Investigation into the potential risk of acid sulfate soils on proposed development in the City of Greater Geelong

Report to the City of Greater Geelong, the Corangamite Catchment Management Authority and the Victorian Department of Primary Industries

CSIRO Land and Water Client Report
July 2005
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Cover Photograph:

Description: The view across Corio Bay, Geelong, Victoria
Photographer: Phil Davies
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Investigation into the potential risk of acid sulfate soils on proposed development in the City of Greater Geelong

Jim Cox¹, Peter Dahlhaus², Phil Davies¹ and Troy Clarkson³

¹ CSIRO Land and Water; CRC for Landscape Environments and Mineral Exploration
² Dahlhaus Environmental Geology Pty Ltd; Affiliate CSIRO Land and Water
³ Victorian Department of Primary Industries

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Executive Summary

Based on previous work, including a very good review by Primary Industries Research Victoria, a total of 11,745 ha of acid sulfate soils were reported within the Greater Geelong City shire, ranking it as the second greatest for extent of acid sulfate soils of all shires in Victoria.

This pilot study was commenced to identify if acid sulfate soils would have an impact on future development in the City of Greater Geelong, and to determine if a major study of acid sulfate soils was warranted. Thus a desktop study was commenced to develop a series of overlays of the spatial distribution of specific parameters that the literature said were needed for potential acid sulfate soil development (e.g. low lying areas). From this an overlay was developed to predict possible acid sulfate soil distribution within the City of Greater Geelong and compared to the zones targeted for development. Twelve sites were then chosen to confirm the presence of acid sulfate soils in the field.

At three sites, samples were collected for laboratory testing for acid sulfate soils. The other sites were discounted because either there was no visible evidence of acid sulfate soils or they were within obvious wetlands and zoned “Public Conservation and Resource” areas. A previous study has shown that some of the wetlands have acid sulfate soils, but they were not sampled for laboratory testing as there will be no development on them.

The laboratory analyses showed only one soil layer at one of the sites (Point Henry, PH02) that was sampled had at most a “marginal” acid sulfate soil potential. A site at Avalon (AV02) would produce foul odours if developed. Prior to any development, these areas should be more widely sampled for potential acid sulfate soils as the laboratory tests indicated their disturbance could lead to the release of acidity, with significant risk of damage to infrastructure and downstream ecosystems.
1 Introduction

1.1 Background

1.1.1 General

Rampant et al., 2003 have mapped the potential extent of ASS distribution along the Victorian coastline at 1:100,000 (Figure 1). Corangamite Catchment Management Authority (CCMA) reportedly has the second highest areal distribution of acid sulfate soils (ASS) of all CMAs in Victoria, with an estimated total extent of 13,845 ha (Rampant et al., 2003). Of this total, 11,745 ha are reported as being found within the Greater Geelong City shire, ranking it as the second greatest for extent of ASS of all shires in Victoria. This study was commenced to investigate the potential risk of ASS on proposed development in the City of Greater Geelong.

Figure 1. Distribution of coastal acid sulfate soils [Rampant et al. 2003].

1.1.2 Actual and potential ASS

Acid sulfate soils have pH < 3.5 and contain iron sulfides (pyrite, FeS$_2$) or mono-sulfides (FeS) (Table 1). They are usually dark grey and soft; and can be clay or sand. When iron sulfides are exposed to air (drained or disturbed) they produce sulfuric acid. Acid sulfate soils can overlie PASS (potential ASS) which are iron sulfides contained in waterlogged sediments with a pH 6.5-7.5. The waterlogging prevents oxidation and production of sulfuric acid. Most ASS formed within the past 10,000 yrs after the last major sea level change (Graham and Larson, 2000).

Coastal ASS/PASS occurrences in Australia have largely been mapped (mangrove swamps, salt marshes, estuaries and tidal lakes) at a relatively broad scale (e.g. 1:100,000), although there have been some assessments made in Queensland and South Australia at finer scales (e.g. Merry et al., 2003). Inland ASS and PASS have not been mapped. They usually occupy relatively small areas associated with (saline) groundwater discharge but may be large in total extent.
Table 1 Acid sulfate soils - site characteristics [Ahern et al., 1998].

