# 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

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

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# Executive Summary

Based on previous work, including a very good review by the Centre for Land Protection Research of the Victorian Department of Primary Industries, 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.

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# 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.

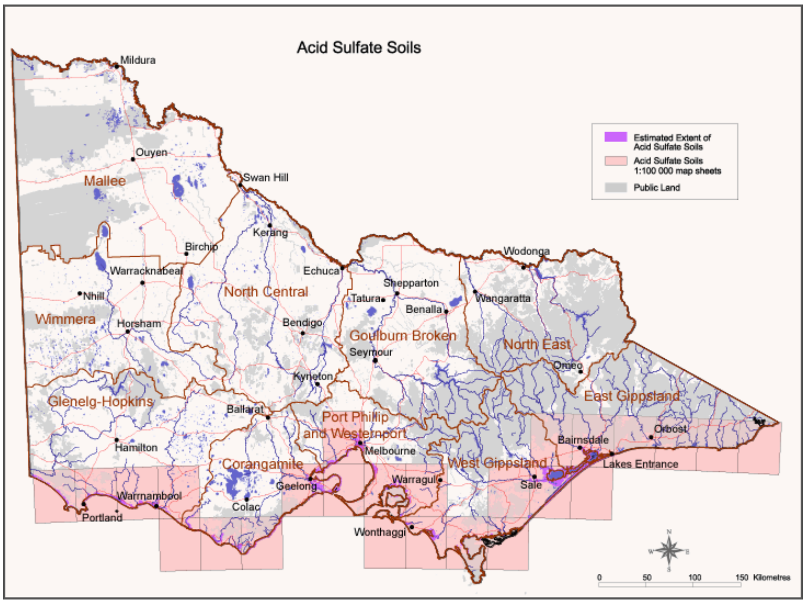



**Figure 1. Distribution of coastal acid sulfate soils [Rampant *et al*. 2003].**

### 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].

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

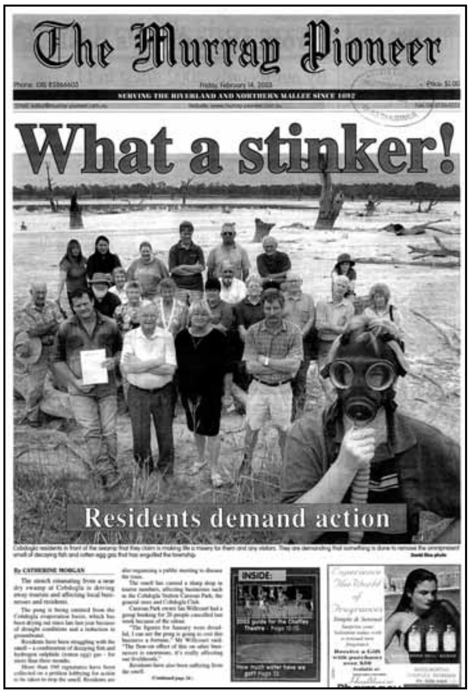
### 1.1.3 Impacts of ASS

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 $H_2S$ and volatile S gases are thought to contribute to the noxious smells (Lamontagne *et al*. 2004; Figure 2).


The Murray Pioneer

SERVING THE RIVERLAND AND NORTHERN MALLEE SINCE 1892

What a stinker!

Residents demand action

INSIDE:

Figure 2. News clipping from the Murray Pioneer, 14 February 2004.

### 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].**

### 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 $CaCl_2$);
- 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 $CaCO_3$ 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 - $S_{CR}$);
- Acid volatile sulfides – $S_{AV}$; 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 + $SO_4$ + Organic S).

Reduced inorganic S can be further subdivided into elemental S ($S^0$), 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 ($S_{Cr}$) measures the total reduced S, including $S^0$. 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 $S^0$ + 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:

TRIS = AVS + $S_{Cr}$

where $S_{Cr} = S^0$ + 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).

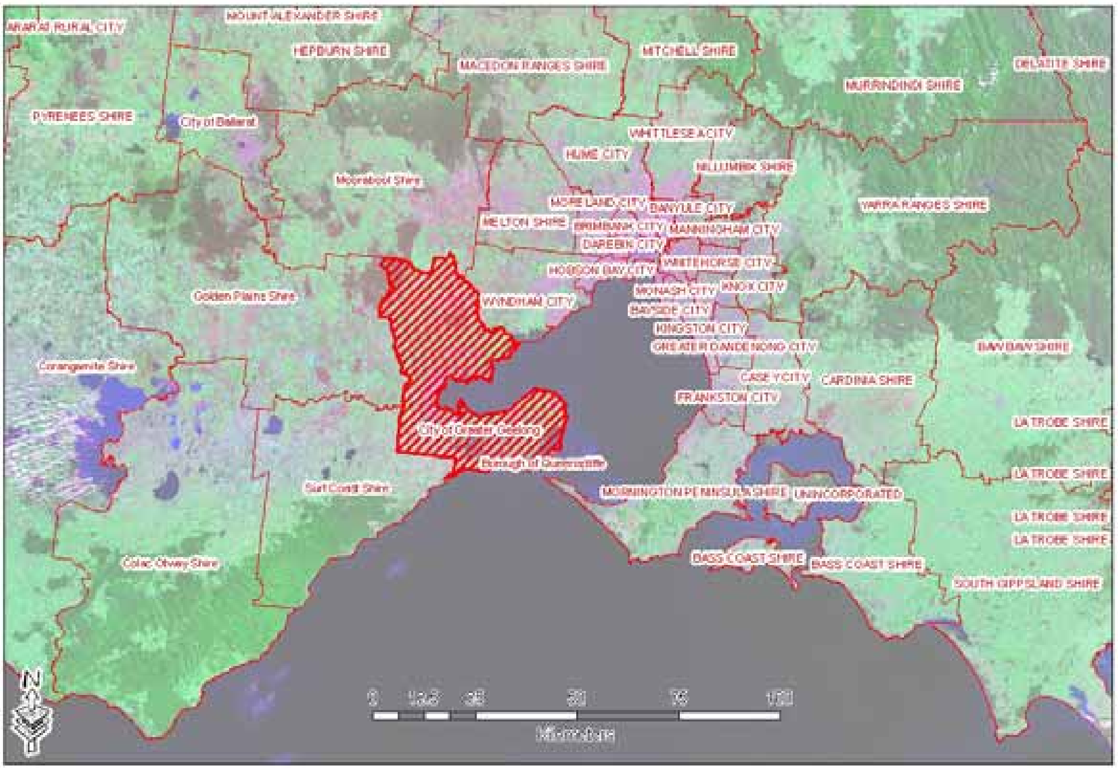



**Figure 5. Location: City of Greater Geelong.**

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.

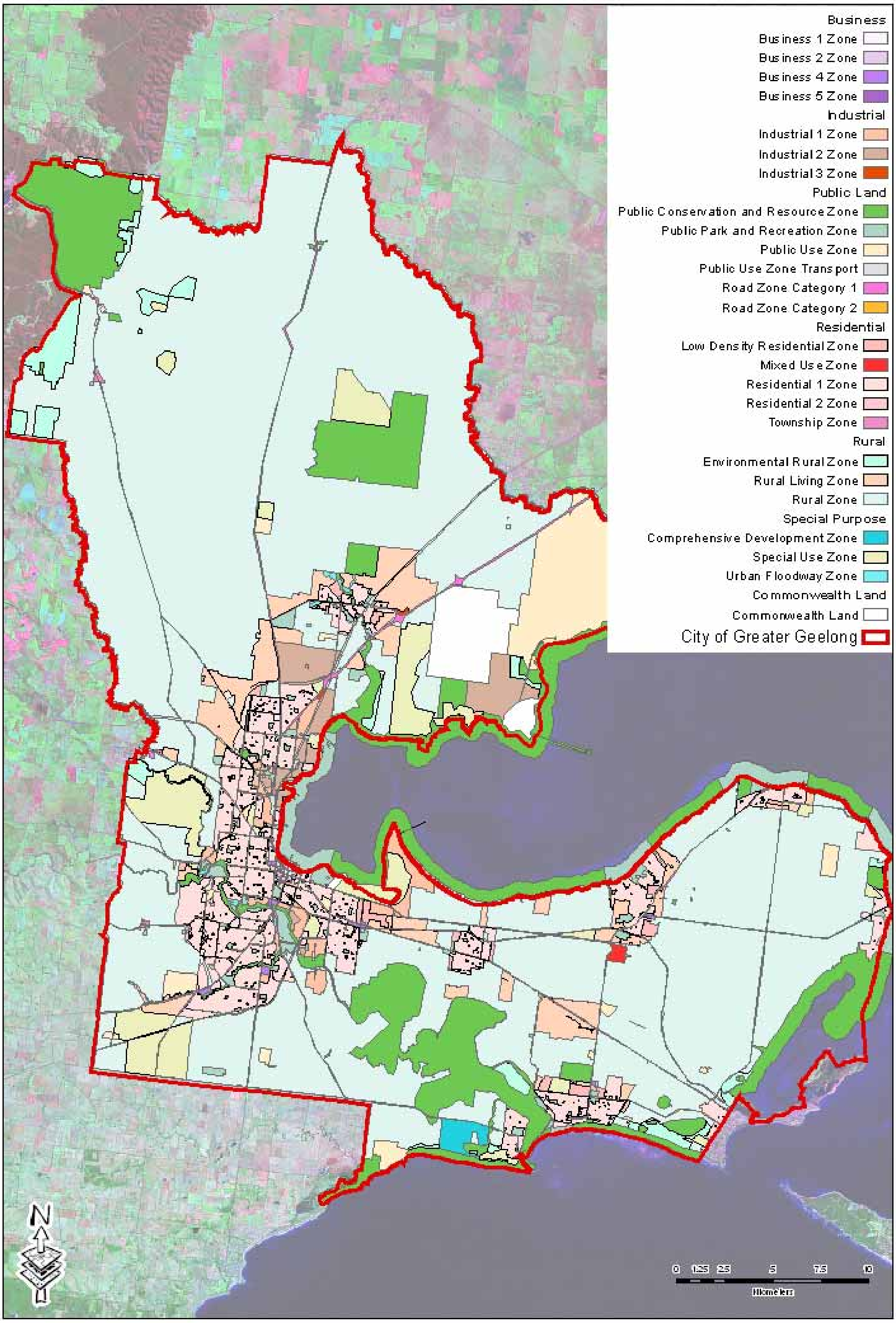



**Figure 6. Planning zones.**

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).

