Acid sulfate soils in the Perth metropolitan area of Western Australia

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Abstract
Acid sulfate soils (ASS) occur widely in the Perth metropolitan area of Western Australia. Projects likely to disturb ground or groundwater level are required to develop an ASS management plan if the sulfur content at the site is above 0.03%. In this context, a broad scale investigation was conducted to refine the ASS risk map and better manage the development activity in Perth metropolitan area. Soil cores for depths up to 6 metres were extracted from 162 sites. The cores were logged and analysed in the field for pH in water (pH_F) and 30% hydrogen peroxide (pH_{FOX}) at 0.25 m depth intervals. Samples for laboratory based sulfur analysis were taken where field pH_{FOX} data (<3.0) indicated occurrence of ASS.

Highly leached Bassendean Dune System is one of the major surface geological formation in Perth region of the Swan Coastal Plain. In the topographic lows of the Bassendean formation, humus podzol soils with a strongly cemented dark brown, organic B horizon (coffee rock) are common. In the topographic mid slopes and crests, iron-humus podzol and iron podzol respectively occur. All these soils are sandy, highly leached and consequently poorly buffered. Evidence of ASS materials was found in over 80% of the investigated sites. Up to 11% sites contain chromium reducible sulphur (S_{Cr}) above the current ASS action criteria (0.03%) in the top 2 m soil horizon. These sites are mostly in the estuarine sediments near the lakes and rivers. Forty five sites (27%) contain S_{Cr} >0.03% at depths between 2-6 m. About 43% of the sites show zones of pH_{FOX} lower than action criteria (<3.0) but their S_{Cr} content are below 0.03% s. Rest of the sites, about 20%, have pH_{FOX} >3.0. These sites are either clay-rich flood plains along the river or occasional old land-fill sites.

About 33% of the investigated sites show pH_{FOX} values well below 3.0 while their sulphur content is below the current action trigger level (0.03%s). The host soil material for these sites is extremely poorly buffered Bassendean sand. It appears that current action trigger level for these sandy soils in SCP may need to be reviewed.

Key Words
Acid sulfate soils, Swan Coastal Plain, Groundwater acidity

Introduction
Activities likely to disturb ASS, either directly or by lowering the water table, are managed appropriately in Western Australia by planning guidelines for urban and industrial land development projects (Western Australian Planning Commission 2003). Inappropriate excavation or dewatering of ASS materials is avoided and where necessary for economic or social reasons, An ASS management plan is developed and executed according to state guidelines (Department of Environment and Conservation 2004). These management processes currently utilise predictive ASS maps that are based on geological and soils maps (Degens 2006). The aim of this study was to estimate the actual extent and severity of ASS and refine the ASS boundary for Perth metropolitan area.

Methods and Materials
Perth city extends about 25 km north, 20 km south and 20 km east from its city business centre on the bank of Swan River. Swan Coastal Plain (SCP), a Quaternary surface of the Perth Basin has a subdued topography developed by aeolian and alluvial processes (Davidson 1995). Extensive leaching on topographic highs, seawater invasion and deposition of fresh alluvial materials has shaped the nature of soil materials in the area. Prominent landform in SCP is a series of coastal dunes systems that are roughly parallel to the present coastline (McArthur 1991). The most easterly dune system covering most of the present study area is the highly leached Bassendean Dune System. Next towards the west respectively are, relatively younger and carbonate rich, Spearwood Dune System and Quindalup Dune System. The study particularly focussed on lower part of the Bassendean Dune System where groundwater table depth is less than 3 m.

Sample sites were generally located along rivers and paleodrainages marked by chains of wetlands (Semeniuk and Semenuik 2005). In areas of high risk such as sumplands and damplands, sites were selected at about 1 km distance. Soil cores were typically obtained from 6 m depths and logged for texture, colour, mottles, organic materials and any concretions. Field pH in water (pH_F) and 30% hydrogen peroxide (pH_{FOX}) was analysed at 0.25 m depth intervals. Sampling for laboratory based SPOCAS suites of analyses was based on pH_F and pH_{FOX} profiles. Generally, a representative sample was taken from a zone where pH_{FOX} dropped below 3.0. The samples were placed in air-tight zip lock bags and maximum possible air was excluded before closing the zip locks. The sample bags were kept in field refrigerators for transport to laboratory. Potential acidity in un-oxidised sulfides was estimated by the chromium reducible sulfur method (QASSIT method 22B; Ahern *et al.* 2004).

