Australian Government
Department of Transport and Regional Services

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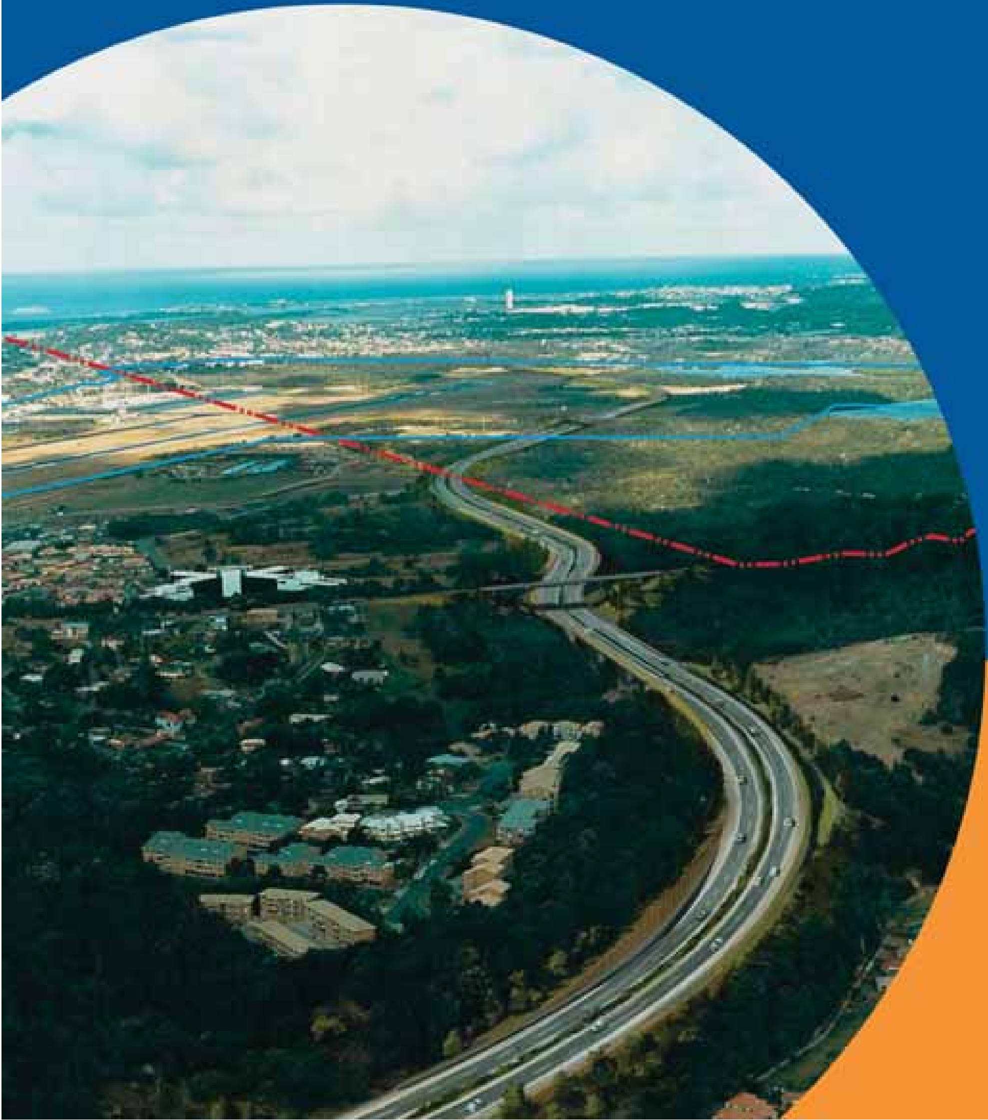
# TUGUN BYPASS

## stewart road to kennedy drive



# Technical Papers

December 2004

# Tugun Bypass Environmental Impact Statement

## Technical Paper Number 5
## Acid Sulphate Soil Management

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### Tugun Bypass Alliance

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# Glossary

| Term | Meaning |
|---|---|
| Aerobic | Requiring free oxygen |
| Anaerobic | Not requiring free atmospheric or dissolved oxygen |
| ANZECC | Australian and New Zealand Environment and Conservation Council |
| Aquifer | A layer of rock or soil able to hold or transmit water |
| ASS | Acid sulphate soils - soils containing sulphide minerals which have potential to generate acid on oxidation or have already started. See AASS and PASS. |
| AASS | Actual acid sulphate soils that have been oxidised and acid generation is in progress |
| ASSMAC | Acid Sulphate Soil Management Advisory Committee |
| Estuarine | From a river mouth that has been inundated by the sea |
| Flocculation | The process of forming aggregates or compound masses of particles |
| Geomorphic | Pertaining to the form of the Earth or it's surface features |
| Holocene | The most recent epoch of geological time |
| Hydrocycloning | A process that allows particles of different sizes to be separated |
| Hydrology | To do with the waters of the Earth and it's atmosphere |
| Interdune | Between dunes |
| Leachate | Water that has dissolved soluble substances from rock or soil |
| $molH^+$ | Measure of Total Potential Acid |
| NATA | National Association of Testing Authorities Australia |
| PASS | Potential acid sulphate soils, that are not generating acid but have potential to do so if oxidising conditions are introduced. |
| Piezometer | A tool that measures water table levels |
| POCAS | Peroxide Oxidation Combined Acidity and Sulphate, laboratory tests for identification of acid sulphate soils |
| Precipitation | Rain or snow falling to ground |
| QASSIT | Queensland Acid Sulphate Soils Investigation Team |
| Sluicing | A process that allows particles of different sizes to be separated during dredging. |
| $S_{POS}$ | Peroxide Oxidisable Sulphur |
| SPT | Standard penetration test |
| Swales | Long narrow depression between beach ridges |
| TDS | Total dissolved solids |
| TPA | Total potential acid |
| Wick drains | Vertical drains inserted into a soil to aid in groundwater removal |

# 1. Introduction

## 1.1 Summary of the Technical Paper

### 1.1.1 Existing Environment

This technical paper examines the potential of construction of the proposed Tugun Bypass to activate acid sulphate soils (ASS). The area that would be occupied by the proposal is a low lying coastal area. The geology includes recent beach dune deposits and estuarine and floodplain sediments. These conditions are typical of environments in which acid sulphate soils exist. Groundwater pH in this area is low and species adapted to low pH conditions exist in the area.

Acid sulphate soils contain sulphide minerals which on exposure to the atmosphere oxidise to form acid, metals in solution and sulphate. The acid and metals can cause environmental harm including killing aquatic organisms, corrosion of structures and stunting or killing vegetation.

Acid sulphate soils are either:

- actual acid sulphate soils (AASS), meaning that oxidation has already happened either by natural processes or by past disturbance; or
- potential acid sulphate soils (PASS), meaning that the soil materials contain sulphide minerals that would oxidise if exposed to the atmosphere by excavation or lowering of groundwater levels.

As this area is a typical area in which acid sulphate soils might occur and the proposed construction would involve excavation and a limited amount of groundwater lowering, there is potential that acid sulphate soils might be activated.

### 1.1.2 Potential for Acid Sulphate Soils

Mapping by Queensland Department of Natural Resources suggests that the area is not a high risk area for acid sulphate soils while mapping by NSW Department of Land and Water Conservation defines the area as disturbed terrain, although adjacent mapped areas have been identified as high potential acid sulphate soil areas.

Field investigation conducted during the geotechnical investigation tested soil or sediment pH in 109 samples. The findings show that the southern part of the proposal would be developed across a low lying area typical of acid sulphate soil occurrence. Field investigation suggested the presence of actual acid sulphate soils in some areas, and identified potential acid sulphate soils in most of the samples.

Evaluation of the groundwater chemistry also shows that some of the groundwater has been affected by acid sulphate soils an indication that actual acid sulphate soils exist.

The proposed development which includes road construction, tunnel excavation and some groundwater dewatering thus has potential to oxidise the potential acid sulphate soils and generate acid.

Potential impacts would predominantly be groundwater chemistry changes such as, lowered groundwater pH, increased heavy metals in solution, increased aluminium in solution, and raised total dissolved solids.

Groundwater discharges to the Cobaki Broadwater and related wetlands, thus potential environmental harm could be noticed in these environments.

### 1.1.3 Impact Mitigation

The proposed development would involve excavation activities, alterations to surface and groundwater flows and lowering of groundwater levels, particularly in the vicinity of the proposed road tunnel. For this reason mitigation measures have been included in the construction methods and have been incorporated into the design of the road tunnel.

Construction mitigation includes:

- prevention of excessive drawdown during dewatering by reinjection of the groundwater so that only the immediate area where dewatering is required would be dewatered;
- using construction methods that require minimal dewatering; and
- dewatering in phases, related to small segments of construction.

Operational mitigation includes the incorporation of cross tunnel drains to allow free groundwater movement across the tunnels, thus ensuring that groundwater flows and levels are not affected by the proposal.

### 1.1.4 Management Strategy

The presence of acid sulphate soils does not preclude development as the issue can be managed. The development would require a detailed management plan, to be developed following the Acid Sulphate Soil Management Advisory Committee (Stone *et al.*1998) guidelines. At this stage a management strategy is outlined. This includes:

- **Background Trends -** Pre-construction monitoring of groundwater chemistry to establish the background trend and natural variability of the system. Natural acid tolerant species exist in this environment, thus site specific criteria are required in preference to guideline levels and pH control would be aimed at maintaining the natural pH condition. Given the sensitivity of frog species to pH levels, the NSW Environment Protection Authority have indicated that they would be willing to liase with relevant agency personnel (e.g. National Parks and Wildlife Service) and specialist consultants to determine the most appropriate discharge criteria for those basins discharging to frog habitat prior to the commencement of construction works. Refer to Technical Paper Number 12 for further details.
- **Soil pH -** The soils are potentially acid forming, thus excavated material would need treatment with agricultural lime, containment in bunded areas to prevent leachate escape and testing to determine pH and rate of acid generation (if any).

  The results of testing would be used to determine the ratios that are required for treatment.

  Leachate from excavated material would be captured. Chemical tests would determine whether the leachate is affected by acid sulphate soils and the level of treatment that might be necessary.

- **Groundwater pH -** Deviations from long-term trends would require treatment to restore groundwater chemistry. These would be determined by monitoring before, during and after the development.

  Groundwater pH and indicators of actual acid sulphate soil impacts on groundwater chemistry would be monitored.

## 1.2 Reporting of Study Findings in the EIS

The studies for the Tugun Bypass environmental impact assessment commenced in 2000. In the subsequent four years the results of the various studies have been used to refine the concept design of the proposal. Further studies were also commissioned to ensure that all aspects of the various environmental issues were fully understood.

The long time period of the assessment has meant that the content of some of the earlier reports has been superseded by newer work. Changes to the design of the bypass have also been introduced to take account of these studies.

In the event that there is a contradiction between the technical papers and the text of the EIS, the EIS takes precedence as it reports the current understanding of issues, impacts and the concept design.

# 2. Methodology

## 2.1 Introduction to Acid Sulphate Soils

Acid sulphate soil is the common name given to sediments and soils containing iron sulphides that, after exposure to oxygen (drying) and rewetting generate sulphuric acid. The majority of acid sulphate sediments have formed by natural processes in recent geological time (the last 10,000 years). The conditions of their formation usually limit the occurrence of these soils to low lying parts of coastal floodplains, rivers and creeks.

Actual acid sulphate soils (AASS) are those containing highly acidic soil horizons from the oxidation of iron sulphides. These soils have a pH of 4 or less (in dry season conditions). They can usually be identified by the presence of yellow mottles and coatings of jarosite (iron sulphate).

Potential acid sulphate soils (PASS) contain iron sulphides that have not been exposed to air or oxidised. They pose an environmental risk as they would become very acidic when exposed to air as may happen during excavation, draining or groundwater pumping.

This technical paper presents the findings of an initial desktop study and a more detailed field investigation into the occurrence of actual acid sulphate soils that may be encountered during the construction of the proposed Tugun Bypass including road and rail tunnels. The findings show that the southern part of the proposal would be developed across an area typical of acid sulphate soil occurrence. Field investigation confirmed the presence of actual acid sulphate soils. Thus development, including excavation and related dewatering, has the potential to oxidise the actual acid sulphate soil and generate acid.

Hydrochemical impacts of such acid include lowered groundwater pH, increased heavy metals in solution, increased aluminium in solution, and raised total dissolved solids. On discharge and mixing with water bodies, the groundwater introduces this changed chemistry to surface water.

Environmental consequences include fish and other aquatic organism (particularly gilled organisms) kills due to toxicity of heavy metals. Surface water generally has higher dissolved oxygen than groundwater and the iron in solution precipitates as iron hydroxide ($Fe(OH)_3$) which forms a rust coloured coating that kills sedentary aquatic organisms.

Structural impacts are corrosion of concrete and metal structures.

The presence of actual acid sulphate soil does not preclude development as the issue can be managed. This paper links to other technical papers and shows how mitigation has been included in the design and construction methods to minimise impacts and presents a management strategy to ensure that undesirable impacts from actual acid sulphate soil do not result from the implementation of the proposal.

## 2.2 Purpose of the Acid Sulphate Soil Study

The purpose of this study was to investigate the potential impacts of disturbing actual acid sulphate soils during the construction phase of the proposed bypass including road tunnel and prepare a management strategy for use during construction and operation of the Tugun Bypass.

Acid sulphate soil mapping has been completed in this area by NSW Department of Land and Water Conservation and Queensland Department of Natural Resources. A compilation of these maps is provided as Figure 2.1. The mapping shows that some areas of potential and actual acid sulphate soil (PASS and AASS) exist adjacent to the proposed transport corridor, while much of the area affected by the proposal is described as disturbed ground, has low potential or is unmapped.

Field investigation during the geotechnical studies involved testing for potential and actual acid sulphate soils (Technical Paper Number4). Groundwater samples, taken for this investigation and as part of the contamination study (Technical Paper Number 6) were also evaluated to determine whether acid sulphate soil impacts could be identified from the groundwater chemistry.

The results of these investigations have been evaluated using guidelines given in the Acid Sulphate Soil Manual (Stone *et al.* 1998), guidelines prepared by the Queensland Acid Sulphate Soils Investigation Team (QASSIT) (Ahern *et al.* 1998), and technical papers from the *Acid Sulphate Soils, Environmental Issues, Assessment and Management Conference* (Ahern et *al.* 2000).

## 2.3 Geotechnical Investigation

A geotechnical investigation was carried out along the proposed route for the Tugun transport corridor which included the installation of 21 boreholes and seven test pits (Figure 2.2). Acid sulphate soil field and laboratory tests were conducted on samples from the test pits and bores to assess the likely presence of potential or actual acid sulphate soils. The following provide details of the sampling:

- sampling of all test pits from near surface, and at approximately 0.5, 1.0, 1.5, 2.0 and 3.0 m below existing grade;
- boreholes BH-6 to BH-11(excluding BH-9 and BH-10) (Figure 2.2) were sampled to a depth of 3 m using the standard penetration test (SPT) sampler at intervals of 0.5 m below existing grade; and
- boreholes BH-9 and BH-10 (Figure 2.2), in the proposed road and rail tunnel area, were sampled at 0.5 m intervals using the SPT sampler to a depth of 3 m then at 1 m intervals to a depth of 12 m below existing grade.

The acid sulphate soil sampling was conducted in accordance with the *Guidelines for Sampling and Analysis Procedure for Lowland Acid Sulphate Soils (ASS) in Queensland* (Ahern *et al.* 1998) and *Acid Sulphate Soil Manual* by Acid Sulphate Soil Management Advisory Committee (ASSMAC) (Stone *et al.* 1998). Excerpts from the former document are provided in Appendix A.

A total of 109 soil samples was taken. All samples were tested in the field for actual and potential acid sulphate soils and then frozen and stored for laboratory testing if required.

At the conclusion of the field testing, 45 samples were chosen for further laboratory peroxide oxidation combined acidity and sulphate (POCAS) testing. Samples were chosen so that at least one came from each test location along the proposed alignment. All samples producing a positive field result, obtained from within the road and rail tunnel area between chainages 5,300 to 5,800, were tested.

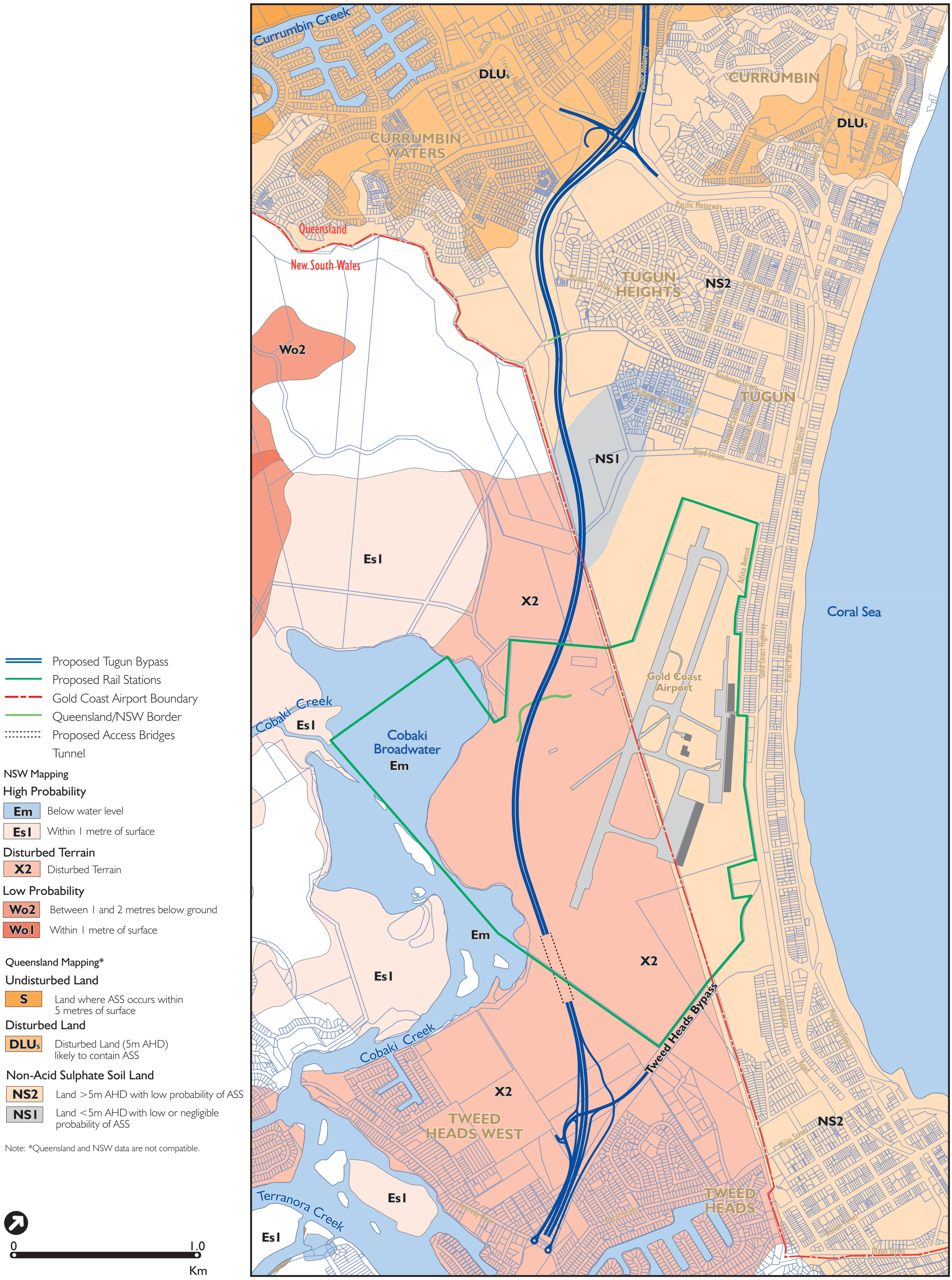

Figure 2.1 **Areas with Potential Acid Sulphate Soils**

Source: Acid Sulphate Soil Risk Maps (9641 S4)/Acid Sulphate Soils - Tweed Heads to Redcliffe (DNR-SEA-1-A0 3234)
* Queensland Acid Sulphate Soil Risk Map has been compiled using different assessment criteria from that in NSW.

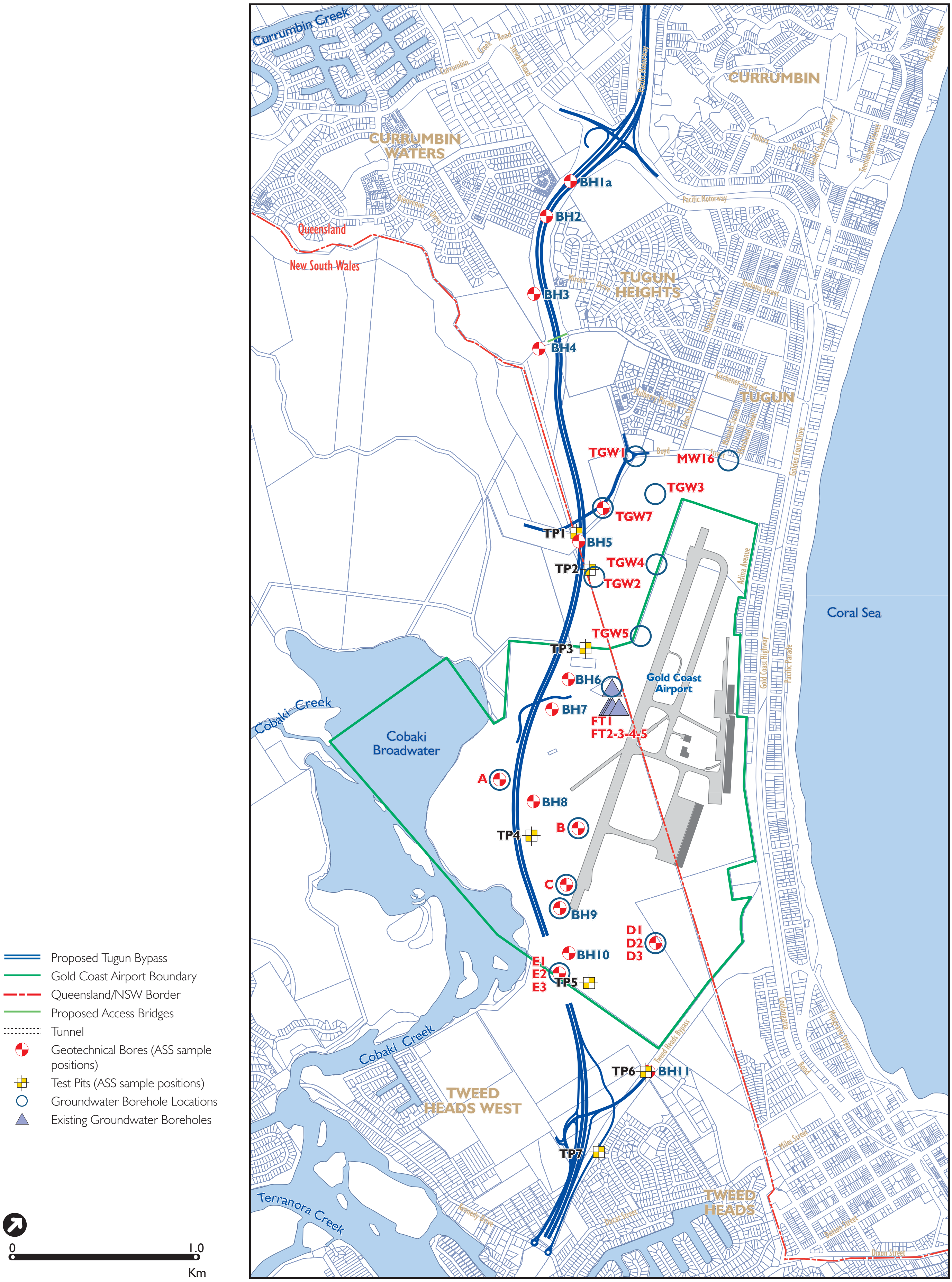

Figure 2.2 **Borehole and Test Pit Locations**

## 2.4 Groundwater Analysis

Seven of the geotechnical bores were completed as monitoring piezometers to investigate groundwater conditions in the proposed road and rail tunnel area. Other monitoring bores exist at the Gold Coast Airport fire fighting training area and associated with the Tugun Landfill.

