygenation of water by MBO may be the most widespread risk because MBO can deoxygenate water even in areas that are naturally well-buffered against acidification. Currently there is no method of assessing the deoxygenation risk of MBO but some of the factors may include:

- potential for natural causes or management actions that re-suspend MBO sediments,
- sediment monosulfide concentration and form,
- water column residence time, and
- monosulfide reaction rates.

The residence time of suspended sediment in drains is a function of sediment particle size and water velocity. Simpson *et al.* (1998) found iron monosulfides in re-suspended sediment to react completely within 8 hours. By comparison, Lu *et al.* (2003) estimated channel residence times of 10-15 h for eroded soil, which is likely to have a coarser particle size, and thus a shorter residence time than suspended sulfidic material. The drain sediments observed in this survey have coarser particle sizes and are usually loamy sands or sandy loams. This indicates that, within the context of Tilley Swamp drains, MBO should have sufficient time to deoxygenate once suspended in the water column. The effect of deoxygenation is expected to exist within a localised area and is a natural process of wetlands.

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ 2000) recommend that dissolved oxygen levels remain above 85% of the saturation level. However, oxygen saturation levels decrease with increasing salinity and temperature. For a temperature of 25°C, this is equivalent to 7 mg/L in fresh water and 5.4 mg/L in water at a salinity of 25 mg/L. Thus, the deoxygenation risk will become greater at higher salinities because less oxygen will be present in the water column to start with. The guidelines also recommend measurement of diurnal variations as algae produce oxygen during the day, while algae and bacteria consume oxygen at night. Floods and channel cleaning

operations have been identified as sources of sulfidic material re-suspension in coastal drains (Sullivan *et al.*, 2002). Anecdotal evidence suggest that rapid changes in water levels during wetland wetting/drying operations can also re-suspend large amounts of sediments. The most likely scenario that will result in re-suspension of MBO in Tilley Swamp is drain cleaning and maintenance.

3.5.3. Sulfate-containing salt efflorescences

The salt efflorescence or evaporite deposits sampled in the drains proved to be an assemblage of sulfate-containing minerals (as detected by x-ray diffraction; Appendix Table A6). Movement and accumulation of such soluble salts is typical of drained soils but, these salt efflorescences mainly consist of salts with thenardite (Na_2SO_4), eugsterite ($\text{Na}_4\text{Ca}(\text{SO}_4)_3 \cdot 2\text{H}_2\text{O}$), gypsum ($\text{CaSO}_4 \cdot \text{H}_2\text{O}$), halite (NaCl), bloedite ($\text{Na}_2\text{Mg}(\text{SO}_4)_2 \cdot 4\text{H}_2\text{O}$) and possibly barite (BaSO_4). Geochemical analyses of these saline soil materials indicate high concentrations of sulfate, magnesium, calcium and sodium ions (Appendix Table A7). This is caused by the somewhat unique geochemistry of the combined groundwater, drainage water and drained soils in the Tilley Swamp region. Sulfides produced in bottom sediments and at the base of the drain react with the oxygen in the air to form sulfuric acid. The acid either drains into the drain or reacts with carbonates and salts in specific layers within the soils (to form sulfates – liberating dissolved iron, calcium, magnesium, sodium and other elements such as arsenic (As). The components (Na, Ca, Mg, Cl, Ba and SO_4) of the evaporite minerals were derived by leaching of oxidized iron sulfides and then precipitated as specific minerals (eugsterite, thenardite, bloedite and gypsum) at various stages during the drying/evaporation of the drained soils (Figure 11).

The significance of the minerals found in these salt efflorescences is that they appear each summer and are environmental indicators. A change in the minerals found will indicate a change in the nature of the salts entering the system from drain or ground waters.



Figure 11. Close-up view of salt efflorescences in eroded cavities between the hard carbonate layer and underlying iron-rich mottled clays at site TS2, depth 140 cm

The predominance of sulfate evaporite minerals in the Tilley Swamp drains is largely due to the chemistry of the inflowing drainage water (Appendix Table A3). The sulfate-containing salt minerals accumulate steadily in the lower part of the drain immediately below/under the hard carbonate/ calcrete layer and above the sulfidic layer (Figure 11) because of limited lateral movement of water to carry the soluble salts away in the drains.

These recently accumulated, sulfate-containing salt efflorescences indicate the somewhat unique contemporary soil-hydrological condition within the drained soil. The shallow drainage water and composition of the soil solution contains sodium, calcium, magnesium, chloride, barium and, most importantly, sulfate ions (Appendix Table A3). The data we have gained indicates that these salts are seasonal pedogenic products and result from the evaporation of saline sulfatic drainage water produced from the oxidation of sulfidic material at depth. More work should be undertaken to confirm seasonal changes in mineralogical composition. Similar observations have been made of salt efflorescences in the Great Konya Basin in Turkey by Driesen and Schrool (1973) who also identified halite with gypsum and other sulfate minerals (e.g. thenardite). Gumuzzio *et al.* (1982) have identified mixtures of thenardite and mirabilite in salt efflorescences of Spanish soils (i.e. in winter rainfall areas). They reported that the mineralogical composition varied with



Figure 12. View showing salt efflorescences in eroded cavities between the hard carbonate layer (top left) and underlying iron-rich mottled clays (yellowish-greenish-grey to olive) with increasing black, (reduced) sulfidic materials with depth.

the winter type being characterised by mirabilite-thenardite-epsomite and a summer type constituted thenardite-bloedite. More recently, a remarkably similar assemblage of sulfate minerals (eugsterite, thenardite, bloedite, gypsum and halite) were

identified in salt efflorescences in drained, alkaline sulfidic marshes in southern Iraq by Fitzpatrick (2004).

During winter rainfall events these soluble sulfate-containing minerals play important roles in the transient storage of components (Na, Ca, Mg, Cl, Sr and SO₄), which will dissolve to form the saline monosulfidic black ooze in the drains.

3.5.4. Elevated metal concentrations

Some soil materials showed levels of As (at site TS2 especially, see Appendix Table A7), Sr, Ba, and possibly Se above the trigger value specified by the Australian and New Zealand Guidelines for Fresh and Marine Water Quality interim sediment quality guidelines. When this occurs, the guidelines recommend further investigation of background levels and the “availability” of the metal through the use of other assays such as dilute acid extraction. In the absence of any other sources of these elements, these occurrences are regarded as natural and not due to environmental contamination.