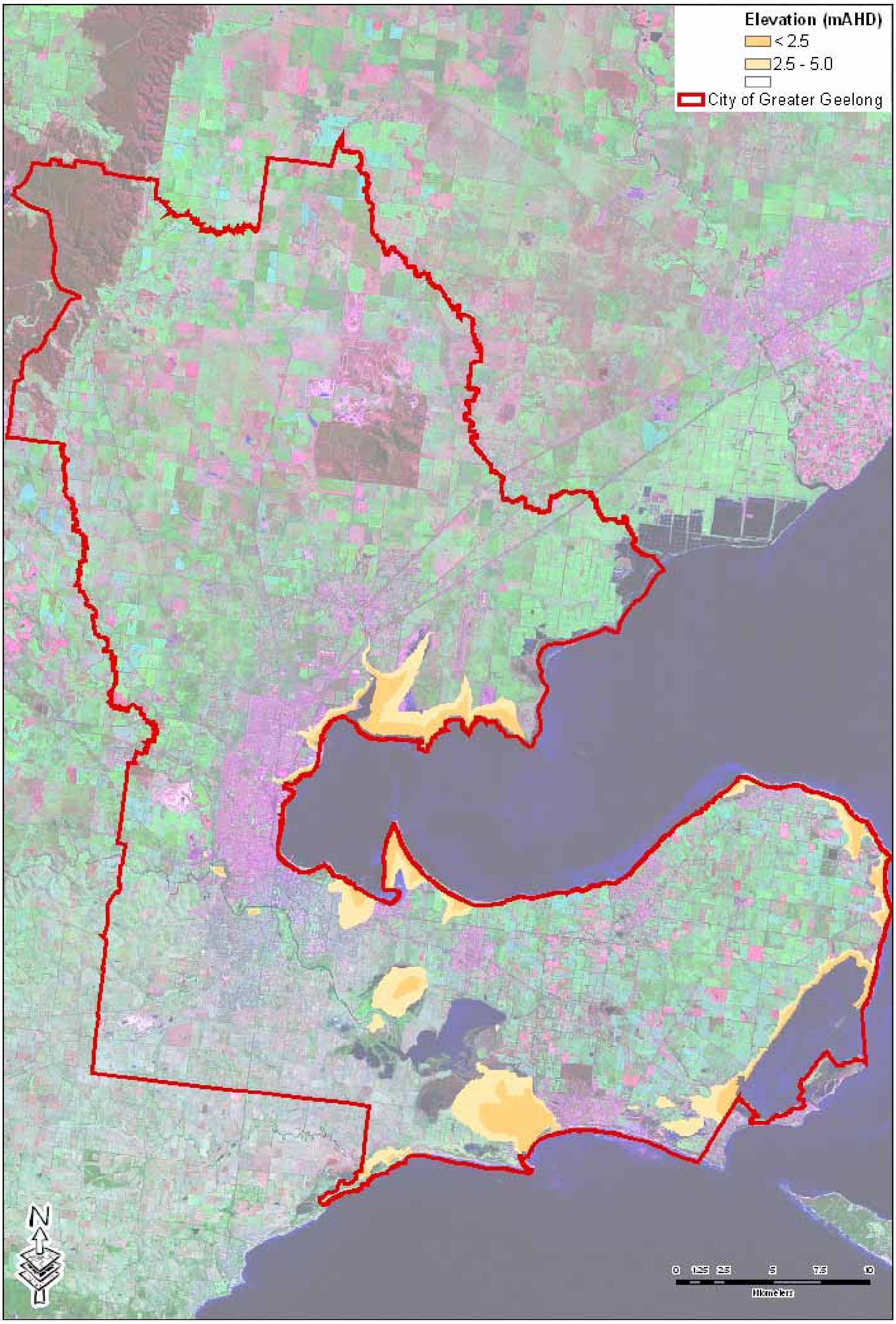



**Figure 7. Map of land with elevation < 2.5 and < 5.0 m AHD.**

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).

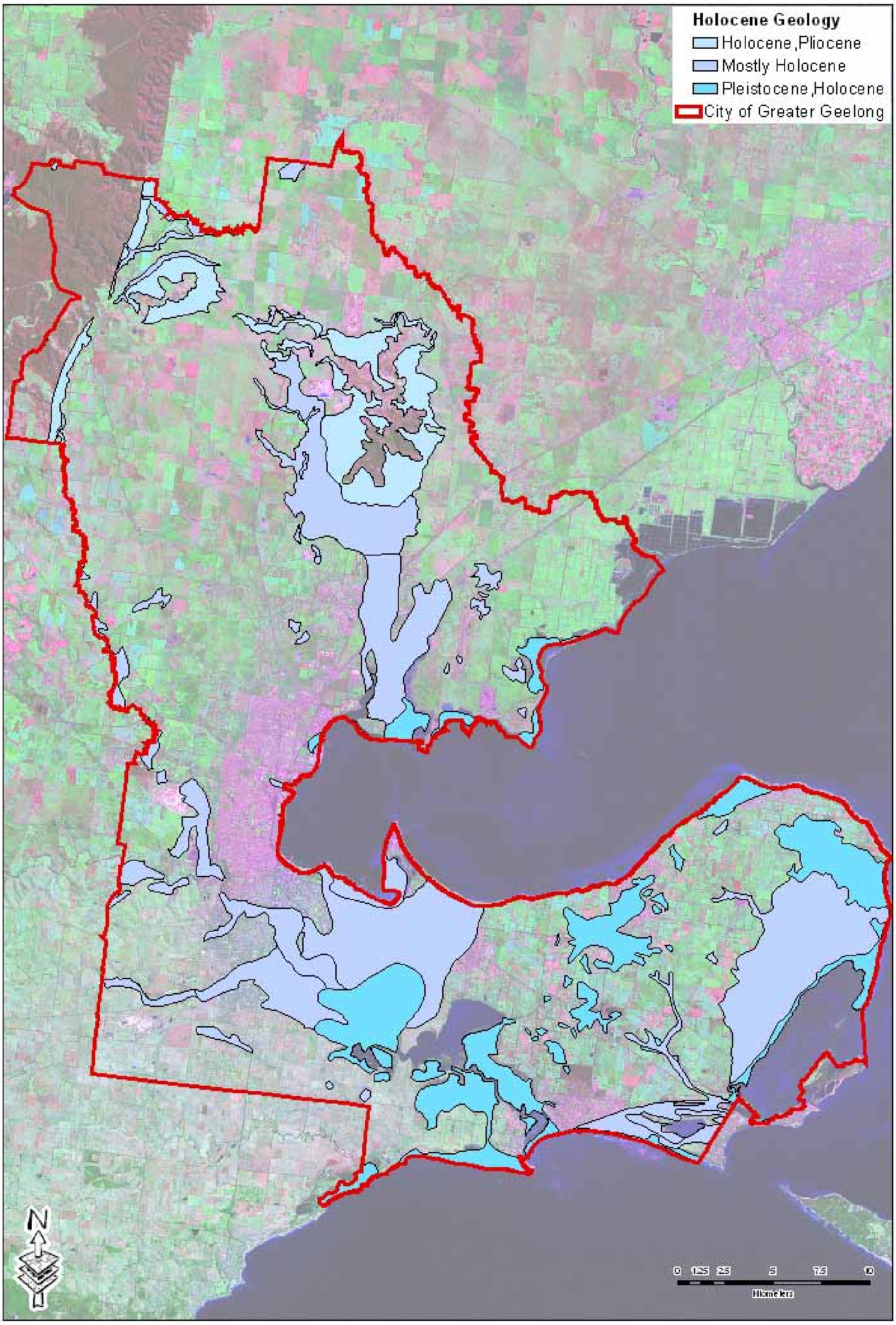



**Figure 8. Holocene sediments.**

Figure 9 shows wetland areas in the City of Greater Geelong. Acid sulfate soils may occur naturally in these environments.

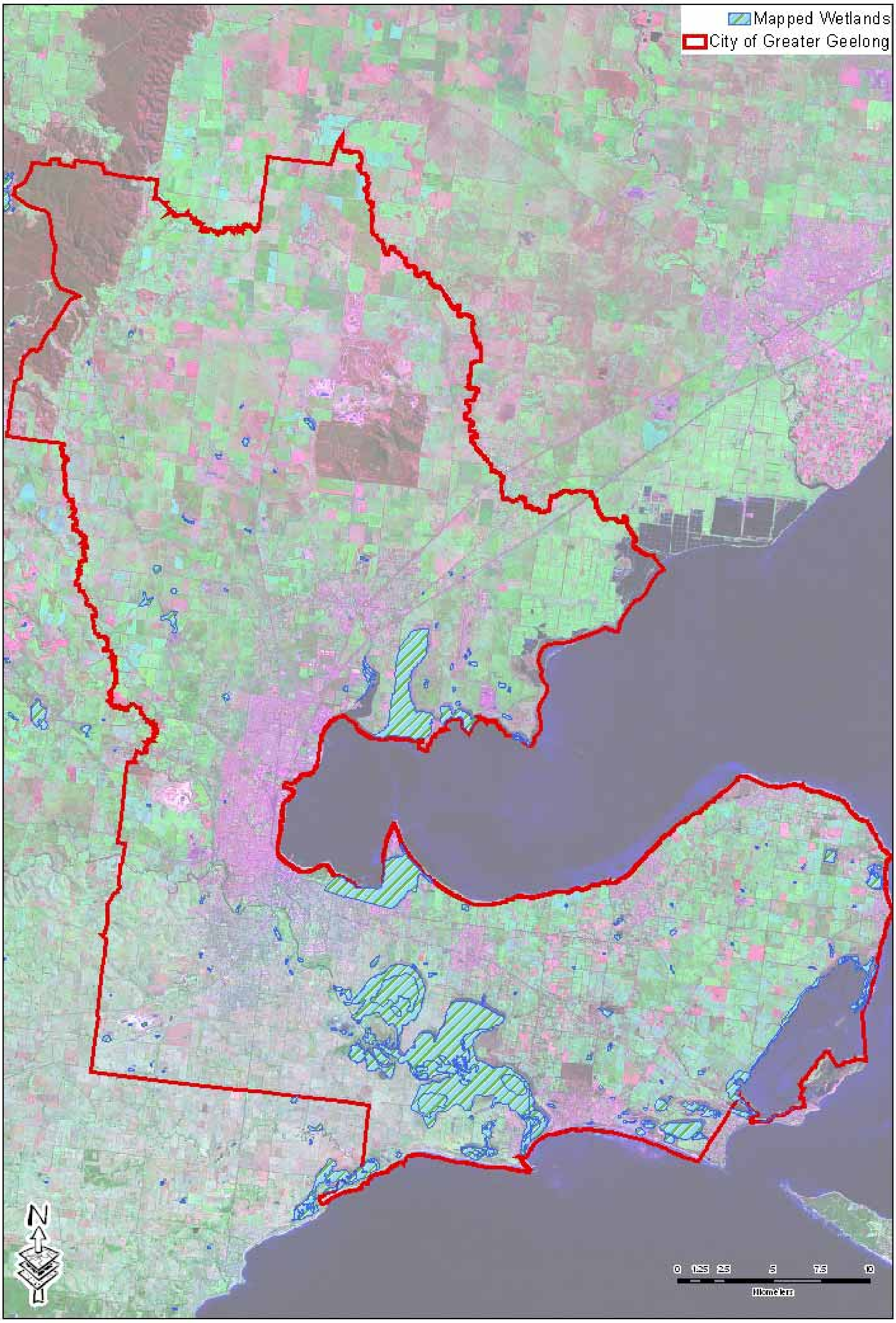



**Figure 9. Mapped wetland areas.**

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).

