Preliminary assessment of the acid sulphate soils hazard in the Auckland region

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ABSTRACT

Acid Sulphate Soils have recently been encountered on projects in Whangarei and Auckland. These naturally occurring soils are rich in sulphide minerals that have the potential to cause changes in soil and water chemistry when they oxidise. This oxidation process occurs naturally but may be induced by human activities including excavations and groundwater drawdown. These changes include acid generation which can lead to significant harm to flora and fauna. Discharges of affected water have been linked to major fish kills and can also lead to sub-lethal effects, such as red spot disease in fish. It can cause the rapid decay of concrete and metal structures, resulting in significant maintenance costs and failure risks.

The presence of Acid Sulphate Soils is well documented overseas but is less well reported in New Zealand, and little research has been done into the extent and implications of these soils here. The lack of readily available information about the distribution of Acid Sulphate Soils makes it challenging for New Zealand regulators, infrastructure owners and designers to take these potentially damaging conditions into account in a consistent and effective way.

This paper presents the findings of a study in the Auckland Region commissioned by Auckland Council to assess the potential spatial distribution of acid sulphate soils. It is intended to provide a baseline for future research, and to inform current land development projects so that the potential risk can be considered during investigation, design and construction.

1 INTRODUCTION

1.1 Formation and distribution of acid sulphate soils

Acid sulphate soils (commonly abbreviated to ASS) are naturally occurring soils and sediments which contain sulphide minerals that have the potential to cause water and soil to acidify when they oxidise. Acid sulphate soils are a common occurrence in many parts of the world. They are known to occur throughout Australia and have been regulated there for many years. Their effects are usually more severe in warmer climates, such as northern and eastern Australia, but they are known to exist and have significant effects in cooler climates such as Tasmania. Northern New Zealand, including Auckland, has many characteristics that imply there is a high potential for acid sulphate soils.

These naturally occurring soils are commonly found in coastal and near-coastal sediments (Dear et al., 2014) that were inundated during the last interglacial period when sea levels were high (about 10,000 years ago). The sulphides prevalent in acid sulphate soil landscapes are formed in waterlogged soils and sediments by bacteria which reduce the naturally occurring sulphate in

water to form sulphides. This occurs in anaerobic aquatic environments and most frequently in warm, calm, marine environments which are high in organic matter (Macdonald, et al., 2002). Typical examples are shown in Figure 1. These conditions predominantly occur in areas similar to wave-protected mangroves, saltmarshes, outer barrier tidal lakes, and backswamps. The sulphides produced by the reducing bacteria form insoluble fine grained metal sulphides (commonly pyrite) that precipitate out of solution.

Figure 1: Examples of potential acid sulphate soils

Acid sulphate soils are stable while they remain in a waterlogged state as this limits oxidation. When exposed to oxygen the sulphides become unstable and oxidise, producing sulphuric acid and mobile metal ions.

Exposure of acid sulphate soils to oxygen commonly occurs when the watertable is lowered, or when the soil is disturbed by excavation. The aeration and ripening of these soils can be significantly enhanced through extensive artificial drainage of landscapes containing acid sulphate soil (Dent, 1986).

1.2 Significance of acid sulphate soils

Acid generation from the oxidation of iron sulphides can result in the change of soil pH to less than 4 (Wilson, 1995). Very low pH conditions can have deleterious effects on flora and fauna (Sammut et al., 1993). An example of such effects is the oxidation of pyritic sediments in Gwelup, Western Australia, which led to adverse effects on the ecology due to acidification and arsenic enrichment of the groundwater. These changes in groundwater chemistry can persist in the long-term and can lead to the water becoming unsuitable for use or consumption (Appleyard et al, 2006). The Richmond River in New South Wales, Australia has experienced numerous leaching events of acidified water enriched with metals being discharged from acid sulphate soils. These discharges have been linked to major fish kills and can also lead to sub-lethal effects, such as red spot disease in fish (Corfield, 2000).