Key Findings:

- The acidity is likely to be rapidly neutralised in this highly alkaline, calcareous environment.
- Monosulfides in drains may be mobilised by increased flows, but its main effect is likely to be rapid de-oxygenation of the drain waters.

3.6. Advise the appropriate wetting/drying regime for the Tilley Swamp soil type(s) and the subsequent associated risks to native and productive vegetation

Regular wetting and drying during and following inundation has been part of the natural environment of Tilley Swamp for a very long time. The difference in future may be the ionic concentration of solutes in drain and inundation water rather than significantly altered ionic composition as composition is likely to be controlled by groundwater entering the Tilley Swamp system (including drain waters). Concentrations are likely to be diluted in flood events and concentrate on evapotranspiration, but are unlikely result in significantly different soil condition. If inundation water is significantly more dilute than drain water, and drainage is possible (eg, alongside constructed drains and natural drainage ways), soil salinities may decrease if water is not impounded into spring and summer when evaporation rates are high. However, those parts of the area that have shallow or perched water tables are likely to remain saline as the soils dry out.

Native vegetation is likely to be adapted to regular inundation, but not so agricultural plants, which are unlikely to survive inundation for more than a few weeks or an evaporative build-up of salinity in surface soil layers. It is possible that boron concentrations in surface soils may become excessive for non-tolerant agricultural plants with evaporation. Native vegetation may succumb to prolonged oxygen removal from the root zone if the high soil organic matter levels rapidly result in reducing conditions in still water. Juvenile *Melaleuca halimifolium* plants cannot tolerate inundation of more than 6 to 9 weeks (Denton and Ganf, 1994). A wetland plant specialist should be able to advise on this situation.

Key Findings:

- In the natural state, the soils and mature plants of this environment are adapted to inundation.
- Pasture plants of the agricultural areas in Tilley Swamp are not adapted and will not survive any prolonged inundation.

3.7. Identify appropriate mitigation strategies for identified risks

Mitigation of potential risks is probably mostly related to the length of the period of inundation. It is assumed that maintenance of the current state of soil condition in Tilley Swamp and Morella Basin is the desired outcome of an inundation event.

As Morella Basin is an ephemeral wetland system and parts of the western side of Tilley Swamp have samphire vegetation, these areas should cope with extended periods of dry and inundation.

To minimise further salinisation of Tilley Swamp it is important not to extend the period of inundation into those times of the year when evaporation rates become high.

The southern end of Tilley Swamp is less saline and sodic than the north (and Morella), so minimising the period of inundation and evaporation should help keep this area in a condition that is similar to its present state.

Agricultural land is most likely to be detrimentally affected by extended inundation because the plant species generally do not tolerate anoxic conditions, salinity, sodicity and, potentially, high soil boron concentrations. Salinity (and boron) levels of surface soils should progressively decrease with leaching by rainfall over successive winters when inundation ceases, but salts will concentrate in any low lying area.

The development of reducing conditions, especially in soils with high organic carbon levels (usually supporting melaleucas), may be detrimental to vegetation through the lack of oxygen in root zones over extended periods. Sulfides will also be generated with reducing conditions and the high concentrations of sulfur in soils and groundwaters, but the ubiquitous calcium carbonate should be more than adequate to neutralise any acid formed on the re-entry of oxygen into the soils. If the capacity of melaleuca to withstand waterlogging is well known and it is desirable to maintain this vegetation, this should strongly influence the acceptable period of inundation in Tilley Swamp.

Key Findings:

- It is important that there not be large areas of standing water during the hotter parts of the year when evaporation rates if increasing salinity and de-oxygenation are to be minimised.
- The southernmost part of Tilley Swamp is less saline than the north and may need protection from very saline water.

3.8. Advise an appropriate monitoring program to measure impact or change to the Tilley Swamp watercourse as a result of water retention and subsequent changes to soil condition

Some guidelines appropriate to Tilley Swamp can be found at: <http://www.deh.gov.au/water/rivers/nrhp/wetlands/chapter4-bool.html>

3.8.1. Recommended actions for soil observations during and following the first period of inundation

- a) Observe actual distribution of inundating water to confirm that predicted from the DEM.
- b) Monitor condition of pastures and melaleucas during inundation. Soil redox probes with data loggers should be installed at sensitive monitoring sites to follow the onset of reducing conditions and correlate with plant health.
- c) Salinities and ionic composition of impounded waters should be monitored during inundation.
- d) At the end of the first summer after a period of inundation in Tilley Swamp, selected sites used in this study should be re-sampled and analysed using the simple 1:5 water extract for pH, EC, cations and anions. Soil samples should be retained and archived with the samples from this study, allowing for re-analysis of the original samples at future dates.
- e) Monitoring the occurrence and composition (chemical and mineralogical) of salt efflorescences in summer as this should provide a more sensitive indicator of changed condition.
- f) Monitoring the seasonal occurrence and composition (chemical and mineralogical) of monosulfidic black ooze in drain sediments and on the edge of drains.

These actions should provide valuable information for understanding the effect on soils of inundation and give better guidance for management of future inundations and maintenance of a sustainable system for the longer term.

3.8.2. Recommended actions in long term after several periods of water retention

Subject to the results of observations made during the first inundation, it is expected that significant changes to soil condition may not be apparent until after several inundations. Plants may be a more sensitive indicator. A repeat monitoring of the third subsequent inundation is recommended (subject to observations from the first monitoring), unless an event is significantly different in magnitude (greater) from the first monitored event.

Regardless, the occurrence and composition (chemical and mineralogical) of salt efflorescences should be monitored once every summer. Also, the seasonal occurrence and composition (chemical and mineralogical) of monosulfidic black ooze in drain sediments and on the edge of drains must be monitored once every summer and winter.

Key Findings:

A future monitoring program should include:

- Confirming the distribution of inundation waters;
- Occasional re-sampling and analysis of soils;
- Continuous data logging of redox probes during an inundation event if further understanding of the reducing conditions is required;
- Checking the composition of salt efflorescences and monosulfidic oozes as indicators of environmental change.