Samples were taken in January 2001 for acid sulphate soils investigation and additional samples are available from the contaminated land study (Technical Paper Number6). The purpose of evaluating the water chemistry is to identify acid (derived from actual acid sulphate soils) impacts on groundwater. The presence of such impacts would show that groundwater has in the past been affected by acid sulphate soils. The sampled bores together with existing monitoring bores are shown on Figure 2.2.

# 3. Existing Environment

## 3.1 Identification of Acid Sulphate Soil Potential

The potential for the presence of acid sulphate soils can be determined using existing information and by comparison with maps and published criteria.

The NSW Department of Land and Water Conservation and Queensland Department of Natural Resources have published acid sulphate soils risk maps and a list of geomorphic criteria to determine if acid sulphate soils are likely to be present. A compilation of the Acid Sulphate Soil Risk Maps (9641 S4) for Tweed Heads and (9541 S1) for Bilambil are presented as Figure 2.1. This indicates the extent and risk of acid sulphate soils within the study area. The mapping is not definitive but suggests a low potential for acid sulphate soils along the proposed alignment, however in the vicinity of the road tunnel higher potential acid sulphate soil areas have been mapped.

The geomorphic criteria are listed in Table 3.1.

**Table 3.1: Geomorphic Criteria Indicating Presence of Acid Sulphate Soils**

| Geomorphic Criteria[1] | Criteria Represented in Study Area |
|---|---|
| Sediments of recent geological age (Holocene) | In southern section from chainage 2,500 to Kennedy Drive. |
| Soil horizons less than 5 mAHD. | As shown in Figure 3.1. |
| Marine or estuarine sediments and tidal lakes. | Estuarine sediments. |
| Coastal wetlands or black swamp areas. | Coastal. |
| Waterlogged or scalded areas. | Not in alignment but in adjacent areas. |
| Interdune swales. | Not identified but possibly exist at depth. |
| Coastal sand dunes (if deep excavation or drainage is proposed). | Most sediment in study area suggests origin as coastal sand dunes. |
| In areas where the dominant vegetation is mangroves, reeds, rushes, and other swamp tolerant vegetation such as Swamp Mahogany, Paperbark and Swamp Oak. | All these vegetation types are impinged by the proposed alignment as shown in Technical Paper Number 12 (see particularly Figure 4.1). |
| In areas identified in geological descriptions or maps as bearing sulphide minerals, coal deposits or former marine sediments. | Not available for this area. |
| Deep older estuarine sediments greater than 10 m below ground surface. | Clay bands 10 and 22 m below surface at BH-5 and silty sand below 10 m below surface at BH-11 are possibly of estuarine origin. |

Note 1: Derived from the Acid Sulphate Soil Management Advisory Committee (Stone *et al.* 1998).

Acid sulphate soils are classified as actual if the sulphides in the soil have been oxidised by exposure to the atmosphere at some time, or potential if the soils contain unoxidised sulphides. As parts of the area have been sand mined and sediments disturbed to approximately 3 m, it is likely that sulphide oxidation may have been initiated in the past.

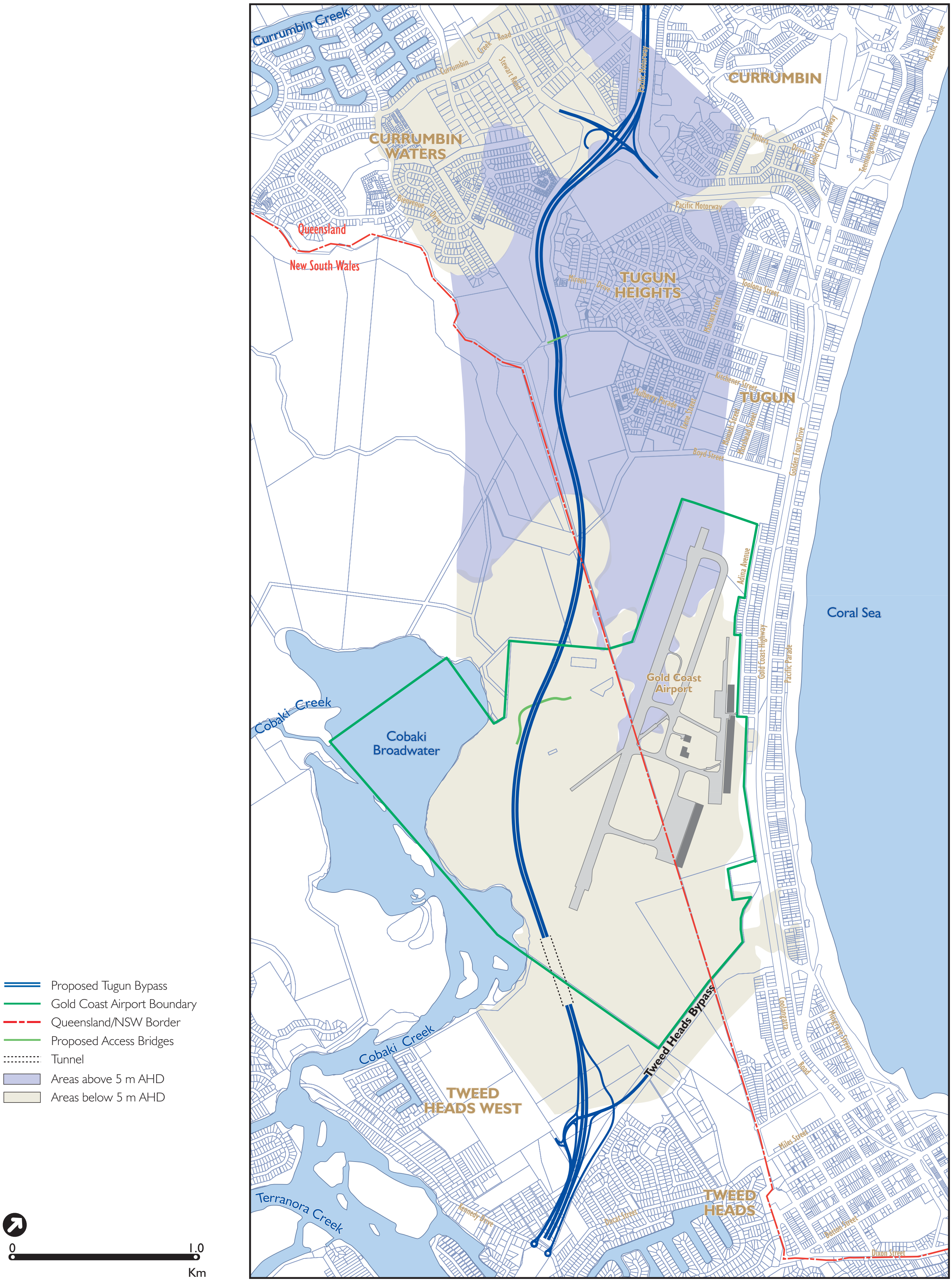

Figure 3.1 **Soil Horizons Less Than 5m AHD**

Given these observations, there is a high probability for the occurrence of acid sulphate soils within the alluvial soil profile in the southern section of the proposed alignment.

**Sample Positions**

Field testing was carried out at 28 investigation points which included geotechnical bores and test pits. The location of these points is shown on Figure 2.2 and their positions described in Table 3.2.

**Table 3.2: Acid Sulphate Soil Test Positions**

| Bore Identification | | Easting (m) | Northing (m) | Surface Elevation (mAHD) | Number of Field Tests | Number of Laboratory Tests |
|---|---|---|---|---|---|---|
| Installed during geotechnical or contaminated land investigation | | | | | | |
| 1 | BH-A | 549,248.14 | 6,883,451.41 | 2.78 | 5 | 5 |
| 2 | BH-B | 549,739.96 | 6,883,603.65 | 2.45 | 5 | 5 |
| 3 | BH-C | 549,928.78 | 6,883,330.16 | 2.34 | 5 | 5 |
| 4 | BH-D1 | 550,507.62 | 6,883,485.69 | 4.60 | 5 | 5 |
| 5 | BH-D2 | 550,504.58 | 6,883,484.44 | 4.72 | | |
| 6 | BH-D3 | 550,501.98 | 6,883,483.27 | 4.73 | | |
| 7 | BH-E1 | 550,272.21 | 6,882,970.55 | 1.00 | 4 | 3 |
| 8 | BH-E2 | 550,270.67 | 6,882,973.40 | 0.98 | | |
| 9 | BH-E3 | 550,269.14 | 6,882,976.19 | 1.04 | | |
| 10 | BH-1a | 547,022.52 | 6,886,022.99 | 6.00 | 5 | 5 |
| 11 | BH-2 | 547,078.99 | 6,885,779.91 | 20.17 | | |
| 12 | BH-3 | 547,355.52 | 6,885,445.99 | 34.08 | | |
| 13 | BH-4 | 547,595.98 | 6,885,248.81 | 62.40 | | |
| 14 | BH-5 | 548,548.73 | 6,884,685.74 | 3.68 | | |
| 15 | BH-6 | 549,085.57 | 6,884,121.18 | 4.12 | 5 | 2 |
| 16 | BH-7 | 549,141.56 | 6,883,935.29 | 4.15 | 5 | 5 |
| 17 | BH-8 | 549,459.13 | 6,883,512.67 | 2.24 | 5 | 5 |
| 18 | BH-9 | 550,010.85 | 6,883,224.55 | 1.29 | 10 | 10 |
| 19 | BH-10 | 550,211.03 | 6,883,089.45 | 1.22 | 11 | 8 |
| 20 | BH-11 | 551,010.05 | 6,882,963.46 | 0.65 | 5 | 2 |
| 21 | TGW7 | 548,546.00 | 6,884,687.00 | 3.63 | 6 | 6 |
| 22 | TP-1 | 548,512.48 | 6,884,705.72 | 3.03 | 6 | 1 |
| 23 | TP-2 | 548,718.46 | 6,884,623.40 | 3.68 | 4 | 4 |
| 24 | TP-3 | 549,028.91 | 6,884,305.37 | 4.19 | 6 | 6 |
| 25 | TP-4 | 549,601.96 | 6,883,378.03 | 2.32 | 5 | 5 |
| 26 | TP-5 | 550,427.50 | 6,883,056.69 | 0.67 | 6 | 6 |
| 27 | TP-6 | 551,014.57 | 6,882,969.09 | 0.71 | 6 | 3 |
| 28 | TP-7 | 551,167.71 | 6,882,453.08 | 1.05 | 6 | 6 |

Water samples were taken from 15 bores as indicated on Figure 2.2 and listed in Table 3.3. Some existing bores were used for groundwater level measurement and in some cases groundwater sampling. Limited records of previous measurement in 15 of these bores were available.

**Table 3.3: Groundwater Sampling Points**

| Bore Identification | | Easting (m) | Northing (m) | Groundwater Elevation (mAHD) |
|---|---|---|---|---|
| 1 | BH-A | 549,248.14 | 6,883,451.41 | 1.23 |
| 2 | BH-B | 549,739.96 | 6,883,603.65 | 1.58 |
| 3 | BH-C | 549,928.78 | 6,883,330.16 | 0.79 |
| 4 | BH-D1 | 550,507.62 | 6,883,485.69 | 0.97 |
| 5 | BH-D2 | 550,504.58 | 6,883,484.44 | 1.01 |
| 6 | BH-E2 | 550,270.67 | 6,882,973.40 | 0.14 |
| 7 | BH-9 | 550,010.85 | 6,883,224.55 | 0.50 |
| 8 | FT1 | 549,252.88 | 6,884,259.94 | 3.10 |
| 9 | TGW1 | 548,423.55 | 6,885,231.73 | 2.95 |
| 10 | TGW2 | 548,777.48 | 6,884,581.73 | 3.45 |
| 11 | TGW3 | 548,665.84 | 6,885,147.66 | 4.829 |
| 12 | TGW4 | 548,953.44 | 6,884,899.39 | 2.74 |
| 13 | TGW5 | 549,192.19 | 6,884,536.20 | 2.99 |
| 14 | TGW7 | 548,546.00 | 6,884,687.00 | 3.459 |
| 15 | MW16 | 548,792.00 | 6,885,596.00 | 4.566 |
| Existing Bores with some previous records | | | | |
| 1 | MW14 | 548,979.00 | 6,885,581.00 | |
| 2 | MW15 | 548,609.00 | 6,885,276.00 | |
| 3 | MW16 | 548,792.00 | 6,885,596.00 | |
| 4 | MW18 | 548,691.00 | 6,885,164.00 | |
| 5 | TGW1 | 548,423.55 | 6,885,231.73 | 4.61 |
| 6 | TGW2 | 548,777.48 | 6,884,581.73 | 4.74 |
| 7 | TGW3 | 548,665.84 | 6,885,147.66 | 7.70 |
| 8 | TGW4 | 548,953.44 | 6,884,899.39 | 5.50 |
| 9 | TGW5 | 549,192.19 | 6,884,536.20 | 5.12 |
| 10 | TGW6 | 549,109.17 | 6,884,389.79 | 4.48 |
| 11 | FT1 | 549,252.88 | 6,884,259.94 | 4.68 |
| 12 | FT2 | 549,263.13 | 6,884,241.06 | 4.66 |
| 13 | FT3 | 549,284.94 | 6,884,255.49 | 4.34 |
| 14 | FT4 | 549,300.43 | 6,884,278.66 | 4.18 |
| 15 | FT5 | 549,345.86 | 6,884,328.86 | 4.35 |

## 3.2 Soil Test Results

The results of the field tests are presented in Appendix B. Results of detailed laboratory tests namely peroxide oxidation combined acidity and sulphate (POCAS) are listed in Table 3.4 and the reports included in Appendix C.

Field indicator tests include:

- *Actual Acid Sulphate Soil Test*: pH of a soil water paste; pH < 4 may indicate actual acid sulphate soil; and
- *Potential Acid Sulphate Soil Test*: pH of the soil after the addition of a small volume of 30 percent hydrogen peroxide; pH < 3 may indicate potential acid sulphate soil.

## Table 3.4: Results of Peroxide Oxidation Combined Acidity and Sulphate Testing (POCAS)

| Sample Location[1] | Sample Depth (m) | Sample level (mAHD) | TAA[2] (moles H$^+$/tonne) | TPA[3] (moles H$^+$/tonne) | $S_{POS}$[4] (%) |
|---|---|---|---|---|---|
| TP-2 | 0.5 | 3.18 | 0 | 0 | 0.00 |
| TP-2 | 1.5 | 2.18 | 0 | 0 | 0.00 |
| TP-2 | 2.0 | 1.68 | 0 | 0 | 0.00 |
| TP-3 | 0.0 | 4.19 | 3 | 0 | 0.00 |
| TP-3 | 0.5 | 3.69 | 0 | 3 | 0.00 |
| TP-3 | 1.5 | 2.69 | 1 | 0 | 0.00 |
| TP-4 | 1.5 | 0.82 | 4 | 9 | **0.04** |
| TP-4 | 2.0 | 0.32 | 6 | **26** | **0.06** |
| TP-5 | 0.0 | 0.67 | 17 | 0 | **0.08** |
| TP-5 | 0.5 | 0.17 | 0 | 0 | 0.00 |
| TP-5 | 1.0 | -0.33 | 17 | **141** | **0.06** |
| TP-5 | 1.5 | -0.83 | 11 | **96** | **0.17** |
| TP-5 | 2.0 | -1.33 | 1 | **21** | **0.09** |
| TP-5 | 3.0 | -2.33 | 1 | **31** | **0.09** |
| TP-6 | 0.5 | 0.21 | 0 | **66** | **0.17** |
| TP-6 | 1.0 | -0.29 | 0 | **16** | **0.16** |
| TP-6 | 2.0 | -1.29 | 0 | **35** | **0.29** |
| TP-7 | 0.0 | 1.05 | 2 | 0 | 0.00 |
| TP-7 | 1.5 | -0.45 | 5 | **89** | **0.18** |
| TP-7 | 2.0 | -0.95 | 7 | **49** | **0.09** |
| BH-1a[4] | 1.0-1.45 | 5.0-4.55 | 11 | **0** | **0.03** |
| BH-1a[4] | 1.5-1.95 | 4.5-4.05 | 15 | 3 | 0.00 |
| BH-1a[4] | 2.0-2.45 | 4.0-3.55 | 16 | 12 | 0.00 |
| BH-6 | 1.0-1.45 | 3.12-2.67 | 0 | 0 | 0.00 |
| BH-6 | 3.0-3.45 | 1.12-0.67 | 6 | 0 | 0.00 |
| BH-7 | 0.0 | 4.15 | 2 | 0 | 0.00 |
| BH-7 | 1.0-1.45 | 3.15-2.70 | 1 | 0 | 0.00 |
| BH-8 | 0.0 | 2.24 | 2 | 0 | 0.00 |
| BH-8 | 1.0-1.45 | 1.24-0.79 | 0 | 0 | 0.00 |
| BH-9 | 1.0-1.45 | 0.29- -0.16 | 0 | 0 | 0.02 |
| BH-9 | 1.5-1.95 | -0.21- -0.66 | 1 | **20** | **0.05** |
| BH-9 | 2.0-2.45 | -0.71- -1.16 | 0 | **19** | **0.05** |
| BH-9 | 2.5-2.95 | -1.21- -1.66 | 6 | 6 | **0.04** |
| BH-9 | 4.0-4.45 | -2.71- -3.16 | 9 | 5 | **0.04** |
| BH-9 | 5.5-5.95 | -4.21- -4.66 | 1 | 0 | 0.00 |
| BH-9 | 7.0-7.45 | -5.71- -6.16 | 2 | 0 | 0.00 |
| BH-9 | 8.5-8.95 | -7.21- -7.66 | 2 | 0 | 0.00 |
| BH-9 | 10.0-10.45 | -8.71- -9.16 | 3 | 1 | 0.01 |
| BH-9 | 11.5-11.95 | -10.21- -10.66 | 0 | 1 | 0.00 |
| BH-10 | 0.5-0.95 | 0.72-0.27 | 13 | 0 | **0.07** |
| BH-10 | 1.0-1.45 | 0.22- -0.23 | 6 | **51** | **0.49** |
| BH-10 | 1.5-1.95 | -0.28- -0.73 | - | - | - |
| BH-10 | 2.0-2.45 | -0.78- -1.23 | - | - | - |
| BH-10 | 2.5-2.95 | -1.28- -1.73 | 7 | **80** | **0.89** |
| BH-10 | 4.0-4.45 | -2.78- -3.23 | 4 | **71** | **0.15** |
| BH-10 | 5.5-5.95 | -4.28- -4.73 | 1 | 8 | **0.04** |
| BH-10 | 8.5-8.95 | -7.28- -7.73 | 0 | **24** | **0.08** |
| TGW7 | 0.5 | 3.13 | <2 | 14 | <0.02 |
| TGW7 | 1.0 | 2.63 | <2 | <2 | **0.04** |
| TGW7 | 1.5 | 2.13 | <2 | 6 | <0.02 |
| TGW7 | 2.0 | 1.63 | <2 | 8 | <0.02 |
| TGW7 | 2.5 | 1.13 | <2 | 10 | <0.02 |
| TGW7 | 3.0 | 0.63 | <2 | 10 | <0.02 |

**Shaded and Bold** = Values exceeding ASSMAC (Stone *et al*. 1998) Action Criteria:

ASSMAC (Stone *et al*. 1998) Action Criteria – Coarse Texture (Sands). If these values are exceeded a management plan is required. **18** **0.03**

Note 1: Locations are shown on Figure 2.2.
2: Total Actual Acidity
3: Total Potential Acidity
4: Potential Oxidisable Sulphur

Moles H$^+$/tonne is a measure of the hydrogen ions that can be generated by a tonne of soil material. Since pH is a measure of the hydrogen ion concentration in a liquid, moles per tonne is a measure of the impact that the soil could have on pH if allowed to generate acid.

Levels of acid and oxidisable sulphur within a soil or sediment can indicate the level of risk to the environment if the soil is disturbed. The Acid Sulphate Soils Management Advisory Committee guidelines (Stone *et al.* 1998) have outlined action criteria based on the percentage of oxidisable sulphur ($S_{POS}$) and total potential acidity (TPA). The oxidisable sulphur and TPA action criteria values for coarse texture (sands) are 0.03 percent and 18 moles H$^+$/tonne respectively. If either of these values is exceeded, a management plan is required.

## 3.3 Groundwater Analysis Results

An indicator of the impact from acid sulphate soils can be derived from ground and surface water chemistry. Field testing for temperature and pH should be undertaken and laboratory analysis should include chloride, sulphate, iron, aluminium and total dissolved solids. Ground and surface water chemistry results from boreholes along the proposed alignment are outlined in Table 3.5.