The sulphuric acid generated by the oxidation of pyritic minerals is highly corrosive and can cause corrosion of concrete structures. Acid attacks concrete by dissolving both hydrated and unhydrated cement compounds as well as calcareous aggregates, evidenced by the loss of cement paste and aggregate from the matrix. If the steel in reinforced concrete becomes exposed to the acidic conditions, rust staining, cracking and spalling may also occur. The cement can decalcify, expand and crack, which can weaken the overall integrity of the concrete structures, in particular, structural foundations, bridge abutments, pipes, pavements and other concrete elements that are in contact with acidic soil and/or groundwater. This risk is of particular relevance to infrastructure that is designed to have a long life expectancy.

In 2014 Whangarei District Council identified problems with buried pipe work in a development in Ruakaka as concrete within the storm water system had begun to suffer chemical corrosion. Investigations into the cause of the corrosion identified the presence of acid sulphate soils. Extensive earthworks and lowering of the water table occurred during development. The continual draining of the site through subsoil drains caused sulphides in the soils to react with oxygen and release sulphuric acid. The acid then corroded the concrete pipes (Whangarei District Council, 2017). The local press have reported that this has resulted in a claim by Whangarei District Council in the order of $8 million against the designer and contractor (NZ Herald, 2016).

Although oxidation of iron sulphides may occur within a localised area, affected water may impact the surrounding areas some distance away from the original site. Acids and metals mobilised in soil leachate are usually transported episodically in concentrated slugs, usually after high rainfall events. As a result, leachate that is normally within acceptable limits may exceed these limits under episodic release conditions.

There is little awareness of acid sulphate soils in New Zealand, potentially because the infrastructure is relatively modern and the effects of acid sulphate soils have not been observed, and because development is only now being forced into lower quality land. Limited research has been done into the extent and implications of acid sulphate soils in New Zealand. Key pieces of research include the assessments of acid sulphate soils occurrence in Auckland and other northern parts of New Zealand in the 1970s and 1980s (Dent, 1980, 1986 and Metson et al, 1977).

The lack of readily available information about the potential distribution of acid sulphate soils makes it challenging for New Zealand regulators, infrastructure owners and designers to take these potentially damaging conditions into account in a consistent and effective way.

2 OBJECTIVES

A joint study was undertaken in 2016 by GHD and Auckland Council to provide information on the likelihood of acid sulphate soils occurring in the Auckland region to inform planners and developers of the potential risks.

3 METHODOLOGY

A desktop mapping exercise was undertaken using multi-criteria analysis to identify areas of the Auckland region that represent the greatest risk in terms of acid sulphate soils occurrence.

The desktop spatial assessment process began with the identification of the inputs (such as geology or soil maps) which inform the acid sulphate soils probability of occurrence. Based on a review of local and international literature these inputs were then divided into classes (such as geological units or soil types). Each class was given a rating of high, medium, low, or negligible based upon the probability of acid sulphate soil occurrence within that particular class based on a literature review.

A ground truthing exercise was then undertaken to validate and adjust the ratings identified in the desk study. This was targeted at key geological inputs, as described later. Finally, the ratings were overlain in GIS to produce a map of the results (Figure 2).

3.1 Map inputs

A summary of map inputs is provided here. For full details please refer to the Auckland Council Technical Report 2017/001 (currently in publication and due out later in 2017). An explanation of the function of primary and secondary inputs is provided in Section 3.3.