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5. Appendices

Appendix Table A1: GPS locations of sampling sites. The datum used was AGD66, UTM projection

Site	Zone	Easting	Northing
TS1	54	396390	5970076
TS2	54	397786	5970376
TS3	54	397216	5972508
TS4	54	397231	5972496
TS5	54	380526	6001053
TS6	54	380413	6000841
TS7	54	380385	6001025
TS8	54	380067	6000677
TS9	54	379980	6000504
TS10	54	380707	5999895
TS11	54	385960	5996338
TS12	54	385530	5995310
TS13	54	385193	5994159
TS14	54	386013	5993000
TS15	54	386238	5992511
TS16	54	390294	5990535
TS17	54	389025	5990222
TS18	54	389014	5990132
TS19	54	388157	5989921
TS20	54	387781	5989801
TS21	54	387717	5989084
TS22	54	387077	5988574
TS23	54	393244	5980614
TS24	54	393100	5981725
TS25	54	392401	5981730
TS26	54	391125	5981221

Appendix Table A2: Brief description of soil samples.

Sample No	Depth (cm)	Munsell Colour		Brief description
		Matrix	Mottle	
TS1	North side, Petherick Rd; clearing with (native) grasses among saltwater tea tree.			
TS1.1	0 - 5	10YR 4/1 d		SL. Loose, grey
TS1.2	5 - 10	10YR 5/2 d		SL. Organic, crumb, shells, many roots
TS1.3	10 - 20	10YR 6/2 d		Hard, shells, massive, bleached
TS1.4	20 - 45	10YR 4/1 d		LS. Very firm, calcareous, shelly, clean quartz
TS1.5	45 - 53	10YR 3/1 d		LS. Massive, more clayey (CS or LS+)
TS1.6	53+	calcrete		Calcrete, laminae at surface, shell inclusions
TS2	Petherick Rd, eastern side of Tilley Swamp, southern end; drain cutting.			
TS2.1	0 - 10	10YR 5/2 d		SCL. Organic
TS2.2	50 - 70	10YR 7/2	10YR 5/2 (40%)	LC. Soft carbonate
TS2.3	120 - 130	calcrete		Calcrete/silcrete?, hard with shells
TS2.4	140 - 141	salt		Salt efflorescence
TS2.5	141 - 150	7.5YR 4/7 d		CS. Ferruginised sand
TS2.6	150 - 160	10YR 5/8 m		CS. "Ochre" orange
TS2.7	160 +	2.5Y 5/3 m	2.5Y 2/0	LS. Olive brown with black (pyritic) mottles
TS2.8	160 - 170			Pyritic with clay and carbonate
TS3	North of Petherick Rd; clearing with (native) grasses among saltwater tea tree.			
TS3.1	0 - 5	10YR 5/2 d		L. Friable, granular structure, many roots
TS3.2	10 - 20	10YR 7/2 d		CL. Bleached, "vesicular", very hard, large roots
TS4	Close to TS3, slightly lower lying with occasional samphire.			
TS4.1	0 - 5	10Yr 4/1 d		L. Grey
TS4.2	10 - 20	10YR 5/2 d		LMC. Pale grey
TS5	Northern margin Morella Basin; good samphire cover.			
TS5.1	0 - 5	10YR 4/2 d		LS, very organic. Many roots, angular carbonate
TS5.2	10 - 20	10YR 6/2 m		LS. Y-br, loose with 1 cm clay lamellae
TS5.3	20 - 60	2.5Y 7/2 m		LS. Pale yellow, loose, pipestems towards bottom
TS5.4	60 - 90	2.5Y 7/3 m		LS. Pale yellow, loose, pipestems, calcareous
TS5.5	90 - 115	2.5Y 7/3 m		LS. As above, with pipestems
TS5.6	115 - 125	2.5Y 7/3 m		LS. As above, angular carbonate, no pipestems
TS5.7	125	2.5Y 7/3 m		Hard carbonate fragments
TS6	Low point in north Morella Basin; samphire and white, filamentous surface cover.			
TS6.1	0 - 3	10YR 5/1 m		ZL. Grey, angular peds (15 – 30 mm)
TS6.2	3 - 20	10YR 6/1 m		LC. Much shell, massive
TS6.3	20 - 60	10YR 6/2 m		LC. Many shells, pores, fine roots
TS6.4	70 - 90	10YR 7/1 m		CLS. Grey, shelly, overlying clayier material (not sampled)
TS7	A little higher than TS6; samphire sparser.			
TS7.1	0 - 1	10YR 6/1 m		SCL. Clayey crust (wash on)
TS7.2	1 - 5	10YR 5/2 m		CL. Organic (former surface)
TS7.3	5 - 20	10YR 6/2 m		Bleached, calcareous loam
TS7.4	20 - 50	10YR 7/2 m		CLS. As above, with shell