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Soil Characteristics</th>
<th>Water Characteristics</th>
<th>Other Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Acid Sulfate Soil</td>
<td>• field pH ≤ 4; • jarositic horizons (pale yellow mineral deposits). Where the watertable fluctuates, jarosite may precipitate along cracks or root fissures in the soil; • iron oxide mottling in soil left exposed to air (e.g. excavated or dredged material); • presence of shell.</td>
<td>• pH &lt; 5.5 in surface ponding, drains, ground water or adjacent streams; • clear or milky blue-green water flowing within or from the site (aluminium released from acid sulfate soils can act as a flocculating agent); • iron stains on drain or pond surfaces, or iron-stained water deposits.</td>
<td>• scalded or bare low-lying areas; • corrosion of concrete and/or steel structures.</td>
</tr>
<tr>
<td>Potential Acid Sulfate Soil</td>
<td>• pH usually neutral but may be acidic – positive peroxide test; • waterlogged soils –bluegrey or dark greenish grey unripe muds, mid to dark grey estuarine silty sands or sands or dark grey estuarine/tidal lake bottom sediments; • presence of shell.</td>
<td>• pH usually neutral but may be acidic.</td>
<td></td>
</tr>
</tbody>
</table>

1.1.3 Impacts of ASS

The impacts of ASS can be numerous (Sammut and Lines-Kelly, 1996; National Working Party on Acid Sulfate Soils, 2000) and include:

- Sulfuric acid mobilises Fe, Al, Mn and Cd, and lowers soil pH making some soils toxic to plant growth causing scalding (similar to salinity);
- Sulfuric acid corrodes concrete, iron and steel foundations and piping;
- Acid waters can cause rust coloured stains and slimes;
- Plastic corrugated drainage becomes blocked by iron oxides;
- Drainage waters can release sufficient sulfuric acid and Al to cause fish disease and mortality;
- Acid waters can mobilise aluminium and heavy metals such as cadmium which can be adsorbed by fish and aquatic life;
- Effects on aquaculture industries;
- Poor quality stock water;
- Bitumen road failure;
- Irreversible soil shrinkage;
- Low bearing capacity of soils;
- Human health problems: algae, heavy metals in drinking water, dermatitis, eye inflammations; and
- Arsenic toxicity.

1.1.4 Foul smells caused by ASS

Wetlands rich in sulfidic materials produce noxious smells when drying. Both H₂S and volatile S gases are thought to contribute to the noxious smells (Lamontagne et al. 2004; Figure 2).
1.1.5 Deoxygenation caused by ASS

The re-suspension of sulfidic materials can rapidly consume water column oxygen and cause fish kills (e.g. Bush et al., 2002; Sullivan et al., 2002) (Figure 3). This may be an issue during managed wetting/drying cycles in wetlands or the flushing of coastal drains during storm events.

Figure 3. Sulfidic sediment plume from Little Duck Lagoon to Salt Creek [Mardi van der Wielen, River Murray Catchment Water Management Board].
1.1.6 Acidification caused by ASS

The oxidation of sulfidic materials generates sulfuric acid. If acid production is greater than the acid neutralising capacity (ANC), ecosystem acidification can occur (Figure 4). Acidification results in elevated dissolved metal concentration and fish kills (e.g. Sammut et al., 1996).

![Figure 4. Bottle Bend Lagoon acidified to pH < 3 during a drawdown in 2002 [McCarthy et al. 2003].](image)

1.1.7 Occurrence of coastal acid sulfate soils

Coastal ASS can be found where elevation is below 5 m. ASS layers are common at or less than 1.5 m above high tide level but may be buried by many metres of alluvial material when located in major river systems. Differing coastal geomorphological histories result in ASS layers being found at even greater heights above high tide level. River and estuarine floodplains, swamps and tidal flats; and incised river channels often many kilometres inland up to 5 m above mean high tide level are potential areas for finding ASS.

1.1.8 Occurrence of inland acid sulfate soils

Inland ASS can be found under the following conditions:

- Non tidal;
- Swamps, marshes;
- Saline, sulfate rich groundwaters;
- Pyrite (Fe and S rich) geology;
- Dryland salinity;
- Erosion; and
- Mine spoils.
1.1.9 Processes

The requirements for formation of PASS are:

- Sulfate in water (> 10 mg/L; seawater or saline groundwater);
- Sediments containing iron oxides and organic matter; and
- Flushing (otherwise acidity will always equal alkalinity).

The requirement for the maintenance of PASS is waterlogging (saturation).