Primary Input	**Rationale and source**
Geology	Should give a reliable indicator of soil type. The published geological units adopted were assessed on considerations including the environment in which they were formed (e.g. marine or sulphur rich sediments, presence and type of organics) and laboratory results obtained during the ground truthing assessment. Swamp deposits and peat bogs were given a high rating, and alluvial/colluvial deposits were given a medium rating. See the Auckland Council Technical Report for the full list. (Source: GNS QMap)
Elevation	Provides an excellent indication of areas likely to contain marine and sulphur rich sediments, higher watertables, swamp environments and peat environments at low elevations which are all associated with acid sulphate soils. The elevation classes adopted were based on likely historical sea level taking into account geological uplift. (Source: Auckland Council LiDAR based Digital Elevation Model)
Wetlands	Can provide an environment in which acid sulphate soils may form and persist. (Source: Auckland Council GIS. This was adopted from the two layers available which were created by Auckland Council and the Department of Conservation)
Landcover	Vegetation provides an indication of soil types and conditions due to the characteristic tolerances or preferences of certain species such as mangrove, rush, and coastal shrubs. (Source: Landcare Research New Zealand)
Auckland Council generalised soil types	Gives an approximate indication of soil types including those that could indicate a present or historic environment in which acid sulphate soils could have been produced and persisted. The alluvial soils layer was deemed to add some value to the soil classification input. (Source: Auckland Council GIS)
Secondary Input	**Rationale and source**
Fundamental soil layers New Zealand soil classification	Soil classification was adopted as it provides an indication of soil types (such as those affiliated with marine sediments) the soil chemical properties such as acidity, sulphur content and anaerobic conditions. (Source: Landcare Research New Zealand)
Fundamental soil layers New Zealand pH	A measure of acidity and alkalinity and therefore can help inform where acid sulphate soils may occur. (Source: Landcare Research New Zealand)

3.2 Ground truthing

Ground truthing involved the collection of samples from each input class (such as geological units or soil types) to provide quantitative data to validate the ratings which are given to each input class during the desktop assessment. This is intended to reduce the level of conservatism adopted

during the desktop assessment and multi-criteria analysis, and to produce results which are more representative of field conditions.

This ground truthing assessment involved a targeted intrusive investigation across the Auckland region to validate key geological inputs. Locations for investigation were selected to provide a representative geographical distribution across the areas of the Auckland region identified as containing swamp deposits and peat bogs, alluvial/colluvial deposits, or beach deposits.

Soil samples were collected from three depths at each location (at target depths of 0.5 m, 1.0 m and 2.0 m below ground level), with two selected for field pH testing (90 samples in total) and one sample for full Suspended Peroxide Oxidation Combined Acidity and Sulphur (SPOCAS) analysis (45 samples in total) in accordance with ISO 14388-3:2014.

The pH results showed that nine of the 90 samples were highly acidic soils (pH <5). Two samples are considered to be Actual Acid Sulphate Soils because the pH was less than 4.

The SPOCAS analysis suggested that there is a high potential for acid generation in many of the sediments sampled. In 29 of the 45 samples analysed, the Titratable Peroxide Acidity (TPA) results were above the action criteria of 18 mol H^+ / t, with the highest TPA reported being 4,080 mol H^+ / t.

The three geological classes that were checked (swamp deposits and peat bogs, alluvial/colluvial deposits, and beach deposits) showed diverse responses to laboratory testing and were easily distinguished into three unique risk ratings based upon the results.

The swamp deposits and peat bogs geological input consistently returned high potential acid sulphate soils laboratory results. The desktop likelihood rating of high probability of acid sulphate soils occurring in these areas was retained.

The alluvial/colluvial deposits were the most extensive and geographically diverse of the geological inputs tested. This input also had the greatest variation in laboratory results with acid generation results at both the very high and very low ends of the spectrum. The high results were often associated with areas where other inputs were overlapping with the geological input. For example, many of the high acid generating samples were taken from areas where the geology input layer also intersected areas of low pH, high risk soil, wetland, or areas of low elevation. This complexity reflects that the geological classification was not the sole input contributing to the potential for acid generation in these areas. The presence of peat in this layer consistently returned high potential acid sulphate soil laboratory results and should be seen as an indicator for acid sulphate soils within this input. The result is that the alluvial/colluvial layer remained a medium risk. This is because even though high acid generation results were sometimes associated with this unit, these high risk areas were captured by other inputs and to classify the entirely of the input as high would not be representative of the other conditions observed. It should be noted that when the alluvial/colluvial layer is in the vicinity of another high or medium risk input, the likelihood of having acid sulphate soils appears to be greatly increased.