Appendix Table A2: cont.				
TS7.5	60 - 80	10YR 7/2 m		CLS. As above
TS7.6	80 - 90	N5/ m		SL. Blue-grey, reduced, sulfidic?, coarser
TS7.7	90 - 115	5Y 7/2 m		Abrupt to white, wet, heavy clay
TS8	SW side of drain, north Morella Basin; similar vegetation to TS7.			
TS8.1	0 - 1	2.5Y 7/3 m		Algal filament crust
TS8.2	1 - -5	10YR 4/1 m		Organic, calcareous
TS8.3	5 - 20	10YR 6/2 m		Grey calcareous loam, many shells, iron-stained root channels
TS8.4	20 - 50	10YR 6/2 m		As above
TS8.5	50 - 55	10YR 2/2 m		Calc. loam with clayey nodules
TS8.6	55 - 70	10YR 7/3 m		Pale grey, increasing clay, few shells
TS8.7	70 - 75	10YR 5/2 m	10YR 3/1 30%	Increasing clay content, om?, moist
TS8.8	75 - 90	10YR 7/3 m		Similar to above, increasing clay content
TS8.9	90 - 115+	10YR 7/3 m		MC
TS9	SW margin of north Morella Basin (6 m from edge); heavy cover of samphire.			
TS9.1	0 - 1	10YR 2/1 m		"Fluffy", high organic matter.
TS9.2	1 - 18	10YR 3/2 m		SL. Organic, shelly
TS9.3	18 - 30	10YR 5/2 m		LS. Pale, with many shells
TS9.4	30 +			Calcrete
TS10	Morella Basin, about 200 m SW of drain; salt pan, no vegetation.			
TS10.1	0 - 1	10YR 6/2 m		Algal filament mat, clayey, with shells
TS10.2	1 - 5	10YR 6/3 m		CL. Organic, granular, old roots
TS10.3	5 - 20	10YR 7/2 m		LC. Pale, sticky, friable, shelly
TS10.4	20 - -50	10YR 7/2 m		LC. Pale y-br, many fine, old roots,
TS10.5	50 - 75	10YR 8/2 m		MC. White, wet, HC, no roots
TS11	NE corner of Tilley Swamp; drain with saltwater tea tree.			
TS11.1	0 - 5	10YR 3/1 d		SL. Highly organic, melaleuca roots
TS11.2	5 - 20	10YR 3/1 d		SL. Organic, shelly
TS11.3	20 - -70	10YR 4/1 m		SL. Grey-brown, calcareous, shelly (1-4 mm)
TS11.4	70 - -120	5Y 6/2 m		CLS. Olive grey clay
TS11.5	120 - 150			Calcrete, hard
TS11.6	150 - 200	5GY 4/1 m	2.5Y 2/0 40%	MHC. Dark green, with black mottles, old? tree roots
TS11.7	200 - 250	2.5Y 2/0 m	5GY 4/1 40%	SL. V sharp black mottles (60%) in olive green; shells, large roots with pyrite
TS11.8	250 - 300+	2.5Y2/0 m	oxidises to grey	Saturated at water level in drain
TS12	Tilley Swamp, northern end; small grassy clearing in tea tree.			
TS12.1	0 - 10	10YR 4/1 m		Dark grey-br (dry) shelly, with profuse roots at bottom of A; abrupt wavy
TS12.2	10 - 30	10YR 5/1 d		LC. Columnar, with shell, very hard
TS12.3	30 - 50	10YR 5/1 d		Pale brown calcareous loam
TS12.4	50 - 75	10YR 7/3 m		LS. Calcareous, pinkish brown
TS12.5	75 - 100	10YR 6/2 m		As above, sandier
TS12.6	100 - 125+	10YR 7/2 m		CL. White, wet clay
TS13	Tilley Swamp, northern end; among small tea trees			
TS13.1	0 - 1	10YR 5/2 d		Fibrous organic crust
TS13.2	1 - 5	10YR 4/2 d		Brown organic A; many fine roots
TS13.3	5 - 15	10YR 4/1 m?		Continues, paler, larger roots
TS13.4	15 - 30	10YR 6/2 m?		Pinkish brown, heavier texture

Appendix Table A2: cont.				
TS13.5	30 - 60+	10YR 7/2 m?		Light coloured, LMC with root channels, moist; similar to deep clay at TS12
TS14	Among tea tree, immature.			Not sampled
TS15	Footslope, western margin of Tilley Swamp; footslope seepages.			
TS15.1	0 - 20	10YR 4/2 d?		SL. Dark brown (dry) organic loam, many shells; abrupt to
TS15.2	20 - 30	10YR 4/1 d		(Z)CL. Columnar clay, shelly
TS15	30 - 50	10YR 2/1 d	shiny	Dark grey-brown, dry, clay with shells and black tar like material (manganese oxide?) on ped faces
TS15.3	50 - 70	10Yr 4/1 d		Loamy, massive, v hard, some clayey parts
TS15.4	70 - 80	10YR 5/2 d		Light grey-br sandier, moist, E horizon
TS15.5	80 - 85	10YR 2/2 d		MHC. With organic matter, friable, moist, S-?
TS15.6	85 +			Calcrete
TS16	Eastern side of Tilley Swamp, Safari Rd; drain with samphire and mature tea tree with Gahnia.			
TS16.1	0 - 5	10YR 4/1 d		L. Root mat (brown) sampled from among melaleucas 20 m E of drain, drain side has samphire
TS16.2	5 - 20	10YR 2/1 d		SL. Black, very organic with many shells, sharp to
TS16.3	20 - 50	10YR 5/2 m		LS to CS. Gr-br, calcareous with shells
TS16.4	50 - 90	5Y 4/1	2.5Y 2/0 20%	SL. Green clay with carbonate nodules (soft and hard), abrupt wavy
TS16.5	90 - 100	2.5Y 2/0 m	5Y 4/1 20%	SCL. Clayey, organic layer above calcrete, green mottling
TS16.6	100 - 150			Calcrete, laminae at top
TS16.7	150 - 151	2.5Y 6/2		Salt efflorescence sampled from just below calcrete
TS16.8	150 - 250	5GY 5/1		SL. Irregular calcrete with green clay, wet, massive
TS16.9	250 +	2.5Y 2/0		LS. MBO from drain
TS17	N side Safari Rd; cleared land.			
TS17.1	0 - 5	10YR 4/1 d		CL. Loose, very organic, calcareous, dry shelly
TS17.2	5 - 15	10YR 5/1 d		CL. Pale, calcareous organic, hard, shelly
TS17.3	15 - 27	10YR 8/1 d		LC. Pale, calcareous, very hard, vertical root channels
TS17.4	27 +			V hard, calcareous material - calcrete?
TS18	S side Safari Rd, opposite TS17; among mature tea trees, heavy litter accumulation.			
TS18.1	2 - 0	10YR 2/2 d		Coarse litter of twigs and leaves
TS18.2	0 - 3	10YR 2/2 d		Peat. O layer, humified, many roots
TS18.3	3 - 8	10YR 4/1 d		SL, peaty. A horizon, calcareous, few large (to 30mm) horizontal roots, few shells
TS18.4	8 - 20	10YR 5/1 d		LC. Massive, very hard, some organic staining near upper part of layer
TS19	As for TS17; among tea tree.			Not sampled
TS20	Similar to TS18.			Not sampled
TS21	Similar to TS18.			Not sampled
TS22	S side of Safari Rd, just W of cleared field; immature tea tree, little ground cover.			
TS22.1	0 - 2	10YR 3/1 d		L. O horizon, humified