Analysis of groundwater results to determine whether groundwater has been affected by acid sulphate soils have been suggested by Acid Sulphate Soils Management Advisory Committee (Stone *et al.* 1998) using the chloride to sulphate ratio ($Cl^-/SO_4^{2-}$). The criteria for this assessment are summarised in Table 3.6.

**Table 3.5: Results of Groundwater Tests**

| Borehole Number | pH | Alkalinity (mg/L as $CaCO_3$) | EC (µS/cm) | Cl (mg/L) | $SO_4$ (mg/L) | Fe (mg/L) | Mn (mg/L) | Al (mg/L) | Cl/$SO_4$ |
|---|---|---|---|---|---|---|---|---|---|
| TGW1 | 5.14 | 24 | 397 | 65 | 20 | 6.68 | 0.063 | | 3.3 |
| TGW2 | 6.02 | 220 | 712 | 50 | 50 | 2.87 | 0.198 | | 1.0 |
| TGW3 | 5.76 | 250 | 685 | 35 | 25 | 4.06 | 0.15 | | 1.4 |
| TGW4 | -- | 41 | -- | 55 | 8 | 0.45 | 0.014 | | 6.9 |
| TGW5 | 5.33 | 21 | 244.1 | 21 | 7 | 1.78 | 0.03 | | 3.0 |
| TGW7 | 6.85 | 730 | 2227 | 98 | 220 | 10.9 | 1.43 | | **0.4** |
| FT1 | 6.33 | 140 | 444 | 12 | 16 | 0.49 | 0.187 | | 0.8 |
| BH-A | 4.35 | 0.7 | 83.5 | 3 | 3 | 0.33 | -- | | **1.0** |
| BH-B | 5.03 | nd | 50.2 | 8 | 1 | 0.3 | -- | | 8.0 |
| BH-C | 4.70 | 6.4 | 73 | 9 | 2.7 | 3.3 | 0.071 | 0.56 | **3.3** |
| BH-D1 | 4.94 | 2 | 176.2 | 38 | nd | 1.86 | -- | | |
| BH-D2 | 5.30 | 6.4 | 330 | 88 | 1.1 | 2.2 | 0.087 | 0.25 | 80.0 |
| BH-E2 | 6.24 | 8.6 | 915 | 180 | 4 | 0.75 | -- | | 45.0 |
| BH-E2 | 6.10 | 55.7 | 610 | 150 | 1.3 | 0.48 | 0.028 | 0.18 | 115.4 |
| BH-9 | 5.54 | 3.6 | 251.6 | 11 | 34 | 3.12 | -- | | **0.3** |
| BH-9 | 5.90 | 68 | 250 | 13 | 2 | 5.8 | 0.13 | 0.2 | 6.5 |
| MW16 | 6.46 | 68 | 350 | 28 | 28 | 10.2 | 0.212 | | 1.0 |

**Table 3.6: Cl/$SO_4$ Indicator Criteria**

| pH | $Cl^-/SO_4^{2-}$ (by mass)[1] | Assessment |
|---|---|---|
| 6-8 | approx 7 | No sulphide material present or sulphide material is present, however it has not been oxidised at any time. |
| <5 | approx 7 | No sulphide material present or sulphide material has been oxidised at some time and low pH can be attributed to other causes. |
| 6-8 | <2, if <5 do further analysis | Presence of sulphide material plus the presence of a buffering agent. |
| <5 | <2, if <5 do further analysis | Presence of sulphide material with little buffering agent. |

Note 1: This test only applies if the water salinity is that of seawater, the test becomes less applicable as the water becomes fresher. Thus for fresh water the indicators are not clear and must be considered in the light of other test results such as field indicators.

In the light of acid sulphate soils impacts, the water chemistry results suggest:

- Samples with marine influenced water, such as at boreholes BH-D and BH-E where conductivity suggests high salinity, have high Cl/$SO_4$ ratios and relatively high pH. These waters thus suggest that they are not affected by acid sulphate soil oxidation.
- Groundwater from BH-C, BH-A and BH-9 have low Cl/$SO_4$ ratios suggesting acid sulphate soils influence. Evaluation of the field results shows uncertain results at BH-A but more certain results from BH-9 and BH-C. When combined with the additional laboratory tests, these results show that acid sulphate soils are influencing groundwater chemistry in that area.
- The other water samples have been taken from existing bores and soil testing results (if undertaken) are not available. The water is generally fresh, making the evaluation of the Cl/$SO_4$ ratio uncertain. TGW7 is the exception where the water chemistry is affected by leachate from the Tugun Landfill and the result cannot be evaluated in the light of acid sulphate soils influence.

There is an indication that groundwater chemistry is already affected by sulphide oxidation. The strongest evidence comes from the vicinity of borehole BH-9.

Chemistry results are presented in detail in Technical Paper Number 6 while the results obtained for this investigation are presented in Appendix D.

## 3.4 Implications of the Subsurface Results

The subsurface materials comprise the Neranleigh-Fernvale beds that outcrop and form the elevated, hilly ground north of Boyd Street. The rocks comprise alternating greywacke and argillite beds and dip at approximately 50° west. These rocks and related soil horizons do not have potential to generate acid sulphate soils.

From Boyd Street southward, younger unconsolidated sediments deposited in coastal and estuarine environments cover the older rocks. The following sediment types were identified:

- Fine to medium grained sand - this material occasionally has thin clay bands or beds. In one occurrence shell fragments were noted. The sediment could be grey or brown. The sediment represents wind and (minor) wave deposits in a beach environment, the thin clay bands representing occasional estuarine inundation.

Colour differences are related to groundwater table position and oxidation history in the subsurface.

- Silty sand - this material is probably related to estuarine deposition. Colour variation is due to oxidation as in the fine to medium grained sand.
- Gravel - two occurrences of gravel were noted. These represent channel sands and indicate past positions of the Coolangatta Creek.
- Coffey rock, is cemented sediment and might comprise all the above sediment types but more commonly the fine to medium sand. It has been cemented by iron oxides often related to heavy mineral bands.

The sediments occur as discontinuous, inter-fingering lenses showing the dynamics of the depositional environment.

Recent sediment disturbance related to sand mining (the process removes a small proportion of the sand (heavy minerals) and replaces the remaining sand). Thus there are some areas where the natural sedimentary structures and facies relationships have been destroyed.

The field soil pH testing shows that many samples do not have actual acid sulphate soils present and many of the tests gave an uncertain result. Potential acid sulphate soils were identified in most field tested samples.

The results of subsurface descriptions and acid sulphate soils tests are summarised in Figure 3.2. This figure includes some interpretation of the shape and continuity of the subsurface layers. Although the continuity is uncertain, the depths at which these sediment were encountered shows vertical variability. Similar horizontal variability can be expected.

The acid sulphate soils tests show fairly consistent results in spite of the implied horizontal and vertical variability. This suggests that the sulphide material is relatively evenly distributed throughout the sediments. This could be because the sulphide was formed following deposition of the sediments.

The results show that at any depth in most test sites, the subsurface materials have high potential acid sulphate soils. In most areas, the tests did not identify actual acid sulphate soils but many sites have uncertain results. The laboratory results show that many (24 of 46) of the samples have high potential oxidiseable sulphur and high total potential acidity (16 of 46). The results are apparently not depth related.

The field tests were not conclusive in terms of actual acid sulphate soils. However when all the results are considered, the uncertain ones are confirmed by laboratory and water analysis. This is due to:

- the pervasive, potential acid sulphate soils shown by field tests;
- soils that contain oxidiseable sulphur or acid genetation potential are considered to present an environmental risk (above set criteria); and
- evidence that water chemistry has been influenced by acid sulphate soils.

Furthermore, the subsurface material has potential to generate more acid if the subsoils or groundwater table are disturbed. Thus development of a management plan would be necessary before construction begins.

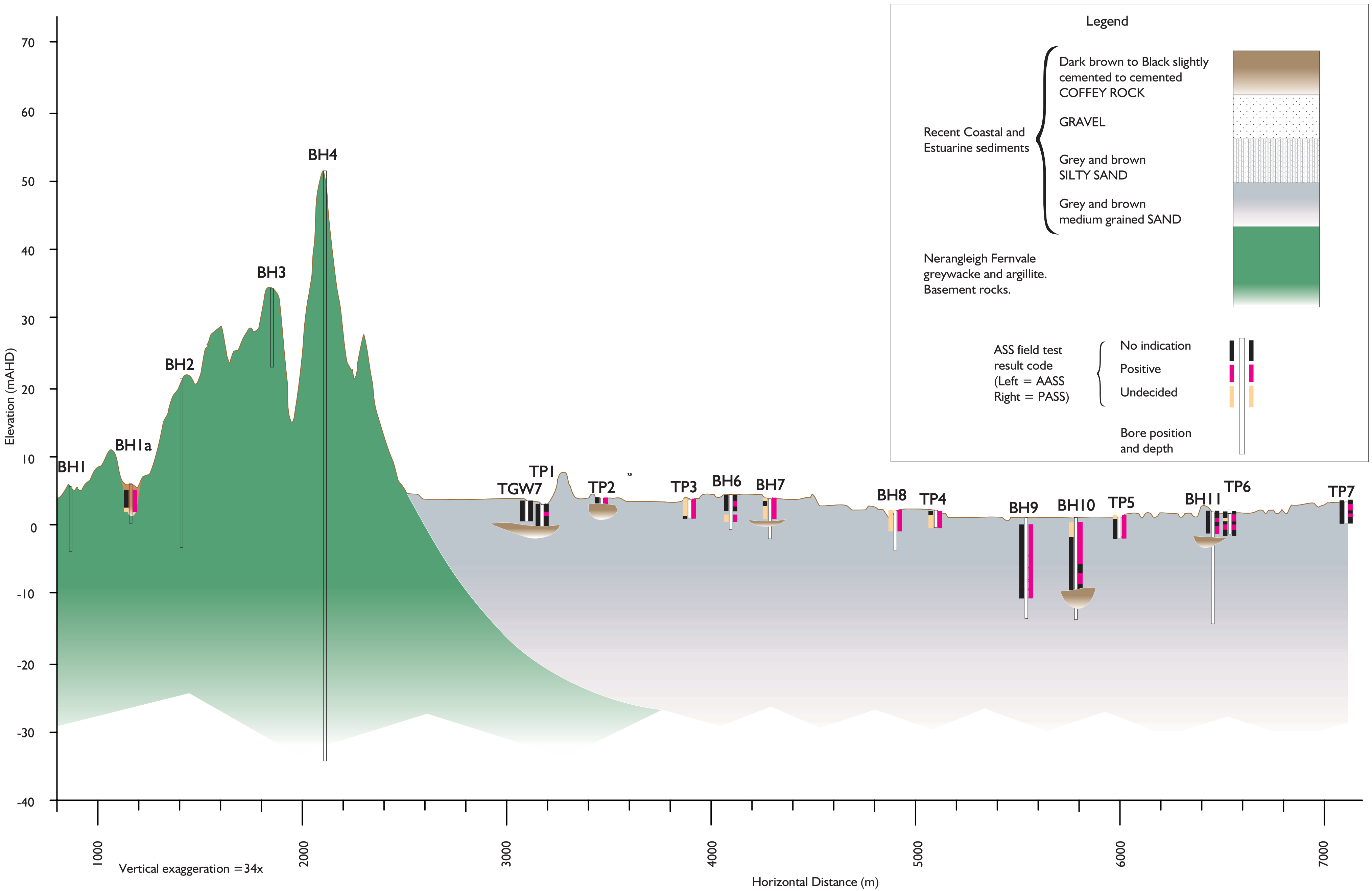

Figure 3.2 **Section Along Alignment Showing Subsurface Investigation Results**

# 4. Potential Impacts

## 4.1 Potential Environmental Impacts

Acidification impacts reduce the conservation, commercial and recreational value of tidal streams and estuaries. Major environmental impacts within waterways include fish kills, fish diseases, habitat degradation and changes to aquatic plant communities. There is also some evidence of impacts on frog populations and waterfowl habitat. Over the past decade, fish kills directly attributable to acid sulphate soil disturbance have been observed in environmentally sensitive areas throughout Australia. Activation of the acid sulphate soils has been due to man-induced disturbance and in some cases by natural processes.

The degree of impact due to acid sulphate soils varies from site to site because of a range of factors including:

- the nature of the disturbed environment;
- the extent of the development;
- whether the development is major or minor, dispersed or concentrated;
- the nature of the adjacent waterways;
- the concentration and mobility of acid, aluminum and iron;
- local hydrology and groundwater systems; and
- the sensitivity of the receiving waters and their biota.

Resource inventories and site classifications need to consider potentially adverse effects felt in areas upstream, on-site, and downstream to assess the impact of any proposed development. Excavation and dredging for a new marina, for example, would inevitably change the hydrology of upstream areas. If the upstream area contains acid sulphate soils, any increased drainage would lead to a lowered water table. This, in turn, may cause these soils to dry out, thereby triggering sulphide oxidation and eventual release of acid, aluminum and iron. The assessment and management of acid sulphate soils has therefore not only to be based on good site specific investigations but must also be holistic enough to look at any potential offsite effects.

A number of Australian researchers have investigated or documented the environmental and economic impacts of acid sulphate soils disturbance. White *et al.* (1995) and Sammut *et al.* (1996) have published reviews of recent work and the information that follows is drawn from these sources. Impacts on fisheries and coastal hydrology are covered in more detail in Technical Paper Number 7 and Technical Paper Number 12.

### 4.1.1 Fish and Marine Organism Deaths

The most obvious affects of acid sulphate soil oxidation are on fish because of reported fish kills and the evidence of dead fish in the water. In spite of this, other organisms in estuaries, such as crustaceans, annelid worms, shellfish and oysters are more vulnerable than fish to acid run-off because of their lack of mobility.

In most cases involving acid sulphate soils, high intensity rainfall after extended dry periods triggers localised mobilisation of acid. Run-off transports the acid to local waterways which exposes marine animals to rapid changes in pH toxic levels of aluminum and manganese, iron precipitation and hydrogen sulphide (Sammut *et al.* 1996). Low levels of dissolved oxygen may also accompany an acid event, accelerating death.

An example of this process occurred in south-east Queensland in November 1995. The Pimpama River and estuary suffered a massive fish kill associated with the breaking of an extended drought. Shortly after the event, the river water flowing over the barrage was measured at pH 3.7 and run-off water draining from a disturbed area under development from below the barrage was measured at pH<2 (fish are generally affected at pH <5.5).

### 4.1.2 Fish Disease

Exposure to acidified water damages fish skin and gills, impairing the general health of fish stocks and increasing their susceptibility to infection by *Aphanomyces* spp., the ulcer-causing fungus of epizootic ulcerative syndrome (EUS) (Sammut *et al.* 1996). EUS, also known as *red-spot* disease, is an ulcerative skin disease of fish characterised by red lesions that leave them unsaleable and may cause fish deaths. Outbreaks of EUS can affect up to 80 percent of the fish catch in acidified waters.

### 4.1.3 Habitat Degradation

Waterway habitat degradation is possibly the most significant impact of acid sulphate soil drainage. Acidic water destroys food resources, displaces biota to other areas, precipitates iron oxide that smothers vegetation and microhabitat and alters the chemical and physical properties of the water. The acid not only affects general habitat but also many spawning and nursery grounds. In tidal reaches, mud flats are often smothered by iron flocs many kilometres from the source of acid.

When water quality begins to improve after an acid event, there is normally a lag in the recovery of the biota. This recovery process can be interrupted by further periodic acidification (Sammut *et al.* 1996). Some estuarine systems, particularly those which are poorly flushed with tidal water and seasonally have low salinity, are considered particularly vulnerable to acid water discharges (Willet *et al.* 1993). The profusion of acid-tolerant aquatic plants, clear or green-tinged water and schools of acid-tolerant fish, may give a false impression of a healthy system.

### 4.1.4 Human and Animal Health

Aluminum-rich waters may have significant impacts on human and animal health (White *et al.* 1995). These impacts could include stunted growth, poor health and mental impairment. Because high acidity induces sediment flocculation, aluminum-rich waters can be exceptionally clear, creating the impression that they may be considered fit for consumption. However, in most Australian estuaries, waters tend to be brackish and are not often used for drinking or stock watering. Stock often refuse to drink acidic waters. Cases of industrial dermatitis, caused by the handling of or skin contact with acid soil materials, have been reported. Epidermal absorption of heavy metals is also a theoretical possibility, although this is unconfirmed.

In addition to direct health impacts, acid drainage may have indirect impacts on human and animal health (White *et al.* 1995). Possibilities include interaction of acidic drainage with disease-carrying organisms. Certain species of swamp mosquito, for example, prefer acid drainage for breeding (Green 1993). Higher iron levels (possibly due to acid sulphate soils) in Deception Bay, north of Brisbane, have been linked with the toxic blue-green algae (*Lyngbya majuscula)* (Abal *et al.* 1998).

## 4.2 Potential Economic Impacts

Impacts on agriculture and engineered structures can have major economic implications, both in the destructive power of acid sulphate soils and in preventative or mitigation measures. Activities that may be affected by acid sulphate soils impacts are listed in Table 4.1.

**Table 4.1: Common Land Uses in Areas of Acid Sulphate Soils**

| Industry/Activity | Land Use |
|---|---|
| Urban development | housing, resorts, marinas, canal estates, golf courses. |
| Infrastructure | roads, railways, bridges, flood gates, dredging, boat ramps. |
| Mining | sand extraction, gravel extraction, dredging. |
| Aquaculture | prawns, oysters, fish. |
| Agriculture | sugar cane, dairying, tea tree, grazing, cropping, ponded pasture. |
| Undeveloped areas | mangrove swamps, salt marshes, national, state and local parks and reserves, coastal wet lands, coastal lakes. |

The overall annual cost of acid sulphate soils disturbance and management to Queensland is estimated to be $180 million (Ahern *et al.* 2000).

### 4.2.1 Agriculture

Acid sulphate soil products affect all types of vegetation, with severity varying between localities (land, freshwater, marine) and plant species. In general, plant growth is stunted at low pH, with poor vegetation soil prone to erosion. Acidic drains, soil and scalds in a number of coastal swamps have remained unvegetated for years because of low pH. Affected pastures are often only revegetated by acid-tolerant plants such as *Polygonum* spp., if at all (Sammut *et al.* 1996).

The effect on plant productivity can come from one or more of the following:

- toxic effects of aluminum, iron and manganese at low pH. The $Al^{3+}$ ion in particular appears to change the balance of ions of other metals;
- low pH causes a deficiency in plant base elements such as calcium, magnesium and potassium or a deficiency in nutrient availability particularly phosphorus. At low pH, aluminum and iron can form relatively insoluble phosphates. Thus the phosphate is 'locked up' and unavailable for plant uptake; and
- indirect (non-chemical) effects that can add to plant stress levels include:
    - increased attack by plant pathogens;
    - decreased numbers of soil microbes, particularly those responsible for nitrogen fixation; and
    - physiological damage to plants such as the stunting of roots which can produce plant water stress even in situations where there is adequate soil moisture.

### 4.2.2 Corrosion of Metal and Concrete

Metals such as iron and aluminum are quickly corroded in acidic solutions (White *et al.* 1995) and it has been reported that acid waters can attack aluminum boats. Steel is also attacked under acidic and reducing conditions although some forms of stainless steel are resistant.

The minerals making up concrete (portlandite $Ca(OH)_2$) are corroded by sulphuric acid, accelerating maintenance and replacement costs of bridges and pipes. Steel reinforced concrete structures loose their integrity, concrete is corroded exposing steel which then also corrodes, weakening the structure.

### 4.2.3 Subsidence

Many unconsolidated estuarine muds and clays, associated with acid sulphate soils, have low load bearing capacity (White *et al.* I995). A consequence of this is that foundations or earthworks built on these materials may settle or subside unevenly and slowly.

On roadways the pumping action of passing traffic, since it involves dewatering of unconsolidated materials, tends to exacerbate settling problems. Preventative and mitigation measures in areas so affected may require piles, load spreading membranes, and additional drainage, all adding to the costs of the project.

### 4.2.4 Groundwater Impacts

Acid sulphate affected water contains high levels of dissolved metals. When groundwater is pumped or drained, exposure of the water to oxygen causes precipitation of iron hydroxide.

In drains or seeps, oxygenation occurs by exposure to the atmosphere or by mixing with fresh water with high dissolved oxygen. This causes the precipitation of iron hydroxide. In the aquifer this could happen by air entrainment during excessive pumping or by groundwaters of different quality mixing during extractive pumping.

Results include:

- blocking or impairment of drain systems (White *et al.* 1995);
- well screen/slot and pump clogging, in excessive cases aquifers may be clogged; and
- acidification of aquifer water.

These affects have led to a moratorium on the issuing of bore licenses in the sugar cane growing area of Moore Park, Bundaberg, until further investigations are undertaken.

## 4.3 Potential Impacts of the Proposed Development

### 4.3.1 Introduction

This technical paper indicates that several regions in the low-lying sections of the proposed corridor have been identified as containing acid sulphate soils or potential acid sulphate soils.

Any disturbance of existing site conditions in these areas would require management. Construction of a major road, road tunnel and drainage structures over these areas would undoubtedly result in disturbance and possible impacts from the acid sulphate soils.

The following potential impacts could result from the implementation of the proposed development:

**During Construction**

- Groundwater pumping for road and rail tunnel construction could lower the water table and expose acid sulphate soils to oxidation.
- Excavation and clearing works below the water table has the potential to lower groundwater levels and expose acid sulphate soils to oxidation.
- Excavated material would be stockpiled, or used as fill in other parts of the development. If it contains sulphide minerals, it has potential to generate acid.

**During Operation**

- The operational phase has potential to affect groundwater flow directions, either by changing run-off and recharge characteristics or by the physical obstruction created by the road tunnel or road subgrade materials. Such obstruction may cause local changes in groundwater elevation thus activating acid sulphate soils.

All impacts have been considered and mitigation measures incorporated into either the design of the proposed development to prevent alteration of groundwater flow conditions and related acid sulphate soil activation, or the construction methods to prevent acid sulphate soil oxidation.

These potential impacts are discussed in more detail in the following sections. Appropriate methods of acid sulphate soils management are discussed in Chapter 5.

### 4.3.2 Construction Activities

Construction activities over the nominated acid sulphate soil locations are likely to affect acid sulphate soils through excavation and alteration of surface water and groundwater flows in areas of drain installation and the road tunnel.