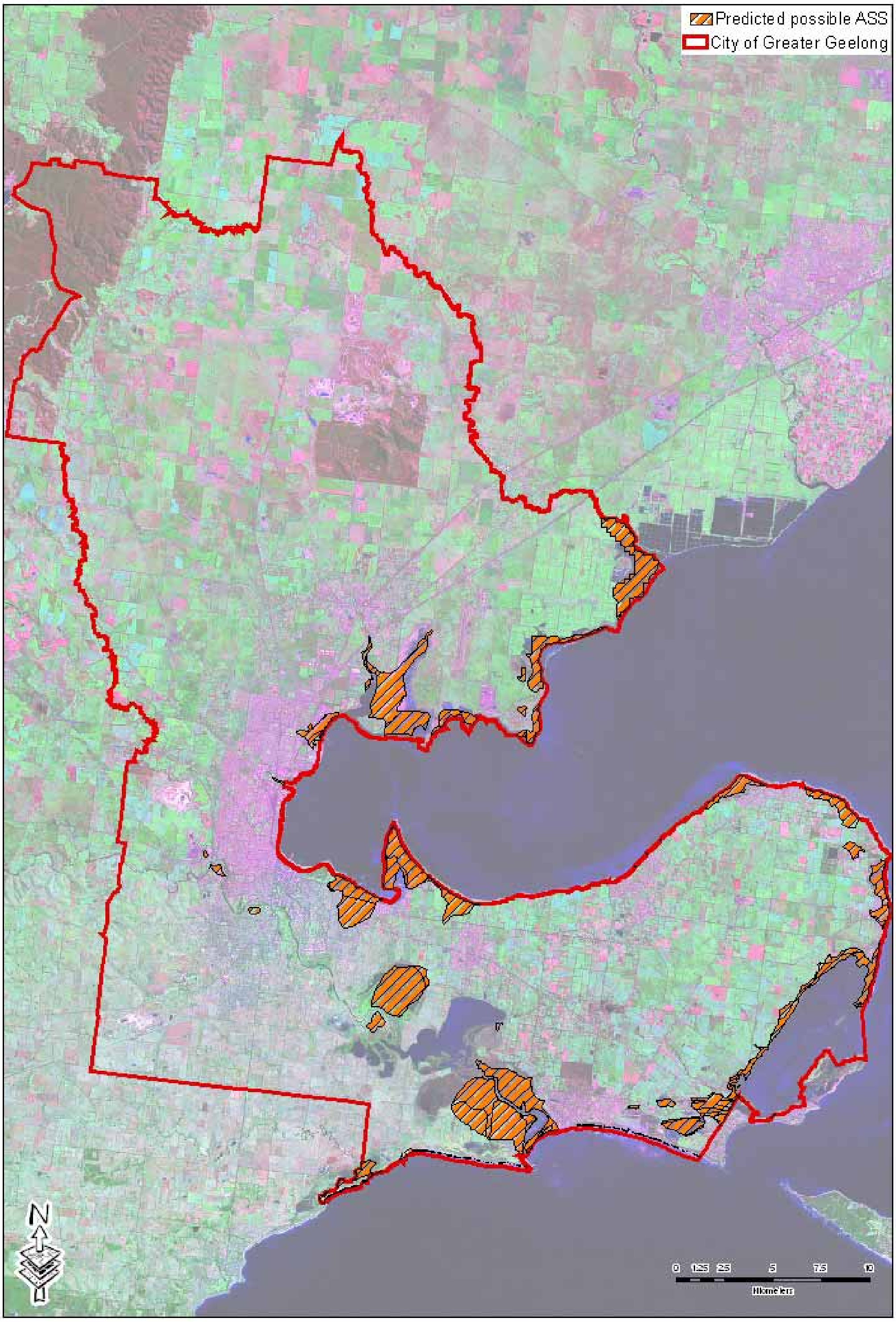



**Figure 10. Assessment of predicted possible ASS distribution.**

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.

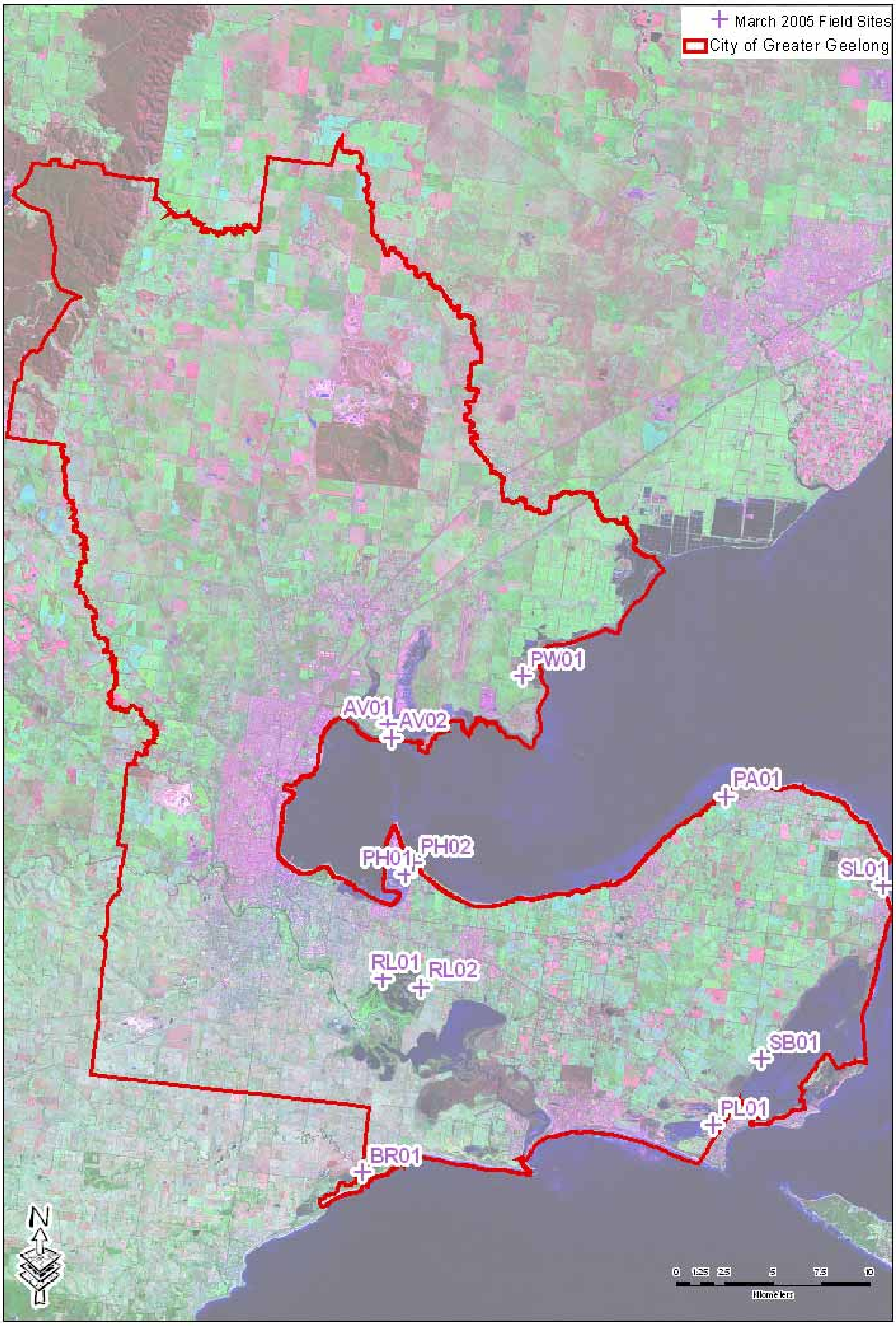



**Figure 11. Location of field sites visited March, 2005.**

## 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 $S_{CR}$ 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.**

| Sample[a] | Depth | Moisture | EC (1:5 soil:$H_2O$) | pH (1:5 soil: $H_2O$) | pH (0.01M $CaCl_2$) | Cl | Total C | Org. C | $CO_3$ as $CaCO_3$ | Total S | $S_{CR}$[b] | $S_{AV}$[c] | Gross APP | Gross ANC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | % | dS/m | | | mg/kg | % | % | % | % | | | eq/g | eq/g |
| AV02.1 | 0 - 20 | 61.7 | 55.3 | 8.2 | 8.2 | 150000 | 8.4 | 5.7 | 21.8 | 1.39 | 0.50 | 0.04 | 3.00 | 43.6 |
| PH02.1 | 0 - 2 | 73.6 | 57.7 | 7.3 | 7.3 | 159000 | 18.3 | 18.1 | 2.3 | 1.74 | 0.28 | | 1.70 | 4.6 |
| PH02.2 | 2 - 20 | 63.6 | 35.5 | 7.5 | 7.4 | 72600 | 6.6 | 6.2 | 3.1 | 0.51 | 0.03 | | 0.18 | 6.2 |
| PH02.3 | 20 - 35 | 73.7 | 46.6 | 7.5 | 7.5 | 116000 | 10.8 | 10.6 | 1.9 | 1.68 | 0.69 | | 4.10 | 3.8 |
| PH02.4 | 35 - 50 | 23.6 | 7.3 | 9.2 | 8.9 | 12600 | 0.8 | 0.2 | 4.5 | 0.01 | 0.03 | | 0.18 | 9.0 |
| RL01.1 | 5 - 10 | 49.4 | 3.1 | 5.8 | 5.5 | 4640 | 8.3 | 8.2 | 0.5 | 0.13 | 0.03 | | 0.18 | 1.0 |
| RL01.2 | 20 - 30 | 35.8 | 4.1 | 7.0 | 6.8 | 5180 | 3.3 | 3.3 | < 0.5 | 0.10 | 0.02 | | 0.02 | < 1.0 |
| RL01.3 | 30 - 35 | 17.1 | 1.9 | 8.1 | 7.9 | 2280 | 0.1 | 0.1 | < 0.5 | 0.01 | 0.00 | | 0.00 | < 1.0 |

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


Ahern, C.R., Stone, Y. and Blunden, B. (1998). *Acid Sulfate Soils Assessment Guidelines.* Published by the Acid Sulfate Soils Management Advisory Committee, Wollongbar, NSW, Australia.

Bush, R.T., Fyfe, D. and Sullivan, L.A. (2002). Distribution and occurrence of monosulfidic black ooze (Mbo) in coastal acid sulfate soil landscapes, Abstracts of the 5th International Acid Sulfate Soil Conference, Sustainable Management of Acid Sulfate Soils, August 25th –30th, Tweed Heads, NSW, Australia, 2002.

Dalrymple, R.W., Zaitlin, B.A. and Boyd, R. (1992). Estuarine facies models – conceptual basis and stratigraphic implications. *Journal of Sedimentary Petrology*, 62, 1130-1146.

Graham, T.L. and Larsen, R.M. (1999). *The role of coastal geoscience in understanding acid sulfate soil development*. In Acid Sulfate Soils and their Management in Coastal Queensland: Forum and Technical Papers. Hey KM, Ahern CR, Eldershaw VJ, Anorov JM and Watling KM (eds), Brisbane 21–23 April, 1999. Department of Natural Resources, Indooroopilly, Queensland, Australia.

Graham, T.L. and Larson, R.M. (2000). *Coastal geomorphology: progressing the understanding of acid sulfate soil distribution*. (13)1-10. In Acid sulfate soils: environmental issues, assessment and management, technical papers. (Eds CR Ahern, KM Hey, KM Watling and VJ Eldershaw), Brisbane, 20-22 June, 2000. Department of Natural Resources, Queensland.

Lamontagne, S., Hicks, W.S., Fitzpatrick, R.W. and Rogers, S. (2004). Survey and description of sulfidic materials in wetlands of the Lower River Murray Floodplains: Implications for floodplain salinity management. CRC for Landscape Environments and Mineral Exploration, Open File Report 165.