Appendix Table A2: cont.				
TS22.2	2 - 5	10YR 4/1 d		L. Organic; many roots
TS22.3	5 - 20	10YR 5/2 d		SCL. Grey organic; carbonate; shelly
TS22.4	20 - 50	10YR 5/2 d	10YR 4/2 20%	CL. Pale, calcareous; moist; shelly
TS22.5	50 - 80	10YR 7/2 d	10YR 5/2 20%	LC. Pale y-grey; clay loam; large shells
TS22.6	80 - 105	10YR 7/2 d	10YR 5/2 20%	CL ⁺ . As above; dk grey root channels
TS22.7	105 - 115	10YR 4/1 d		LC. Gritty, organic clay over calcrete
TS23	Eastern side of Tilley Swamp, drain at 1 km south of road; cutting grass and pasture.			
TS23.1	0 - 5	10YR 4/1 d		CL. Organic, some shell
TS23.2	5 - 20	10YR 2/1 d		LC. Organic A, roots
TS23.3	20 - 80	10YR 7/2 d		LC. Pale grey matrix
TS23.4	20 - 80	10YR 2/2 d		LC. Organic, root channels
TS23.5	80 - 90	5YR 6/2 m		MC. Green clay; calcrete nodules
TS23.6	90 - 120			Hard calcrete
TS23.7	120 - 200	10YR 7/2 m		MC. Soft, gritty carbonate
TS24	Similar to TS23, but from drain close to where it crosses the road.			
TS24.1	120 - 150			Calcrete, hard, platy
TS24.2	150 - 151			Efflorescence
TS24.3	150 - 185	5YR 6/3 m	10YR 5/8 20%	MC. Olive green with orange mottles
TS24.4a	185 - 195	5G 4/1 m	10YR 2/1 40%	SL. Black mottles in olive green matrix
TS24.4b		5Y 4/3 m	2.5Y 5/2 30% 10YR 2/1 20%	SL. Colour and mottle variation
TS24.5	195+	5Y 4/3 m	2.5Y 5/2 40% 10YR 2/1 20%	SL. Black pyritic in grey matrix
TS24.6	200+	2.5Y 2/0 m		SL. MBO from drain
TS25	West of TS24, north of road; 2-3 m tea tree, little ground cover.			
TS25.1	0 - 5	10YR 2/1 d		Organic surface
TS25.2	50 - 60	10YR 6/2 d		Pale grey-brown, sandy E?, soft carbonate floaters
TS25.3	60 - 70	5Y 6/3 m?		Pale greenish clay over hard calcrete
TS26	Low point at western side of Tilley Swamp; samphire, soil moist.			
TS26.1	0 - 5	10YR 3/2 m?		SL. Very organic, some shell
TS26.2	5 - 20	10YR 4/1 m		SL. Organic, very shelly
TS26.3	20 - 60	10YR 4/1 m		SL. Grey, shelly
TS26.4	60 - 80	2.5Y 5/2 m		LS. Pale grey, bleached patches
TS26.5	80 - 85	2.5Y 5/2 m		Grey/olive clay with sand
TS26.6	85+			Calcrete

Where: MBO = monosulfidic black ooze; Soil texture groups (according to McDonald *et al.*, 1990):

1. The Sands = sand (S), loamy sand (LS), clayey sand (CS).
2. The Sandy Loams = sandy loam (SL).
3. The Loams = Loam (L); sandy clay loam (SCL); Silty loam (ZL).
4. The Clay loams = Clay loam (CL).
5. The Light Clays = light clay (LC).
6. The Medium-Heavy Clays = Medium clay (MC), Heavy clay (HC).

Appendix Table A3: Summary of main chemical properties (average of 5 or 6 measurements) of Morella Basin drain water (Morella sample site) and Water Valley Drain at Petherick Rd (DWLBC data).

Analysis (unit)	Morella Basin	Water Valley at Petherick Rd
pH	8.1	8.1
EC (dS/m)	10.6	9.76
TDS (g/L)	5.5	5.6
Ca (mg/L)	109	127
Mg (mg/L)	225	234
K (mg/L)	54	33
Na (mg/L)	1640	1706
HCO ₃ ⁻ (mg/L)	647	538
Cl ⁻ (mg/L)	3435	3017
SO ₄ ⁼ (mg/L)	408	384
Si – reactive (mg/L)	18.5	11.7
Alkalinity as CaCO ₃ (mg/L)	530	442
Langelier Index	1.2	1.2
SAR	25.5	20.8

Appendix Table A4: pH, EC, elemental ions and SAR in 1:5 soil:water extracts.