Specific activities likely to affect acid sulphate soils include:

- erosion and sedimentation control structures including site clearing and excavation for sedimentation ponds, silt traps and open drains;
- stormwater drainage systems including site clearing and excavation for culverts, pipes trenches and open drains;
- embankment construction including site clearing and possible over-excavation for subgrade treatment (bridging, stabilisation or replacement), construction of haul roads, stockpiling of site materials, placement of fill, soil consolidation, installation of wick drains to increase consolidation rates, subsoil drains and toe drains;
- bridge construction including working platforms, pile construction and possible (temporary) diversion of waterways;
- road tunnel construction including dewatering, excavation for diaphragm walls, excavation for drainage structures, tunnel excavation, pile construction, and open cut excavation for approach and departure portals, (Figure 4.1); and

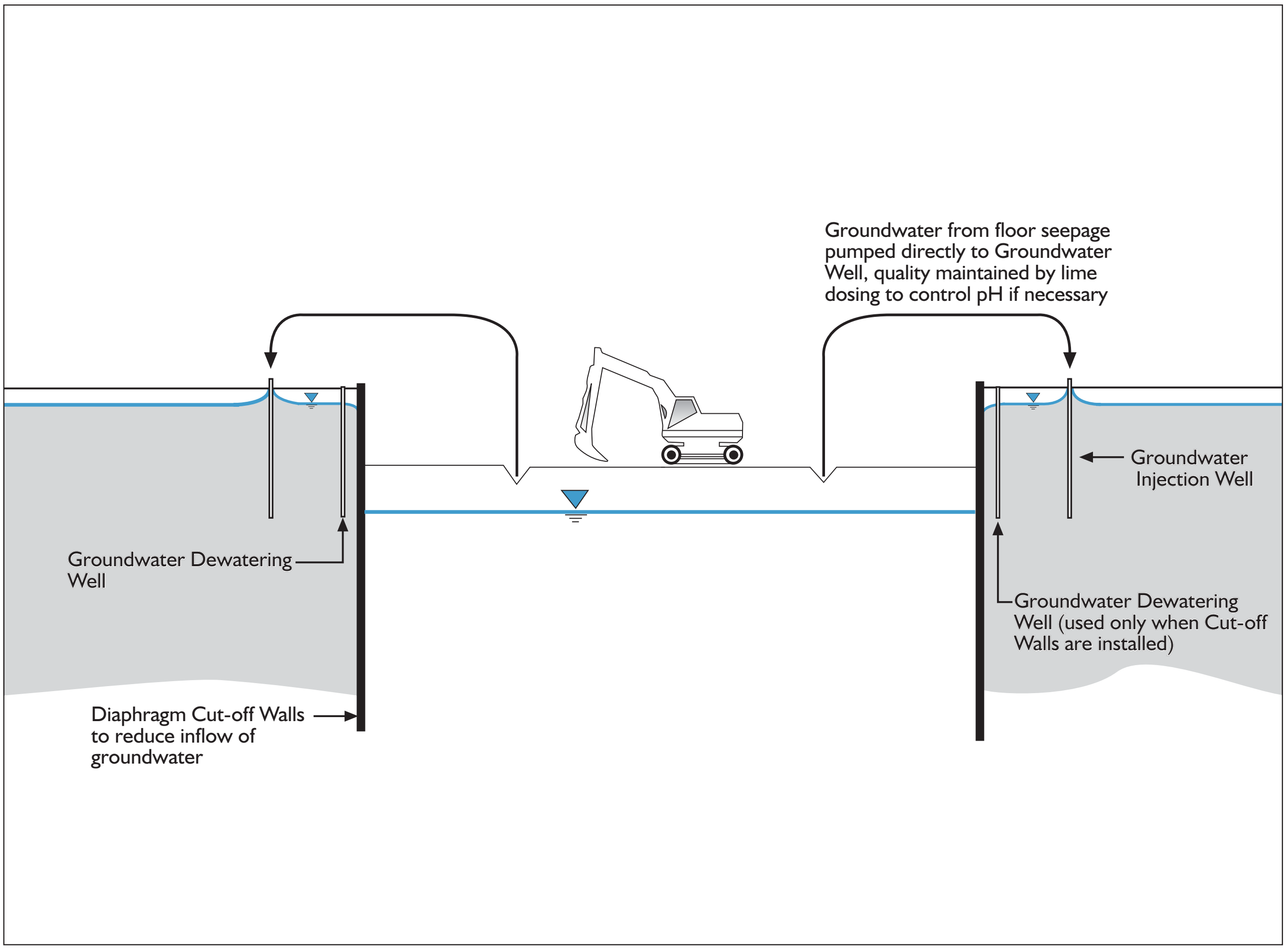

Figure 4.1 **Indicative Construction Method for Cut and Cover Tunnel**

- initial stage of tunnel construction including installation of dewatering system for future excavation and excavation for diaphram walls, tunnel roof and drainage structures.

Specific details about proposed construction activities and staging are contained in Technical Paper Number2.

### 4.3.3 Impacts of Construction

**Excavation**

A number of aspects of road construction in low-lying areas are likely to require soil excavation, including (but not limited to) clearing and stripping topsoils, excavation and replacement of sub-grade, trenching, culvert construction and tunnel construction and excavation. It is normal practice to keep these activities to a minimum in acid sulphate soils areas. However where acid sulphate soils are exposed, these soils require treatment and control as discussed in Chapter 5.

**Ground Heave**

Soil disturbance could also occur by heaving of soft soil under construction equipment loads or lateral displacement of soils under the toe of large embankments. Where such heaving occurs near the water table the effect could be to displace soil from the anaerobic zone below the water table into the aerobic zone above where oxidation of potential acid sulphate soils can occur. It is anticipated that such heaving would be minimal (under good construction practices) and lateral displacement of embankment toes should be limited to minor localised areas (and mostly offset by settlement of the underlying soils). Limited volumes of soil disturbed in such a manner should mean that the effects of these localised areas of acid generation should be negligible. Thus no treatment options are likely to be required, although monitoring as discussed in Section 5.3 is recommended.

**Groundwater Draw-down**

Local draw-down of the water table would be necessary during construction of the cut and cover road tunnel between chainages 5,000 to 6,700 and construction of the rail tunnel walls and roof. The installation of drains below the water table can also have the effect of local draw-down of the groundwater table. Both these activities can result in the exposure of previously submerged potential acid sulphate soils. This could oxidise resulting in acid generation.

**Groundwater Flow**

The road tunnel and approach ramps would normally introduce a permanent impervious barrier, 1,060 m long, to groundwater movement. Unless mitigated this would have a permanent impact on groundwater movement to the Cobaki Broadwater and may cause water-logging of land up-gradient of the tunnel and lowering of water table on the down-gradient side. For this reason the tunnel and ramp design includes a drainage system to alleviate this problem. The rail tunnel could create similar impacts along a 400 m corridor and would be similarly mitigated.

Settlement of unconsolidated material under embankment loading could also result in changes to the subsoil permeability. Such changes could effect groundwater flow patterns. In areas where wick drains are installed to accelerate consolidation, the increase in vertical permeability should help counteract the general decrease due to loading.

### Groundwater Discharge

Groundwater would be extracted from the excavation during construction of the road tunnel to draw the level of the water table down.

In areas where wick drains are installed to accelerate consolidation of soft soils, groundwater would be expelled via the vertical drains.

Groundwater in acid sulphate soil areas has been assessed as slightly acidic (pH is between 4.5 and 6) and contains iron and aluminium levels exceeding ANZECC guidelines for fresh water environments. All discharge waters would therefore need to be tested and treated if necessary (based on pre-construction monitoring) to meet ANZEEC and Airports (Environment Protection) Regulations 1997 standards prior to release.

### Concrete Attack

Concrete structures such as culverts, bridge piles and foundations and lined drains are all susceptible to sulphate attack. Chemical reactions between sulphate and calcium hydroxide or sulphate and calcium aluminate result in an increase in the volume of the solids which are responsible for expansion and disruption of concrete. Reference should be made to relevant Australian Standards, NSW Road and Traffic Authority guidelines and Cement and Concrete Association Technical Notes for exposure classifications and appropriate modifications to cement mixtures to repel/prevent sulphate attack.

# 5. Management Strategy

## 5.1 Detailed Assessment and Testing

Table 3.1 in Clause 3 of the assessment section of Acid Sulphate Soils Management Advisory Committee (ASSMAC) manual (Stone *et al*. 1998) provides guidelines for the likely environmental risks from a project, and Clauses 3 and 4 cover the testing requirements for soil and water quality. The factors used for assessment place the proposed Tugun Bypass and rail tunnel in the very high risk category. With the application of agricultural lime expected to be greater than 5 tonnes for the entire proposal, the proposal is also in the very high treatment category.

The testing and assessment regime prior to and during construction of the proposal should reflect this level of risk and adhere closely to the ASSMAC and Queensland Acid Sulphate Soils Investigation Team (QASSIT) guidelines (Stone *et al*. 1998, Ahern *et al*. 1998). Areas identified as 'hotspots' in the preliminary investigations and those that would experience large-scale disturbances such as the road and rail tunnel sites, should receive increased levels of testing and sampling. Methods to reduce the level of pyrites in the soil in these areas should also be considered. These include sluicing or hydrocycloning to remove the pyritic fines that can be placed back below the water table. This would reduce the reliance on liming to neutralise the acids.

Given the site sensitivities and the need to maintain background pH levels as opposed to liming to reach neutral conditions, the environmental management plan would need to detail the appropriate process for training on-site personnel and construction workers.

## 5.2 Control and Management Procedures

### 5.2.1 General Strategies

There is a range of procedures for the treatment of acid sulphate soils disturbed during construction activities. These can be implemented individually or jointly as part of a combined approach. General procedures include:

- avoidance – where acid sulphate soils areas are avoided altogether (total avoidance) or development activities are adjusted so that the more severe areas are left undisturbed (partial avoidance). Along the southern section of the proposed alignment, avoidance is unlikely to be an option;
- oxidisation prevention – acid sulphate soils are innocuous if they are not allowed to oxidise. Oxidisation can be prevented by avoidance, water table control, in-situ capping or removal and burial below the water table;
- acid and pH control – acid present or produced by oxidation in the soil can be controlled by the addition of alkalizing agents such as agricultural lime;
- leachate treatment – where the sulphide content of a soil is very low, deliberate oxidisation, collection and treatment of the leachate might be appropriate. This method is generally only applicable to sand, given the lengthy drying times for clay, and would require detailed pilot trials prior to implementation; and

- disposal to landfill – the acid sulphate soils may be removed and disposed of in an appropriate landfill. Untreated acid sulphate soils would be treated as a contaminated soil for the purposes of transport and disposal.

Acid control is considered to be the most effective treatment option for the identified acid sulphate soils areas. This option has proved to be effective on a number of projects. In controlling acid generation from excavated material, pH controls would be aimed at maintaining the natural pH condition (refer to Section 1.1.4).

### 5.2.2 Strategy Options

**Excavation – General**

The control of acid generation from excavated material can be achieved by using lime. The recommended method is outlined as follows:

- Determine the depth and extent of areas requiring excavation, using Acid Sulphate Soil Risk Maps (9641 S4) for Tweed Heads and (9541 S1) for Bilambil as a preliminary guide to the likelihood of encountering acid sulphate soils.
- Conduct site specific soil sampling and testing (POCAS) program in accordance with ASSMAC or QASSIT guidelines, including field and laboratory testing of each potentially affected strata at each test location.
- Determine liming rates based on POCAS testing results. The amount of lime required (kg $CaCO_3$/tonne soil = kg $H_2SO_4$/tonne soil). When estimating the lime requirement, a factor of safety of 1.5 to 2 should be applied to allow for inefficient mixing of lime.
- Stockpiles of agricultural lime should be kept on site at all times. The supply should be covered and stored in a bunded area to prevent accidental release to potentially sensitive receiving waters. Similarly, a supply of hydrated lime should be kept on site at all time to treat acid leachate.
- Provide suitably sized and located acid sulphate soils treatment areas, with impermeable base and side bunds to contain soil and leachate and direct run-off to lined collection ponds. The treatment area should be divided into at least two separately bunded areas, one for liming and mixing soils and a second for containment and monitoring.

**Excavation to Embankment Fill**

For materials that are to be excavated from the road tunnel site and placed directly into the road embankment:

- The base of the embankment pad would be limed with a precautionary amount of fine agricultural lime at a minimum rate of 2.5 tonnes per hectare to control acidic leachate (Ahern *et al*. 2000). This is opposed to the liming rate of 50 tonnes per hectare to be applied when creating a pad on which to treat acid sulphate soils.
- Excavated soil would be placed in the embankment area within one day of excavation. Soil would be spread out in a maximum 200 mm thick layer and covered with the required amount of lime as determined from the acid sulphate soils analysis. Soils would be dried out to allow trafficking and mixing with a rotary hoe or equivalent. Thorough mixing and aeration is essential and testing trials would be conducted to ensure effective treatment before compaction of the layer.

- The final profile of the embankment would be top soiled and vegetated to restrict the ingress of water to minimise the possibility of leachate from the embankment.

**Excavation to Stockpiles**

- Excavated soil would be placed in the treatment area within one day of excavation. Soil would be spread out in a maximum 300 mm thick layer and covered with the required amount of lime. Soils would be dried out to allow trafficking and mixing with a rotary hoe or equivalent. Thorough mixing and aeration is essential and trials should be conducted to ensure effective treatment.
- If stockpiles are to be left in place for later use they would be top-soiled and vegetated so as to restrict the ingress of water to minimise the possibility of leachate production.
- Separate catch ponds would be required for treatment and stockpiling areas and collected waters monitored as outlined in Section 5.3.

**Ground Heave**

No control measures are proposed for ground heave as the affected volumes are expected to be minimal (refer to Technical Paper Number 4). Review of potential control measures may be necessary based on the results of monitoring.

### 5.2.3 Water Quality Management

**Groundwater Draw-down**

Dewatering for construction of the road tunnel is discussed in detail in Technical Paper Number9. Potential impacts have been considered and investigated by groundwater modelling. Groundwater modelling also tested mitigation measures included in the design and construction techniques. Early models tested the impacts and design and construction techniques were modified to prevent or mitigate any impacts. Later models tested the proposed construction approaches to ensure that undesirable groundwater drawdowns can be prevented by the proposed methods and design. These methods included investigations during both the construction and operational phases of the bypass.

**Groundwater Flow**

The road tunnel would normally impede natural groundwater flows towards the Cobaki Broadwater. This could raise water levels on the upgradient side of the tunnels while lowering water levels on the downgradient side with resultant potential for activating acid sulphate soils. The road tunnel and approach ramp design includes drainage so that after construction, groundwater would be able to freely move past the barrier, water levels would equilibrate and the natural flow reinstated. The rail tunnel would be similarly mitigated.

These aspects are covered in detail in Technical Paper Number9, where the impacts and effectiveness of mitigation were tested by groundwater modelling. In this paper a monitoring program is also proposed where water levels and water quality is monitored during and after construction. The bores used for the construction phase would be used to establish a monitoring program operating during the operational phase of the highway. Monitoring would aim to ensure that the drainage system is working effectively and identify maintenance that may be necessary, for example due to blockage in the drainage system.

Water quality monitoring would be used to determine whether in-line dosing to adjust groundwater pH would be necessary. This would be based on pre-construction monitoring to establish natural trends so that the groundwater quality is maintained within natural bounds rather than adhering to a less applicable guideline. Details are provided in Technical Paper Number 9.

**Groundwater Discharge**

Groundwater would be pumped for dewatering of the tunnel excavations. This water, provided no oxygen is allowed to enter the pumping system, would be pumped back into the ground below the water table. This method avoids oxidation and the generation of acid.

Water seeping from the floor of the excavation into specially prepared drains, would be exposed to the atmosphere. This could result in a possible change in acidity making it necessary for this water to be pumped to a detention basin for testing and treatment, if necessary, before being returned as groundwater.

Wick drains would discharge water to drainage channels at the toe of the embankment from where it would flow to longitudinal drains. Some of the water is likely to be acidic and would require treatment to return it to pH within the natural range. Toe drains would need to contain finely crushed limestone to neutralise possible acidic effluent. Weirs should be placed so that water would be detained for a sufficient period to ensure neutralisation.

**Concrete Attack**

The impacts of concrete attack can be minimised using procedures outlined in relevant Australian Standards, NSW Road and Traffic Authority and the Queensland Department of Main Roads (Main Roads) guidelines, and Cement and Concrete Association Technical Notes. Examples of possible control measures include the use of sacrificial concrete, specialised concrete/cement admixtures, protective coatings and limestone facing. The appropriate control measure to be used would be determined during detailed design.

## 5.3 Monitoring Program

### 5.3.1 Soil Disturbance

**Excavation**

Where excavated and treated acid sulphate soils are used as fill, in embankments, median strips or acoustic mounds, water collected in surface drains in these areas should be collected in catch ponds, treated as a leachate and tested as indicated below.

Leachate collected from either the treatment or containment areas should be tested for pH, total dissolved solids, Cl:$SO_4$ ratio, iron and aluminium before discharge. Any discharged leachate must comply with ANZECC water quality assessment and the Airports (Environment Protection) Regulations 1997 criteria prior to release. Catch pond sediments should be assessed in the same way as treated soils.

Soils treated in bunded areas should be verified for adequate treatment in accordance with ASSMAC (Stone *et al.* 1998) and Queensland Department of Natural Resources and Mines (Ahern *et al.* 2000) management guidelines. Soils with POCAS testing results greater than 5.5 can be removed from the treatment areas and placed in a bunded containment stockpile(s) prior to suitable approved reuse.

The frequency of monitoring of leachate from areas where acid sulphate soils are used as fill is to be determined as part of detailed design and incorporated into the project environmental management plan. The sampling frequency would be sufficient to identify trends and would include the monitoring of run-off following significant rainfall events greater than 25 mm.

#### Ground Heave

To confirm that ground heave is negligible, shallow groundwater should be collected from piezometers installed on either side of the embankment. Groundwater levels should be monitored and samples tested as part of the overall groundwater monitoring strategy discussed in Section 5.3.2.

### 5.3.2 Water Quality

#### Groundwater Drawdown and Groundwater Flow

Groundwater drawdown would only occur during road and rail tunnel construction. The excavation methods selected include mitigation to maintain drawdown at a minimum (within the immediate area of excavation) and over a limited distance (phased construction approach). This has been tested by modelling as detailed in Technical Paper Number 9. The results show that mitigation prevents extended or prolonged drawdown during all phases of construction. Thus large volumes of dewatered aquifer would not result. An extended period of such dried conditions would be necessary for acid generation. The temporary, small-scale dewatering required during construction is unlikely to generate acidic groundwater.

A program would be implemented to monitor water quality during the construction period. This would involve establishing a baseline trend over one year of monitoring (prior to construction) to show the natural variations that can be expected in the system. If the monitored values show a trend that deviates from the baseline, the injected water would be treated, before injection, by in-line dosing.

Pre-construction monitoring intervals would be monthly with continuous pH monitoring during construction using automated devices that record pH at 12 hourly intervals. These devices trigger an alarm if pH goes outside the recommended range. Weekly monitoring would be undertaken for other parameters, followed by monthly intervals for a period of at least 12 months following construction (including a wet season). Increased frequency of monitoring may be required where site events dictate. Monthly monitoring for a period of 12 months following construction is anticipated where trends from weekly monitoring indicate there is no significant deviation from baseline conditions. A network of piezometers located outside the areas expected to be affected, would also be installed to assess regional groundwater flows and provide a comparison with groundwater monitoring adjacent to embankments and excavations during and after construction.

Critical parameters include groundwater levels, pH, electrical conductivity, aluminium, iron, chloride and sulphate concentration. Data would be graphed against time to allow a visual check to be undertaken to identify any deviation. Deviation from baseline trends would initiate mitigation measures as discussed in Technical Paper Number 9.

Existing drains may have lowered groundwater levels in some parts of the development with resultant acid sulphate soils activation having taken place or presently active. This would be tested as part of the baseline monitoring. Typically, representative samples of drain water would be tested for pH, electrical conductivity, total dissolved solids, $Cl:SO_4$ ratio, iron and aluminium.

Groundwater levels would be monitored weekly during construction (daily during tunnel construction) to ensure that the mitigation approach is working and general groundwater drawdown does not result. During the operational phase, groundwater levels would be monitored for a minimum of 12 months in bores adjacent to the tunnel to ensure that cross-tunnel drainage is operating efficiently. This would involve evaluating groundwater levels against pre-construction conditions and against antecedent trends.

**Groundwater Discharge**

The condition of on-site and off-site water discharge needs to be regularly checked. An automatic recording device which records pH, electrical conductivity, time, date and discharge volumes would be employed and be maintained for ongoing operational monitoring.

In areas of wick drain installation, groundwater discharged from drainage channels at the toe of the embankment to longitudinal drains would be collected and tested for pH, total dissolved solids, $Cl/SO_4$ ratio, iron and aluminium before discharge.

**Concrete Attack**

Concrete structures would be periodically inspected during Main Roads and NSW Roads and Traffic Authority asset management inspections. Groundwater, pH and sulphate levels would be monitored as part of the main program.

## 5.4 Contingency Procedures

Should adverse results be identified by the monitoring, the following procedures would be applicable.

### 5.4.1 Soil Disturbance

**Excavation**

If excavated soil pH levels are outside recommended levels, the soils must be retreated with agricultural lime or possibly pH reducing agents with amounts based on the test results. Leachate collected in the bunded areas would also be tested if a deviation from the baseline pH or other monitoring criteria (as established by pre-construction monitoring) is noted. Treatment with lime or a pH reducing agent may be necessary.

**Ground Heave**

Ground heave is also dependent on pore water pressure within the soil. Should pore pressures rise in excess of a geotechnically predetermined level, placement of fill would be halted and pressures allowed to dissipate prior to recommencement of embankment construction.

### Groundwater Quality

In-line dosing to treat groundwater would be used if monitoring identifies evidence of pH fluctuations outside the natural range.

### Groundwater Drawdown

Drawdown would be mitigated by reinjection of extracted groundwater and monitoring of groundwater levels used to ensure that it does not propagate beyond the immediate construction area where drawdown is necessary.

The mitigation approach can be managed for example, by increasing rates of reinjection or by using additional reinjection wells. Propagation of drawdown would result in the adjustment of the reinjection management.

### Groundwater Flow

Groundwater flow would be impeded during construction, although extraction and reinjection would re-establish flows, and the flow path would be different, via bores, pumps and pipes. Water level monitoring would ensure that this approach is operating effectively.