The requirements for formation of ASS are:

- Exposure of PASS to air. Pyrite and monosulfides oxidise when brought into contact with atmospheric oxygen. If the amount of acidity produced exceeds the buffering capacity of the soil, acidification occurs.

1.1.10 Environments

The environments in which ASS can be found:

- Natural – PASS covered by water and vegetated. Small amounts of acid released from the soil are neutralised by tidal flows, flood waters etc; and
- Modified (drained/modified for agricultural production) – Water levels drop and expose PASS. Acid is generated and can be released into streams and/or groundwater.
1.2 Aims of the report

1.2.1 General

This was a pilot study to improve knowledge of ASS in the City of Greater Geelong and indicate whether there is a potential risk of ASS being disturbed as a result of development.

The specific aims of the study were to:

• Assess, with a desktop study, the potential for ASS within future development areas of the City of Greater Geelong;
• Analyse the appropriate landscape parameters and the municipal development overlays to determine possible high risk PASS areas within the City of Greater Geelong;
• Identify at least two (and up to five) possible PASS sites that may have high ASS risk;
• Sample the sites and test the soils to determine the soil properties and ASS risk;
• Report on the study, with particular emphasis on any risks identified and the potential impact on assets at both the municipal and catchment scales; and
• Liaise with State Government agencies to ensure the outcomes are in-line with previous and current state-wide studies.

1.2.2 Expected output

• A pilot study to improve the knowledge of acid sulfate soil distribution in south-west Victoria;
• A brief report outlining the results, potential impact and potential management of ASS for the areas targeted for development within the City of Greater Geelong and which help determine the need to develop acid sulfate soil management overlays for all municipalities in the CCMA region;
• Information to improve the awareness of acid sulfate soils within local government and to help them evaluate the need to develop tools (eg. management overlays) to reduce the risk of disturbing these soils if developed.
2 Methods

2.1 Framework

The framework to the assessment of ASS threat to development included: a desktop assessment and selection of sites, a site visit, and sampling and laboratory testing of selected soils.

2.2 Desktop assessment

The desktop assessment involved the collation and analysis of spatial data sets within a geographic information system (GIS). Based on guidelines set by QDNR (Graham and Larsen, 1999) and local knowledge, it was determined that the following data sets were needed for the desktop analysis, though not all were available (or easily obtainable) for the area:

- Elevation;
- Existing ASS maps;
- Generic soil maps;
- Geological maps;
- Topographic and orthophoto maps;
- Floristic maps;
- Spatial water table levels; and
- Aerial photography.

Synthesis of the information that was available suggested ASS were most likely to occur in:

- Land with elevation < 5 m AHD (i.e. coastal areas and incised river channels less than 5 m elevation, as ASS are common at or less than 1.5 m above high tide level in SE Queensland but may be buried by many metres of alluvial material when located in major river systems. Elsewhere in Queensland, differing coastal geomorphological histories result in ASS being found at even greater heights above high tide level);
- Geological formations (bearing sulfide materials e.g. pyrite bands, coal deposits or marine shales, buried estuarine or Holocene sediments);
- River and estuarine floodplains and tidal flats, swamps and coastal alluvial valleys;
- Low lying coastal wetlands, waterlogged or scalded areas; and
- Areas with mangroves, saltcouch, paperbark, or swamp oak.

The major constraint to the desktop assessment as a primary indicative tool was that without supporting laboratory soil analyses it would not give an indication of the quantity of pyrite present. Additional information such as oxidation rates and leaching potential of ASS (and calculation of liming rates for their management, if needed) was only possible after detailed laboratory and interpretative assessment.

2.3 General site investigation

Observations were made at each field site to determine the potential risk of ASS as well as the collection of soil samples for chemical analyses. Observations included:

- Nature of disturbance;
- Specific location of disturbance;
- Total area of site;
- Volume of material to be disturbed; and
- Soil field tests (texture, colour, mottling etc).
2.4 Specific site selection and sampling

Twelve sites were selected for study based upon the results of the desktop investigation. These were investigated during a field visit in late March, 2005. Appendix 1 shows site information sheets for each of the twelve sites. Visual observations were made at each site (Table 1), which resulted in three being considered for sediment sampling. The profile sampling strategy at each site was based on the nature of sediments, changes in lithology and depth to standing water.