ID No	Depth cm	pH _{1:5}	EC _{1:5} dS/m	Cl _{1:5} mg/L	Ca _{1:5} mg/L	K _{1:5} mg/L	Mg _{1:5} mg/L	Na _{1:5} mg/L	S _{1:5} mg/L	Sr _{1:5} mg/L	B _{1:5} mg/L	SAR _{1:5}
TS1.1	0 - 5	8.7	0.15	7	18.4	4.1	5.4	8.7	1.4	0.6	0.2	0.5
TS1.4	20 - 45	9.4	0.11	4	4.6	4.6	6.0	9.6	0.4	0.2	0.1	0.7
TS1.5	45 - 53	9.6	0.15	9	2.4	5.7	3.0	23.1	0.3	0.1	0.2	2.3
TS2.1	0 - 10	8.7	0.22	19	14.5	13.6	7.3	15.2	1.9	0.4	0.1	0.8
TS2.2	50 - 70	9.7	0.36	14	1.0	4.5	1.0	79.3	4.4	0.0	0.4	13.3
TS2.5	141 - 150	9.1	1.61	390	3.8	11.5	11.7	321.7	42.0	0.3	0.5	18.3
TS2.6	150 - 160	9.1	1.29	346	12.0	7.6	13.5	230.8	16.3	0.7	0.1	10.8
TS2.7	160 +	9.0	8.11	2600	83.7	41.0	155.2	1545.	218.7	5.4	0.5	23.0
TS2.8	150 - 170	9.1	2.24	656	15.9	16.2	21.6	436.8	40.1	0.8	0.2	16.7
TS3.1	0 - 5	8.6	0.18	7	18.1	6.8	6.8	8.3	3.2	0.7	0.2	0.4
TS3.2	10 - 20	9.3	0.14	3	4.9	3.8	8.7	9.9	1.4	0.2	0.2	0.6
TS4.1	0 - 5	8.5	0.30	17	18.3	20.5	9.0	19.1	4.1	0.6	0.2	0.9
TS4.2	10 - 20	9.3	0.25	15	3.4	8.0	5.4	39.0	1.6	0.1	0.3	3.0
TS5.1	0 - 5	8.4	19.4	6920	204.8	118.5	452.6	4225.	570.7	12.9	2.3	37.5
TS5.2	10 - 20	9.2	1.84	528	11.0	13.3	17.9	343.3	31.1	0.4	0.2	14.8
TS5.3	20 - 60	9.2	1.52	420	9.9	10.4	15.2	279.3	29.1	0.4	0.2	12.9
TS5.4	60 - 90	9.2	1.46	412	10.8	9.1	14.5	269.3	23.0	0.4	0.2	12.5
TS5.5	90 - 115	9.5	0.57	140	5.3	4.8	5.3	99.4	7.5	0.2	0.1	7.3
TS5.6	115 - 125	9.4	0.63	162	6.3	4.7	6.4	108.6	7.3	0.3	0.1	7.3
TS6.1	0 - 3	8.8	24.3	9420	195.5	118.8	700.0	5497.	691.4	12.2	1.7	41.0
TS6.2	3 - 20	8.6	9.45	3500	51.8	58.2	109.0	2090.	131.4	3.7	0.9	37.6
TS6.3	20 - 60	8.7	4.52	1544	49.9	27.5	34.3	1006.	82.6	3.9	0.6	26.7
TS6.4	70 - 90	8.8	4.87	1652	64.0	30.8	52.4	998.2	90.8	5.0	0.4	22.3
TS7.1	0 - 1	8.6	23.1	8620	818.5	116.6	685.6	4973.	1307.	40.7	3.7	30.9
TS7.2	1 - 5	8.8	21.8	8600	138.0	131.1	430.4	4983.	366.4	7.9	1.2	46.9
TS7.4	20 - 50	9.0	3.91	1340	25.9	23.1	53.0	841.1	82.7	2.4	0.3	21.6
TS7.5	60 - 80	9.1	3.22	1048	20.2	18.1	47.3	640.9	65.4	2.1	0.1	17.7
TS7.6	80 - 90	9.2	3.56	1158	25.5	18.8	54.4	691.1	69.6	2.7	0.1	17.6
TS7.7	90 - 115	9.2	3.59	1258	12.1	33.4	22.1	903.3	93.4	1.0	0.5	35.5
TS9.2	1 - 18	8.7	12.46	4560	96.0	65.5	235.4	2591.	270.9	6.3	1.3	32.2
TS9.3	18 - 30	9.2	2.54	778	15.9	15.7	29.9	491.4	43.3	0.9	0.2	16.7
TS10.1	0 - 1	8.4	17.86	6100	763.4	104.9	524.2	3503.	1204.	41.9	3.3	23.8
TS10.2	1 - 5	8.6	22.12	8440	230.2	139.4	531.4	4932.	684.1	17.8	1.5	40.6
TS10.3	5 - 20	8.6	8.78	3000	49.9	58.5	82.0	1877.	117.6	4.1	1.2	37.8
TS10.4	20 - -50	8.6	6.66	2500	68.8	43.0	74.5	1619.	155.4	6.3	1.3	32.1
TS10.5	50 - 75	8.5	8.17	2840	86.6	46.0	88.5	1804.	164.7	7.7	0.9	32.4
TS11.1	0 - 5	8.4	10.78	3140	73.4	128.8	52.0	2492.	380.3	4.1	5.7	54.2
TS11.2	5 - 20	8.8	13.47	4800	46.5	108.5	79.3	3140.	145.3	2.8	1.1	64.6
TS11.3	20 - -70	9.2	10.13	3500	40.8	68.5	73.9	2269.	92.1	2.5	0.4	48.7
TS11.4	70 - -120	8.7	8.57	2960	18.9	62.6	75.9	1929.	109.7	0.7	0.5	44.0
TS11.6	150 - 200	8.7	5.91	2180	20.5	69.3	49.3	1474.	111.4	0.7	0.4	40.0
TS11.7	200 - 250	9.0	3.20	960	31.2	39.2	34.4	658.2	99.4	1.3	0.3	19.2
TS11.8	250 - 300+	8.9	3.05	832	65.5	35.3	41.5	580.3	148.7	2.5	0.3	13.7
TS12.2	10 - 30	9.1	4.22	1352	20.7	35.6	17.6	955.2	66.6	1.6	2.5	37.2
TS12.4	50 - 75	9.3	2.27	678	12.4	15.2	23.2	437.5	33.1	1.2	0.5	16.8
TS12.6	100 - 125+	9.3	5.25	1850	27.2	28.7	102.2	1115.	92.3	3.2	0.3	21.8
TS15.1	0 - 20	8.5	0.19	16	16.3	9.5	4.3	15.2	2.9	0.5	0.3	0.9
TS15.2	20 - 30	10.0	3.63	778	25.6	80.7	1.8	857.6	120.5	1.1	1.4	44.1
TS15.5	80 - 85	9.6	0.30	12	1.2	6.4	0.6	65.0	1.4	0.0	0.3	12.0
TS16.1	0 - 5	8.9	8.07	2880	13.5	73.2	78.1	1987.	177.1	0.9	2.1	45.6
TS16.2	5 - 20	9.2	8.99	3380	17.7	81.5	85.2	2230.	158.3	0.8	0.7	48.5