McCarthy, B., Conallin, A. and Walsh, R. (2003). Aquatic survey of Bottle Bend Lagoon, near Buronga NSW: Salinisation and acidification impacts. CRC for Freshwater Ecology report for NSW Murray Wetland Working Group Inc. Report No. 2/2003. Murray-Darling Freshwater Research Centre, Albury, New South Wales, Australia.

Maher, J.M. and Martin, J.J. (1987). Soils and landforms of south-western Victoria. Part 1. Inventory of soils and their associated landscapes. Research Report series No. 40. Department of Agriculture and Rural Affairs.

Merry, R.H., Fitzpatrick, R.W., Barnett, E.J., Davies, P.J., Fotheringham, D.G., Thomas, B.P. and Hicks, W.S. (2003). South Australian Inventory of Acid Sulfate Soil Risk (Atlas). Final project report to Coastal Acid Sulfate Soils Program (CASSP). March, 2003.

National Working Party on Acid Sulfate Soils (2000). National strategy for the management of coastal acid sulfate soils. NSW Agriculture, Wollongbar. http://www.mincos.gov.au/pdf/natass.pdf.

Pritchard, D.W. (1967). What is an estuary, physical viewpoint. In: G. H. Lauf (editor): Estuaries. American Association for the Advancement of Science, Washington D.C., publ. no. 83.

Queensland Government (2002). State Planning Policy 2/02. Planning and Managing Development Involving Acid Sulfate Soils. Department of Local Government and Planning and Department of Natural Resources and Mines, Queensland.

Rampant, P., Brown, A. and Croatto, G. (2003). Acid sulfate soil hazard maps: Guidelines for coastal Victoria. Research Report No. 12. Centre for Land Protection Research, Department of Primary Industries.

Reinick, H.E. and Singh, I.B. (1980). *Depositional sedimentary environments*. Berlin, Springer-Verlag, 549 pp.

Robinson, N., Rees, D., Reynard, K., MacEwan, R., Dahlhaus, P., Imhof, M., Boyle, G. and Baxter, N. (2003). A land resource assessment of the Corangamite region. Department of Primary Industries.

Sammut, J., White, I. and Melville, M.D. (1996). Acidification of an estuarine tributary in eastern Australia due to the drainage of acid sulfate soils. *Marine and Freshwater Research*, 47, 669-684.

Sammut, J. and Lines-Kelly, R. (1996). *An Introduction to Acid Sulfate Soils*. Seafood Council, ASSMAC, Department of Education, Science and Training.

Sullivan, L.A., Bush, R.T. and McConchie, D.M. (2000). A modified chromium-reducible sulfur method for reduced inorganic sulfur: Optimum reaction time for acid sulfate soil. *Australian Journal of Soil Research*, vol. 38, pp 729-734.

Sullivan, L.A., Bush, R.T. and Fyfe, D. (2002). *MBOs and drain management in ASS landscapes: some relevant issues*. In Tuckean Mid-conference Field Trip Papers. 5th International Acid Sulfate Soils Conference, Tweed Heads, NSW, Australia, 2002.

White, I., Melville, M.D., Wilson, B.P. and Sammut, J. (1997). Reducing acidic discharges from coastal wetlands in estern Australia. *Wetlands Ecology and Management*, 5, 55-72.

## 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 andresist 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: $KFe_3(SO_4)_2(OH)_6$.

**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: $H_2O$)** –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

| Sample | Na | Mg | Al | Si | P | S | Cl | K | Ca | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | As |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % | % | % | % | % | % | % | % | ppm | ppm | ppm | ppm | ppm | ppm |
| AV02.1 | 17.73 | 2.9 | 1.871 | 7.98 | 0.1517 | 1.445 | 18.16 | 0.776 | 7.415 | 0.1516 | 0.00455 | 0.00146 | 0.03064 | 1.003 | <2.0 | 4.9 | 15.7 | 71.1 | <0.5 | <0.4 |
| PH02.1 | 15.02 | 2.75 | 2.232 | 5.475 | 0.1625 | 1.306 | 17.02 | 0.7499 | 0.8124 | 0.1364 | 0.0059 | 0.00183 | 0.01975 | 0.9185 | <2.0 | 46.4 | 28.2 | 258.4 | <0.5 | <0.4 |
| PH02.2 | 10.08 | 2.099 | 3.133 | 9.336 | 0.204 | 0.6247 | 10.13 | 0.9562 | 1.76 | 0.2145 | 0.01186 | 0.01668 | 0.07981 | 21.45 | <2.0 | <0.8 | <0.6 | 4279 | <0.5 | 61.6 |
| PH02.3 | 11.05 | 2.246 | 3.411 | 11.79 | 0.1047 | 1.545 | 12.24 | 1.144 | 0.7878 | 0.257 | 0.01348 | 0.00467 | 0.01975 | 1.752 | 44 | <0.8 | 21.9 | 342.2 | 6.9 | 8.3 |
| PH02.4 | 0.66 | 0.75 | 7.767 | 22.35 | 0.0312 | 0.1645 | 0.4006 | 1.52 | 0.343 | 0.5471 | 0.01283 | 0.01058 | 0.05309 | 3.565 | <2.0 | 62.9 | 19.5 | 69.7 | 23.5 | 25 |
| RL01.1 | 2.18 | 0.0878 | 0.0968 | 18.74 | 0.0407 | 0.2555 | 3.07 | 0.219 | 2.543 | 0.08218 | <0.0015 | 0.01106 | 0.0147 | 0.1086 | 13 | <0.8 | 9.7 | 12.1 | <0.5 | <0.4 |
| RL01.2 | 0.56 | 0.701 | 7.836 | 20.21 | 0.0709 | 0.1516 | 0.3947 | 1.673 | 0.3237 | 0.6397 | 0.01434 | 0.01042 | 0.02879 | 3.648 | <2.0 | 36.4 | 23.2 | 85.2 | 8.9 | <0.4 |
| RL01.3 | 0.47 | <0.0100 | 0.601 | 36.89 | 0.0164 | 0.0761 | 0.3874 | 0.2211 | 0.04598 | 0.162 | <0.0015 | 0.00126 | 0.01594 | 0.1539 | 37 | <0.8 | 2.6 | 28.8 | 1.5 | <0.4 |

# Appendix 1. (continued)

| Sample | Se | Br | Rb | Sr | Y | Zr | Nb | Mo | Cd | Sn | Sb | I | Cs | Ba | La | Ce | Nd | Pb | Th | U |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm |
| AV02.1 | 1.8 | 724.3 | 56.5 | 569.9 | 4.6 | 40.3 | 5.4 | 12.7 | 0.7 | 3 | <0.8 | 48.6 | <1.5 | 64.4 | <2.0 | 6.8 | <3.0 | 38.7 | 12.3 | <0.9 |
| PH02.1 | <0.4 | 1069 | 77.6 | 119.1 | 3.5 | 62.4 | 3 | 10.3 | 1 | 3.7 | <0.8 | 110.2 | <1.5 | 32.1 | 11.1 | 12.5 | <3.0 | 133.7 | 23.3 | <0.9 |
| PH02.2 | <0.4 | 713.6 | 45.6 | 145.7 | 12.4 | 77.5 | <0.8 | 7.4 | 0.4 | 1148 | 15 | <1.5 | <1.5 | 55.4 | 18.6 | 17.2 | <3.0 | 994 | 48.5 | <0.9 |
| PH02.3 | 4 | 1242 | 92.8 | 122.9 | 15.4 | 137.5 | 11.4 | 22.8 | 0.5 | <0.5 | 1.2 | 149.2 | <1.5 | 83.9 | 15.9 | 21 | <3.0 | 27.5 | 14.6 | 7.8 |
| PH02.4 | 1.6 | 115.4 | 125 | 94.4 | 31.5 | 173.8 | 16.4 | 2.7 | <0.3 | <0.5 | <0.8 | <1.5 | 7.5 | 233.6 | 25.9 | 45.3 | <3.0 | 24.8 | 18 | 11.2 |
| RL01.1 | <0.4 | 52.5 | 10.9 | 67.3 | 7.7 | 173.3 | 10.1 | 7.8 | 0.4 | 1.4 | <0.8 | <1.5 | <1.5 | 52.7 | <2.0 | <2.5 | <3.0 | 2.2 | 7.3 | <0.9 |
| RL01.2 | 1 | 143.5 | 125 | 101.4 | 36.6 | 171.8 | 15.9 | 1 | 0.4 | 6.4 | 26.2 | <1.5 | 6.8 | 330.1 | 35.3 | 53.2 | 34.4 | 670.6 | 64.8 | 6.3 |
| RL01.3 | <0.4 | 4.6 | 11.7 | 18.1 | 12.6 | 245.5 | 12.2 | <0.5 | <0.3 | 1.5 | <0.8 | <1.5 | 4.6 | 53.3 | 12.3 | <2.5 | <3.0 | 7.6 | 10.6 | <0.9 |

# Appendix 2. Site information sheets

SITE INFORMATION SHEET

| Site | Date | Observer | Photograph (filename) | | |
|---|---|---|---|---|---|
| AV01 | 30/03/05 | Cox/Davies | avalon_AV01-01.jpg | avalon_AV01-02.jpg | avalon_AV01-03.jpg |

| Locality Description |
|---|
| Avalon. ~ 200 m north of Avalon College entrance, Avalon Beach Road. |

| Locality Details | | | | | |
|---|---|---|---|---|---|
| Easting | Northing | Elevation | Datum | Coordinate System | Zone |
| 274005 | 5782176 | 2 m | GDA-94 | UTM (meters) | 55 |

| *Landform Element (circle) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C | R | S | U | M | L | **F** | V | D | X | N |

| Surface Cover (%) | | | Dominant Vegetation | | |
|---|---|---|---|---|---|
| Soil | Vegetation | Rock | Type | % | Height |
| 95 | 5 | | Pasture | 100 | |

| Soil Sample | | | | | |
|---|---|---|---|---|---|
| | | | | | |

| †Soil Landform Unit | |
|---|---|
| Unit No. | Description (filename) |
| 205 | City of Geelong urban extent |

| Notes |
|---|
| Open pit dug for water pipe repairs. |

*Landform Element Types:
C *Crest* U *Upper slope* F *Flat* Slope Qualifier:
R *Ridge* M *Mid-slope* V *Open depression* X *Convex*
S *Simple slope* L *Lower slope* D *Closed depression* N *Concave*

†After Robinson *et al.*, 2003

SITE INFORMATION SHEET

| Site | Date | Observer | Photograph (filename) | | |
|---|---|---|---|---|---|
| BR01 | 30/03/05 | Cox/Dahlhaus | breamlea_BR01-01.jpg | breamlea_BR01-02.jpg | |

| Locality Description |
|---|
| Breamlea. 600 m north of township on Breamlea Road. |

| Locality Details | | | | | |
|---|---|---|---|---|---|
| Easting | Northing | Elevation | Datum | Coordinate System | Zone |
| 272695 | 5759096 | 2 m | GDA-94 | UTM (meters) | 55 |

| *Landform Element (circle) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C | R | S | U | M | L | **F** | V | D | X | N |

| Surface Cover (%) | | | Dominant Vegetation | | |
|---|---|---|---|---|---|
| Soil | Vegetation | Rock | Type | % | Height |
| | 100 | | Native grasses | 100 | |

| Soil Sample | | | | | |
|---|---|---|---|---|---|
| | | | | | |

| †Soil Landform Unit | |
|---|---|
| Unit No. | Description (filename) |
| 202 | 202.pdf |

| Notes |
|---|
| Wetland on opposite side of road to Breamlea Flora Reserve. |

*Landform Element Types:
C *Crest* U *Upper slope* F *Flat* Slope Qualifier:
R *Ridge* M *Mid-slope* V *Open depression* X *Convex*
S *Simple slope* L *Lower slope* D *Closed depression* N *Concave*