Bulk samples were packed in airtight conditions, frozen and transported to the laboratory for characterisation.

2.5 Laboratory methods

2.5.1 Sediment chemical analysis

Upon return to Adelaide, each of the bulk sediment samples was sub-sampled in the following ways:
- Approximately 200 g retained and frozen; and
- 250 ml sample of wet soil placed in a plastic vial and freeze-dried.

Once freeze-dried, the samples were submitted for the following analytical determinations:
- Electrical conductivity;
- pH (1:5 soil:water);
- pH (0.01M CaCl₂);
- Chloride;
- Total soil carbon by LECO™ furnace; and carbonate carbon to determine the neutralising capacity, i.e. there is sufficient capacity to neutralise all potential acid if the CaCO₃ content is 3 times that of total sulphur. Total carbon/carbonate carbon also help estimate the amount of organic carbon present, the substrate required for the generation of PASS by bacteria. Soil organic carbon was estimated by subtraction of carbonate carbon values from total carbon;
- Total sulfur by LECO™ furnace;
- Sulfide sulfur (to determine how much reduced sulfur is present);
- Inorganic sulfur (chromium reducible sulfur - Sₐᵥ);
- Acid volatile sulfides – Sₐᵥ; and
- Total element analysis.

The total S content of a sample was considered to consist of three fractions: total reduced inorganic S (TRIS), oxidised S (or sulfate) and organic S (i.e. Total S = TRIS + SO₄ + Organic S).

Reduced inorganic S can be further subdivided into elemental S (S₀), acid volatile S (AVS) and pyrite S. To determine these various fractions, two analytical methods were used in various combinations. One method measures only AVS and the chromium reduction method (Sₐᵥ) measures the total reduced S, including S₀. These methods can be employed on separate samples or sequentially.

If done on separate samples the AVS measurement gives AVS alone and the chromium reduction method the TOTAL of S₀ + AVS + pyrite-S. In this instance the total reduced
inorganic S content of the sample (TRIS) equals the value for the chromium reducible S (i.e. TRIS=S_{Cr}).

However if done sequentially on the same sample, the AVS is first removed when it is measured and the REMAINING reduced S, which consists of elemental S and pyrite S, is then measured by the chromium reduction technique. In which case:

\[ \text{TRIS} = \text{AVS} + S_{Cr} \]

where \( S_{Cr} = S^0 + \text{pyrite-S}. \)

By subtracting TRIS from total S, the sum of organic-S and sulfate is obtained. Some assumptions about the likely significance of the organic fraction then need to be made.
3 Results

3.1 Spatial analyses

Figure 5 shows the spatial extent of the City of Greater Geelong (hatched).

Figure 5. Location: City of Greater Geelong.
Figure 6 shows the planning zones for the City of Greater Geelong. This information was used to help in deciding where sampling for ASS should occur.
Figure 7 shows areas within the City of Greater Geelong that are below both 2.5 m and 5 m AHD. One of the criteria for acid sulfate soils is that they are found below 5 m elevation (Ahern et al., 1998; Queensland Government, 2002).

Figure 7. Map of land with elevation < 2.5 and < 5.0 m AHD.
Figure 8 shows areas within the City of Greater Geelong that have Holocene epoch sediments. Holocene epoch sediments can be high in pyrite material in Australia and are thus areas where acid sulfate soils may be likely to have formed (White et al., 1997; Graham and Larson, 2000).

Figure 8. Holocene sediments.
Figure 9 shows wetland areas in the City of Greater Geelong. Acid sulfate soils may occur naturally in these environments.
Figure 10 shows those areas predicted as possibly having ASS, based on GIS overlay modelling of the various spatial criteria for occurrence of ASS. The results show an areal extent of 4.7% of ASS within the City of Greater Geelong, compared to 9.2% as mapped by Rampant et al. (2003).

Figure 10. Assessment of predicted possible ASS distribution.
Figure 11 shows the location of twelve sites chosen for investigation where it was thought that acid sulfate soils may have an impact on future development in the City of Greater Geelong.

Figure 11. Location of field sites visited March, 2005.
3.2 Laboratory analyses

Of the 12 sites which were visited, only three were thought to contain both ASS and pose a problem for future development. To determine if PASS/ASS did occur at these sites, soil samples were collected from site AV02, 0-20 cm; site PH02, 0-2 cm, 2-20 cm, 20-35 cm, and 25-50 cm; and site RL01, 5 to 10 cm, 20-30 cm and 30-35 cm).