Results and Discussion

Most of the 162 sites sampled were located on sumpland and damplands in the Bassendean Dune System. The groundwater table in these areas is within 2m metres and soils are extremely sandy with minimum capacity to resist changes in pH.

Field soil pH measurements

As a general rule soil pH_{FOX} is expected to lower than pH_F by 2-3 units due to oxidation some oxidisable soil components. A significantly lower pH_{FOX} value (<3.0 and < pH_F by 2 at least units) is considered indicative of ASS occurrence in form of sulfides. A total of 133 sites showed such soil pH profiles. About 18 % sites showed pH profiles where pH_{FOX} did not significantly vary from pH_F. No samples were taken from these sites for laboratory analysis. In several instances pH_{FOX} showed significant departure from pH_F even in the aerobic surface horizons where sulfides are not generally expected to persist. Lower pH_{FOX} in these cases are partly attributed to oxidation of certain organic species and poorly crystalline and readily hydrolysable Fe and Mn oxides.

SPOCAS and total titratable acidity analysis.

A total of 423 samples from 133 sites were analysed for SPOCAS and total titrateable acidity. As discussed above, these samples were taken on the basis of field pH_F and pH_{FOX}. More than 40% of these are derived from white to gray sands that occur below the B horizon which often consists of loose brown sands (incipient coffee rock) to indurated brown sand (coffee rock) material. These sands are often below the groundwater table. About 40% of the samples fall in the category of coffee rock. Less than 15% of the samples were derived from estuarine sediments that include peats and clay and organic matter rich sediments.
Estuarine sediments showed the highest S_{Cr} content with a median of 0.14. The median S_{Cr} content for sandy materials was 0.02, which is same as the detection limit for S_{Cr}. Clearly, the S_{Cr} content of sandy soil materials, which make up bulk of the samples, is very low. These soils however show pH_{FOX} values well below 3.

PASS characteristics and distribution

Evidence of PASS materials was found in over 80% of the investigated 162 sites. Up to 11% contained S_{Cr} >0.03% in the top 2 m soil horizon. These were classified Class 1a. These sites were mostly in the estuarine sediments near the lakes and rivers. Forty five sites (27%) contained S_{Cr} >0.03% at depth between 2-6 meters and were given risk Class 1b.

About 43% of the investigated sites had zones of low pH_{FOX} (<3.0) but their S_{Cr} content were either below 0.03% or below the detection limit of the laboratory used for this study. All of these were given moderate risk Class 2. Some of these however showed high TAA levels (>0.03%) and were furthered divided into Class 2a. Rest of the sites had neither high S_{Cr} or TAA. These were put into Class 2b. Rest of the investigated sites, about 20%, did not have low pH_{FOX} and therefore were given Class 3. These sites were either clay-rich flood plains along the river or occasional old land-fill sites.
Majority of the investigated contained PASS materials within 3 metre depth. Often, the PASS material was hosted by extremely sandy soils that are poorly buffered and highly porous. These sandy soils are likely to be readily drained with movement in groundwater table or their excavation.

Conclusions

Soils containing PASS materials occur widely within Perth metropolitan area. The occurrence is most common in sumplands near the lake environments and along the Swan and Canning river systems. However

they also widely occur in damplands and higher positions in the topography. The Bassendean sands that host the PASS materials are extremely poorly buffered.

A large number of sites (33%) with $pH_{FOX} < 3.0$ contained below 0.03%S or undetectable amount of S_{CR}. It is surprising that these soils with undetectable amount of S_{CR} would have such a low pH_{FOX}. It appears that current acidity trigger value (0.03%S) is too high for poorly buffered soils of Swan Coastal Plain. Current trigger value has been solely based on coastal landscapes of eastern seaboard where clay rich sediments and silt are common. This ASS mapping program has highlighted an urgent need to resolve the net acidity trigger value (0.03%S) for sandy upland soils of WA.

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