†After Robinson *et al.*, 2003

SITE INFORMATION SHEET

| Site | Date | Observer | Photograph (filename) | | |
|---|---|---|---|---|---|
| AV02 | 30/03/05 | Cox/Davies | avalon_AV02-01.jpg | avalon_AV02-02.jpg | |

| Locality Description |
|---|
| Avalon Beach. Near boat ramp on Avalon Beach Road. |

| Locality Details | | | | | |
|---|---|---|---|---|---|
| Easting | Northing | Elevation | Datum | Coordinate System | Zone |
| 274221 | 5781689 | < 1 m | GDA-94 | UTM (meters) | 55 |

| *Landform Element (circle) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C | R | S | U | M | L | **F** | V | D | X | N |

| Surface Cover (%) | | | Dominant Vegetation | | |
|---|---|---|---|---|---|
| Soil | Vegetation | Rock | Type | % | Height |
| 100 | | | | | |

| Soil Sample | | | | | |
|---|---|---|---|---|---|
| AV02.1 | | | | | |

| †Soil Landform Unit | |
|---|---|
| Unit No. | Description (filename) |
| 205 | City of Geelong urban extent |

| Notes |
|---|
| Disused salt evaporation pan. |

*Landform Element Types:
C *Crest* U *Upper slope* F *Flat* Slope Qualifier:
R *Ridge* M *Mid-slope* V *Open depression* X *Convex*
S *Simple slope* L *Lower slope* D *Closed depression* N *Concave*

†After Robinson *et al.*, 2003

SITE INFORMATION SHEET

| Site | Date | Observer | Photograph (filename) | | |
|---|---|---|---|---|---|
| PA01 | 29/03/05 | Cox/Dahlhaus | portarlington_PA01-01.jpg | portarlington_PA01-02.jpg | |

| Locality Description |
|---|
| Portarlington. South of Ramblers Road. |

| Locality Details | | | | | |
|---|---|---|---|---|---|
| Easting | Northing | Elevation | Datum | Coordinate System | Zone |
| 291610 | 5778651 | 3.5 m | GDA-94 | UTM (meters) | 55 |

| *Landform Element (circle) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C | R | S | U | M | L | **F** | V | D | X | N |

| Surface Cover (%) | | | Dominant Vegetation | | |
|---|---|---|---|---|---|
| Soil | Vegetation | Rock | Type | % | Height |
| | 100 | | Native grasses | 100 | |

| Soil Sample | | | | | |
|---|---|---|---|---|---|
| | | | | | |

| †Soil Landform Unit | |
|---|---|
| Unit No. | Description (filename) |
| 82 | 82.pdf |

| Notes |
|---|
| Adjacent to Flora and Fauna Reserve. |

*Landform Element Types:
C *Crest* U *Upper slope* F *Flat* Slope Qualifier:
R *Ridge* M *Mid-slope* V *Open depression* X *Convex*
S *Simple slope* L *Lower slope* D *Closed depression* N *Concave*

†After Robinson *et al.*, 2003

SITE INFORMATION SHEET

| Site | Date | Observer | Photograph (filename) | |
|---|---|---|---|---|
| PH01 | 29/03/05 | Cox/Davies | [illegible] | [illegible] |

| Locality Description |
|---|
| Port Henry. South of Windmill Road, near corner with Point Henry Road. |

| Locality Details | | | | | |
|---|---|---|---|---|---|
| Easting | Northing | Elevation | Datum | Coordinate System | Zone |
| 274921 | 5774552 | 5 m | GDA-94 | UTM (meters) | 55 |

| *Landform Element (circle) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C | R | S | U | M | L | F | V | D | X | N |

| Surface Cover (%) | | | Dominant Vegetation | | |
|---|---|---|---|---|---|
| Soil | Vegetation | Rock | Type | % | Height |
| 35 | 60 | 5 | | | |

| Soil Sample | | | | | |
|---|---|---|---|---|---|
| | | | | | |

| †Soil Landform Unit | |
|---|---|
| Unit No. | Description (filename) |
| 205 | City of Geelong urban extent |

| Notes |
|---|
| |

*Landform Element Types:
C *Crest* U *Upper slope* F *Flat* Slope Qualifier:
R *Ridge* M *Mid-slope* V *Open depression* X *Convex*
S *Simple slope* L *Lower slope* D *Closed depression* N *Concave*

†After Robinson *et al.*, 2003

SITE INFORMATION SHEET

| Site | Date | Observer | Photograph (filename) | |
|---|---|---|---|---|
| PL01 | 29/03/05 | Cox/Dahlhaus | [illegible] | [illegible] |

| Locality Description |
|---|
| Point Lonsdale. Western end of Pethero Road. |

| Locality Details | | | | | |
|---|---|---|---|---|---|
| Easting | Northing | Elevation | Datum | Coordinate System | Zone |
| 290963 | 5761534 | 6 m | GDA-94 | UTM (meters) | 55 |

| *Landform Element (circle) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C | R | S | U | M | L | F | V | D | X | N |

| Surface Cover (%) | | | Dominant Vegetation | | |
|---|---|---|---|---|---|
| Soil | Vegetation | Rock | Type | % | Height |
| | 100 | | Pasture | 100 | |

| Soil Sample | | | | | |
|---|---|---|---|---|---|
| | | | | | |

| †Soil Landform Unit | |
|---|---|
| Unit No. | Description (filename) |
| 197 | 197.pdf |

| Notes |
|---|
| Future residential development site. |

*Landform Element Types:
C *Crest* U *Upper slope* F *Flat* Slope Qualifier:
R *Ridge* M *Mid-slope* V *Open depression* X *Convex*
S *Simple slope* L *Lower slope* D *Closed depression* N *Concave*

†After Robinson *et al.*, 2003

SITE INFORMATION SHEET

| Site | Date | Observer | Photograph (filename) | |
|---|---|---|---|---|
| PH02 | 29/03/05 | Cox/Dahlhaus | [illegible] | [illegible] |

| Locality Description |
|---|
| Port Henry. Adjacent carpark at eastern end of Windmill Road. |

| Locality Details | | | | | |
|---|---|---|---|---|---|
| Easting | Northing | Elevation | Datum | Coordinate System | Zone |
| 275327 | 5773143 | 1.5 m | GDA-94 | UTM (meters) | 55 |

| *Landform Element (circle) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C | R | S | U | M | L | F | V | D | X | N |

| Surface Cover (%) | | | Dominant Vegetation | | |
|---|---|---|---|---|---|
| Soil | Vegetation | Rock | Type | % | Height |
| 15 | 85 | | | | |

| Soil Sample | | | | | |
|---|---|---|---|---|---|
| PH02.1 | PH02.2 | PH02.3 | PH02.4 | | |

| †Soil Landform Unit | |
|---|---|
| Unit No. | Description (filename) |
| 205 | City of Geelong urban extent |

| Notes |
|---|
| |

*Landform Element Types:
C *Crest* U *Upper slope* F *Flat* Slope Qualifier:
R *Ridge* M *Mid-slope* V *Open depression* X *Convex*
S *Simple slope* L *Lower slope* D *Closed depression* N *Concave*

†After Robinson *et al.*, 2003

SITE INFORMATION SHEET

| Site | Date | Observer | Photograph (filename) | |
|---|---|---|---|---|
| PW01 | 30/03/05 | Cox/Davies | [illegible] | [illegible] |

| Locality Description |
|---|
| Point Wilson. East of Avalon airport on Point Wilson Road. |

| Locality Details | | | | | |
|---|---|---|---|---|---|
| Easting | Northing | Elevation | Datum | Coordinate System | Zone |
| 281047 | 5784917 | 4 m | GDA-94 | UTM (meters) | 55 |

| *Landform Element (circle) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C | R | S | U | M | L | F | V | D | X | N |

| Surface Cover (%) | | | Dominant Vegetation | | |
|---|---|---|---|---|---|
| Soil | Vegetation | Rock | Type | % | Height |
| 15 | 80 | 5 | Sedges | 60 | |

| Soil Sample | | | | | |
|---|---|---|---|---|---|
| | | | | | |

| †Soil Landform Unit | |
|---|---|
| Unit No. | Description (filename) |
| 205 ? | City of Geelong urban extent |

| Notes |
|---|
| Conservation Park. |

*Landform Element Types:
C *Crest* U *Upper slope* F *Flat* Slope Qualifier:
R *Ridge* M *Mid-slope* V *Open depression* X *Convex*
S *Simple slope* L *Lower slope* D *Closed depression* N *Concave*

†After Robinson *et al.*, 2003

SITE INFORMATION SHEET

| Site | Date | Observer | Photograph (filename) | | |
|---|---|---|---|---|---|
| RL01 | 29/03/05 | Cox/Dahlhaus | [illegible] | [illegible] | [illegible] |

| Locality Description |
|---|
| Reedy Lake. Southern end of Moolap Station Road. |

| Locality Details | | | | | |
|---|---|---|---|---|---|
| Easting | Northing | Elevation | Datum | Coordinate System | Zone |
| 273792 | 5769166 | 5 m | GDA-94 | UTM (meters) | 55 |

| *Landform Element (circle) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C | R | S | U | M | L | F | V | D | X | N |

| Surface Cover (%) | | | Dominant Vegetation | | |
|---|---|---|---|---|---|
| Soil | Vegetation | Rock | Type | % | Height |
| | 100 | | Rushes | 100 | |

| Soil Sample | | | | | |
|---|---|---|---|---|---|
| RL01.1 | RL01.2 | RL01.3 | | | |

| †Soil Landform Unit | |
|---|---|
| Unit No. | Description (filename) |
| 200 | 200.pdf |

| Notes |
|---|
| Wildlife Reserve. |

*Landform Element Types:
C *Crest* U *Upper slope* F *Flat* Slope Qualifier:
R *Ridge* M *Mid-slope* V *Open depression* X *Convex*
S *Simple slope* L *Lower slope* D *Closed depression* N *Concave*

†After Robinson *et al.*, 2003

SITE INFORMATION SHEET

| Site | Date | Observer | Photograph (filename) | | |
|---|---|---|---|---|---|
| SB01 | 29/03/05 | Cox/Davies | | | |

| Locality Description |
|---|
| Swan Bay. ~ 10 km north of Queenscliffe. Corner of Portarlington-Queenscliffe and Nye Roads. |

| Locality Details | | | | | |
|---|---|---|---|---|---|
| Easting | Northing | Elevation | Datum | Coordinate System | Zone |
| 293517 | 5764985 | 2 m | GDA-94 | UTM (meters) | 55 |

| *Landform Element (circle) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C | R | S | U | M | L | F | V | D | X | N |

| Surface Cover (%) | | | Dominant Vegetation | | |
|---|---|---|---|---|---|
| Soil | Vegetation | Rock | Type | % | Height |
| 20 | 80 | | Grasses | 70 | |

| Soil Sample | | | | | |
|---|---|---|---|---|---|
| | | | | | |

| †Soil Landform Unit | |
|---|---|
| Unit No. | Description (filename) |
| 82 | 82.pdf |

| Notes |
|---|
| |

*Landform Element Types:
C *Crest* U *Upper slope* F *Flat* Slope Qualifier:
R *Ridge* M *Mid-slope* V *Open depression* X *Convex*
S *Simple slope* L *Lower slope* D *Closed depression* N *Concave*