Table 2 summarises the results of laboratory analyses on samples that were collected and includes calculations of gross acid production potential (APP) and gross acid neutralising capacity (ANC). Based upon these calculations, the ANC provided by the abundance of CaCO$_3$, is more than sufficient to account for any potential acidification in all the samples. Total element analysis is in Appendix 2.

One horizon from Point Henry soil profile (PH02.3) can be considered marginally ASS, with an net acid generating potential (NAGP) = 0.3. However, as the soil of this profile has a large acid neutralising capacity (ANC), an acid-base account of the whole profile would most likely indicate a minimal ASS risk.

A sample from Avalon (AV02.1) has a high S$_{SR}$ which indicates a potential for production of noxious smells, should the site ever be dried out and developed in the future. The high amounts of CaCO$_3$ found in this sample are in keeping with it being a “closed” system. i.e. there is no opportunity for seawater flushing of carbonates, which would increase the risk of forming potential ASS.
Table 2. Summary results of sediment analysis.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Depth</th>
<th>Moisture</th>
<th>EC (1:5 soil:H₂O)</th>
<th>pH (1:5 soil: H₂O)</th>
<th>pH (0.01M CaCl₂)</th>
<th>CI mg/kg</th>
<th>Total C %</th>
<th>Org. C %</th>
<th>CO₃ as CaCO₃ %</th>
<th>Total S %</th>
<th>S_CR b eq/g</th>
<th>S_AV c eq/g</th>
<th>Gross APP</th>
<th>Gross ANC</th>
</tr>
</thead>
<tbody>
<tr>
<td>AV02.1</td>
<td>0 - 20</td>
<td>61.7</td>
<td>55.3</td>
<td>8.2</td>
<td>8.2</td>
<td>150000</td>
<td>8.4</td>
<td>5.7</td>
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<td>1.39</td>
<td>0.50</td>
<td>0.04</td>
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<td>57.7</td>
<td>7.3</td>
<td>7.3</td>
<td>159000</td>
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<td>18.1</td>
<td>2.3</td>
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<tr>
<td>PH02.3</td>
<td>20 - 35</td>
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<td>0.8</td>
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<td>0.03</td>
<td>0.18</td>
<td>9.0</td>
<td></td>
</tr>
<tr>
<td>RL01.1</td>
<td>5 - 10</td>
<td>49.4</td>
<td>3.1</td>
<td>5.8</td>
<td>5.5</td>
<td>4640</td>
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<td>8.2</td>
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<td>1.0</td>
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</tr>
<tr>
<td>RL01.2</td>
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<td>35.8</td>
<td>4.1</td>
<td>7.0</td>
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<td>5180</td>
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<td>&lt; 0.5</td>
<td>0.10</td>
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<td>&lt; 1.0</td>
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<td>1.9</td>
<td>8.1</td>
<td>7.9</td>
<td>2280</td>
<td>0.1</td>
<td>0.1</td>
<td>&lt; 0.5</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>&lt; 1.0</td>
<td></td>
</tr>
</tbody>
</table>

a Sample numbers relate to site location (refer Figure 11) and layer depth.
b Chromium-reducible sulfur. As per the method of Sullivan et al., 2000. A value > 0.05 may signify ASS, depending on buffering capacity of the soil.
c Acid-volatile sulfur. Indicates those metal monosulfide materials (e.g. FeS) that evolve hydrogen sulfide when treated with hydrochloric acid.
4 Conclusions

This was a pilot study to identify the risk of ASS/PASS having a negative impact on proposed development in the City of Greater Geelong. It should not be regarded as a detailed study into the extent of ASS/PASS in the region.

Acid sulfate soils are found throughout the City of Greater Geelong (Rampant et al., 2003). However, areas of potential development in the short-term (5 to 10 years) are at low risk. The planning scheme already protects/excludes most areas of ASS/PASS from development. They are mostly confined to Public Conservation and Resource areas. Exceptions to this were the sites of a disused salt evaporation pond at Avalon (AV02) and tidal flat adjacent to the smelting plant at Point Henry (PH02). The site at Avalon has potential to produce foul odours, if it were ever redeveloped, due to the high $S_{CR}$ of the soil. However the large ANC of the soil should guard against issues of acidification, should the site be disturbed through excavation. The site at Point Henry was the only one tested which had any acid sulfate soil potential and this was considered marginal at most. There is potential for infrastructure to be affected so ASS should be checked before major development (mostly industrial).