ID No	Depth cm	pH _{1:5}	EC _{1:5} dS/m	Cl _{1:5} mg/L	Ca _{1:5} mg/L	K _{1:5} mg/L	Mg _{1:5} mg/L	Na _{1:5} mg/L	S _{1:5} mg/L	Sr _{1:5} mg/L	B _{1:5} mg/L	SAR _{1:5}
TS16.3	20 - 50	9.3	7.11	2640	29.3	51.3	82.3	1633.	82.1	1.3	0.6	34.8
TS16.4	50 - 90	9.0	5.54	1934	32.3	61.4	43.8	1280.	106.0	0.7	0.5	34.3
TS16.5	90 - 100	8.4	6.83	2440	79.7	76.2	70.0	1580.	167.3	0.9	0.5	31.0
TS16.8	150 - 250	9.3	0.89	187	3.0	12.7	4.1	182.3	30.0	0.1	0.2	16.0
TS16.9	250 +	8.5	2.74	702	78.2	67.3	63.0	421.0	150.8	3.9	0.3	8.6
TS17.1	0 - 5	8.5	0.25	18	17.1	15.8	8.3	20.3	5.8	0.6	0.4	1.0
TS17.2	5 - 15	9.3	0.33	28	4.9	16.4	4.6	53.7	5.4	0.2	0.7	4.2
TS17.3	15 - 27	10.0	0.36	15	1.8	11.6	2.0	71.1	3.0	0.1	1.0	8.7
TS18.1	2 - 0	7.5	4.03	1328	75.2	n/a	64.6	1163.	149.6	2.1	3.3	23.7
TS18.2	0 - 3	7.8	3.36	1358	83.5	n/a	68.8	1123.	179.1	2.7	1.5	21.9
TS18.3	3 - 8	9.1	3.29	946	12.9	51.5	13.5	693.0	59.4	0.5	1.5	32.0
TS18.4	8 - 20	9.6	3.74	1144	8.0	45.9	17.6	843.9	67.6	0.6	1.9	38.0
TS22.1	0 - 2	8.1	5.87	2080	124.6	53.4	96.8	1240.	155.5	7.3	0.8	20.2
TS22.3	5 - 20	8.9	5.28	1992	40.1	42.7	75.1	1168.	105.4	3.4	1.0	25.0
TS22.4	20 - 50	9.1	4.65	1604	38.4	32.4	74.9	954.7	81.5	3.5	0.4	20.5
TS22.5	50 - 80	9.3	4.35	1486	32.7	26.0	85.6	900.2	85.4	3.2	0.3	18.7
TS22.6	80 - 105	9.2	3.91	1628	39.3	30.4	90.4	956.9	86.7	3.3	0.3	19.1
TS22.7	105 - 115	9.0	3.33	1058	21.6	29.0	38.9	677.8	69.0	1.5	0.4	20.0
TS23.1	0 - 5	8.5	22.91	8480	122.0	216.1	159.5	5472.	344.4	4.8	2.0	76.4
TS23.2	5 - 20	8.8	12.81	4500	32.5	110.9	61.8	2791.	131.0	1.4	0.9	66.0
TS23.3	20 - 80	9.5	5.52	2020	13.5	49.0	23.4	1325.	65.8	0.9	0.7	50.3
TS23.4	20 - 80	9.3	8.77	2860	11.8	64.1	27.9	1926.	89.3	0.8	0.6	69.4
TS23.5	80 - 90	9.2	4.20	1450	10.3	34.1	15.5	981.6	37.1	0.6	0.7	44.9
TS23.7	120 - 200	9.1	6.12	2320	37.3	25.6	102.2	1365.	53.8	1.7	0.2	26.1
TS24.3	150 - 185	9.2	5.30	1942	5.3	30.5	10.5	1277.	36.6	0.2	1.0	73.6
TS24.4a	185 - 195	9.2	4.82	1618	21.2	45.6	57.1	1044.	81.2	1.0	0.2	26.6
TS24.5	195+	9.5	1.29	298	6.2	20.4	8.8	242.1	43.5	0.3	0.3	14.6
TS24.6	200+	9.2	1.11	248	15.7	18.1	15.6	191.5	54.8	0.7	0.2	8.2
TS26.1	0 - 5	8.5	17.07	6400	179.9	168.7	312.8	3784.	390.9	13.0	2.5	39.3
TS26.2	5 - 20	9.0	6.48	2360	42.2	60.4	101.4	1468.	138.9	3.6	1.2	27.8
TS26.3	20 - 60	9.2	4.63	1584	39.4	26.9	84.8	945.1	83.6	3.1	0.3	19.3
TS26.4	60 - 80	9.2	3.14	1032	28.7	18.5	50.6	600.4	49.1	1.8	0.1	15.5

Appendix Table A5: Total C, S, Inorganic C as CaCO₃, elemental ions and SAR in saturation extracts.

Sample ID	Total C %	Org.C %	CO ₃ as CaCO ₃ %	Total S %	Saturation Percent %	EC _{se} dS/m	Cl _{se} mg/L	Ca _{se} mg/L	K _{se} mg/L	Mg _{se} mg/L	Na _{se} mg/L	S _{se} mg/L	Sr _{se} mg/L	B _{se} mg/L	SAR _{se}
TS1.1	10.7	3.5	59.4	0.11	59	0.8	100	77	10	28	56	10	2.5	0.3	1.4
TS1.5	1.5	0.2	11.0	0.03	26	2.1	604	19	21	45	365	23	0.9	0.6	10.4
TS7.2	12.2	4.1	67.2	0.25	81	104	51600	834	720	2684	28409	1968	48	1.8	107.8
TS7.4	n/a	n/a	63.3	n/a	51	31	12000	212	168	602	6851	651	22	0.9	54.3
TS7.6	10.2	0.3	82.3	0.17	47	30	11800	214	160	583	6639	631	23	0.6	53.3
TS9.2	9.4	3.5	49.0	0.19	60	70	33900	801	421	2006	18577	1801	50	3.2	79.7
TS9.3	8.7	0.7	66.2	0.05	44	23	8960	197	124	415	4826	415	12	1.1	44.7
TS10.1	n/a	n/a	55.0	n/a	81	68	32100	1022	496	2677	17754	2952	51	9.0	66.3
TS10.2	12.2	6.1	50.4	0.46	79	97	48000	1006	706	3115	26522	3108	55	2.7	93.1
TS10.3	n/a	n/a	61.9	n/a	59	47	20600	404	347	731	11366	658	36	2.5	77.9
TS10.4	10.4	1.8	71.5	0.13	70	39	16100	495	238	613	9180	792	47	2.4	65.1
TS10.5	n/a	n/a	81.2	n/a	79	40	17400	538	233	630	9467	812	50	1.8	65.6
TS11.2	5.9	1.6	35.3	0.12	65	70	23800	444	662	700	19112	878	29	3.6	131.5
TS11.3	5.1	0.4	39.4	0.09	62	65	29900	363	500	663	17095	688	24	1.7	123.3
TS11.4	0.05	<0.1	0.9	0.07	42	72	34400	247	506	1264	19394	1114	11	1.4	110.6
TS11.6	0.17	<0.1	1.3	0.12	45	51	22800	247	451	892	12718	973	11	0.6	84.4
TS11.7	1.2	0.1	9.6	0.07	34	31	12700	521	291	660	7261	1140	22	0.7	49.8
TS11.8	2.1	0.4	14.2	0.13	34	31	12100	803	292	729	7358	1662	32	1.0	45.2
TS15.2	3.6	1.8	15.1	0.08	59	24	7950	30	559	8	5839	886	1.4	4.1	245.2
TS15.5	0.58	<0.1	4.5	0.02	47	1.9	474	9.3	17	23	387	20	0.3	0.7	15.4
TS17.2	12.4	2.9	79.6	0.09	53	2.0	303	44	77	46	329	48	2.0	2.2	8.3
TS18.3	13.4	6.1	61.0	0.16	66	19	6950	154	298	234	4270	406	7.3	3.2	50.5
TS18.4	11.9	2.0	82.7	0.12	51	30	11200	86	361	318	7264	622	8.6	6.2	80.9
TS22.3	10.9	2.0	74.3	0.13	83	27	11000	292	218	531	6193	546	25.1	3.6	49.9
TS22.5	11.9	0.8	91.9	0.13	56	32	12500	239	210	747	7228	646	23.8	1.5	51.9
TS22.7	5.6	0.7	40.5	0.09	50	28	10600	271	180	582	6083	592	20.3	0.9	47.7

Appendix Table A6 X-ray Diffraction analyses of selected samples.