†After Robinson *et al.*, 2003

SITE INFORMATION SHEET

| Site | Date | Observer | Photograph (filename) | | |
|---|---|---|---|---|---|
| RL02 | 29/03/05 | Cox/Dahlhaus | [illegible] | [illegible] | [illegible] |

| Locality Description |
|---|
| Reedy Lake. Eastern side of lake, western end of O'Halloran Road. |

| Locality Details | | | | | |
|---|---|---|---|---|---|
| Easting | Northing | Elevation | Datum | Coordinate System | Zone |
| 275770 | 5768719 | 2.5 m | GDA-94 | UTM (meters) | 55 |

| *Landform Element (circle) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C | R | S | U | M | L | F | V | D | X | N |

| Surface Cover (%) | | | Dominant Vegetation | | |
|---|---|---|---|---|---|
| Soil | Vegetation | Rock | Type | % | Height |
| 20 | 80 | | Grasses | 70 | |

| Soil Sample | | | | | |
|---|---|---|---|---|---|
| | | | | | |

| †Soil Landform Unit | |
|---|---|
| Unit No. | Description (filename) |
| 200 | 200.pdf |

| Notes |
|---|
| Wildlife Reserve. |

*Landform Element Types:
C *Crest* U *Upper slope* F *Flat* Slope Qualifier:
R *Ridge* M *Mid-slope* V *Open depression* X *Convex*
S *Simple slope* L *Lower slope* D *Closed depression* N *Concave*

†After Robinson *et al.*, 2003

SITE INFORMATION SHEET

| Site | Date | Observer | Photograph (filename) | | |
|---|---|---|---|---|---|
| SL01 | 29/03/05 | Cox/Davies | [illegible] | [illegible] | |

| Locality Description |
|---|
| Saint Leonards. Eastern side of salt lake, just off The Esplanade. |

| Locality Details | | | | | |
|---|---|---|---|---|---|
| Easting | Northing | Elevation | Datum | Coordinate System | Zone |
| 299849 | 5773975 | 1 m | GDA-94 | UTM (meters) | 55 |

| *Landform Element (circle) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C | R | S | U | M | L | F | V | D | X | N |

| Surface Cover (%) | | | Dominant Vegetation | | |
|---|---|---|---|---|---|
| Soil | Vegetation | Rock | Type | % | Height |
| 100 | | | | | |

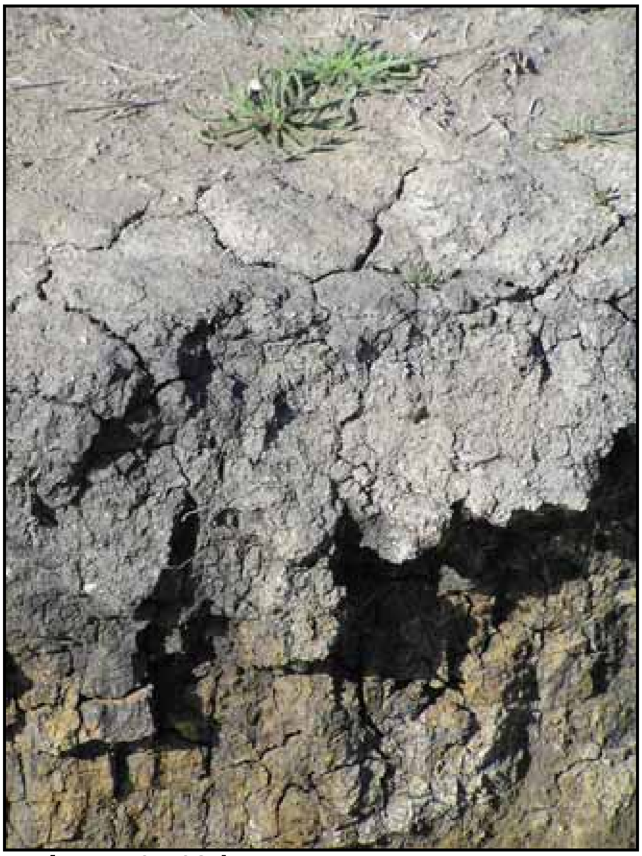
| Soil Sample | | | | | |
|---|---|---|---|---|---|
| | | | | | |

| †Soil Landform Unit | |
|---|---|
| Unit No. | Description (filename) |
| 82 | 82.pdf |

| Notes |
|---|
| Salt lake, conservation reserve. |

*Landform Element Types:
C *Crest* U *Upper slope* F *Flat* Slope Qualifier:
R *Ridge* M *Mid-slope* V *Open depression* X *Convex*
S *Simple slope* L *Lower slope* D *Closed depression* N *Concave*

†After Robinson *et al.*, 2003



Avalon_AV01-02.jpg

Avalon_AV01-03.jpg

Avalon_AV02-01.jpg

Avalon_AV02-02.jpg

Breamlea_BR01-01.jpg


**Portarlington_PA01-02.jpg**


**Point_Lonsdale_PL01-01.jpg**


**Point_Henry_PH01-01.jpg**


**Point_Wilson_PW01-02.jpg**


**Point_Henry_PH02-03.jpg**


**Reedy_Lake_RL01-01.jpg**


**Reedy_Lake_RL01-03.jpg**


**Reedy_Lake_RL02-01.jpg**


**Reedy_Lake_RL02-03.jpg**


**Saint_Leonards_SL01-02.jpg**

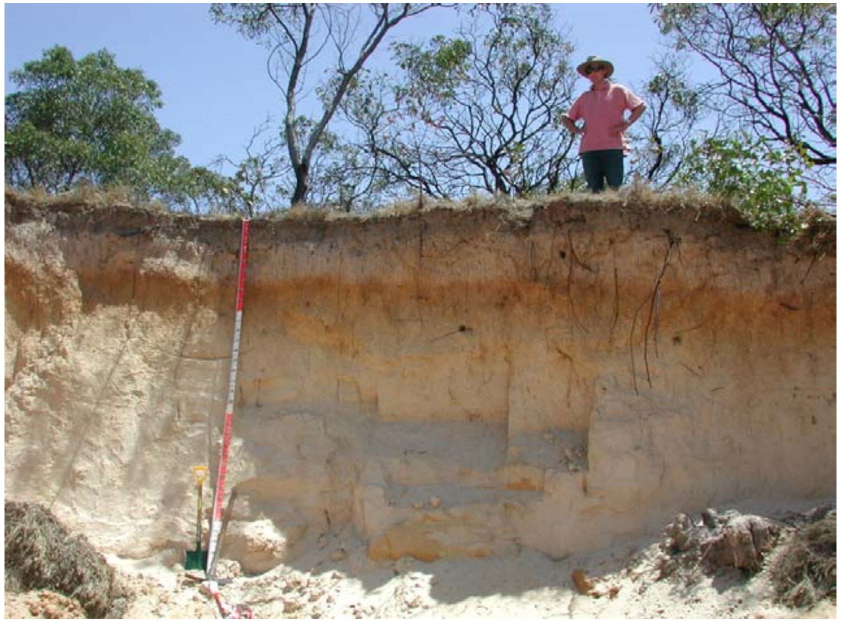

**Saint_Leonards_SL01-03.jpg**

## Soil-landform unit 82

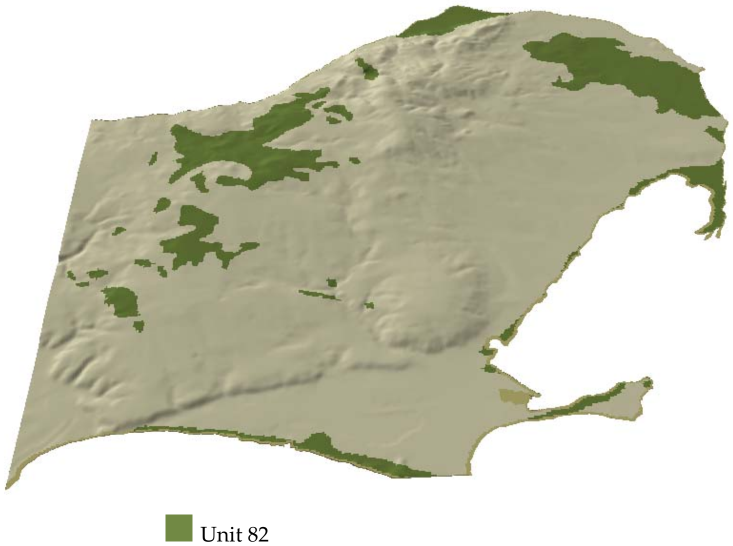
Area: 4020 ha
0.30% of CMA region

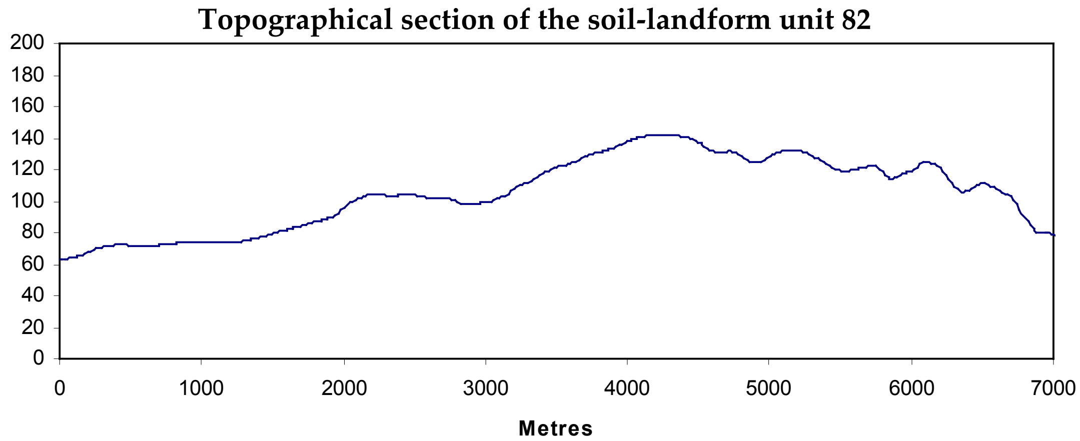

This unit of undulating rises and plains includes a few occurrences on the Bellarine Peninsula as a dunefield in the Curlewis area sitting on Neogene terrain (plateau) and to the south of Portarlington at a lower elevation east of the Neogene plateau. Unit components comprise dunes and depressions. The soils are sands (Tenosols, Podosols) or sands over clay (Sodosols) The steep dunes are very rapidly drained but susceptible to wind and sheet erosion, particularly where vegetation cover is removed. Nutrient decline (retention) is also a susceptibility. Land use is grazing (sheep and beef), minor cropping, recreation and mineral extraction.