There is potential for ASS to affect regional assets, as explained in Section 1.1.2. Further work may be warranted to assess both inland and coastal ASS throughout the CCMA region. Investigations should specifically target potential development areas where ASS may affect the regional assets.
References


Glossary

**Acid Sulfate Soil (ASS)** – a soil or soil horizon which contains sulfides or an acid soil horizon affected by oxidation of sulfides. Acid sulfate soils are the common name given to naturally occurring sediments and soils containing iron sulfides (principally iron sulfide or iron disulfide or their precursors). The exposure of the sulfide in these soils to oxygen by drainage or excavation leads to the generation of sulfuric acid.

*Note: The term acid sulfate soil generally includes both actual and potential acid sulfate soils. Actual and potential acid sulfate soils are often found in the same soil profile, with actual acid sulfate soils generally overlying potential acid sulfate soil horizons.*

**Actual acid sulfate soils (AASS)** – soils containing highly acidic soil horizons or layers resulting from the aeration of soil materials that are rich in iron sulfides, primarily sulfide. This oxidation produces hydrogen ions in excess of sediment’s capacity to neutralise the acidity resulting in soils of pH of 4 or less when measured in dry season conditions. These soils can usually be identified by the presence of yellow mottles and coatings of jarosite.

**Potential acid sulfate soils (PASS)** – soils which contain iron sulfides or sulfidic material which have not been exposed to air or oxidised. The field pH of these soils in their undisturbed state can be pH 4 or more and may be neutral or slightly alkaline. However, they pose a considerable environmental risk when disturbed, as they will become very acidic when exposed to air and oxidised.

**AHD (Australian Height Datum)** – mean sea level based on official tide gauges around the coastline.

**Alluvial** – material deposited by a stream or running water.

**ANC** - Acid Neutralising Capacity. A measure of a soil’s inherent ability to buffer acidity and resist the lowering of the soil pH.

**Estuarine** - of, or pertaining to an estuary.

**Estuary** – a simple geomorphological definition of an estuary is “…a funnel shaped opening of a river in the sea” (Reinick and Singh 1980). Other definitions include criteria such as being tidally effected and dilution of marine and fresh water. A generally accepted definition is that of Pritchard (1967) who describes an estuary as “…a semi-enclosed coastal body of water which has free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage”. A more recent geologically orientated definition by Dalrymple, Zaitlin and Boyd (1992) has recognised that estuaries form by the drowning of river valleys as sea level rises, and recognise the limits of an estuary by sedimentary criteria. They define an estuary as “…the seaward portion of a drowned valley system which receives sediment from both fluvial and marine sources and which contains facies influenced by tide, wave and fluvial processes. The estuary is considered to extend from the landward limit of tidal facies at its head to the seaward limit of coastal facies at its mouth”.

**Holocene** – a period of time from about 10,000 years ago to the present, an epoch of the Quaternary period.

**Horizon** - with reference to soils, a layer of soil, approximately parallel to the land surface, with morphological properties different from layers below and/or above it.

**Jarosite** – ochre-yellow or brown hydrous potassium iron sulfate mineral: \( \text{KFe}_3(\text{SO}_4)_2(\text{OH})_6 \).

**Monosulfides** – (FeS) Fe III is reduced to Fe II by bacterial action and then combines with dissolved sulfides to form FeS.

**Oxidise** - the process of reacting with oxygen.

**pH(1:5 soil: H}_2\text{O)** – pH of a 1:5 solution of soil and deionised water.
pH(0.01M CaCl$_2$) – pH of a 1:5 solution of soil and 0.01 molar CaCl$_2$.

Pyrite – pale-bronze or brass-yellow, isometric mineral: FeS$_2$; the most widespread and abundant of the sulfide minerals.

$S_{AV}$ - Acid volatile sulfides. Reactive reduced sulfur phases (such as iron 'monosulfides') that oxidise readily on contact with air. They are often associated with organic-rich sediments, drains and lake bottoms, and oxidise rapidly when exposed to oxygen.

$S_{CR}$ - Chromium-reducible sulfur. Provides a measure of reduced inorganic sulfide content. This method is not subject to interferences from organic sulfur.