The ground truthing of the beach deposits input predominantly yielded a low to negligible risk of acid sulphate soil. However, some results showed the potential for acid generation at low to medium levels. Due to this variability and the majority of the results being of low risk, the decision was made to retain the beach deposits input class at a low probability of acid sulphate soils.

3.3 Rating calculation

The rating for each location was based on the highest primary input rating. This approach meant that an area with one high probability class (e.g., the presence of mangroves) and six low probability classes would be mapped as a high probability of occurrence. The decision to adopt

this approach was based upon the fact that one high probability of occurrence rating was considered to be more of concern than a large number of medium probabilities of occurrence.

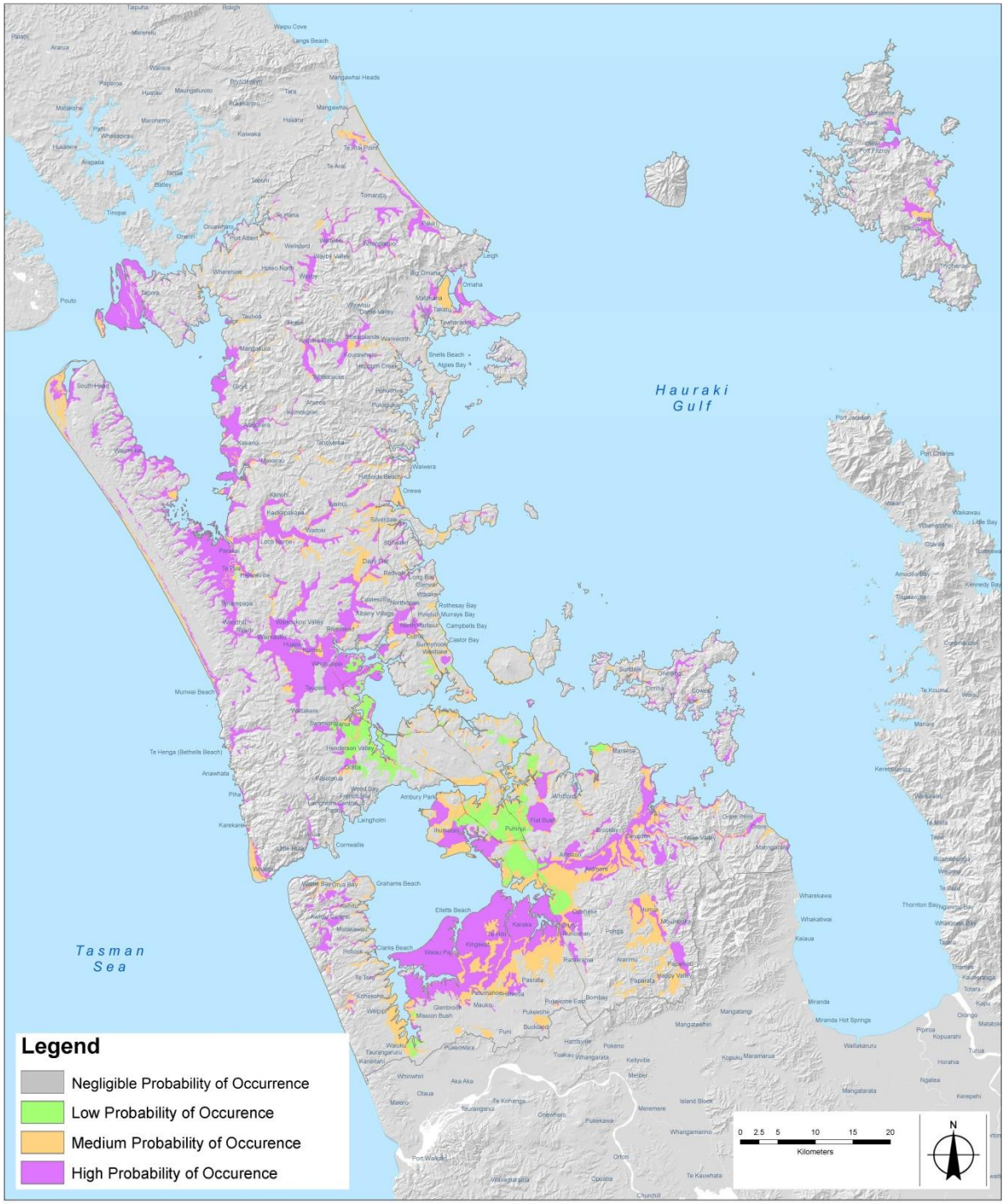

Figure 2: Preliminary map of the potential for acid sulphate soils in the Auckland Region

Where the secondary input rating was higher than the primary input rating, this rating was applied only in areas where the primary input rating suggested there was greater than negligible probability of occurrence. A site with a high probability rating in a secondary input would only show as high on the map in areas where one of the primary inputs also showed a probability of occurrence higher than negligible. This approach prevented sites being identified as having

potential for acid sulphate soils when the less reliable secondary factors were the only factors indicating a potential problem.

4 LIMITATIONS

The geology ground truthing assessment established that the desktop study weighting applied to the three geological classes appears to be reasonable. It does, however, raise questions around the approach for mapping the potential acid sulphate soil risk when multiple controlling factors are overlapping one another.

Limitations associated with the accuracy of the desktop study inputs were discovered on multiple occasions during the geology ground truthing investigations. These ranged from the incorrect mapping of areas to the lack of historic wetlands information and region-wide geomorphological maps. The effects of these limitations were diverse, with the lack of historic wetland extent data being an issue that may be most important. Current and historic wetlands appeared to be consistently associated with high potential of acid sulphate soil occurrence; however, due to the lack of data, these assumptions were based on field observations and aerial imagery.