Looking east along the Drysdale-St Leonards Road over Neogene sourced plains and rises



Dune at Curlewis golf club




Looking south-east over rises and plains north of St Leonards

| *Component* | 1 | 2 |
|---|---|---|
| *Proportion of soil-landform unit* | 70% | 30% |
| **CLIMATE** | | |
| Rainfall (mm) | Annual: 610 | |
| Temperature (°C) | Minimum 10, Maximum 19 | |
| Precipitation: less than potential evapotranspiration | October-April | |
| **GEOLOGY** | | |
| Age and lithology | Quaternary coastal sand dunes and minor alluvium, Neogene fluvio-marine sand | |
| Geomorphology | 6.2.5 Sedimentary plain, rise or low hill alluvium, alluvial terraces, floodplains and coastal plains of the Western Plains and 3.3.1 Dissected low hills plateaux of the Southern Uplands | |
| **LAND USE** | Uncleared areas: Nature conservation; active and passive recreation<br>Cleared areas: Sheep and beef cattle grazing; minor cropping (cereal); regional development | |
| **TOPOGRAPHY** | | |
| Landscape | Undulating rises and plains | |
| Elevation range (m) | 1–95 | |
| Local relief (m) | 2–15 | |
| Drainage pattern | Dendritic–parallel | |
| Drainage density (km/km²) | 0.7 | |
| Landform | Dunes | |
| Landform element | Dune | Depression |
| Slope and range (%) | 10 (0–25) | 3 (0–10) |
| Slope shape | Straight | Concave |
| **NATIVE VEGETATION** | | |
| Ecological Vegetation Class | Coastal Dune Scrub Mosaic (4.1%), Coastal Saltmarsh (3.9%), Grassy Woodland (2.6%), Heathy Woodland (1.9%), Calcarenite Dune Woodland (1.7%), other (1.4%) | |
| **SOIL** | | |
| Parent material | Sand, minor silt and clay | Sand, silt and clay |
| Description (Corangamite soil group) | Pale sands (8) and sodic yellow and brown often mottled texture contrast (11) | Pale sands (8) and sodic yellow and brown often mottled texture contrast (11) |
| Soil type sites | **CLRA7**, CLRA44, CLRA5 | **CLRA5**, CLRA39, CLRA7 |
| Surface texture | Loamy sand | Sandy loam |
| Permeability | Very high | High |
| Depth (m) | > 2 | > 2 |
| **LAND CHARACTERISTICS, POTENTIAL AND LIMITATIONS** | Deep sands or sands over clay. Often unconsolidated material with low water and nutrient holding capacity in sands. Susceptible to sheet and wind erosion | Deep sands or sands over clay or texture contrast. Often unconsolidated material with low water and nutrient holding capacity in sands or lighter upper soil. Susceptible to sheet and wind erosion |

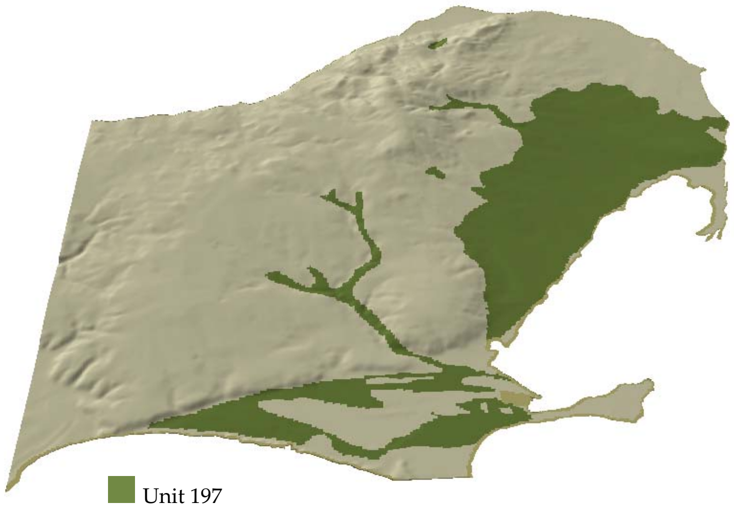
## Soil-landform unit 197

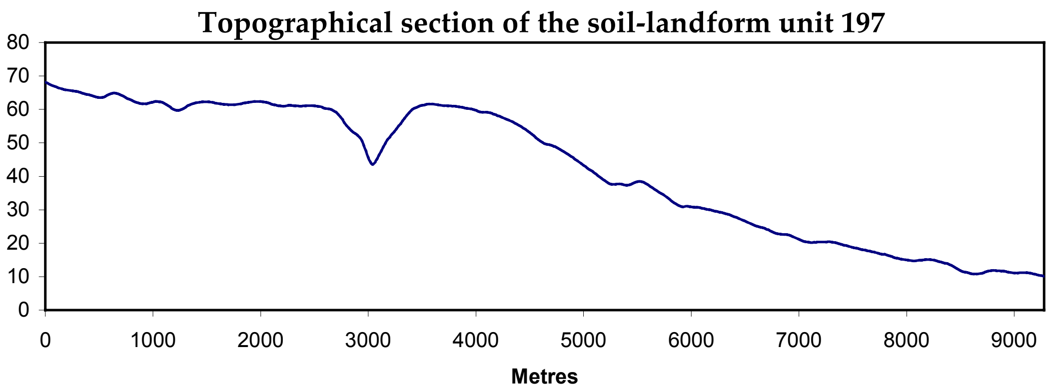
Area: 5206 ha
0.39% of CMA region


This single unit of level and undulating plains is on the east coast of the Bellarine Peninsula, drains into Swan Bay and receives drainage from the Neogene plateau (Unit 77) and the Palaeogene basaltic low hills (Unit 80) to the west. Some Neogene ferruginised sediments occur on the coast at St Leonards. The soils are strongly sodic mottled brown texture contrast with light surface soils which are susceptible to sheet erosion. Rainfall while relatively low is annually variable. This unit is susceptible to waterlogging where inundation is sufficient. Surface soil nutrient and structure decline and susceptibilities are also concerns. Land use is extensive grazing (beef and sheep) and minor cropping.

Looking south over Swan Bay and the undulating sedimentary plains of this unit

Level plain west of St Leonards




Bleached texture contrast soils are dominant across the unit

| | | |
|---|---|---|
| *Component* | 1 | 2 |
| *Proportion of soil-landform unit* | 80% | 20% |
| **CLIMATE** | | |
| Rainfall (mm) | Annual: 620 | |
| Temperature (°C) | Minimum 10, Maximum 19 | |
| Precipitation: less than potential evapotranspiration | October–March | |
| **GEOLOGY** | | |
| Age and lithology | Recent clay, sand and gravel and coastal sand dunes, Neogene fluvio-marine sand | |
| Geomorphology | 6.2.5 Alluvium, alluvial terraces, floodplains and coastal plains of the Sedimentary Western Plains | |
| **LAND USE** | Uncleared: Nature conservation; passive and active recreation<br>Cleared areas: Sheep and beef cattle grazing; regional development | |
| **TOPOGRAPHY** | | |
| Landscape | Level and gently undulating plains | |
| Elevation range (m) | 4–90 | |
| Local relief (m) | 2–5 | |
| Drainage pattern | Dendritic | |
| Drainage density (km/km$^2$) | 1.4 | |
| Landform | Plains/Stagnant plains | |
| Landform element | Flat | Depression |
| Slope and range (%) | 1 (0–1) | 1(0–2) |
| Slope shape | Straight | Concave |
| **NATIVE VEGETATION** | | |
| Ecological Vegetation Class | Calcarenite Dune Woodland (1.7%), Plains Grassy Woodland (1.4%), Coastal Saltmarsh (1.0%), Other (0.8%) | |
| **SOIL** | | |
| Parent material | Gravel, sand, silt and clay | Sand, silt and clay |
| Soil description | Sodic brown often mottled texture contrast soils (32) | Black cracking clays (31) and sodic brown, often mottled texture contrast soils (32) |
| Soil type sites | **CLRA4** | CLRA15, CLRA35, CLRA4 |
| Surface texture | Fine sandy loam | Light clay, fine sandy loam |
| Permeability | Low | Very low |
| Depth (m) | > 2 | > 2 |
| **LAND CHARACTERISTICS, POTENTIAL AND LIMITATIONS** | Texture contrast soil, low water holding capacity and low to moderate nutrient holding capacity in upper lighter soil, higher in subsoil. Strongly sodic subsoil, hardsetting, coarse structure. Low subsoil permeability and slow site drainage is common. Susceptible to compaction and structure decline and waterlogging. Some susceptibility to sheet and wind erosion. | Texture contrast soil and expansive clay soil, low water holding capacity and low to moderate nutrient holding capacity in upper lighter soil, higher in subsoil and cracking clay soils. Strongly sodic subsoil, hardsetting, coarse structure. Soils tend to have a low permeability. Very slow site drainage. Susceptible to waterlogging, compaction and structure decline. |

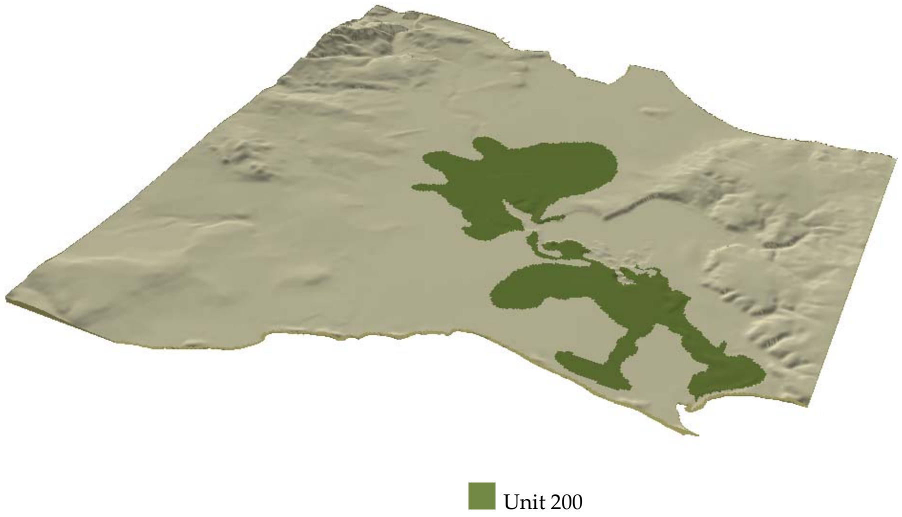
## Soil-landform unit 200

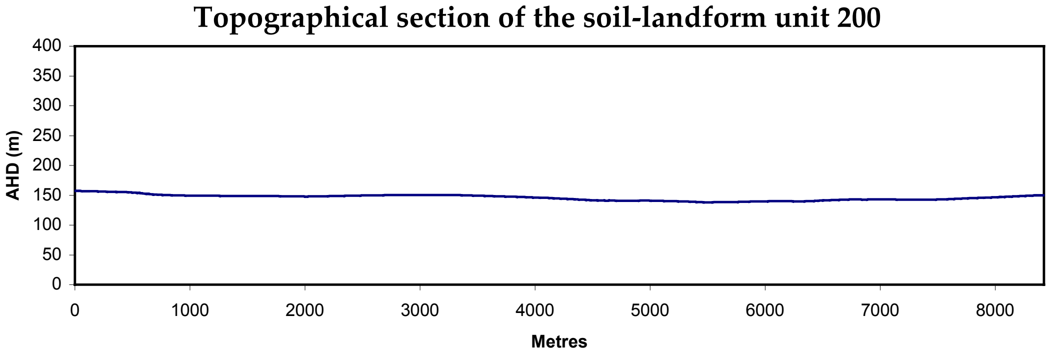
Area: 7186 ha
0.54% of CMA region


Across the dissected sedimentary plains of the Western Plains are numerous swamps and closed depressions that host a wide variety of flora and fauna. These permanent swamps have been identified as occurring south of Geelong on Recent clay, sand and gravels, coastal sand dunes and minor basalt. Many of the swamps have been cleared previously with some untouched by land clearance. Vegetation classes of these swamps include Coastal Saltmarsh, Reed Swamp, Plains Freshwater Sedge Wetland, Cane Grass-lignum Halophyllic Herbland and Calcarenite Dune Woodland. Land use is mainly restricted to grazing owing to the waterlogged state of soils in most years. Soils include the grey cracking clays and sandy soils that reflect Recent alluvium deposits. While waterlogging is the major limitation, salinity is also expressed at the surface in many of these swamps as spiny rush.