Groundwater flow would be re-established after construction via drains through the tunnel and approach ramps, these would respond to natural groundwater level fluctuations and groundwater flow would not be impeded. Groundwater level monitoring would be used to monitor the effectiveness of the drains. Deviation of groundwater levels or changes in response to rainfall events would indicate changed hydraulic properties. The drains have been designed with access so that if their hydraulic efficiency changes with time, maintenance can be carried out and the pipes cleared.

### Groundwater Discharge

If the pH of the water flow over weirs in the embankment toe drain and detention ponds changes by 0.2 pH units from background trends, water in the drains and ponds would be treated with lime of a pH reducing agent to achieve the required target range.

### Concrete Attack

If monitoring indicates that more stringent control measures are required, the concrete structures should be inspected by a structural engineer to determine if design modifications are necessary.

## 5.5 Reporting

Monthly monitoring reports would be prepared by the site supervisor during construction. Reports would include all monitoring results, any non-conformance to the management plan and all corrective actions taken to maintain performance requirements. Reports would be sent to Main Roads and Gold Coast Airport Limited monthly or immediately after a monitoring event which failed to meet the criteria in the management plan. All records would be maintained on site for review/audit on request.

A report proforma would be developed to make this process easy and consistent.

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# Appendix A

## Excerpts relating to Sampling from: *Guidelines for Sampling and Analysis of Lowland Acid Sulphate Soils in Queensland*

# 4. MAPPING AND SAMPLING

## 4.1 Mapping

A detailed map of acid sulfate soil occurrence/absence and an assessment of sulfide/pyrite content by depth is an essential prerequisite for deciding whether a proposed development/disturbance is feasible from an environmental, engineering and economic perspective. The proposal may have to be abandoned, modified, or planned excavations re-routed, if acid sulfate soils with substantial sulfide content are encountered.

Initial assessment of the likelihood of ASS occurring can be made using aerial photography, maps and information on geomorphology, soils, geology, height above sea level, land use, hydrology and any soil or water tests previously done in or around the area, (Smith and Ahern, 1996; Naylor *et al.,* 1995). Generally, projects that disturb soils located above 10m AHD, and 5m AHD for shallow disturbance, should be relatively safe and require only some confirmatory exploration and sampling. Common exceptions to this generalisation include activities that involve deep disturbance such as quarrying activities, mining and construction of deep on farm dams above 10 m AHD (Anderson *et al.*, 1996).

Soil sample intensity is somewhat dependent on the nature, depth and size of the disturbance proposed and the sensitivity of the surrounding environment. Most ASS investigations will require sufficient sampling to create three-dimensional maps and cross sectional diagrams of oxidisable S % content by depth for presentation in the ASS report.

## 4.2 Sampling Intensity

**The number of profiles or boreholes required for the (ASS) component of most Qld Environmental Impact Statements is:**

Table 1 Minimum number of sampling holes

| *Area of site* | *Number of boreholes* |
|---|---|
| Up to 1 ha | 4 holes |
| 1-2 ha | 6 holes |
| 2-3 ha | 8 holes |
| 3-4 ha | 10 holes |
| > 4 ha | 2 holes/ha |

More detailed transect sampling (50m intervals) will usually be required along proposed excavations e.g. canals, lakes, drainage channels and borrow pits.

Additional samples may need to be taken in areas of more intensive disturbance or in potential 'hot spots'. In these areas, sampling may be required on a 50-75 metre grid. This sampling intensity is not expected on areas of the site where the likelihood of acid sulfate soils occurring is low e.g. located above 5 m AHD or soils on hard rock. However, justification for reduced sampling intensity and some confirmatory sampling and laboratory analysis will still be required for these areas.

Sampling of material to be **dredged** from coastal rivers, lakes, dams and wetlands should be undertaken according to the transect spacing described above. Samples should be collected to at least one metre below the maximum depth of expected material extraction, ensuring that samples from all sedimentary layers are included. Careful attention must be paid when collecting underwater sediment samples to ensure that all sediment particle sizes are collected (a vibro-suction corer is usually suitable). The fine silt and clay fraction of the dredged material may contain high concentrations of sulfide however this material can easily drain from the sample during collection. In some wet dredging operations, acid sulfate material (usually silt and clay) can separate from the bulk material (sand) during stockpiling. Assessment of such dredged material may require that the constituent fractions of the resource be separated and tested accordingly, as interpretation of soil analysis on the dredge material may be complicated due to the neutralising influences of shell or seawater in the sample. Conventional laboratory analysis must include the measurement of calcium, (optionally magnesium and sodium) in the POCAS test (Method code 21X) and/or the HCl extract of the TOS method (Method 20Bh). Acid Neutralising Capacity (ANC e.g. Method 19B1) may assist. Where considerable difference exists between the results of the acid trail and the sulfur trail, kinetic type tests involving leaching columns and incubation may be required.

Each borehole should be sampled and details recorded as follows:

(i) **The location of each borehole** using Australian Metric Grid or Latitude and Longitude (to 0.1 of a second) **and its existing surface height** (AHD) **must be accurately surveyed and recorded in the report.** This assists in identifying sulfide-bearing layers which comprises essential data in development of proposed earthworks and management plans. The expected accuracy (± x metres) of the GPS or survey equipment used must be also specified. Investigations involving only minor disturbance may derive sufficient location information and contour data from detailed orthophoto maps which are available for some areas.

(ii) Field descriptions of horizons using the nomenclature of the Australian Soil and Land Survey Field Handbook (McDonald *et al.,* 1990) for each site/borehole should be submitted in the report. Field texture, colour, mottles (particularly presence of straw yellow jarosite, hue of 2.5Y or yellower and chroma of 6 or more) and field pH are essential measurements. See Appendix for field pH tests that must be recorded by horizon or every 0.5m depth interval. **Field pH and peroxide pH must be recorded every 0.25 m depth.** Any presence of shell or carbonate material in the soil must be recorded, along with a measure or estimate of their abundance and size distribution. Suspected carbonate material can be tested in the field by a positive reaction/effervescence with 1M HCl.

(iii) Starting from the present soil surface, collection of soil samples should not exceed 0.5 m intervals down the profile, **to at least one metre (1 m) below the depth of the proposed disturbance or to at least two metres (2 m) below the land surface, whichever is greater** (i.e. at least four samples would be required when sampling a profile to a depth of 2 m). Where distinct horizons occur, then sampling should be confined to within that horizon but sampling intervals should not be greater than 0.5 m apart. Where alteration of the watertable height by drainage, pumping, etc. is envisaged then sampling to at least one (1) m below the depth of the final estimated water table height is required. (These sampling requirements are essentially the same as those required in the '*NSW ASS Manual 1998*'). **Ensure all depths/horizons are collected** (even when field assessments indicate the absence of ASS) **as re-drilling is expensive.** Ideally, soil samples should constitute at least 0.5kg each to allow sufficient sample for physical and chemical analysis. Their analysis may be requested as part of the EIS assessment, such as an audit process, or other unforeseen uses. Quantitative laboratory tests will need to be conducted on every 0.5m depth interval, unless strong justification is provided. Laboratory analysis confirming the absence of sulfides is often just as important as determining the actual sulfide content on a positive sample.

(iv) The depth below the surface of any watertable must be recorded and where encountered, a water sample collected for analyses. Depending on flow rates and tidal influences, this may require returning to the site some hours later. The water sample should be analysed for at least pH, Electrical Conductivity (EC), chloride, sulfate, aluminium, calcium and iron. Ideally, the container should be filled to the top to exclude air and chilled immediately. For those users with field equipment, EC and pH should be measured immediately. A separate sample, acidified with acid is required for iron analysis. The addition of acid prevents iron precipitation, which can occur due to oxidation of a disturbed sample. This sample cannot be used for further analysis due to contamination with acid..

Quantitative laboratory tests should be conducted on all soil samples. The texture action category, (coarse, medium, fine; see Table 1) needs to be clearly indicated to laboratories for all soil samples as this affects method selection, the detection limit required and general interpretation of the result. As sampling and laboratory analyses can be an expensive process, **a staged approach to sampling is suggested.** When selecting samples for comprehensive laboratory analysis in stage 1, a number of profiles should be analysed for each 0.5 m interval or horizon rather than selecting random samples from many profiles. The emphasis should be on those sites most likely to contain sulfides based on elevation, soil type and results of field tests. It must be stressed that proving an apparent non ASS profile is clear by laboratory analysis is extremely important as that soil will not require special management.

Subject to assessment of Stage 1 sampling and analytical results, the sampling intensity may be adjusted or reduced by mutual agreement with the relevant government authorities. However, the onus will be on the applicant, developer or consultant to provide information demonstrating that less sampling and laboratory analysis is justified and that if sampling is reduced the potential for environmental harm will not be increased.

In addition to preliminary mapping, some operations such as **dredging or sluicing** may require sampling at the output pipe every 500 $m^3$ of material for analytical determination to calculate lime requirements. Where performance of an operation is shown to be consistent then the sampling intensity may be reduced by mutual agreement.

### 4.3 Sampling Equipment

Various manual and mechanical sampling equipment may need to be employed. Choice of equipment will depend on soil texture, wetness and layers in the profile. Commonly used equipment are listed and commented on below:

***Manual***

- Jarret auger - usually restricted to the upper profile of dry and moist soil only and generally not be suitable for sands.
- Tapered gouge auger - suitable for soft muds, but not sands.
- Push tube with tapered tip - limited sample retention as suction is created on extraction and sample loss can be a problem (adding a sealable cap before extraction improves retention). It is generally not suitable for saturated sands.

- Dormer sand auger - acceptable for many soils but saturated sands may fall out and the walls of the borehole may collapse.
- Piston sampler - good for saturated sands but limited to the length of the piston as walls collapse as it is withdrawn. Using a suitable size poly pipe for casing can increase the depth of excavation on saturated sands but care is needed to limit contamination or sample mixing.

***Mechanical***

- Hydraulic push tube - hard to remove sample from tube on sticky soils, wet sands fall out (adding a sealable cap before extraction improves retention).
- Spiral auger- mixes sample, **generally unsatisfactory.**
- Hollow flight screw auger incorporating an internal 'split tube' sampler - uses a hollow screw auger with an internal sampler that can be withdrawn regularly. The internal sampler is fitted with a 'split tube' and takes suitable good cores but can have trouble with compression on muds and loss of sample on sands below the watertable. A "catcher" often improves retention on sands. Some well equipped drilling rigs can also use within the hollow auger a Standard Penetration Test (SPT) sampler or thin walled 50 mm diameter tube designated U50 (undisturbed, 50mm diameter) for sampling. 'Gemco' is one of the brands available commercially.
- Backhoe, excavator - excellent until the watertable is reached, sampling taken at measured intervals down the face. Once below the watertable, wall collapse is a substantial problem for effective sampling and personal safety. Good for sites with lots of shell as it allows a larger sample to be collected without shattering the shell, a common problem with most other sampling techniques. **Work place safety issues** need to be addressed when digging pits. If entering a pit for sampling one needs to consider the possibility of poisonous hydrogen sulfide gas overcoming the person. A rope and harness should be used and one member must always remain outside the pit to pull the other person up should such an occasion arise. Do not enter a pit to assist a gas affected person without proper breathing apparatus.
- Wash bore drilling combined with a driven Standard Penetration Test (SPT) split tube sampling - a bentonite and polymer solution which is continually pumped under pressure usually holds the borehole walls intact for deep drilling on saturated sands. Contamination of sample can be a problem even when the upper part of the core is rejected.
- Core sampling employing a suction and vibrating technique – is recommended and ideal on wet sands, muds and soft soils, giving accurate depths and intact cores. Compressed air is used to remove the sample from the tube. If the upper profile is hard and dry, a hydraulic push tube or auguring device may be required until soft moist material lower in the profile is encountered. (Contact QASSIT for further information. Their machine samples intact cores to 5m. The length of the tube limits sampling depth and the height of the mast needed to pull the tube out).

**Sands** below the watertable are difficult to sample, while those sites encountering gravel layers are the most challenging. At present sampling using an excavator is recommended for gravels. The further the sampling is below the watertable the more difficult it is likely to be. Gravel and sand fractions immersed in a 'pyritic soup' have been found to contain pyrite framboids in their fine pores and fractures or as mud coatings (Saffigna *et al.*, 1996). Such materials are difficult to sample representatively.

Washing down and cleaning of sampling equipment is an absolute must to avoid sample contamination. A high pressure washing system is essential for mechanical drilling equipment.

Trace amounts of sulfidic material from previous sampling may contaminate a sample with no sulfide present, resulting in a positive test. This can lead to unnecessary and costly earthworks and liming procedures being required on soils with no acid producing potential. Therefore an ASS consultant or a trained ASS technician must be present and supervise all drilling and sampling.

Details of the drilling/sampling equipment used, together with the drilling operator's name and contact phone numbers must be provided in the report.

## 5. ADVICE AND INSPECTION

An acceptable stage one sampling plan should be negotiated with the **local** referral agencies' officers from DNR, DEH, DPI (Fisheries), DLGP and Local Government relevant to the application. A site inspection, together with observations and field tests on some borehole samples, will usually be a necessary part of developing a staged sampling plan. It is advisable to consult all relevant authorities before drilling and sampling commences.

On proposals where ASS may be a complex or significant issue, Local and State Government referral agencies often seek/require the technical input/assessment of the Queensland Acid Sulfate Soils Investigation Team (QASSIT) at DNR's Resources Sciences Centre, Indooroopilly. Such involvement will usually require site inspections during the drilling/sampling phase. The developer/consultant should plan on a charge based on cost recovery of QASSIT's time, equipment, travel, etc. Forward planning and bookings are essential for pre-sampling discussions, site inspections, and follow up discussions/advice.

Early consultation, agreement on numbers of sample sites, depths and laboratory analyses, and follow up discussions on formulating an acceptable Environmental Management Program (EMP) based on laboratory results, should ensure smooth transition to a technically sound EMP and Environment Impact Statement (EIS). The staged approach allows a lower cost, preliminary assessment of potential ASS difficulties and an estimate of further sampling and development costs. This assists the developer to decide whether it is economically and environmentally responsible to continue with the proposal, amend it, or abandon it before costs 'blow-out'.

### 5.1 Tendering

When calling tenders for ASS investigations, developers/contractors should request quotes based on **the number of sites/cores drilled, a sample every 0.5 m interval and detailed laboratory analyses.** Without a sample based approach, the cheapest quote often involves insufficient number of sites, samples and analysis, resulting in costly delays or rejection by government authorities. Only experienced and appropriately qualified ASS consultants such as a Certified Professional Soil Scientist (CPSS) should be employed.

It can also be cost efficient to **stage** the approach on large projects. When the results of the initial sampling are known and presented at an informal meeting, all parties can decide on the most efficient and cost effective sampling measures (if any) that are required to complete the ASS investigation and or ASS management plan. Authorities may ultimately insist on full sampling and analyses as per these guidelines. The onus is on the proponent to justify that sufficient sampling has been undertaken to understand and manage the site without causing environmental harm. Many proposals contain site specific issues that are cannot possibly be covered within the general guidelines. Consultation will help eliminate rejection on the grounds of a technically inadequate EIS and EMP.

Specialised sampling equipment capable of taking uncontaminated core samples from the specified depths is a vital component of any ASS investigation. ***Inappropriate equipment/sampling procedure will render the laboratory results unrepresentative and hence invalidate the ASS component of the report.***

## 6. SOIL SAMPLE CARE/PREPARATION

In the field, all **visible shell** should be removed from soil samples. It is essential that shell material be removed in the field at the time of sampling otherwise it must be sieved out (2 mm sieve) prior to sample grinding. This is usually difficult on clayey samples as they often set hard on drying making removal of shell without breakage/shattering extremely difficult. Broken or ground shell creates fresh exposure, increases the actual reactive surface area, overestimates the true neutralising capacity and hence falsely reduces the TPA result. Most drilling techniques shatter some shell and this should be considered when selecting appropriate sampling methods for a site. Additionally, shells found in ASS commonly have a coating of relatively insoluble gypsum, silica or iron compounds, rendering much of their carbonate content ineffective for neutralisation. If large quantities of coarse shell occur at a site and it is intended to use shell materials to reduce potential liming rates, then extra tests may be useful. Extra tests may include incubation of a portion of undried sample including any shells for a number of months to provide some measure of oxidation and neutralisation rates, or determining (with separate large bulk samples) the percentage of shell present in the soil and the neutralising capacity of the uncrushed shell.

**Waterproof labels**, capable of withstanding oven drying at 85 $^0$C, are essential due to the high moisture content of most samples. These can be pre-printed with appropriate name and job description on waterproof paper using a laser printer, then labelled in the field with site and depth using a **waterproof marking pen.** Samples and the correct label should be placed without delay into **sealable polyethylene bags** (with air excluded). Sample bags must also be externally labelled and all depths from the one hole/profile placed in a larger bag to improve efficiency and limit possible mistakes on receipt at the laboratory.

Immediately place the entire profile into a **portable freezer** (or **esky containing dry ice**) to quickly cool the samples and minimise sulfide oxidation (when dry ice or a freezer is not available ordinary ice or freezer blocks are the next best but are less efficient, and some minor oxidation may occur). Samples must be kept cold and transported in an insulated container to a laboratory for immediate oven drying within 24 hours of sampling. If this is not possible then they must be frozen until ready for insulated transport to the laboratory for pre-analysis drying. The laboratory should be notified prior to receipt of soil samples. This will reduce the risk of samples sitting in loading bays for extended periods of time (potentially oxidising).

Separate field samples may be required to determine bulk density to convert gravimetric results to a volumetric basis for field management plans (eg. rates of lime per $m^3$). A sample of known volume can be sampled using equipment such as a cut off syringe. Volumetric samples are sometimes used for 'field laboratory' measurements of TPA using a time shortened version of Dent and Bowman (1996a, 1996b). Such an approach may be useful for quick site management decisions once earth moving operations are under way, but results should be calibrated by regular dispatch of a subsample to a laboratory for complete analysis. Oven dried samples and full laboratory analyses will be required for preparing the ASS report and site mapping.

At the time of sampling, **soil colour, soil texture, field pH** (pH$_{F}$ ; method 21Af, see Appendix) and **field pH after oxidation with 30 % peroxide** (pH$_{FOX}$; method 21Bf) should be determined within regular 0.5 m depth intervals or soil horizons in the profile and at least on all depths sampled for further laboratory analyses. Field pH and peroxide pH should be done at every 0.25m. These field tests together with the strength of the peroxide reaction, can indicate those depths where sulfides occur. This may assist in allocating like samples to particular batches in the laboratory, optimising procedures and improving the accuracy and detection limits. The field pH can be measured on saturated soil using a combination **spear point pH probe and field pH meter.** If pH$_{KCl}$ is substantially lower than pH$_{F}$ then some oxidation of the sample during transport or drying may have occurred. Typically, pH reductions of 0.2 to 1 unit have been recorded on oven drying, without any measurable oxidation of sulfides. Oxidation of black iron monosulfides (FeS) and other unstable sulfide and iron compounds commence on disturbance and specialised sampling equipment is required to prevent oxidation. Fortunately, such compounds rarely occur in significant amounts. The use of volumetric sampling and analytical methods may be more suitable when highly unstable compounds are abundant. A method for Acid Volatile Sulfur (AVS) is contained in *Laboratory Methods Guidelines* (Ahern *et al.*, 1998a).

### 6.1 Storing/Retaining Samples for Audit Purposes

All soil samples collected in the field for ASS investigations should be well marked and ~~retained for possible future call or audit purposes. Storage in an oven dried state as described~~ in the next section is the safest and preferred approach, although most laboratories will charge a fee for drying and storage. Where not all samples are sent to the laboratory, particularly when conducting a stage one approach, a less desirable method of storage is freezing. All samples or a subsample of approximately 50 g must be retained until the end of the project unless they become an unreasonable impost then approval to discard should be negotiated with the regulatory authority. Stored samples could be important in defence of legal action. Special arrangement may need to be made with the laboratory to retain at least 50 g of sample, as most commercial laboratories would discard samples about a month after results are reported.

## 7. LABORATORY ANALYSES AND ACTION CRITERIA

On arrival at the laboratory, soil samples must be either immediately oven dried or kept frozen until ready to oven dry. Refrigeration will not prevent oxidation as jarosite can be seen forming in refrigerated samples stored for some weeks.

Wet muddy/clayey cores should be placed on **waterproof non-metallic dishes** (high density microwave cookware is usually suitable) and cut into smaller pieces as soon as partial thawing allows. Quick oven drying in a **forced air draft, high capacity oven at 80-85 °C** (to prevent oxidation of pyrite) for at least 48 hours is required (Ahern *et. al,* 1996a). Bulkier clay samples may require several days longer to ensure complete drying. If an estimate of field moisture is required, retain a representative portion of the soil, place in a suitable non-metallic moisture container, and weigh and determine moisture content as per method 2B1 (Rayment and Higginson, 1992).

Many large frozen samples may overload the rapid drying capacity of the oven and some minor oxidation of sulfide and substantial reduction in pH may occur (Hicks and Bowman, 1996).

Laboratories should examine the **drying capacity** of their ovens and either apply appropriate sample loadings or purchase a quick drying fan forced oven.

After drying, any coarse material not previously removed (especially **shell and gravel**) should be extracted or removed by preliminary sieving (2 mm). When required, the weight of the residual coarse material (>2 mm) may be measured and calculated as a percentage of the total sample weight. Samples which do not easily break up after oven drying (such as some heavy clays), should be rolled/crushed/ground to pass through a 2 mm sieve. It is recognised that grinding equipment is laboratory specific but it is recommended that samples for ASS analyses be fine-ground (<0.5 mm or finer), to ensure greater homogeneity. This means a smaller sample weight and less volume of reagents can be used during analysis, reducing costs. The sample should be stored in a cool dry place in an air-tight plastic or inert container for subsequent laboratory use.

### 7.1 Samples Containing 'Monosulfides'

Some common locations of material containing significant monosulfides are bottom sediments of quiet coastal lakes and streams and weed infested drains where a fresh source of organic material causes the active formation of sulfides, particularly characterised by a 'smelly black ooze'.

Samples suspected of containing **metastable sulfides** ('monosulfides') should be frozen immediately after they are sampled in the field with the use of dry ice then **freeze-dried** in the laboratory. Bush and Sullivan (1997) showed that greigite ($FeS_{1.34}$ or $Fe_3S_4$) readily oxidises within hours at room temperature and oxidises in minutes on drying at 88°C. Special precautions to prevent oxidation at sampling and drying are costly and laborious and generally used on research samples rather than routine samples. Provided monosulfide content is low then any oxidation on drying should be detectable by a significant lowering (>1 unit) of laboratory pH compared to field pH. The change would not be easily detectable using the sulfur trail but the acid trail should show a high Total Actual Acidity (TAA) result. Dioxane replacement of moisture (Crockford and Willett, 1995) may be useful where no freeze drying facilities are available. Greigite is relatively stable once dried (Bush and Sullivan, 1997). See also Bush and Sullivan (1998) Acid Volatile Sulfur Method in *NSW ASS Manual* (Stone *et al.*, 1998).