While ground truthing has been carried out on three of the geology classes, results from this intrusive investigation are likely to be influenced by other controlling factors in some locations. These factors, such as unidentified historic wetlands or geomorphology, may either have not been captured in the adopted inputs or the inputs may not have been sufficiently accurate.

No assessment has been made of the potential for soils of volcanic origin to generate acid. It is assumed that the sub-aerial nature of our volcanics, combined with their non-acidic parent geology, would result in a low risk of acid generation.

This assessment considers the risk of there being acid sulphate soils present but does not consider whether those acid sulphate soils are problematic or not. For example, if the rate of reaction of slow, or the site conditions are right, then there may not be significant detrimental effects.

5 CONCLUSIONS

The acid sulphate soils probability map provides an indication of the relative likelihood of occurrence in the Auckland region. It will assist planners and developers in taking acid sulphate soils into consideration when assessing land capacity for development.

Ground truthing has been conducted on three classes (swamp deposits and peat bogs, alluvial/colluvial deposits, and beach deposits) within the geology input. Only two samples were found to be Actual Acid Sulphate Soils (pH is less than 4.0). However, a large number of the locations assessed were identified as Potential Acid Sulphate Soils with a very high potential for acid generation if disturbed or if groundwater levels fall.

The map produced by this study is based on a desktop study and limited ground truthing, and is therefore only appropriate for use as high level guidance. It intended to be updated as new field data becomes available. The authors request that test results (particularly Field pH, Chromium Reducible Sulphur and SPOCAS) are uploaded to the NZ Geotechnical Database and sent to ross.roberts@aucklandcouncil.govt.nz to be incorporated in future revisions of the map.

As a result of the variable quality of the input parameters a very simple approach to assessing the likelihood of occurrence was used. It is hoped that as more laboratory data becomes available, and better information sources are produced (including the GNS Urban Mapping Project), that a

more rigorous statistical correlation can be developed that will significantly improve the quality of the assessment presented in this paper.

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