The Moolap Sunklands have a very diverse range of wildlife and habitats in this very unique wetlands within the Corangamite CMA region

Located west of Barwon Heads, this swamp forms part of the Moolap Sunklands. The vegetation most prominent here is the Reed Swamp class




Reed swamp vegetation class of the Moolap Sunklands

| *Component*<br>*Proportion of soil-landform unit* | 1<br>2% | 2<br>38% | 3<br>40% | 4<br>20% |
|---|---|---|---|---|
| **CLIMATE** | | | | |
| Rainfall (mm) | Annual: 640 | | | |
| Temperature (°C) | Minimum 9, Maximum 19 | | | |
| Precipitation: less than potential evapotranspiration | October–March | | | |
| **GEOLOGY** | | | | |
| Age and lithology | Quaternary clay, sand and gravel, coastal sand dunes and minor basalt | | | |
| Geomorphology | 6.2.5 Alluvium, alluvial terraces, floodplains and coastal plains of the Sedimentary Western Plains | | | |
| **LAND USE** | Uncleared: Nature conservation; water supply<br>Cleared: Cropping (cereal); sheep and beef cattle grazing | | | |
| **TOPOGRAPHY** | | | | |
| Landscape | Swamps and depressions associated with sedimentary plains | | | |
| Elevation range (m) | 4–148 | | | |
| Local relief (m) | 1–2 | | | |
| Drainage pattern | Deranged | | | |
| Drainage density (km/km²) | 2.7 | | | |
| Landform | Alluvial plains | | | |
| Landform element | Dune | Depressions | Swamp | Undulating plain |
| Slope and range (%) | 2 (0–5) | 1 (0–2) | 1 (0–2) | 2 (1–4) |
| Slope shape | Convex | Straight | Straight | Convex |
| **NATIVE VEGETATION** | | | | |
| Ecological Vegetation Class | Coastal Saltmarsh (20.5), Reed Swamp (8.3%), Plains Freshwater Sedge Wetland (1.3%), Cane Grass-Lignum Halophyllic Herbland (1.2%), Calcarenite Dune Woodland (1.1%) | | | |
| **SOIL** | | | | |
| Parent material | Aeolian sediments; clay silt and sand | Sedimentary derived alluvium; clay silt and sand | Sedimentary derived alluvium; clay silt and sand | Sedimentary derived alluvium; clay silt and sand |
| Description (Corangamite Soil Group) | Grey and black clays (31) | Grey and black clays (31) | Grey and black clays (31) | Grey and black clays (31) |
| Soil type sites | SW37, CLRA15, CLRA35 | **SW37**, CLRA5, **SW39** | SW37, CLRA15, CLRA35 | SW37, CLRA15, CLRA35 |
| Surface texture | Light clay | Light clay | Light clay | Light clay |
| Permeability | High | Low | Low | Low |
| Depth (m) | >2 | >2 | >2 | >2 |
| **LAND CHARACTERISTICS, POTENTIAL AND LIMITATIONS** | Uniform expansive clays, high to very high water holding capacity and nutrient holding capacity depending on depth. Sodic subsoils, surface soils may be self-mulching. Low site drainage. Susceptibility to waterlogging. | Uniform expansive clays, high to very high water holding capacity and nutrient holding capacity depending on depth. Sodic subsoils, surface soils may be self-mulching. Low site drainage. Susceptibility to waterlogging. | Uniform expansive clays, high to very high water holding capacity and nutrient holding capacity depending on depth. Sodic subsoils, surface soils may be self-mulching. Very low site drainage. Susceptibility to waterlogging. | Uniform expansive clays, high to very high water holding capacity and nutrient holding capacity depending on depth. Sodic subsoils, surface soils may be self-mulching. Low site drainage. Susceptibility to waterlogging. |

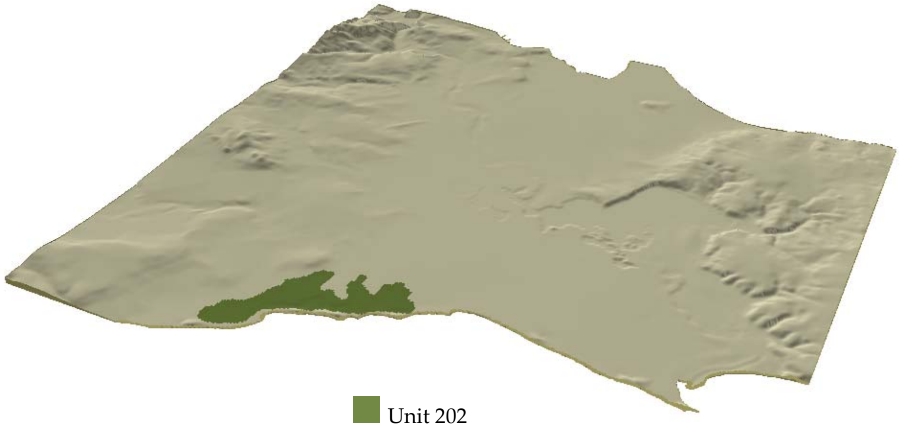
## Soil-landform unit 202

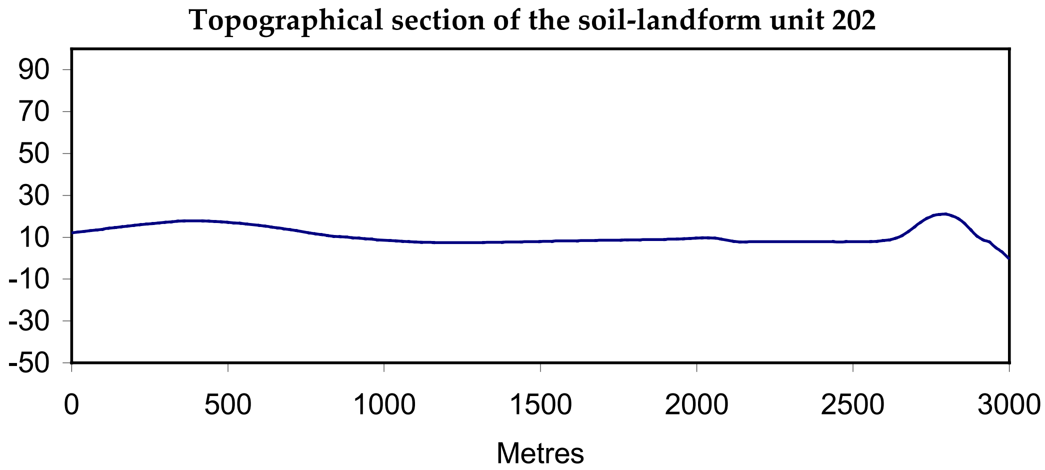
Area: 593 ha
0.04% of CMA region


Many of the outlets of creeks and rivers to the east of the Otway Range possess tidal swamps with braided channels and brackish lagoons. Thompson Creek and Painkalac Creek have such river mouths, although the most extensive swamp lies just outside the present study area, surrounding the mouth of the Barwon River. Only minor differences in height above mean tide level determine the differences between the land components. The marine terraces escape inundation in all but extremely rare combinations of floods and high tide, while most other tracts of land are flooded either regularly or irregularly. Halophytic shrubs and herbs colonise the grey and structureless silty clays found on these swamps. The structure and species of each community are strongly influenced by the height above mean tide level and the degree of salinity of the tidal water. Some parts of these areas have been drained or filled to provide for agriculture or recreational facilities. However, most parts remain in their natural state.

Tidal swamps lie just inland from the coastal dunes and provide valuable habitats for wildlife

Swamp east of Torquay



| *Component* | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| *Proportion of soil-landform unit* | 30% | 30% | 10% | 15% | 15% |
| **CLIMATE** | | | | | |
| Rainfall (mm) | Annual: 625, lowest January (30), highest August (60) | | | | |
| Temperature (°C) | Annual: 14, lowest July (10), highest February (18) | | | | |
| Seasonal growth limitations | Temperature: less than l 0°C (av.) July<br>Precipitation: less than potential evapotranspiration October–early April | | | | |
| **GEOLOGY** | | | | | |
| Age and lithology | Recent estuarine sand, silt, clay and plant remains | | | | Veneer of aeolian sand |
| Geomorphology | 6.2.5 Alluvium, alluvial terraces, floodplains and coastal plains of the Sedimentary Western Plains | | | | |
| **LAND USE** | Cleared areas: Some of the higher areas cleared for grazing, cropping and recreational<br>Uncleared areas: Nature conservation; refuse disposal facilities | | | | |
| **TOPOGRAPHY** | | | | | |
| Landscape | Flat estuarine lowlands with braided channels | | | | |
| Elevation range (m) | 0–4 | | | | |
| Local relief (m) | 1 | | | | |
| Drainage pattern | Deranged | | | | |
| Drainage density (km/km²) | 4.6 | | | | |
| Landform | Marine terraces | Swamps | | | |
| Landform element | - | Upper surface occasionally inundated | Lower surface regularly inundated | Free water surface | Area adjacent to sand dune |
| Slope and range (%) | 1 (0–2) | 0 (0–1) | 0 | | 1 (0–2) |
| Slope shape | Convex | Linear | Linear | | Irregular |
| **NATIVE VEGETATION** | | | | | |
| Structure | (Not known) | Low shrubland | Closed grassland | - | Sedgeland |
| Dominant species | - | *Arthrocnemum arbusculum, Gahnia filum* | *Frankenia pauciflora, Samolus repens, Arthrocnemum arbusculum* | - | *Scirpus nodosus* |
| **SOIL** | | | | | |
| Parent material | Estuarine clay, silt and sand | Estuarine clay, silt and plant remains | Estuarine clay, silt and plant remains | Estuarine clay, silt and plant remains | Aeolian sand, shell grit over estuarine clay, silt and plant remains |
| Description (Corangamite soil group) | Brown, grey or yellow sodic texture contrast soils (32) | Saline soils (12) | Saline soils (12) | Saline soils (12) | Grey sand soils, weakly structured clay underlay (12) |
| Soil type sites | OTR734 | CLRA34, CLRA44 | CLRA34, CLRA44 | CLRA34, CLRA44 | OTR737 |
| Surface texture | Sandy loam | Silty clay loam | Silty clay | Silty clay | Sandy loam |
| Permeability | Moderate | Very low | Very low | Very low | Low |
| Depth (m) | >2 | >2 | >2 | >2 | >2 |
| **LAND CHARACTERISTICS, POTENTIAL AND LIMITATIONS** | Sodic subsoils with high saline groundwater tables are prone to soil salting, surface compaction and sheet erosion. | Occasional influx of estuarine saline water on clays of low mechanical strength leads to soil salting and compaction. | Regular influx of estuarine saline water on clays of low mechanical strength leads to soil salting and compaction. | Minor hazards. | Sodic subsoils with low permeability and high saline groundwater tables are prone to surface compaction and soil salting. |