### 7.2 Safety

As dried ASS may contain dusty, strongly acidic substances such as jarosite, workers involved in grinding such soils should use eye protection and carry out the operation in a dust extraction cabinet or wear a suitable dust mask.

### 7.3 Approved Laboratory Methods

A set of standard methods have been under development for routine laboratory use on soil samples (ASSMAC, 1996; Ahern *et al.* 1996b). These earlier versions were updated at a national methods workshop in October 1996. After some minor amendments and trials by Government, University and private laboratories two methods were approved at a combined meeting in Sydney on 29 August 1997, for standard use in all future ASS environment impact assessments to be submitted to NSW and Qld Government authorities. They have now been published in Ahern *et al.* (1998a) in the *NSW ASS Manual.* An outline of the approved laboratory methods is provided in the Appendix of this document.

# Appendix B

## Acid Sulphate Soils Field Test Results

# Appendix B: Acid Sulphate Soils Field Test Results

| Characteristics | | | | | | |
|---|---|---|---|---|---|---|
| ***Location of bore Site*** | **TP1** | **TP1** | **TP1** | **TP1** | **TP1** | **TP1** |
| ***Map Class*** | | | | | | |
| ***Landscape Characteristics*** | | | | | | |
| ***Depth*** | 0.0-0.1 | 0.4-0.5 | 0.9-1.0 | 1.4-1.5 | 1.9-2.0 | 2.9-3.0 |
| ***Description of Material*** | Sandy SILT; dark brown | SAND; grey | SAND; grey-brown | SAND; grey-brown | SAND; dark brwon cemented | SAND; dark brown |
| ***Field Indicators*** | | | | | | |
| ***pH - Field*** | 6.11 | 6.29 | 6.48 | 5.82 | 6.11 | 6.36 |
| ***Actual Acid Sulfate Soil*** | **No** | **No** | **No** | **No** | **No** | **No** |
| ***Peroxide Reaction*** | None | None | Medium | Mild | Mild | None |
| ***pH after Peroxide*** | 4.33 | 3.99 | 1.46 | 4.15 | 4.28 | 5.1 |
| ***Potential Acid Sulfate Soil*** | **No** | **No** | **Yes** | **No** | **No** | **No** |
| ***CL:SO4 ratio*** | - | - | - | - | - | - |
| ***Pyrite Crystals*** | | | | | | |
| ***Soil analysis S%*** | | | | | | |
| ***Initial Assessment of Soils*** | | | | | | |
| ***Chemical Testing Required?*** | **No** | **No** | **Yes** | **No** | **No** | **No** |

| Characteristics | | | | |
|---|---|---|---|---|
| ***Location of bore Site*** | **TP2** | **TP2** | **TP2** | **TP2** |
| ***Map Class*** | | | | |
| ***Landscape Characteristics*** | | | | |
| ***Depth*** | 0.4-0.5 | 1.5-1.6 | 2.0-2.1 | 2.5-2.6 |
| ***Description of Material*** | SAND; pale grey | SAND; grey-brown | SAND; dark-brown, cemented | SAND; dark brown |
| ***Field Indicators*** | | | | |
| ***pH - Field*** | 6.52 | 6.96 | 7.22 | 6.9 |
| ***Actual Acid Sulfate Soil*** | **No** | **No** | **No** | **No** |
| ***Peroxide Reaction*** | Mild | Mild | Medium | Mild |
| ***pH after Peroxide*** | 2.71 | 2.57 | 1.86 | 2.54 |
| ***Potential Acid Sulfate Soil*** | **Yes** | **Yes** | **Yes** | **Yes** |
| ***CL:SO4 ratio*** | - | - | - | - |
| ***Pyrite Crystals*** | | | | |
| ***Soil analysis S%*** | | | | |
| ***Initial Assessment of Soils*** | | | | |
| ***Chemical Testing Required?*** | **Yes** | **Yes** | **Yes** | **Yes** |

| Characteristics | | | | | | |
|---|---|---|---|---|---|---|
| ***Location of bore Site*** | **TP3** | **TP3** | **TP3** | **TP3** | **TP3** | **TP3** |
| ***Map Class*** | | | | | | |
| ***Landscape Characteristics*** | | | | | | |
| ***Depth*** | 0.0-0.1 | 0.4-0.5 | 0.9-1.0 | 1.4-1.5 | 2.0-2.1 | 2.4-2.5 |
| ***Description of Material*** | SAND; brown | SAND; pale grey | SAND; pale grey | SAND; pale grey | SAND; dark grey | SAND; dark grey cemented |
| ***Field Indicators*** | | | | | | |
| ***pH - Field*** | 4.44 | 5.2 | 4.7 | 4.59 | 4.72 | 5.64 |
| ***Actual Acid Sulfate Soil*** | **Uncertain** | **Uncertain** | **Uncertain** | **Uncertain** | **Uncertain** | **No** |
| ***Peroxide Reaction*** | Mild | Mild | Mild | Mild | Mild | Mild |
| ***pH after Peroxide*** | 2.82 | 2.81 | 2.91 | 2.81 | 2.84 | 2.69 |
| ***Potential Acid Sulfate Soil*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| ***CL:SO4 ratio*** | - | - | - | - | - | - |
| ***Pyrite Crystals*** | | | | | | |
| ***Soil analysis S%*** | | | | | | |
| ***Initial Assessment of Soils*** | | | | | | |
| ***Chemical Testing Required?*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

| **Characteristics** | | | | | |
|---|---|---|---|---|---|
| ***Location of bore Site*** | **TP4** | **TP4** | **TP4** | **TP4** | **TP4** |
| ***Map Class*** | | | | | |
| ***Landscape Characteristics*** | | | | | |
| ***Depth*** | 0.4-0.5 | 0.9-1.0 | 1.4-1.5 | 1.9-2.0 | 2.4-2.5 |
| ***Description of Material*** | SAND; pale grey | SAND; pale grey | SAND; brown-green | SAND; brown-green | SAND; brown-green |
| ***Field Indicators*** | | | | | |
| ***pH - Field*** | 5.66 | 4.73 | 4.32 | 4.24 | 4.4 |
| ***Actual Acid Sulfate Soil*** | **No** | **Uncertain** | **Uncertain** | **Uncertain** | **Uncertain** |
| ***Peroxide Reaction*** | Mild | Mild | Vigorous | Vigorous | Vigorous |
| ***pH after Peroxide*** | 2.65 | 2.8 | 1.5 | 1.11 | 1.37 |
| ***Potential Acid Sulfate Soil*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| ***CL:SO4 ratio*** | - | - | - | - | - |
| ***Pyrite Crystals*** | | | | | |
| ***Soil analysis S%*** | | | | | |
| ***Initial Assessment of Soils Chemical Testing Required?*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

| **Characteristics** | | | | | | |
|---|---|---|---|---|---|---|
| ***Location of bore Site*** | **TP5** | **TP5** | **TP5** | **TP5** | **TP5** | **TP5** |
| ***Map Class*** | | | | | | |
| ***Landscape Characteristics*** | | | | | | |
| ***Depth*** | 0.0-0.1 | 0.4-0.5 | 0.9-1.0 | 1.4-1.5 | 1.9-2.0 | 2.9-3.0 |
| ***Description of Material*** | Silty SAND; dark grey-brown | SAND; pale grey | SAND; green-grey | SAND; green-grey | SAND; dark brown, cemented | SAND; dark brown, cemented |
| ***Field Indicators*** | | | | | | |
| ***pH - Field*** | 5.23 | 6.14 | 6.15 | 5.94 | 5.78 | 5.78 |
| ***Actual Acid Sulfate Soil*** | **Uncertain** | **No** | **No** | **No** | **No** | **No** |
| ***Peroxide Reaction*** | Medium | Vigorous | Vigorous; heat, smoke | Vigorous | Vigorous | Vigorous |
| ***pH after Peroxide*** | 2.91 | 1.47 | 1.38 | 0.12 | 0.95 | 0.8 |
| ***Potential Acid Sulfate Soil*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| ***CL:SO4 ratio*** | - | - | - | - | - | - |
| ***Pyrite Crystals*** | | | | | | |
| ***Soil analysis S%*** | | | | | | |
| ***Initial Assessment of Soils Chemical Testing Required?*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

| **Characteristics** | | | | | | |
|---|---|---|---|---|---|---|
| ***Location of bore Site*** | **TP6** | **TP6** | **TP6** | **TP6** | **TP6** | **TP6** |
| ***Map Class*** | | | | | | |
| ***Landscape Characteristics*** | | | | | | |
| ***Depth*** | 0.0-0.1 | 0.4-0.5 | 0.9-1.0 | 1.4-1.5 | 1.9-2.0 | 2.9-3.0 |
| ***Description of Material*** | SILT; dark brown | SAND; pale brown | SAND; grey-green | SAND; grey-green | SAND; dark brown, cemented | SAND; dark brown |
| ***Field Indicators*** | | | | | | |
| ***pH - Field*** | 5.7 | 5.81 | 4.4 | 6.36 | 3.3 | 6.12 |
| ***Actual Acid Sulfate Soil*** | **No** | **No** | **Uncertain** | **No** | **Yes** | **No** |
| ***Peroxide Reaction*** | None | Medium | Medium | None | Medium | None |
| ***pH after Peroxide*** | 4.12 | 2.62 | 2.6 | 4.88 | 2.02 | 4.95 |
| ***Potential Acid Sulfate Soil*** | **No** | **Yes** | **Yes** | **No** | **Yes** | **No** |
| ***CL:SO4 ratio*** | - | - | - | - | - | - |
| ***Pyrite Crystals*** | | | | | | |
| ***Soil analysis S%*** | | | | | | |
| ***Initial Assessment of Soils Chemical Testing Required?*** | **No** | **Yes** | **Yes** | **No** | **Yes** | **No** |

# Appendix B: Acid Sulphate Soils Field Test Results

| **Characteristics** | | | | | | |
|---|---|---|---|---|---|---|
| ***Location of bore Site*** | **TP7** | **TP7** | **TP7** | **TP7** | **TP7** | **TP7** |
| ***Map Class*** | | | | | | |
| ***Landscape Characteristics*** | | | | | | |
| ***Depth*** | 0.0-0.1 | 0.4-0.5 | 0.9-1.0 | 1.4-1.5 | 1.9-2.0 | 2.9-3.0 |
| ***Description of Material*** | Silty SAND; dark brown-grey | SAND; pale grey | SAND; pale grey | SAND; green-brown | SAND; green-brown | SAND; green-brown |
| ***Field Indicators*** | | | | | | |
| ***pH - Field*** | 6 | 6.42 | 6.58 | 5.8 | 6.7 | 5.78 |
| ***Actual Acid Sulfate Soil*** | **No** | **No** | **No** | **No** | **No** | **No** |
| ***Peroxide Reaction*** | Medium | Medium | Vigorous | Vigorous | Vigorous | Vigorous |
| ***pH after Peroxide*** | 2.16 | 2.27 | 1.93 | 0.08 | 0.21 | 0.11 |
| ***Potential Acid Sulfate Soil*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| ***CL:SO4 ratio*** | - | - | - | - | - | - |
| ***Pyrite Crystals*** | | | | | | |
| ***Soil analysis S%*** | | | | | | |
| ***Initial Assessment of Soils*** | | | | | | |
| ***Chemical Testing Required?*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

| **Characteristics** | | | | | |
|---|---|---|---|---|---|
| ***Location of bore Site*** | **BH1a** | **BH1a** | **BH1a** | **BH1a** | **BH1a** |
| ***Map Class*** | | | | | |
| ***Landscape Characteristics*** | | | | | |
| ***Depth*** | 1.0-1.45 | 1.5-1.95 | 2.0-2.45 | 2.5-2.95 | 4.0-4.45 |
| ***Description of Material*** | Clayey SILT; dark brown | Sandy CLAY; brown | Clayey SAND; grey-brown | Sandy CLAY; grey-brown | Sandy CLAY; pale grey |
| ***Field Indicators*** | | | | | |
| ***pH - Field*** | 5.97 | 5.61 | 5.55 | 5.55 | 5.08 |
| ***Actual Acid Sulfate Soil*** | **No** | **No** | **No** | **No** | **Uncertain** |
| ***Peroxide Reaction*** | Mild | Medium | Medium | Medium | Mild |
| ***pH after Peroxide*** | 2.8 | 2.1 | 2.07 | 2.53 | 2.9 |
| ***Potential Acid Sulfate Soil*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| ***CL:SO4 ratio*** | - | - | - | - | - |
| ***Pyrite Crystals*** | | | | | |
| ***Soil analysis S%*** | | | | | |
| ***Initial Assessment of Soils*** | | | | | |
| ***Chemical Testing Required?*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

| **Characteristics** | | | | | |
|---|---|---|---|---|---|
| ***Location of bore Site*** | **BH6** | **BH6** | **BH6** | **BH6** | **BH6** |
| ***Map Class*** | | | | | |
| ***Landscape Characteristics*** | | | | | |
| ***Depth*** | 0.0-0.1 | 0.5-0.95 | 1.0-1.45 | 1.5-1.95 | 3.0-3.45 |
| ***Description of Material*** | SAND; dark grey-brown | SAND; pale grey | SAND; pale grey | SAND; pale grey | SAND; brown-grey |
| ***Field Indicators*** | | | | | |
| ***pH - Field*** | 6.24 | 6.25 | 6 | 5.76 | 5.05 |
| ***Actual Acid Sulfate Soil*** | **No** | **No** | **No** | **No** | **Uncertain** |
| ***Peroxide Reaction*** | None | None | Mild | None | Mild |
| ***pH after Peroxide*** | 3.83 | 3.77 | 2.9 | 3.38 | 2.42 |
| ***Potential Acid Sulfate Soil*** | **No** | **No** | **Yes** | **No** | **Yes** |
| ***CL:SO4 ratio*** | - | - | - | - | - |
| ***Pyrite Crystals*** | | | | | |
| ***Soil analysis S%*** | | | | | |
| ***Initial Assessment of Soils*** | | | | | |
| ***Chemical Testing Required?*** | **No** | **No** | **Yes** | **No** | **Yes** |

| **Characteristics** | | | | | |
|---|---|---|---|---|---|
| ***Location of bore Site*** | **BH7** | **BH7** | **BH7** | **BH7** | **BH7** |
| ***Map Class*** | | | | | |
| ***Landscape Characteristics*** | | | | | |
| ***Depth*** | 0.0-0.1 | 0.5-0.95 | 1.0-1.45 | 1.5-2.0 | 2.5-2.95 |
| ***Description of Material*** | Silty SAND; dark brown-grey | SAND; pale grey | SAND; pale grey | SAND; pale grey | SAND; dark brown, cemented |
| ***Field Indicators*** | | | | | |
| ***pH - Field*** | 4.6 | 5.9 | 5.5 | 5.25 | 5.24 |
| ***Actual Acid Sulfate Soil*** | **Uncertain** | **No** | **Uncertain** | **Uncertain** | **Uncertain** |
| ***Peroxide Reaction*** | Medium | Medium | Medium | Medium | Medium |
| ***pH after Peroxide*** | 1.6 | 1.59 | 1.6 | 1.45 | 1.59 |
| ***Potential Acid Sulfate Soil*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| ***CL:SO4 ratio*** | - | - | - | - | - |
| ***Pyrite Crystals*** | | | | | |
| ***Soil analysis S%*** | | | | | |
| ***Initial Assessment of Soils*** | | | | | |
| ***Chemical Testing Required?*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

| **Characteristics** | | | | | |
|---|---|---|---|---|---|
| ***Location of bore Site*** | **BH8** | **BH8** | **BH8** | **BH8** | **BH8** |
| ***Map Class*** | | | | | |
| ***Landscape Characteristics*** | | | | | |
| ***Depth*** | 0.0-0.1 | 0.5-0.95 | 1.0-1.45 | 1.5-1.95 | 2.5-2.95 |
| ***Description of Material*** | Silty SAND; dark brown | SAND; pale grey | SAND; pale grey | SAND; pale grey | SAND; dark brown, cemented |
| ***Field Indicators*** | | | | | |
| ***pH - Field*** | 4.5 | 5.2 | 5.2 | 5.1 | 5.2 |
| ***Actual Acid Sulfate Soil*** | **Uncertain** | **Uncertain** | **Uncertain** | **Uncertain** | **Uncertain** |
| ***Peroxide Reaction*** | Vigorous | Vigorous | Vigorous | Vigorous | Vigorous |
| ***pH after Peroxide*** | 0.9 | 1.2 | 1.3 | 1.2 | 1.3 |
| ***Potential Acid Sulfate Soil*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| ***CL:SO4 ratio*** | - | - | - | - | |
| ***Pyrite Crystals*** | | | | | |
| ***Soil analysis S%*** | | | | | |
| ***Initial Assessment of Soils*** | | | | | |
| ***Chemical Testing Required?*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

| **Characteristics** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Location of bore Site*** | **BH9** | **BH9** | **BH9** | **BH9** | **BH9** | **BH9** | **BH9** | **BH9** | **BH9** | **BH9** |
| ***Map Class*** | | | | | | | | | | |
| ***Landscape Characteristics*** | | | | | | | | | | |
| ***Depth*** | 1.0-1.45 | 1.5-1.95 | 2.0-2.45 | 2.5-2.95 | 4.0-4.45 | 5.5-5.95 | 7.0-7.45 | 8.5-8.95 | 10.0-10.45 | 11.5-11.95 |
| ***Description of Material*** | SAND; brown | SAND; brown | SAND; pale grey-brown | SAND; orange-brown cemented | SAND; grey-brown | SAND; grey-brown | SAND; orange-brown | SAND; orange-brown | Silty SAND; yellow | Silty SAND; yellow |
| ***Field Indicators*** | | | | | | | | | | |
| ***pH - Field*** | 6.35 | 6.3 | 6.1 | 5.78 | 6.26 | 5.9 | 5.85 | 6.4 | 6.42 | 6.42 |
| ***Actual Acid Sulfate Soil*** | **No** | **No** | **No** | **No** | **No** | **No** | **No** | **No** | **No** | **No** |
| ***Peroxide Reaction*** | Medium | Vigorous | Vigorous | Vigorous | Vigorous | Medium | Medium | Medium | Medium | Medium |
| ***pH after Peroxide*** | 2.01 | 0.94 | 1.13 | 1.71 | 1.27 | 2.29 | 2.22 | 2.27 | 2.35 | 1.34 |
| ***Potential Acid Sulfate Soil*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| ***CL:SO4 ratio*** | - | - | - | - | - | | | | | |
| ***Pyrite Crystals*** | | | | | | | | | | |
| ***Soil analysis S%*** | | | | | | | | | | |
| ***Initial Assessment of Soils*** | | | | | | | | | | |
| ***Chemical Testing Required?*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

# Appendix B: Acid Sulphate Soils Field Test Results

| Characteristics | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Location of bore Site* | BH10 | BH10 | BH10 | BH10 | BH10 | BH10 | BH10 | BH10 | BH10 | BH10 | BH10 |
| *Map Class* | | | | | | | | | | | |
| *Landscape Characteristics* | | | | | | | | | | | |
| *Depth* | 0.5-0.95 | 1.0-1.45 | 1.5-1.95 | 2.0-2.45 | 2.5-2.95 | 4.0-4.45 | 5.5-5.95 | 7.0-7.45 | 8.5-8.95 | 10.0-10.45 | 11.5-11.95 |
| *Description of Material* | Clayey SILT; dark brown-black | SAND; pale grey | SAND; pale grey | SAND; pale grey | SAND; pale grey | SAND; pale grey | SAND; dark brown-orange | SAND; dark brown-orange | SAND; dark brown-orange | SAND; dar brown-orange | SAND; dark brown, cemented |
| *Field Indicators* | | | | | | | | | | | |
| *pH - Field* | 4.75 | 5.2 | 5.4 | 5.4 | 6.35 | 6.2 | 6 | 5.85 | 8.85 | 6.3 | 5.7 |
| *Actual Acid Sulfate Soil* | Uncertain | Uncertain | Uncertain | Uncertain | No | No | No | No | No | No | No |
| *Peroxide Reaction* | Medium | Medium | Vigorous | Vigorous | Vigorous | Vigorous | Vigourous | Medium | Medium | None | None |
| *pH after Peroxide* | 2.4 | 2.15 | 1.25 | 1.1 | 1.3 | 1.25 | 1.75 | 3.1 | 2 | 3.65 | 3.55 |
| *Potential Acid Sulfate Soil* | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No | Yes | No | No |
| *CL:SO4 ratio* | - | - | - | - | - | - | - | - | - | - | - |
| *Pyrite Crystals* | | | | | | | | | | | |
| *Soil analysis S%* | | | | | | | | | | | |
| *Initial Assessment of Soils* | | | | | | | | | | | |
| *Chemical Testing Required?* | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No | Yes | No | No |

| Characteristics | | | | | |
|---|---|---|---|---|---|
| *Location of bore Site* | BH11 | BH11 | BH11 | BH11 | BH11 |
| *Map Class* | | | | | |
| *Landscape Characteristics* | | | | | |
| *Depth* | 0.0-0.1 | 0.5-0.95 | 1.0-1.45 | 1.5-1.95 | 2.5-2.95 |
| *Description of Material* | SAND; dark brown | SAND; grey-green | SAND; dark brown, cemented | SAND; dark brown, cemented | SAND; dark brown |
| *Field Indicators* | | | | | |
| *pH - Field* | 6.7 | 7.37 | 7.36 | 7.19 | 6.84 |
| *Actual Acid Sulfate Soil* | No | No | No | No | No |
| *Peroxide Reaction* | Mild | Mild | Medium | Mild | Vigorous |
| *pH after Peroxide* | 3.05 | 3.54 | 1.89 | 3.49 | 0.89 |
| *Potential Acid Sulfate Soil* | No | No | Yes | No | Yes |
| *CL:SO4 ratio* | - | - | - | - | - |
| *Pyrite Crystals* | | | | | |
| *Soil analysis S%* | | | | | |
| *Initial Assessment of Soils* | | | | | |
| *Chemical Testing Required?* | No | No | Yes | No | Yes |