D = dominant; CD = co-dominant; S = sub-dominant; M = minor; T = trace

Mineral*	Qtz	Then	Ank	Calcite	Mg-calc	Halite	K-feldspar	Na-feldspar	Goethite	Gypsum	Aragonite	Others
Sample												
TS2.4	D	M	M	-	SD	T	T	-	-	-	-	T Mica
TS2.5	D	-	M	-	M	-	T	T	M	-	-	-
TS2.6	D	-	-	-	M	-	T	T	M	-	-	T Mica
TS2.7	D	-	M	-	SD	T	T	T	T	-	-	-
TS10.1	T	-	-	-	D	M	-	-	-	M	-	-
TS10.2	T	-	T	-	D	M	-	T	-	T	-	M Smec
TS10.5	T	-	CD	-	CD	T	-	-	-	-	-	M Smec
TS11.3	D	-	-	M	M	T	T	T	-	-	M	-
TS11.7	D	-	T	M	T	T	T	T	-	-	T	-
TS11.8	D	-	T	M	M	T	T	T	-	-	T	-
TS16.7	D	M	-	-	M	T	T	-	-	M	-	M Eug ?T Blod
TS18.1	T	-	-	-	D	M	-	-	-	T	-	? Amor
TS18.3	SD	-	-	SD	D		T	-	-	-	T	-
TS18.4	M	-	-	M	D	T	T	-	-	-	T	-
TS24.2	D	T	-	-	SD	T	T	T	-	-	T	-

*** Mineral names:**

Qtz = quartz

Then = Thenardite – Na_2SO_4

Ank = Ankerite - $\text{CaFe}(\text{CO}_3)_2$ with Mg and Mn substitution.

Mg – calc = magnesian calcite

Halite – NaCl

Smec – Smectite

Eug - Eugsterite $\text{Na}_4\text{Ca}(\text{SO}_4)_3 \cdot 2\text{H}_2\text{O}$

Blod – Bloedite $\text{Na}_2\text{Mg}(\text{SO}_4) \cdot 8\text{H}_2\text{O}$

Amor – Amorphous

? – possible component

Appendix Table A7 X-Ray Fluorescence analyses of elements in selected soil samples.

	Na %	Mg %	Al %	Si %	P %	S %	Cl %	K %	Ca %	Ti %	V %	Mn %	Fe %
TS2.5	0.4	1.9	0.14	8.94	0.118	0.06	0.22	0.27	8.97	0.04	0.032	0.54	15.54
TS2.6	< 0.030	0.1	0.59	11.03	0.102	0.03	0.24	0.64	8.56	0.06	0.003	0.02	6.07
TS2.7	1.1	2.1	0.98	10.51	0.028	0.25	1.35	0.60	17.33	0.09	< 0.0015	0.02	1.08
TS10.1	2.7	4.3	< 0.0100	3.18	0.073	1.31	3.26	0.10	24.22	0.02	< 0.0015	0.01	0.09
TS10.2	2.6	5.2	0.06	4.71	0.054	0.47	2.67	0.13	23.25	0.02	< 0.0015	0.01	0.13
TS10.5	1.2	8.4	< 0.0100	4.07	0.015	0.19	0.70	0.03	29.21	0.01	< 0.0015	0.01	0.11
TS11.3	1.5	0.4	0.38	19.87	0.024	0.07	1.41	0.27	17.96	0.05	< 0.0015	0.01	0.20
TS11.7	0.7	0.7	2.06	21.06	0.017	0.18	0.82	0.85	6.69	0.13	< 0.0015	0.01	0.67
TS11.8	0.7	0.7	1.38	14.89	0.030	0.28	0.56	0.69	10.13	0.11	< 0.0015	0.02	0.58
TS18.3	1.1	2.6	0.40	3.45	0.037	0.24	0.82	0.30	24.57	0.06	< 0.0015	0.02	0.27
TS18.4	0.5	3.6	0.28	1.22	0.017	0.16	0.39	0.17	34.80	0.04	< 0.0015	0.02	0.20

	Cu µg/g	Zn µg/g	As µg/g	Se µg/g	Br µg/g	Rb µg/g	Sr µg/g	Y µg/g	Zr µg/g	Mo µg/g	Ba µg/g	Pb µg/g	Bi µg/g
TS2.5	17	< 0.5	4909	< 0.4	78	< 0.5	1446	5	111	11	240	< 1.5	17
TS2.6	< 0.6	1	514	< 0.4	19	40	457	11	71	9	229	9	12
TS2.7	8	6	44	2	55	37	1715	14	76	7	178	17	8
TS10.1	9	16	< 0.4	6	140	21	5146	8	< 0.8	5	93	22	8
TS10.2	13	12	< 0.4	6	242	27	4829	9	< 0.8	5	85	13	7
TS10.5	5	8	< 0.4	5	72	21	5471	10	< 0.8	4	88	8	7
TS11.3	< 0.6	7	< 0.4	3	85	26	2770	12	< 0.8	9	95	7	7
TS11.7	< 0.6	9	< 0.4	< 0.4	21	42	655	13	161	5	199	14	< 1.5
TS11.8	< 0.6	9	< 0.4	2	23	37	1014	12	95	5	183	13	< 1.5
TS18.3	13	11	< 0.4	5	367	35	4255	8	< 0.8	4	88	14	6
TS18.4	2	8	< 0.4	5	114	23	5589	13	< 0.8	2	135	12	5