TRIS - Total reduced inorganic sulfur.

Watertable – portion of the ground saturated with water, often used specifically to refer to the upper limit of the saturated ground.
## Appendix 1. Analytical results for total element analysis of sediments

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<th>Cr</th>
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Appendix 2. Site information sheets
### Site Information Sheet

**Location Description:**
- Site 1: 100 m north of eastern end of Jukanah Road, Jukanah.  
- Site 2: 100 m north of eastern end of Jukanah Road, Jukanah.
- Site 3: 100 m north of eastern end of Jukanah Road, Jukanah.
- Site 4: 100 m north of eastern end of Jukanah Road, Jukanah.

**Locality Details:**
- Site 1: 100 m north of eastern end of Jukanah Road, Jukanah.  
- Site 2: 100 m north of eastern end of Jukanah Road, Jukanah.  
- Site 3: 100 m north of eastern end of Jukanah Road, Jukanah.  
- Site 4: 100 m north of eastern end of Jukanah Road, Jukanah.

**Soil Sample:**
- Site 1: City of Greater Geelong urban extent 100.  
- Site 2: City of Greater Geelong urban extent 100.  
- Site 3: City of Greater Geelong urban extent 100.  
- Site 4: City of Greater Geelong urban extent 100.

**Notes:**
- Wetland on opposite side of road to Broadslea Flora Reserve.

---

**Site Information Sheet**

**Location Description:**
- Site 1: 100 m north of eastern end of Jukanah Road, Jukanah.  
- Site 2: 100 m north of eastern end of Jukanah Road, Jukanah.  
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- Site 4: City of Greater Geelong urban extent 100.

**Notes:**
- Wetland on opposite side of road to Broadslea Flora Reserve.
# SITE INFORMATION SHEET

## Site

<table>
<thead>
<tr>
<th>Date</th>
<th>Observer</th>
<th>Photograph (Filename)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21/03/13</td>
<td>[Person/Institution]</td>
<td>[Filename]</td>
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</tbody>
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## Locality Details

- **Name**: Beedy Lake, Southern end of Montague Station Road.
- **Easting**: 27,790
- **Northing**: 74,790
- **Elevation**: 3 m
- **Datum**: GDA 1994
- **UTM (nominal)**: 55
- **Zone**: 55

## Landform Elements

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<th>Surface Cover (%)</th>
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## Soil Sample

- **RL1.1**

## Soil Landform Unit

- **Unit No.**: 72
- **Description (Filename)**: [Filename]

## Notes

- Wildfire Reserve.

---

# SITE INFORMATION SHEET

## Site

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<td>[Filename]</td>
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## Locality Details

- **Name**: Beedy Lake, Eastern side of lake, western end of O’Halloran Road.
- **Easting**: 27,770
- **Northing**: 74,770
- **Elevation**: 2.8 m
- **Datum**: GDA 1994
- **UTM (nominal)**: 55
- **Zone**: 55

## Landform Elements

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## Soil Sample

- **RL1.1**

## Soil Landform Unit

- **Unit No.**: 72
- **Description (Filename)**: [Filename]

## Notes

- Wildfire Reserve.

---

# SITE INFORMATION SHEET

## Site

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## Locality Details

- **Name**: Beedy Lake, Eastern side of lake, western end of O’Halloran Road.
- **Easting**: 27,770
- **Northing**: 74,770
- **Elevation**: 2.8 m
- **Datum**: GDA 1994
- **UTM (nominal)**: 55
- **Zone**: 55

## Landform Elements

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## Soil Sample

- **RL1.1**

## Soil Landform Unit

- **Unit No.**: 72
- **Description (Filename)**: [Filename]

## Notes

- Wildfire Reserve.

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# SITE INFORMATION SHEET

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<td>[Person/Institution]</td>
<td>[Filename]</td>
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## Locality Details

- **Name**: Beedy Lake, Eastern side of lake, western end of O’Halloran Road.
- **Easting**: 27,770
- **Northing**: 74,770
- **Elevation**: 2.8 m
- **Datum**: GDA 1994
- **UTM (nominal)**: 55
- **Zone**: 55

## Landform Elements

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## Soil Sample

- **RL1.1**

## Soil Landform Unit

- **Unit No.**: 72
- **Description (Filename)**: [Filename]

## Notes

- Wildfire Reserve.