| Characteristics | | | | | |
|---|---|---|---|---|---|
| *Location of bore Site* | BHA | BHA | BHA | BHA | BHA |
| *Map Class* | | | | | |
| *Landscape Characteristics* | | | | | |
| *Depth* | 0.0-0.1 | 0.5-0.95 | 1.0-1.45 | 1.5-1.95 | 2.5-2.95 |
| *Description of Material* | Silty SAND; dark brown | SAND; pale grey | SAND; pale grey | SAND; pale grey | SAND; pale grey |
| *Field Indicators* | | | | | |
| *pH - Field* | 5.1 | 4.1 | 6.1 | 5.8 | 5.4 |
| *Actual Acid Sulfate Soil* | Uncertain | Uncertain | No | No | Uncertain |
| *Peroxide Reaction* | Medium | Medium | Medium | Medium | Medium |
| *pH after Peroxide* | 1.75 | 1.4 | 1.4 | 1.4 | 1.5 |
| *Potential Acid Sulfate Soil* | Yes | Yes | Yes | Yes | Yes |
| *CL:SO4 ratio* | - | - | - | - | - |
| *Pyrite Crystals* | | | | | |
| *Soil analysis S%* | | | | | |
| *Initial Assessment of Soils* | | | | | |
| *Chemical Testing Required?* | Yes | Yes | Yes | Yes | Yes |

| **Characteristics** | | | | | |
|---|---|---|---|---|---|
| ***Location of bore Site*** | **BHB** | **BHB** | **BHB** | **BHB** | **BHB** |
| ***Map Class*** | | | | | |
| ***Landscape Characteristics*** | | | | | |
| ***Depth*** | 0.0-0.1 | 0.5-0.95 | 1.0-1.45 | 1.5-1.95 | 2.5-2.95 |
| ***Description of Material*** | SAND; pale grey | SAND; pale grey | SAND; pale grey | SAND; pale grey | SAND; pale grey |
| ***Field Indicators*** | | | | | |
| ***pH - Field*** | 6.34 | 6.3 | 5.77 | 6.9 | 5.64 |
| ***Actual Acid Sulfate Soil*** | **No** | **No** | **No** | **No** | **No** |
| ***Peroxide Reaction*** | Mild | Mild | Mild | Mild | Mild |
| ***pH after Peroxide*** | 2.5 | 2.58 | 2.65 | 2.75 | 2.75 |
| ***Potential Acid Sulfate Soil*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| ***CL:SO4 ratio*** | - | - | - | - | - |
| ***Pyrite Crystals*** | | | | | |
| ***Soil analysis S%*** | | | | | |
| ***Initial Assessment of Soils*** | | | | | |
| ***Chemical Testing Required?*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

| **Characteristics** | | | | | |
|---|---|---|---|---|---|
| ***Location of bore Site*** | **BHC** | **BHC** | **BHC** | **BHC** | **BHC** |
| ***Map Class*** | | | | | |
| ***Landscape Characteristics*** | | | | | |
| ***Depth*** | 0.0-0.1 | 0.5-0.95 | 1.0-1.45 | 1.5-1.95 | 2.5-2.95 |
| ***Description of Material*** | Silty SAND; dark brown | SAND; dark brown | SAND; dark brown | SAND; pale grey-brown | SAND; pale grey-brown |
| ***Field Indicators*** | | | | | |
| ***pH - Field*** | 3.7 | 3.8 | 3.4 | 5.1 | 4.4 |
| ***Actual Acid Sulfate Soil*** | **Yes** | **Yes** | **Yes** | **Uncertain** | **Uncertain** |
| ***Peroxide Reaction*** | Medium | Medium | Medium | Medium | Medium |
| ***pH after Peroxide*** | 1.8 | 1.7 | 1.7 | 1.99 | 2.15 |
| ***Potential Acid Sulfate Soil*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| ***CL:SO4 ratio*** | - | - | - | - | - |
| ***Pyrite Crystals*** | | | | | |
| ***Soil analysis S%*** | | | | | |
| ***Initial Assessment of Soils*** | | | | | |
| ***Chemical Testing Required?*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

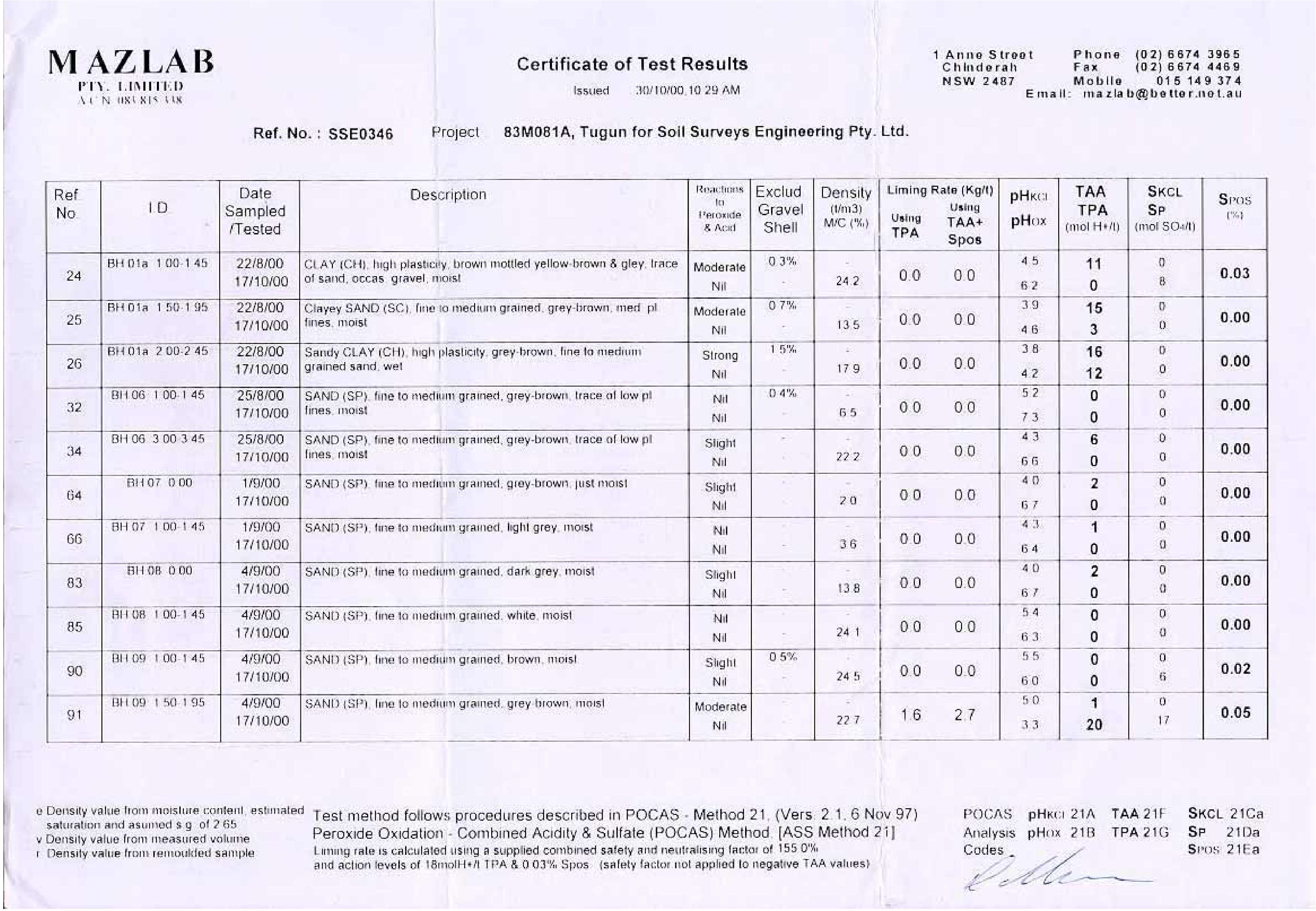
| **Characteristics** | | | | | |
|---|---|---|---|---|---|
| ***Location of bore Site*** | **BHD1** | **BHD1** | **BHD1** | **BHD1** | **BHD1** |
| ***Map Class*** | | | | | |
| ***Landscape Characteristics*** | | | | | |
| ***Depth*** | 0.0-0.1 | 0.5-0.95 | 1.0-1.45 | 1.5-1.95 | 2.5-2.95 |
| ***Description of Material*** | Silty SAND; dark brown | SAND; pale grey-brown | SAND; pale grey-brown | SAND; dark grey | SAND; dark brown-grey, cemented |
| ***Field Indicators*** | | | | | |
| ***pH - Field*** | 5.4 | 5.4 | 5.3 | 4.5 | 4.3 |
| ***Actual Acid Sulfate Soil*** | **Uncertain** | **Uncertain** | **Uncertain** | **Uncertain** | **Uncertain** |
| ***Peroxide Reaction*** | Mild | Mild | Mild | Mild | Mild |
| ***pH after Peroxide*** | 2.6 | 2.6 | 2.6 | 2.75 | 2.7 |
| ***Potential Acid Sulfate Soil*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| ***CL:SO4 ratio*** | - | - | - | - | - |
| ***Pyrite Crystals*** | | | | | |
| ***Soil analysis S%*** | | | | | |
| ***Initial Assessment of Soils*** | | | | | |
| ***Chemical Testing Required?*** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

# Appendix B: Acid Sulphate Soils Field Test Results

| **Characteristics** | | | | |
|---|---|---|---|---|
| ***Location of bore Site*** | **BHE1** | **BHE1** | **BHE1** | **BHE1** |
| ***Map Class*** | | | | |
| ***Landscape Characteristics*** | | | | |
| ***Depth*** | 0.5-0.95 | 1.0-1.45 | 1.5-1.95 | 2.0-2.45 |
| ***Description of Material*** | SAND; pale grey-brown | SAND; pale grey | SAND; pale grey | SAND; pale grey |
| ***Field Indicators*** | | | | |
| ***pH - Field*** | 6.4 | 6.4 | 6.45 | 6.45 |
| ***Actual Acid Sulfate Soil*** | **No** | **No** | **No** | **No** |
| ***Peroxide Reaction*** | None | Vigorous | Vigorous | Medium |
| ***pH after Peroxide*** | 4.1 | 0.9 | 0.9 | 1.2 |
| ***Potential Acid Sulfate Soil*** | **No** | **Yes** | **Yes** | **Yes** |
| ***CL:SO4 ratio*** | - | - | - | - |
| ***Pyrite Crystals*** | | | | |
| ***Soil analysis S%*** | | | | |
| ***Initial Assessment of Soils*** | | | | |
| ***Chemical Testing Required?*** | **No** | **Yes** | **Yes** | **Yes** |

# Appendix C

## Acid Sulphate Soil Laboratory Test Results



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**Ref. No. : SSE0346** Project **83M081A, Tugun for Soil Surveys Engineering Pty. Ltd.**

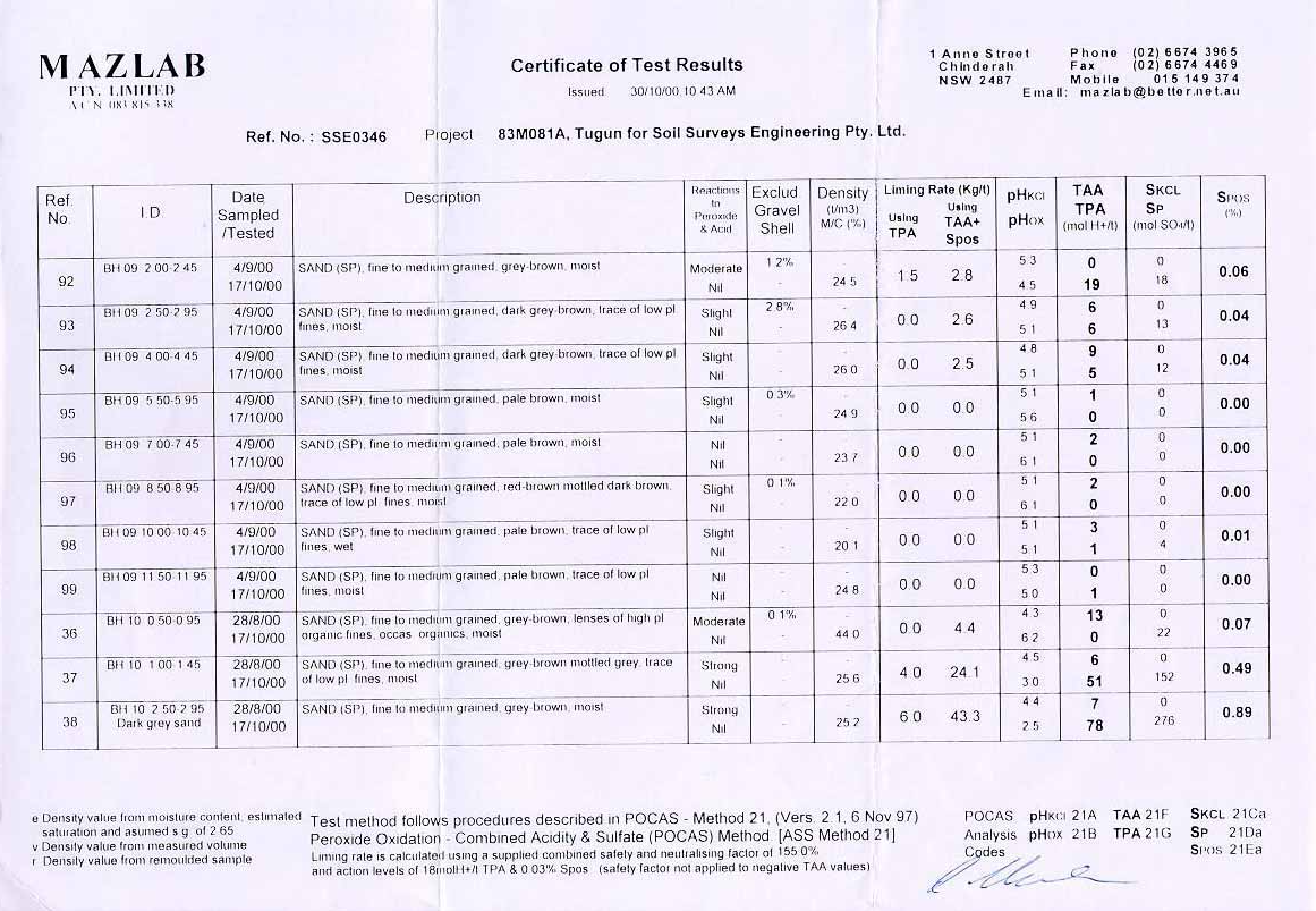
| Ref No | I.D | Date Sampled /Tested | Description | Reactions to Peroxide & Acid | Exclud Gravel Shell | Density (t/m3) M/C (%) | Liming Rate (Kg/t) Using TPA | Liming Rate (Kg/t) Using TAA+ Spos | pHKCl<br>pHox | TAA<br>TPA (mol H+/t) | SKCL<br>SP (mol SO4/t) | SPOS (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | BH 01a 1.00-1.45 | 22/8/00<br>17/10/00 | CLAY (CH), high plasticity, brown mottled yellow-brown & gley, trace of sand, occas. gravel, moist | Moderate<br>Nil | 0.3%<br>- | -<br>24.2 | 0.0 | 0.0 | 4.5<br>6.2 | 11<br>0 | 0<br>8 | 0.03 |
| 25 | BH 01a 1.50-1.95 | 22/8/00<br>17/10/00 | Clayey SAND (SC), fine to medium grained, grey-brown, med. pl fines, moist | Moderate<br>Nil | 0.7%<br>- | -<br>13.5 | 0.0 | 0.0 | 3.9<br>4.6 | 15<br>3 | 0<br>0 | 0.00 |
| 26 | BH 01a 2.00-2.45 | 22/8/00<br>17/10/00 | Sandy CLAY (CH), high plasticity, grey-brown, fine to medium grained sand, wet | Strong<br>Nil | 1.5%<br>- | -<br>17.9 | 0.0 | 0.0 | 3.8<br>4.2 | 16<br>12 | 0<br>0 | 0.00 |
| 32 | BH 06 1.00-1.45 | 25/8/00<br>17/10/00 | SAND (SP), fine to medium grained, grey-brown, trace of low pl fines, moist | Nil<br>Nil | 0.4%<br>- | -<br>6.5 | 0.0 | 0.0 | 5.2<br>7.3 | 0<br>0 | 0<br>0 | 0.00 |
| 34 | BH 06 3.00-3.45 | 25/8/00<br>17/10/00 | SAND (SP), fine to medium grained, grey-brown, trace of low pl fines, moist | Slight<br>Nil | -<br>- | -<br>22.2 | 0.0 | 0.0 | 4.3<br>6.6 | 6<br>0 | 0<br>0 | 0.00 |
| 64 | BH 07 0.00 | 1/9/00<br>17/10/00 | SAND (SP), fine to medium grained, grey-brown, just moist | Slight<br>Nil | -<br>- | -<br>2.0 | 0.0 | 0.0 | 4.0<br>6.7 | 2<br>0 | 0<br>0 | 0.00 |
| 66 | BH 07 1.00-1.45 | 1/9/00<br>17/10/00 | SAND (SP), fine to medium grained, light grey, moist | Nil<br>Nil | -<br>- | -<br>3.6 | 0.0 | 0.0 | 4.3<br>6.4 | 1<br>0 | 0<br>0 | 0.00 |
| 83 | BH 08 0.00 | 4/9/00<br>17/10/00 | SAND (SP), fine to medium grained, dark grey, moist | Slight<br>Nil | -<br>- | -<br>13.8 | 0.0 | 0.0 | 4.0<br>6.7 | 2<br>0 | 0<br>0 | 0.00 |
| 85 | BH 08 1.00-1.45 | 4/9/00<br>17/10/00 | SAND (SP), fine to medium grained, white, moist | Nil<br>Nil | -<br>- | -<br>24.1 | 0.0 | 0.0 | 5.4<br>6.3 | 0<br>0 | 0<br>0 | 0.00 |
| 90 | BH 09 1.00-1.45 | 4/9/00<br>17/10/00 | SAND (SP), fine to medium grained, brown, moist | Slight<br>Nil | 0.5%<br>- | -<br>24.5 | 0.0 | 0.0 | 5.5<br>6.0 | 0<br>0 | 0<br>6 | 0.02 |
| 91 | BH 09 1.50-1.95 | 4/9/00<br>17/10/00 | SAND (SP), fine to medium grained, grey-brown, moist | Moderate<br>Nil | -<br>- | -<br>22.7 | 1.6 | 2.7 | 5.0<br>3.3 | 1<br>20 | 0<br>17 | 0.05 |

e Density value from moisture content, estimated saturation and asumed s.g. of 2.65
v Density value from measured volume
r Density value from remoulded sample

Test method follows procedures described in POCAS - Method 21, (Vers. 2.1, 6 Nov 97)
Peroxide Oxidation - Combined Acidity & Sulfate (POCAS) Method. [ASS Method 21]
Liming rate is calculated using a supplied combined safety and neutralising factor of 155.0%
and action levels of 18molH+/t TPA & 0.03% Spos (safety factor not applied to negative TAA values)

POCAS Analysis Codes

| pHKCl 21A | TAA 21F | SKCL 21Ca |
|---|---|---|
| pHox 21B | TPA 21G | SP 21Da |
| | | SPOS 21Ea |



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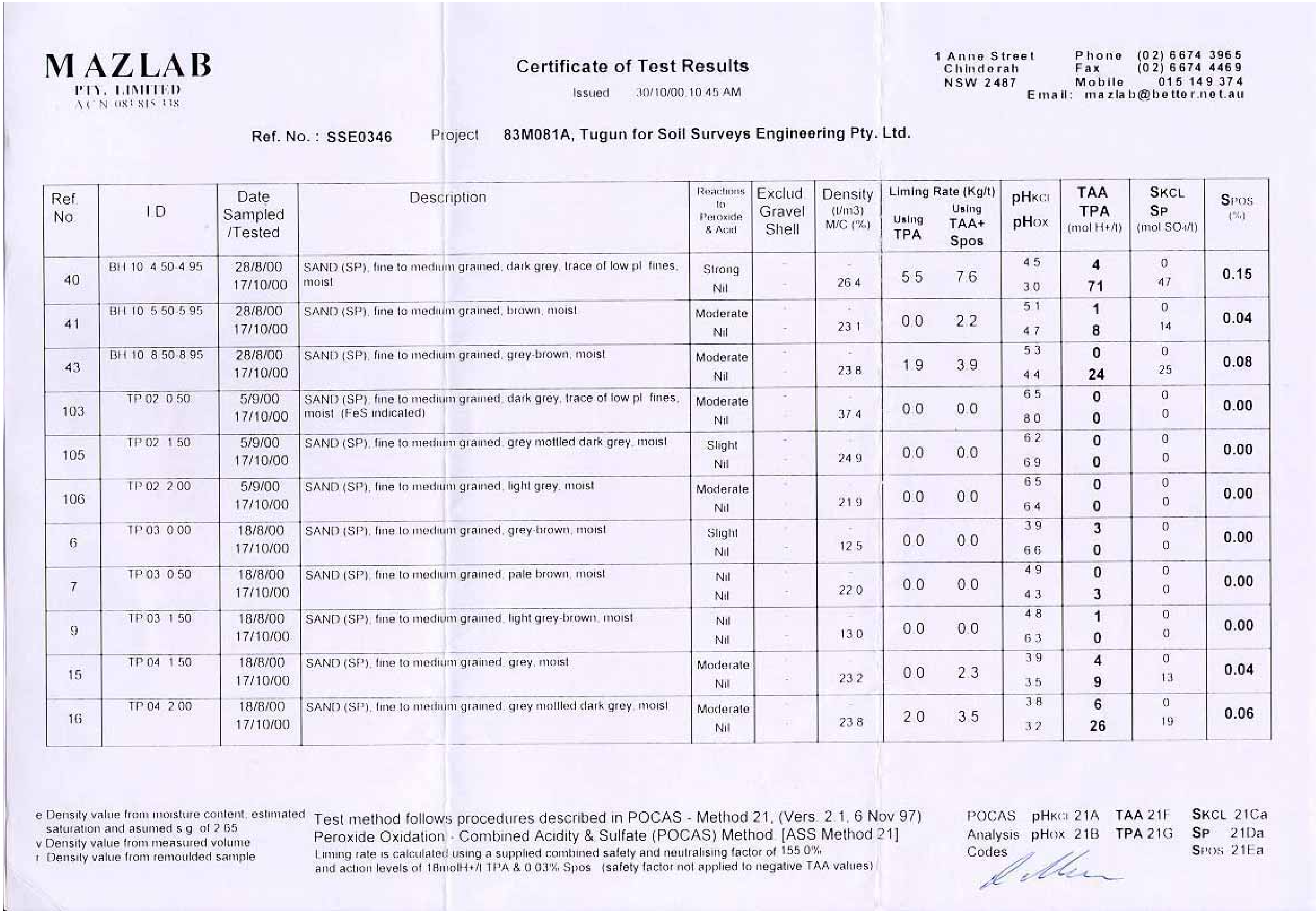
**Ref. No. : SSE0346** Project **83M081A, Tugun for Soil Surveys Engineering Pty. Ltd.**

| Ref. No. | I.D. | Date Sampled /Tested | Description | Reactions to Peroxide & Acid | Exclud Gravel Shell | Density (t/m3) M/C (%) | Liming Rate (Kg/t) Using TPA | Liming Rate (Kg/t) Using TAA+ Spos | pHKCl<br>pHox | TAA<br>TPA (mol H+/t) | SKCL<br>SP (mol SO4/t) | SPOS (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 92 | BH 09 2.00-2.45 | 4/9/00<br>17/10/00 | SAND (SP), fine to medium grained, grey-brown, moist | Moderate<br>Nil | 1.2%<br>- | -<br>24.5 | 1.5 | 2.8 | 5.3<br>4.5 | **0**<br>**19** | 0<br>18 | **0.06** |
| 93 | BH 09 2.50-2.95 | 4/9/00<br>17/10/00 | SAND (SP), fine to medium grained, dark grey-brown, trace of low pl fines, moist | Slight<br>Nil | 2.8%<br>- | -<br>26.4 | 0.0 | 2.6 | 4.9<br>5.1 | **6**<br>**6** | 0<br>13 | **0.04** |
| 94 | BH 09 4.00-4.45 | 4/9/00<br>17/10/00 | SAND (SP), fine to medium grained, dark grey-brown, trace of low pl fines, moist | Slight<br>Nil | -<br>- | -<br>26.0 | 0.0 | 2.5 | 4.8<br>5.1 | **9**<br>**5** | 0<br>12 | **0.04** |
| 95 | BH 09 5.50-5.95 | 4/9/00<br>17/10/00 | SAND (SP), fine to medium grained, pale brown, moist | Slight<br>Nil | 0.3%<br>- | -<br>24.9 | 0.0 | 0.0 | 5.1<br>5.6 | **1**<br>**0** | 0<br>0 | **0.00** |
| 96 | BH 09 7.00-7.45 | 4/9/00<br>17/10/00 | SAND (SP), fine to medium grained, pale brown, moist | Nil<br>Nil | -<br>- | -<br>23.7 | 0.0 | 0.0 | 5.1<br>6.1 | **2**<br>**0** | 0<br>0 | **0.00** |
| 97 | BH 09 8.50-8.95 | 4/9/00<br>17/10/00 | SAND (SP), fine to medium grained, red-brown mottled dark brown, trace of low pl. fines, moist | Slight<br>Nil | 0.1%<br>- | -<br>22.0 | 0.0 | 0.0 | 5.1<br>6.1 | **2**<br>**0** | 0<br>0 | **0.00** |
| 98 | BH 09 10.00-10.45 | 4/9/00<br>17/10/00 | SAND (SP), fine to medium grained, pale brown, trace of low pl fines, wet | Slight<br>Nil | -<br>- | -<br>20.1 | 0.0 | 0.0 | 5.1<br>5.1 | **3**<br>**1** | 0<br>4 | **0.01** |
| 99 | BH 09 11.50-11.95 | 4/9/00<br>17/10/00 | SAND (SP), fine to medium grained, pale brown, trace of low pl fines, moist | Nil<br>Nil | -<br>- | -<br>24.8 | 0.0 | 0.0 | 5.3<br>5.0 | **0**<br>**1** | 0<br>0 | **0.00** |
| 36 | BH 10 0.50-0.95 | 28/8/00<br>17/10/00 | SAND (SP), fine to medium grained, grey-brown, lenses of high pl organic fines, occas. organics, moist | Moderate<br>Nil | 0.1%<br>- | -<br>44.0 | 0.0 | 4.4 | 4.3<br>6.2 | **13**<br>**0** | 0<br>22 | **0.07** |
| 37 | BH 10 1.00-1.45 | 28/8/00<br>17/10/00 | SAND (SP), fine to medium grained, grey-brown mottled grey, trace of low pl. fines, moist | Strong<br>Nil | -<br>- | -<br>25.6 | 4.0 | 24.1 | 4.5<br>3.0 | **6**<br>**51** | 0<br>152 | **0.49** |
| 38 | BH 10 2.50-2.95<br>Dark grey sand | 28/8/00<br>17/10/00 | SAND (SP), fine to medium grained, grey-brown, moist | Strong<br>Nil | -<br>- | -<br>25.2 | 6.0 | 43.3 | 4.4<br>2.5 | **7**<br>**78** | 0<br>276 | **0.89** |

e Density value from moisture content, estimated saturation and asumed s.g. of 2.65
v Density value from measured volume
r Density value from remoulded sample

Test method follows procedures described in POCAS - Method 21, (Vers. 2.1, 6 Nov 97)
Peroxide Oxidation - Combined Acidity & Sulfate (POCAS) Method. [ASS Method 21]
Liming rate is calculated using a supplied combined safety and neutralising factor of 155.0%
and action levels of 18mol H+/t TPA & 0.03% Spos (safety factor not applied to negative TAA values)

| POCAS Analysis Codes | | | |
|---|---|---|---|
| pHKCl 21A | TAA 21F | SKCL 21Ca | |
| pHox 21B | TPA 21G | SP 21Da | |
| | | SPOS 21Ea | |



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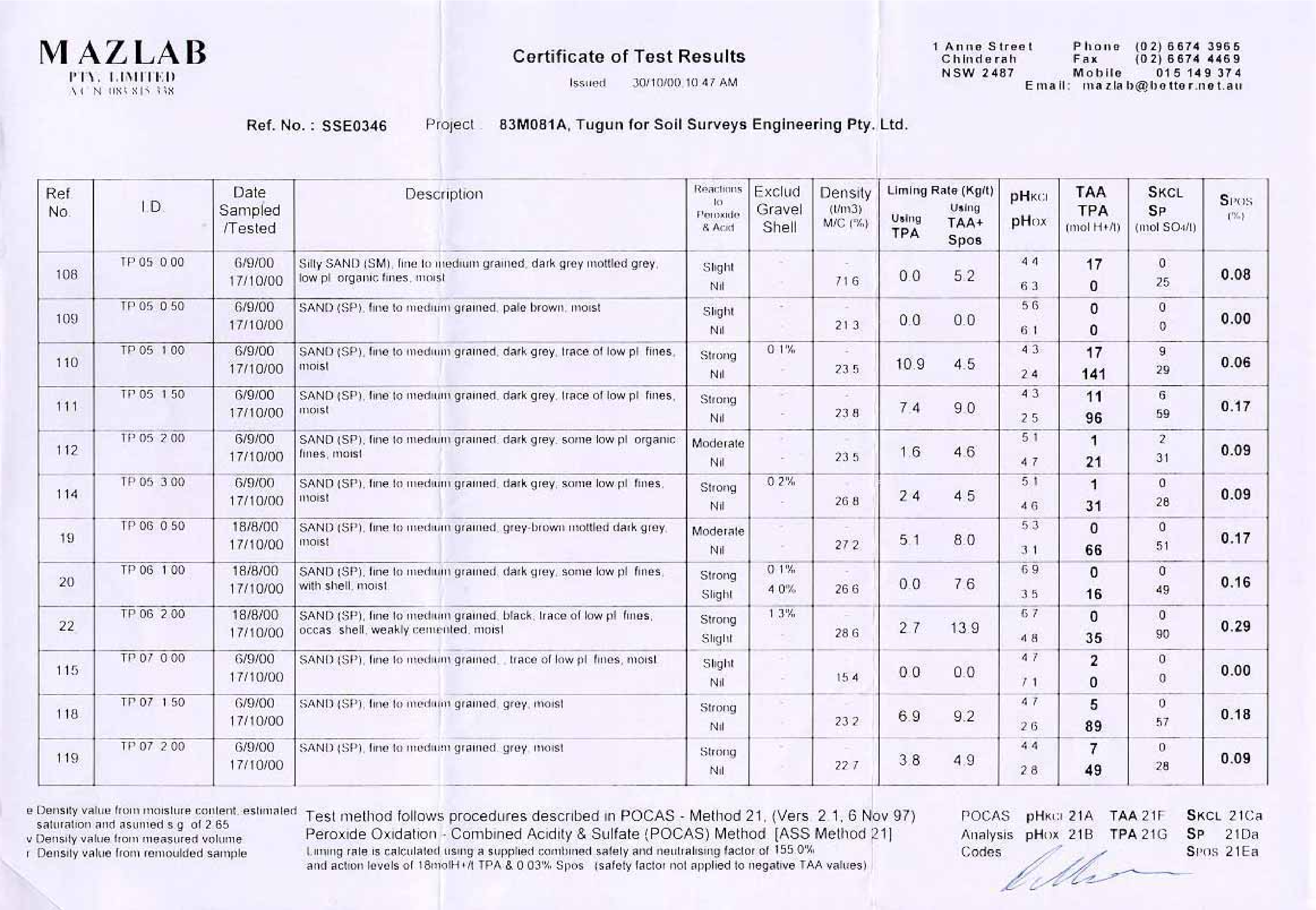
**Ref. No. : SSE0346** Project **83M081A, Tugun for Soil Surveys Engineering Pty. Ltd.**

| Ref. No | I D | Date Sampled /Tested | Description | Reactions to Peroxide & Acid | Exclud Gravel Shell | Density (t/m3) M/C (%) | Liming Rate (Kg/t) Using TPA | Liming Rate (Kg/t) Using TAA+ Spos | pHKCl<br>pHox | TAA<br>TPA (mol H+/t) | SKCL<br>SP (mol SO4/t) | SPOS (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40 | BH 10 4.50-4.95 | 28/8/00<br>17/10/00 | SAND (SP), fine to medium grained, dark grey, trace of low pl fines, moist | Strong<br>Nil | -<br>- | -<br>26.4 | 5.5 | 7.6 | 4.5<br>3.0 | **4**<br>**71** | 0<br>47 | **0.15** |
| 41 | BH 10 5.50-5.95 | 28/8/00<br>17/10/00 | SAND (SP), fine to medium grained, brown, moist | Moderate<br>Nil | -<br>- | -<br>23.1 | 0.0 | 2.2 | 5.1<br>4.7 | **1**<br>**8** | 0<br>14 | **0.04** |
| 43 | BH 10 8.50-8.95 | 28/8/00<br>17/10/00 | SAND (SP), fine to medium grained, grey-brown, moist | Moderate<br>Nil | -<br>- | -<br>23.8 | 1.9 | 3.9 | 5.3<br>4.4 | **0**<br>**24** | 0<br>25 | **0.08** |
| 103 | TP 02 0.50 | 5/9/00<br>17/10/00 | SAND (SP), fine to medium grained, dark grey, trace of low pl fines, moist (FeS indicated) | Moderate<br>Nil | -<br>- | -<br>37.4 | 0.0 | 0.0 | 6.5<br>8.0 | **0**<br>**0** | 0<br>0 | **0.00** |
| 105 | TP 02 1.50 | 5/9/00<br>17/10/00 | SAND (SP), fine to medium grained, grey mottled dark grey, moist | Slight<br>Nil | -<br>- | -<br>24.9 | 0.0 | 0.0 | 6.2<br>6.9 | **0**<br>**0** | 0<br>0 | **0.00** |
| 106 | TP 02 2.00 | 5/9/00<br>17/10/00 | SAND (SP), fine to medium grained, light grey, moist | Moderate<br>Nil | -<br>- | -<br>21.9 | 0.0 | 0.0 | 6.5<br>6.4 | **0**<br>**0** | 0<br>0 | **0.00** |
| 6 | TP 03 0.00 | 18/8/00<br>17/10/00 | SAND (SP), fine to medium grained, grey-brown, moist | Slight<br>Nil | -<br>- | -<br>12.5 | 0.0 | 0.0 | 3.9<br>6.6 | **3**<br>**0** | 0<br>0 | **0.00** |
| 7 | TP 03 0.50 | 18/8/00<br>17/10/00 | SAND (SP), fine to medium grained, pale brown, moist | Nil<br>Nil | -<br>- | -<br>22.0 | 0.0 | 0.0 | 4.9<br>4.3 | **0**<br>**3** | 0<br>0 | **0.00** |
| 9 | TP 03 1.50 | 18/8/00<br>17/10/00 | SAND (SP), fine to medium grained, light grey-brown, moist | Nil<br>Nil | -<br>- | -<br>13.0 | 0.0 | 0.0 | 4.8<br>6.3 | **1**<br>**0** | 0<br>0 | **0.00** |
| 15 | TP 04 1.50 | 18/8/00<br>17/10/00 | SAND (SP), fine to medium grained, grey, moist | Moderate<br>Nil | -<br>- | -<br>23.2 | 0.0 | 2.3 | 3.9<br>3.5 | **4**<br>**9** | 0<br>13 | **0.04** |
| 16 | TP 04 2.00 | 18/8/00<br>17/10/00 | SAND (SP), fine to medium grained, grey mottled dark grey, moist | Moderate<br>Nil | -<br>- | -<br>23.8 | 2.0 | 3.5 | 3.8<br>3.2 | **6**<br>**26** | 0<br>19 | **0.06** |

e Density value from moisture content, estimated saturation and asumed s.g. of 2.65
v Density value from measured volume
r Density value from remoulded sample

Test method follows procedures described in POCAS - Method 21, (Vers. 2.1, 6 Nov 97)
Peroxide Oxidation - Combined Acidity & Sulfate (POCAS) Method [ASS Method 21]
Liming rate is calculated using a supplied combined safety and neutralising factor of 155.0%
and action levels of 18molH+/t TPA & 0.03% Spos (safety factor not applied to negative TAA values)

| | | | |
|---|---|---|---|
| POCAS | pHKCl 21A | **TAA** 21F | SKCL 21Ca |
| Analysis | pHox 21B | **TPA** 21G | **SP** 21Da |
| Codes | | | SPOS 21Ea |



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**Ref. No. : SSE0346** Project : **83M081A, Tugun for Soil Surveys Engineering Pty. Ltd.**

| Ref. No. | I.D. | Date Sampled /Tested | Description | Reactions to Peroxide & Acid | Exclud Gravel Shell | Density (t/m3) M/C (%) | Liming Rate (Kg/t) Using TPA | Liming Rate (Kg/t) Using TAA+ Spos | pHKCl pHox | TAA TPA (mol H+/t) | SKCL SP (mol SO4/t) | SPOS (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 108 | TP 05 0.00 | 6/9/00<br>17/10/00 | Silty SAND (SM), fine to medium grained, dark grey mottled grey, low pl. organic fines, moist | Slight<br>Nil | -<br>- | -<br>71.6 | 0.0 | 5.2 | 4.4<br>6.3 | 17<br>0 | 0<br>25 | 0.08 |
| 109 | TP 05 0.50 | 6/9/00<br>17/10/00 | SAND (SP), fine to medium grained, pale brown, moist | Slight<br>Nil | -<br>- | -<br>21.3 | 0.0 | 0.0 | 5.6<br>6.1 | 0<br>0 | 0<br>0 | 0.00 |
| 110 | TP 05 1.00 | 6/9/00<br>17/10/00 | SAND (SP), fine to medium grained, dark grey, trace of low pl. fines, moist | Strong<br>Nil | 0.1%<br>- | -<br>23.5 | 10.9 | 4.5 | 4.3<br>2.4 | 17<br>141 | 9<br>29 | 0.06 |
| 111 | TP 05 1.50 | 6/9/00<br>17/10/00 | SAND (SP), fine to medium grained, dark grey, trace of low pl. fines, moist | Strong<br>Nil | -<br>- | -<br>23.8 | 7.4 | 9.0 | 4.3<br>2.5 | 11<br>96 | 6<br>59 | 0.17 |
| 112 | TP 05 2.00 | 6/9/00<br>17/10/00 | SAND (SP), fine to medium grained, dark grey, some low pl. organic fines, moist | Moderate<br>Nil | -<br>- | -<br>23.5 | 1.6 | 4.6 | 5.1<br>4.7 | 1<br>21 | 2<br>31 | 0.09 |
| 114 | TP 05 3.00 | 6/9/00<br>17/10/00 | SAND (SP), fine to medium grained, dark grey, some low pl. fines, moist | Strong<br>Nil | 0.2%<br>- | -<br>26.8 | 2.4 | 4.5 | 5.1<br>4.6 | 1<br>31 | 0<br>28 | 0.09 |
| 19 | TP 06 0.50 | 18/8/00<br>17/10/00 | SAND (SP), fine to medium grained, grey-brown mottled dark grey, moist | Moderate<br>Nil | -<br>- | -<br>27.2 | 5.1 | 8.0 | 5.3<br>3.1 | 0<br>66 | 0<br>51 | 0.17 |
| 20 | TP 06 1.00 | 18/8/00<br>17/10/00 | SAND (SP), fine to medium grained, dark grey, some low pl. fines, with shell, moist | Strong<br>Slight | 0.1%<br>4.0% | -<br>26.6 | 0.0 | 7.6 | 6.9<br>3.5 | 0<br>16 | 0<br>49 | 0.16 |
| 22 | TP 06 2.00 | 18/8/00<br>17/10/00 | SAND (SP), fine to medium grained, black, trace of low pl. fines, occas. shell, weakly cemented, moist | Strong<br>Slight | 1.3%<br>- | -<br>28.6 | 2.7 | 13.9 | 6.7<br>4.8 | 0<br>35 | 0<br>90 | 0.29 |
| 115 | TP 07 0.00 | 6/9/00<br>17/10/00 | SAND (SP), fine to medium grained, , trace of low pl. fines, moist | Slight<br>Nil | -<br>- | -<br>15.4 | 0.0 | 0.0 | 4.7<br>7.1 | 2<br>0 | 0<br>0 | 0.00 |
| 118 | TP 07 1.50 | 6/9/00<br>17/10/00 | SAND (SP), fine to medium grained, grey, moist | Strong<br>Nil | -<br>- | -<br>23.2 | 6.9 | 9.2 | 4.7<br>2.6 | 5<br>89 | 0<br>57 | 0.18 |
| 119 | TP 07 2.00 | 6/9/00<br>17/10/00 | SAND (SP), fine to medium grained, grey, moist | Strong<br>Nil | -<br>- | -<br>22.7 | 3.8 | 4.9 | 4.4<br>2.8 | 7<br>49 | 0<br>28 | 0.09 |

e Density value from moisture content, estimated saturation and asumed s.g. of 2.65
v Density value from measured volume
r Density value from remoulded sample

Test method follows procedures described in POCAS - Method 21, (Vers. 2.1, 6 Nov 97)
Peroxide Oxidation - Combined Acidity & Sulfate (POCAS) Method [ASS Method 21]
Liming rate is calculated using a supplied combined safety and neutralising factor of 155.0%
and action levels of 18molH+/t TPA & 0.03% Spos (safety factor not applied to negative TAA values)

| POCAS Analysis Codes | | | |
|---|---|---|---|
| pHKCl 21A | TAA 21F | SKCL 21Ca |
| pHox 21B | TPA 21G | SP 21Da |
| | | SPOS 21Ea |

# Appendix D

## Groundwater Analysis Results

# REPORT OF ANALYSIS

Page: 1 of 2
Report No. RN204156

| | | | |
|---|---|---|---|
| **Client** | : PPK Environment & Infrastructure QLD<br>348 EDWARD STREET<br>BRISBANE QLD 4000 | **Job No.** | : PPKE02/010122 |
| | | **Quote No.** | : QT-00699 |
| | | **Order No.** | : 6428 |
| | | **Date Sampled** | : 22-JAN-2001 |
| | | **Date Received** | : 22-JAN-2001 |
| **Attention** | : Gerard Ryan | **Sampled By** | : CLIENT |
| **Project Name** | : | | |
| **Your Client Services Manager** | : Andrew Bradbury | **Phone** | : 07 3214 2161 |

| Lab Reg No. | Sample Ref | Sample Description |
|---|---|---|
| Q01/000439 | NORTH | Water Tugun |
| Q01/000440 | SOUTH | Water Tugun |
| Q01/000441 | D2 | Water Tugun |
| Q01/000442 | E2 | Water Tugun |

| **Lab Reg No.** | | **Q01/000439** | **Q01/000440** | **Q01/000441** | **Q01/000442** | |
|---|---|---|---|---|---|---|
| **Sample Reference** | **Units** | **NORTH** | **SOUTH** | **D2** | **E2** | **Method** |
| **Trace Elements** | | | | | | |
| Aluminium filtered | mg/L | 0.56 | 0.2 | 0.25 | 0.18 | NT2_47 |
| Iron filtered | mg/L | 3.3 | 5.8 | 2.2 | 0.48 | NT2_47 |
| Manganese filtered | mg/L | 0.071 | 0.13 | 0.087 | 0.028 | NT2_47 |

Signed:

Dr. Honway Louie, Trace Elements - NSW

Date: 1-FEB-2001

| **Lab Reg No.** | | **Q01/000439** | **Q01/000440** | **Q01/000441** | **Q01/000442** | |
|---|---|---|---|---|---|---|
| **Sample Reference** | **Units** | **NORTH** | **SOUTH** | **D2** | **E2** | **Method** |
| **Miscellaneous** | | | | | | |
| Chloride | mg/L | 9.0 | 13 | 88 | 150 | NWB14 |
| Alkalinity-Total as CaCO3 | mg/L | 6.4 | 68 | 6.4 | 55.7 | NW_B1 |
| Conductivity @ 25 degrees C | mS/cm | 0.073 | 0.25 | 0.33 | 0.61 | NW_B9 |
| Sulphate | mg/L | 2.7 | 20 | 1.1 | 1.3 | NW_B14 |
| pH | pH_unit | 4.7 | 5.9 | 5.3 | 6.1 | NW_S11 |

Signed:

Dr Honway Louie, Inorganics - NSW

Date: 1-FEB-2001

# REPORT OF ANALYSIS

Sample(s) were analysed for trace elements after filtration through 0.45um filter.

This Laboratory is accredited by the National Association of Testing Authorities, Australia. [Accreditation No 198].
The tests reported herein have been performed in accordance with its terms of accreditation.

Sample/s analysed as received.
This Report supersedes reports: *RN203472* *RN203593* *RN204025*
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North = BH-C
South = BH-9